ADAMS BROADWELL JOSEPH & CARDOZO
A PROFESSIONAL CORPORATION
ATTORNEYS AT LAW
601 GATEWAY BOULEVARD, SUITE 1000
SOUTH SAN FRANCISCO, CA 94080-7037

TEL: (650) 589-1660
FAX: (650) 589-5062
eklebaner@adamsbroadwell.com

DANIEL L. CARDOZO
THOMAS A. ENSLOW
TANYA A. GULESSERIAN
JASON W. HOLDER
MARC D. JOSEPH
ELIZABETH KLEBANER
RACHAEL E. KOSS
LOULENA A. MILES
ROBYN C. PURCHIA

OF COUNSEL
THOMAS R. ADAMS
ANN BROADWELL
GLORIA D. SMITH

SACRAMENTO OFFICE

520 CAPITOL MALL, SUITE 350
SACRAMENTO, CA 95814-4721
TEL: (916) 444-6201
FAX: (916) 444-6209

September 22, 2010

**By Email and U.S. Mail**

Mary Alice Morency
Clerk of the Board
California Air Resources Board
1001 I Street
Sacramento, CA 95814
http://www.arb.ca.gov/lispub/comm/bclist.php

Re: Comments on the Proposed Regulation for a California Renewable Electricity Standard

Dear Ms. Morency:

We are writing on behalf of the Coalition for Green Jobs, the California State Building and Construction Trades ("CSBCT"), the California State Association of Electrical Workers ("CSAEW"), California State Pipe Trades Council ("CSPTC"), Coalition of California Utility Employees ("CUE"), and California Unions for Reliable Energy ("CURE") to comment on the Functionally Equivalent Document ("FED") prepared by the California Air Resources Board ("ARB") for the proposed Regulations for a California Renewable Electricity Standard ("Project" or "RES"). After carefully reviewing the FED and the supporting documentation available to us, we conclude that the ARB has failed to adequately analyze the Project, its potentially significant impacts, and to propose adequate mitigation to reduce those impacts to a level of insignificance. Due to these deficiencies, the FED must be revised to adequately address all Project impacts. The revised FED must also be recirculated for public review and comment in accordance with the California Environmental Quality Act ("CEQA").

Initially, we note that the ARB does not have the legal authority to adopt the proposed regulation. The California Legislative Counsel has clearly described the legal prohibition on the ARB acting as proposed.[1]

The Coalition for Green Jobs is a broad based coalition of utility and construction trades organized to advocate for the development of renewable energy jobs in California. The Coalition submits these comments to urge ARB to adequately consider the reasonably foreseeable environmental impacts of the proposed Project.

The primary mission of the SBCTC is to improve the health, jobs safety and economic conditions of the members of its affiliates, and of all working men, women and minors in the construction industry, by all lawful means. Through advocacy in both the public and private sectors, the SBCTC also seeks adoption of programs and policies that promote the security and welfare of the general public. SBCTC submits these comments to urge ARB to adequately consider the reasonably foreseeable environmental impacts of the proposed Project.

The CSAEW is an organization of the local unions of the International Brotherhood of Electrical Workers, representing approximately 70,000 electrical workers in California. The members of the unions are trained to install and are currently installing solar electric systems that, and thus have a direct interest in the Project and its potentially significant adverse environmental effects.

The CSPTC is an association of plumbing and pipefitting unions together representing over 30,000 members working in the plumbing and pipe trades throughout California. CSPTC's mission includes protecting the health, safety and reputation of its workers. CSPTC submits these comments to urge ARB to adequately consider the reasonably foreseeable adverse environmental impacts of the proposed Project.

CUE is a coalition of unions whose approximately 35,000 members work at essentially all of the California electric utilities; both publicly owned, and privately owned. CUE has been active in proceedings before the California Public Utilities Commission since 1994. The implementation of a Renewable Electricity Standard will dramatically impact the future development of renewable generation in California, the air quality and the public health of the people of the State, as well as

---

[1] Opinion of the Legislative Counsel Bureau, January 11, 2010, No. 0926039.

the future uses of the State's natural resources. CUE respectfully submits these comments on the FED for the Project, in accordance with CEQA.

CURE is a coalition of unions whose members help solve California's energy problems by building, maintaining, and operating conventional and renewable energy power plants. Poorly designed renewable energy power plants may degrade the environment by destroying historic resources and wildlife habitat areas, causing noise and visual intrusion, and polluting water and soil. Union members live in and around this community and have a direct interest in protecting the air quality in and around conventional and renewable power plant facilities. Union members also have a direct interest in ensuring a safe workplace for workers during Project construction. CURE submits these comments to urge ARB to adequately consider the reasonably foreseeable adverse environmental impacts of the proposed Project.

## I. INTRODUCTION

In implementing its certified regulatory program, the ARB must comply with the basic substantive policies established by CEQA, including the requirements to identify significant adverse environmental direct, indirect, and cumulative impacts of the Project and to adopt mitigation measures to reduce those impacts to a level of insignificance.[2] ARB assumes that the Project would drive additional wind, solar thermal, solar photovoltaic, and geothermal development in the State.[3] ARB also assumes that the regulations would cause a reduction of approximately 13 million metric tons of carbon dioxide over the course of the next ten years.[4] However, according to the Staff Report "compliance with the proposed regulations is expected to directly affect air quality and potentially affect other environmental media as well."[5] Unfortunately, the Staff Report and the FED fail to analyze these impacts as required by CEQA.

ARB proposed the Project, pursuant to Executive Order S-21-09, to require retail sellers to increase the proportion of California electricity consumption that comes from renewable generation to meet a 33 percent renewable electricity standard by 2020. The Project would be implemented concurrently with the

---

[2] *Sierra Club v. State Board of Forestry* (1994) 7 Cal. 4th 1215, 1236-1237; Pub. Res. Code § 21080.5.

[3] Air Resources Board, Proposed Regulation for a California Renewable Electricity Standard, Staff Report: Initial Statement of Reasons, June 2010, p. E-56 (hereafter "Staff Report").

[4] Staff Report, p. IX-2.

[5] Staff Report, p. IX-1.

existing Renewable Portfolio Standard ("RPS") Program, administered by the California Energy Commission and the Public Utilities Commission.[6] However, the Project represents a new and different regulatory scheme for California's electricity sector. The Project would establish non-prescriptive, performance based standards whereby regulated parties can procure electricity or unbundled renewable energy credits (RECs), generated anywhere within the western electric grid, to achieve the 33 percent target. The Project defines the eligible renewable energy resources, the regulated parties, establishes a system for banking and trading RECs, mandates multi-year compliance intervals, and establishes a system for compliance, verification and enforcement. As such, the Project proposes a new regulatory regime and a cap and trade program for renewable energy.

The FED does not analyze these Project components, and their potentially significant impacts on the environment. ARB also failed to establish a defensible environmental baseline for the purpose of assessing the potentially significant Project impact on land use in California. These defects render the FED invalid as an environmental review document under CEQA. Because significant new information must be added to the FED to remedy these deficiencies, the revised FED must be recirculated for public review and comment.[7]

## II. THE FED FAILS TO SATISFY CEQA'S PURPOSE AND GOALS

CEQA has two basic purposes, neither of which the FED satisfies. First, CEQA is designed to inform decision makers and the public about the potential, significant environmental effects of a project.[8] CEQA requires that an agency analyze potentially significant environmental impacts in an environmental review document; in this case, the FED.[9] The FED should result from "extensive research and information gathering," including consultation with state and federal agencies, local officials, and the interested public.[10] To be adequate, the FED should evidence the lead agency's good faith effort at full disclosure.[11] Its purpose is to inform the public and responsible officials of the environmental consequences of their decisions

---

[6] *See* Staff Report, p. VII-1.

[7] *See Cadiz Land Co., Inc. v. Rail Cycle, L.P.* (2000) 83 Cal.App.4th 74, 91.

[8] Cal. Code Regs., tit. 14, § 15002, subd. (a)(1) (hereafter "CEQA Guidelines").

[9] See Pub. Resources Code, § 21000; CEQA Guidelines § 15002.

[10] *Berkeley Keep Jets Over the Bay Comm. v. Board of Port Comm.* (2001) 91 Cal. App.4th 1344, 1367 and *Schaeffer Land Trust v. San Jose City Council*, 215 Cap.App.3d 612, 620.

[11] CEQA Guidelines § 15151; *see also Laurel Heights I* (1998) 47 Cal.3d 376, 406.

*before* they are made. For this reason, the environmental review document has been described as "an environmental 'alarm bell' whose purpose it is to alert the public and its responsible officials to environmental changes before they have reached ecological points of no return.[12] Thus, the environmental review documents protects not only the environment but also informed self-government."[13]

Second, CEQA directs public agencies to avoid or reduce environmental damage when possible by requiring alternatives or mitigation measures.[14] The environmental review document, serves to provide public agencies, and the public in general, with information about the effect that a proposed project is likely to have on the environment and to "identify ways that environmental damage can be avoided or significantly reduced."[15] If a project has a significant effect on the environment, the agency may approve the project only upon a finding that it has "eliminated or substantially lessened all significant effects on the environment where feasible," and that any unavoidable significant effects on the environment are "acceptable due to overriding concerns" specified in CEQA section 21081.[16]

The FED fails to satisfy the basic purposes of CEQA. The core flaw in ARB's analysis is the failure to consider the actual Project under review. Instead of identifying and analyzing the environmental impacts of the proposed Project, the FED characterizes the Project as "essentially an extension of [the RPS Program] that sets a higher renewable electricity goal and applies to all load-serving entities."[17] This description is highly misleading because, as is described more fully below, the Project represents a new regulatory regime, the discrete elements of which have never before been analyzed in a CEQA environmental review document. The FED lacks even a description of the major Project components. Further, instead of analyzing each phase of the Project as envisioned by ARB's proposed compliance schedule, ARB has improperly assumed that many of the current RPS program elements are unchanged and therefore do not require analysis. As a result of these two fundamental flaws, the FED fails entirely to analyze the reasonably foreseeable environmental impacts of the proposed Project and to propose mitigation to reduce any significant Project impacts to a level of insignificance.

---

[12] *County of Inyo v. Yorty* (1973) 32 Cal.App.3d 795, 810.
[13] *Citizens of Goleta Valley v. Bd. of Supervisors* (1990) 52 Cal.3d 553, 564 (citations omitted).
[14] CEQA Guidelines § 15002(a)(2)-(3); *Berkeley Keep Jets Over the Bay Com.,* 91 Cal.App.4th at 1354.
[15] CEQA Guidelines § 15002(a)(2).
[16] CEQA Guidelines § 15092(b)(2)(A)-(B).
[17] Staff Report, Appendix E, p. E-42.

This distorted and truncated analysis of the Project precludes informed decisionmaking and meaningful public participation and violates CEQA.

## III. THE FED FAILS TO PROVIDE A PROJECT DESCRIPTION

CEQA requires that a draft EIR identify and focus on the possible significant environmental impacts of a proposed project.[18] "Where the lead agency could describe the project as either the adoption of a particular regulation ... or as a development proposal which will be subject to several governmental approvals ... the lead agency shall describe the project as the development proposal for the purpose of environmental analysis."[19] Here, the Project is a regulation intended to lead to the development of additional renewable energy facilities. As such, the Project is a development proposal, and should have been so characterized in the FED. When evaluating a project under CEQA, the lead agency must consider each phase of the proposed project to assess its impact on the environment.[20] Here, the Project consists of several discrete regulatory components, including the following major elements:

- <u>33 percent Renewable Retail Sales by 2020</u>

  The Project would implement a requirement that each retail seller have 33 percent of its retail sales of electricity be represented by Renewable Energy Credits (or WREGIS certificates).

- <u>Identifying Eligible Renewable Energy Power Plants</u>

  The Project proposes to identify certain types of power plants as eligible to create Western Renewable Energy Generation Information System ("WREGIS") certificates for compliance: biodiesel, biogas injected into natural gas pipelines, biomass, conduit hydroelectric, digester gas, fuel cells using renewable fuels, geothermal, incremental hydroelectric generation, landfill gas, municipal solid waste, ocean wave, ocean thermal, tidal current, photovoltaic, small hydroelectric, solar thermal, and wind generation.

---

[18] Pub. Resources Code § 21100(b)(1); CEQA Guidelines §§ 15126(a); 15126.2(a).
[19] *Citizens Association for Sensible Development of Bishop Area v. County of Inyo* (1985) 172 Cal.App.3d 151,165 (internal quotations omitted).
[20] CEQA Guidelines § 15126(a).

- Renewable Generation Delivered Anywhere In The Western Grid Can Qualify For Compliance

  The Project vests the ARB with the authority to approve using generation anywhere in the western grid to create certificates that count toward California's 33 percent goal. [21] Under the Project, an eligible resource is any generating plant that participates in WREGIS and is certified as eligible by either the California Energy Commission or the ARB.[22]

- Establishing a System for Trading and Banking of Renewable Energy Credits

  The Project proposes a market-based incentive program to create Renewable Energy Credits ("RECs"), defined as one MWh of electricity generated by an Eligible Renewable Energy Resource,[23] and rules for the trading, banking, and retiring of RECs by regulated entities in order to meet compliance obligations.[24] Under the Project, a REC can be sold to a retail seller, and the actual underlying physical electricity does not have to be delivered to any consumer in California.[25]

None of these Project components are analyzed in the FED. However, each of these Project components will result in potentially significant direct and indirect environmental impacts which must be analyzed in an environmental review document under CEQA.

### A. ARB Failed to Analyze the Whole of the Project

ARB is required under CEQA to analyze the whole of the Project.[26] Here, ARB proposes to require WREGIS certificates for at least 33 percent of each retail

---

[21] *See* Staff Report, Appendix A § 97002(a)(8) and California Energy Commission, Renewable Portfolio Standard Eligibility Guidebook, April 2006, p. 20.
[22] Staff Report, Appendix A, § 97002(a)(8).
[23] Staff Report, Appendix A, § 97002(a)(16).
[24] Staff Report, Appendix A, §§ 97005.
[25] Staff Report, pp. VI-1, VII-1, VII-15.
[26] CEQA Guidelines § 15378.

seller's retail sale of electricity by 2020. However, the FED mistakenly fails to attribute all of the impacts of achieving the first 20 percent of that new obligation to the proposed Project because the RPS Program is already law. This has two fundamental flaws. First, the 20 percent RPS requirement has not been achieved and is not the actual environment now.[27] Second, the RES proposed here is not identical to the RPS program. Features of the RPS program are not included in the RES, and vice versa. Thus, the environmental impacts will be different. The FED makes no attempt to analyze the impacts of achieving the first 20 percent under the RES (in contrast to the 20 percent under the RPS). The FED must analyze each phase of the proposed Project, including the first 20 percent under the RES. ARB must revise its analysis to consider the potentially significant impacts of the entire RES program, not just the last 13 percent.

### B. ARB Failed to Fully Analyze The Impacts of its Selection Eligible Renewable Facilities

Under CEQA, a "project" is defined as "the whole of an action" which has the potential to result in a direct physical change in the environment, or a reasonably foreseeable indirect physical change in the environment.[28] Under CEQA, the definition of "project" is "given a broad interpretation in order to maximize protection of the environment."[29] In performing its analysis, the agency should not piecemeal a project by splitting it into two or more segments such that environmental considerations "become submerged by chopping a large project into many little ones, each with a potential impact on the environment, which cumulatively may have disastrous consequences."[30]

ARB assumes that the Project will not result in even a single new biomass facility in California.[31] In effect, ARB declares biomass a dead technology in California. This conclusion is absurd. California has a massive agricultural industry that produces vast quantities of biomass every year. New biomass projects

---

[27] *See* Comments Section IV.

[28] CEQA Guidelines § 15378.

[29] *Lighthouse Field Beach Rescue v. City of Santa Cruz* (2005) 131 Cal.App.4th 1170, 1180 (internal quotation omitted); see also, *Muzzy Ranch Co. v. Solano County Airport Land Use Com.* (2007) 41 Cal.4th 372, 381-83; *Fullerton Joint Union High Sch. Dist. v. State Bd. of Educ.* (1982) 32 Cal.3d 779, 796-97; *Bozung v. Local Agency Formation Com.* (1975) 13 Cal.3d 263, 277-81.

[30] *Burbank-Glendale-Pasadena Airport Authority v. Hensler* (1991) 233 Cal.App.3d.577, 592.

[31] *See* Staff Report, p. IX-7 Table IX-2 (indicating the same level of increase as expected under the RPS Program); *see also id.* at pp. IX-8, IX-21, IX-29.

are routinely proposed. We seriously doubt that the California biomass industry considers itself a dead technology.

To compound the blunder, the FED inexplicably assumes that additional biomass development ***will*** occur to meet the 20 percent RPS.[32] Somehow, biomass is alive and well for a 20 percent program, but extinct for the 33 percent program. This conclusion is incredible on its face. Moreover, a 20 percent interim goal is part of this Project; ARB must analyze the potentially significant adverse impacts of added biomass facilities in the FED.[33] The impacts that should have been analyzed are described in Section V below.

Here, the Project includes the future development of power plants. The Project will foster a new demand for biomass generation because biomass combustion facilities are eligible renewable resources under the Project. Numerous courts have held that land use changes resulting from regulatory actions must be evaluated in an environmental review document.[34] Contrary to CEQA's mandate that the whole of the Project be analyzed in an environmental review document, the FED does not consider the air quality impacts of eligible renewable energy *facilities*. Rather, FED improperly limits its analysis to the direct emissions of renewable *technologies* and the GHG emissions they would displace, failing to consider the lifecycle environmental impacts of eligible power plants.[35] ARB must revise its air quality analysis to include the lifecycle air quality impacts of eligible power plants. This analysis is critical to the public's understanding of the Project's potentially significant environmental impacts, and is particularly relevant to biomass facilities because their lifetime emissions vary from other types of renewable energy plants.[36]

---

[32] Staff Report, Appendix E, p. E-86.

[33] *See* Staff Report, pp. VII-10; VII-12.

[34] *See Plastic Pipe and Fittings Ass'n v. California Building Standards Com'n* (2004) 124 Cal.App.4th 1390, 1413; *Terminal Plaza Corp. v. City and County of San Francisco* (1986) 177 Cal.App.3d 892, 905; *City of Carmel-By-The-Sea v. Board of Supervisors* (1986) 183 Cal.App.3d 229, 243.

[35] Staff Report, p. IX-4; *see also id.* Appendix E, p. E-105.

[36] *Laurel Heights Improvement Assn. v. Regents of the University of California* (1988) 47 Cal.3d 376; *San Joaquin Raptor/Wildlife Rescue Center v. County of Stanislaus* (1994) 27 Cal.App.4th 713; *Tuolumne County Citizens for Responsible Growth, Inc. v. City of Sonora* (2007) 155 Cal.App.4th 1214; *Communities for a Better Environment v. City of Richmond*, 2010 WL 1645906 (Cal.App. 1 Dist.) (April 26, 2010).

There is substantial dispute regarding the GHG emission reduction capacity of utility scale biomass plants. Unlike wind and PV, biomass combustion plants emit criteria pollutants and greenhouse gases.[37] The FED fails to consider these adverse impacts of biomass plants, because ARB assumes that biomass *technology* is carbon neutral.[38] By failing to consider lifecycle emissions from biomass combustion *plants*, ARB has ignored an important part of the problem. There is a considerable lag between the emission of carbon through biomass combustion and the commensurate reduction of carbon in the atmosphere through recapture.[39] For example, a study considering the Massachusetts Global Warming Solutions Act finds that during the first forty years of implementation, biomass combustion plants emit an equivalent level of GHGs as coal-burning power plants.[40] The same study finds that over the course of forty years of implementation, cumulative total emissions from biomass combustion plants are "substantially higher" than GHG emissions from natural gas plants.[41] Contrary to the Project's regulatory goal, increased biofuel production "could result in "carbon debt" because the quantity of carbon dioxide ($CO_2$) released from direct and indirect land use changes will be far greater than the GHG reductions from the displacement of fossil fuels."[42] Thus, biomass combustion facilities would actually increase the State's carbon debt during the life of the Project.

ARB must revise its analysis to include the potentially significant adverse impacts of the addition of biomass facilities to the State's renewable resource inventory or remove biomass from the list of eligible renewable resources.

---

[37] *See* Staff Report, p. IX-4.

[38] *See* Staff Report, Appendix D, p. D-14.

[39] Manomet Center for Conservation Sciences, *Biomass Sustainability and Carbon Policy Study*, June 2010, pp.6-7, (attached hereto as **Attachment A**).

[40] *Id*. at p.7.

[41] *Id*; *see also* Union of Concerned Scientists, *Land Use Changes and Biofuels Fact Sheet*, p. 2 ("Performance-based policies should reward reductions in global warming pollution over a fuel's full life cycle, based on the best available information and vetted in an open and transparent process.") (attached hereto as **Attachment B**).

[42] Pamela R.D. Williams, et al., 40 Env. Science & Tech. Volume 13, 4,763, *Environmental and Sustainability Factors Associated With Next Generation Biofuels in the U.S.: What Do We Really Know?* (2009). (attached hereto as **Attachment C**).

### C. ARB Failed to Analyze Exporting California's Renewable Generation Industry

Under the Project, WREGIS certificates created by generation anywhere in the western grid would count toward the 33 percent standard. As such, no new generation need be developed within California to comply with the RES requirements. ARB failed to analyze the reasonably foreseeable potentially significant environmental impacts of this Project component.

"Where a physical change is caused by economic or social effects of a project, the physical change may be regarded as a significant effect in the same manner as any other physical change resulting from the project."[43] Currently, California is experiencing an increase in renewable energy development. In the last month, the California Energy Commission ("CEC" or "the Commission") approved 1,500 MW of new solar thermal generation.[44] The Commission will decide whether to approve up to 2,579 MW of new solar by the end of 2010.[45] These projects will provide thousands of hours of new green jobs while advancing the State's renewable energy and climate goals. ARB has not considered the environmental impacts of the potential movement of renewable energy development to locations elsewhere in the western grid, where regulatory conditions may be more attractive to industry. Exporting this industry may result in potentially significant physical changes, such as the loss of the direct air quality benefits of renewable energy facilities.

The ongoing development of renewable energy facilities in California benefits surrounding communities because certain renewable energy technologies, such as solar and wind, have cleaner production processes than traditional fossil fuels. Unlike conventional generation, the direct air emissions from solar and wind facilities approximate zero.[46] If California moves toward cleaner electrical

---

[43] *Citizens Association for Sensible Development of Bishop Area*, 172 Cal.App. at 169.

[44] California Energy Commission Press Release, *Energy Commission Licenses 1,000 MW Solar Power Plant*
*Blythe Project Would Be Largest Concentrated Solar Power Plant in the World*, Sep. 15, 2010 ("The Blythe Solar Power Project is the third project that the Commission has approved in three weeks. The Beacon Solar Energy Project, the first solar thermal power plant permitted in 20 years, was licensed Aug. 25 and the Abengoa Mojave Solar Project on Sept. 8.").

[45] *Id.*

[46] *See* Edward A. Holt, Ernest Orlando Lawrence Berkeley National Laboratory, *The Treatment of Renewable Energy Certificates, Emissions Allowances, and Green Power Programs in State Renewable Portfolio Standards*, April 2007, p. 10.

generation, the air quality benefits of displaced fossil fuel generation would be distributed throughout the State. The potential export of renewable energy development would eliminate, or substantially hamper, the development of cleaner generation in California.[47] In the Staff Report, ARB acknowledges that the export of even a portion of the expected renewable energy development would result in a relative increase of criteria emissions in California.[48] However, the FED and the Staff Report fail to evaluate the significance of this impact. ARB is required under CEQA to evaluate the environmental impacts of the loss of continued renewable development in a revised FED.[49]

### D. ARB Failed to Analyze Its Decision to Allow Unbundled Renewable Energy Credits For Compliance

The Project proposes to allow the unlimited use of unbundled RECs to meet a 33 percent retail sale requirement. This Project component will result in potentially significant land use and air quality impacts. ARB is required to analyze the potentially significant adverse environmental effects of unbundled RECs in a revised FED.

"If the forecasted economic or social effects of a proposed project directly or indirectly will lead to adverse physical changes in the environment, then CEQA requires disclosure and analysis of these resulting physical impacts."[50] Under the Project, California retail sellers could use an unlimited amount of paper RECs to meet RES requirements. As such, retail sellers would be able to meet their obligation to increase retail sales of electricity produced from renewable resources, even if renewable energy is neither ***produced*** nor ***consumed*** in the State. All that would be required is a stack of WREGIS certificates, with no actual renewable

---

[47] *See id* at p. 3.

[48] Staff Report, VII-15; *see also* Staff Report, p. XI-4, Table XI-2 (showing a relative increase in fossil fuel generation and a relative decrease in renewable energy development when the 13 percent increment of additional demand for renewable generation is met with generation from the western grid).

[49] *See Citizens Association for Sensible Development of Bishop Area*, 172 Cal.App. at 170 ("[T]he lead agency *shall* consider the secondary or indirect environmental consequences of economic and social changes, but may find them to be insignificant") (emphasis in original); *Bakersfield Citizens For Local Control v. City of Bakersfield* (2004) 124 Cal.App.4th 1184, 1204-1207 (collecting cases);

[50] *Bakersfield Citizens For Local Control* 124 Cal.App.4th at 1205 (citing *Friends of Davis v. City of Davis* (2000) 83 Cal.App.4th 1004, 1019; *Citizens for Quality Growth v. City of Mt. Shasta* (1988) 198 Cal.App.3d 433, 445-446).

energy powering even a single light bulb in California. This Project component eliminates existing economic incentives for the development of renewable generation in California, and may cause a future increase in the State's dependence on fossil fuels. ARB failed to analyze the reasonably foreseeable, potentially significant environmental impacts of this Project component.

#### i. Potentially Significant Adverse Land Use Impacts of Unbundled RECs

According to the Commission's 2009 Integrated Energy Policy Report, 70 percent of electrical generation in California is from conventional generation.[51] The annual demand growth in California is approximately 1 to 2 percent.[52] Absent incentives for local renewable generation actually supplying energy to customers, future incremental increases in demand will be met with less costly, additional fossil fuel generation rather than renewable resources.[53] As a result, the Project could lead to significant increases in generation fueled by fossil fuel, with all of the classic land use conflicts caused by that generation. ARB must analyze this indirect Project impact in a revised FED.

#### ii. Potentially Significant Adverse Air Quality Impacts of Unbundled RECs

Pollution permit trading regimes are linked to disproportionate regional concentrations of air pollutants.[54] Such trading regimes fail to ensure that increases in air quality are equally distributed, potentially resulting in hot spots where ambient standards are violated.[55] Unbundled RECs that do not result in an actual increase in renewable energy delivered to California consumers would result in the State's existing emitters of GHGs, criteria pollutants and toxic air

---

[51] California Energy Commission, 2009 Integrated Energy Policy Report, p. 3, *available at* http://www.energy.ca.gov/2009publications/CEC-100-2009-003/CEC-100-2009-003-CMF.PDF (last visited 9/20/10).

[52] *See* California Energy Commission, California Energy Demand 2010-2020 Adopted Forecast (Dec. 2009), p. 2.

[53] *See* Holt *supra* note 45, at p. 3.

[54] Jonathan Remy Nash & Richard L. Revesz, *Markets and Geography: Designing Mark)table Permit Schemes to Control Local and Regional Pollutants*, Markets, 28 Ecology L. Q. 569 (2001).

[55] *Id.*; *see also* Richard T. Drury *et al.*, *Pollution Trading and Environmental Injustice: Los Angeles' Failed Experiment in Air Quality Policy*, 9 Duke Env. L & Pol'y F 231, 251-258 (1999).

contaminants to increasing generation. This would cause further deterioration of ambient air quality in parts of the State:

> Pollution trading program can unfairly concentrate pollution in communities where factories [or power plants] purchase emissions reduction credits rather than reduce actual emissions . . . the disproportionate burden thrust on communities surrounding major pollution emitters takes its toll in the form of *increased* risks of toxic exposure and damage to human health.[56]

Unbundled RECs could also lead to potentially significant increases of criteria pollutants in certain locations within California, while allowing for regional reduction of GHG emissions. As such, California fossil fuel generators would be allowed to trade production processes that emit criteria pollutants and toxic air contaminants for generation that results in zero, or negligible, adverse air quality impacts. ARB must analyze these potentially adverse air quality impacts in a revised FED.

## IV. THE FED FAILS TO EMPLOY A DEFENSIBLE ENVIRONMENTAL BASELINE

The FED employs an inaccurate and incomplete baseline, thereby skewing the impact analysis. An accurate description of the environmental setting is critical under CEQA because it establishes the baseline physical conditions against which a lead agency may assess the significance of a project's impacts.[57] Failure to adequately describe the existing setting contravenes the fundamental purpose of the environmental review process, which is to determine whether there is a potentially substantial, adverse change compared to the existing setting.

The baseline environmental setting for CEQA review is the existing environment – not the environmental setting that could exist under existing entitlements and not a hypothetical environmental setting that might possibly exist in the future.[58] In *Communities for a Better Environment v. South Coast Air*

---

[56] Drury et al., *supra* note 53, at 251 (emphasis added).

[57] CEQA Guidelines § 15125(a).

[58] *Communities for a Better Environment v. South Coast Air Quality Management District* (2010) 48 Cal.4th 310, 322 ("*CBE v. SQACMD*"); *see also Environmental Planning and Info. Council v. County*

*Quality Management District* ("*CBE v. SCAQMD*"), the Supreme Court affirmed this basic CEQA rule, rejecting the SCAQMD's approach to the environmental baseline wherein the district measured a proposed project's increased emissions against the maximum emissions that were allowed under a previously issued permit for a refinery.[59] The Court held that the impacts of a proposed project are ordinarily to be compared to the actual environmental conditions existing *at the time of CEQA analysis*, rather than to allowable conditions defined by a plan or *regulatory framework*."[60] In reaching this conclusion, the Court applied well-established case law from numerous appellate court decisions interpreting environmental baseline requirements under CEQA Guidelines section 15125.[61]

The Court further explained that an approach that uses hypothetical environmental conditions as the environmental baseline results in "illusory" comparisons that "can only mislead the public as to the reality of the impacts and subvert full consideration of the actual environmental." [62] Such "result is at *direct* odds with CEQA's intent."[63] ARB's failure to describe the existing setting precludes informed decision making and public participation, contrary to the goals of CEQA.

In contravention to the principles set forth by the Supreme Court in *CBE v. SCAQMD*, ARB based its Project impact analysis on hypothetical regulatory conditions. Specifically, ARB assumed that the environmental baseline for the purpose of this Project is a 20 percent RPS.[64] Rather than consider existing conditions, ARB maintains that a 20 percent RPS has been attained, and that the Project "only leads to the increment of contribution intended to extend the proportion of renewable energy from 20 percent to 33 percent."[65] This analysis fails to consider actual physical conditions, as required by CEQA.

---

*of El Dorado* (1982) 131 Cal.App.3d 350, 354 (*EPIC*) and *Friends of Eel River v. Sonoma County Water Agency* (2003) 108 Cal.App.4th 859, 874.

[59] *CBE v. SCAQMD*, 47 Cal.4th at 322.

[60] *CBE v. SCAQMD*, 48 Cal.4th at 321 (emphasis added).

[61] *Id.* at pp. 321-322, fn. 6-7 (discussing, among other cases, *EPIC*, *supra*, 131 Cal.App.3d at p. 354 and *Save Our Peninsula Com. v. Monterey County Bd. of Supervisors* (2001) 87 Cal.App.4th 99, 121.)

[62] *Id.* (quoting *EPIC* 131 Cal.App. 3d at 358).

[63] *Id.*

[64] Staff Report, Appendix E, p. E-25.

[65] *Id.*

ARB should have relied on physical conditions as they existed in October 2009, when ARB issued its notice of intent to develop the RES.[66] In 2009, California's three largest investor owned utilities collectively showed only a 15.4 percent *contractual* commitment to the procurement of renewable energy generation under the RPS.[67] Even according to most recent RPS compliance filings, dated March 2010, the *contractual commitment* to the procurement of renewable generation by the three largest investor owned utilities in California continues to be below 20 percent.[68] More importantly, when considering actual conditions on the ground, the number of renewable energy plants in existence at the time that ARB initiated environmental review were far fewer than would be expected if even 15 percent of California load were served with renewable generation.

In August 2009, CEC data showed that of the RPS contracts signed by the California IOUs, only 19 percent (measured by gwh) had come to a resolution – either succeeding or failing; of that 19 percent, 57 percent were built on schedule, 10 percent were delayed but ultimately completed, and a full 33 percent were canceled.[69] Thus, for the set of RPS projects for which outcomes were known at that time, almost one third had been canceled. Of the remaining 81 percent of the RPS contracts (again, measured by expected gwh per year of output) whose outcome was pending, 17 percent were running behind schedule.[70] A large contractual failure rate has also been observed in distributed generation. According to a CPUC Staff Progress Report on the California Solar Initiative, the majority of these projects had not reached completion in 2008.[71]

---

[66] *See Cadiz Land Company, Inc. v. San Jose City Council supra*, 83 Ca.App.4th at 86 ("The EIR must describe environmental conditions in the vicinity of the project, "as they exist at the time the notice of preparation is published, or if no notice of preparation is published [or at the time environmental analysis is commenced as well as the potential future conditions discussed in the plan].") (quoting CEQA Guidelines § 15125(e).)

[67] California Public Utilities Commission, Renewable Portfolio Standard Quarterly Report 2010 Q3, p. 2, *available at* http://www.cpuc.ca.gov/NR/rdonlyres/6472286E-6372-47CF-9F3D-2D2C3100BF6D/0/Q32010QuarterlyRPSReporttotheLegislature.pdf (last visited 9/20/10).

[68] California Public Utilities Commission website, March 2010 RPS Compliance Filings, *available at* http://www.cpuc.ca.gov/PUC/energy/Renewables/compliance.htm (last visited 9/20/10).

[69] In the Matter of the Application of Pacific Gas and Electric Company to Implement and Recover in Rates the Cost of its Proposed Photovoltaic (PV) Program, California Public Utilities Commission Docket No. A.09-02-019, Testimony of David Marcus on the Behalf of Coalition of California Utility Employees, August 2009, p. 3:8-13.

[70] *Id.* at p. 3:15-4:2.

[71] *Id.* at p. 4:3-5.

Among projects that did not yet have contracts in August 2009, ISO data suggested a similarly substantial delay and/or failure rate: of 303 renewable resource projects entered into the ISO interconnection queue, 150 (or almost half) have already been withdrawn and only 19 have completed the interconnection process.[72] Except for six small projects, every other renewable energy project still active in the queue has been in the queue for more than a year.[73] By considering only a 13 percent development increment, ARB has significantly understated the Project's potentially significant land use impacts.

ARB fails to state why *nonexistent* market conditions represent a more accurate environmental setting than the electricity sector, as it existed when ARB announced the RES plan.[74] ARB's analytical baseline is exactly the type of hypothetical regulatory baseline rejected by the California Supreme Court mere months ago. ARB must revise its analysis to evaluate the Project's impacts as compared to existing physical conditions, as required by CEQA.

## V. THE FED FAILS TO ANALYZE THE PROJECT'S POTENTIALLY SIGNIFICANT ENVIRONMENTAL EFFECTS

The lead agency's identification of a project's significant environmental effects is one of the primary purposes of an EIR and is necessary to implement CEQA's policy that significant environmental effects are mitigated to the degree feasible before Project approval.[75] A draft EIR must identify and focus on the possible significant environmental impacts of a proposed project.[76] In preparing an EIR, the agency must consider and resolve every fair argument that can be made about the possible significant environmental effects of a project, irrespective of whether an established threshold of significance has been met with respect to any given effect."[77] If after preparing the Initial Study, the lead agency determines that an effect is less than significant, the EIR must provide "a statement briefly indicating the reasons for determining that various effects on the environment of a project are not significant."[78]

---

[72] *Id.* at p. 4:12-17.

[73] *Id.*

[74] *Cf. San Joaquin Raptor Rescue Center v. County of Merced* (2007) 149 Cal.App.4th 645, 658.

[75] Kostka & Zischke, Practice Under the California Environmental Quality Act (2nd Ed. 2010), §13.2.

[76] Pub. Resources Code § 21100(b)(1); CEQA Guidelines §§ 15126(a), 15126.2.

[77] *Protect the Historic Amador Water Ways v. Amador Water Agency* 116 Cal.App.4th 1099, 1109.

[78] *Id. citing* CEQA § 21100(c); *see also* CEQA Guidelines § 15128.

### A. ARB Failed to Analyze the Public Health Impacts of Biomass Plants

Unlike other renewable energy technologies, the combustion of biofuel poses potentially significant public health risks through emissions of toxic air pollutants.[79] The ARB failed to analyze and mitigate for this potentially significant public health impact of biomass plants. A critical element in minimizing toxic air contaminants from biomass plants is the elimination of copper-chromium-arsenic ("CCA")-treated and pentachlorophenol-treated ("penta-treated") wood and painted wood and fines in wood waste used for fuel.[80] CCA is a major arsenic-based treatment chemical used to preserve wood. Although this chemical is no longer used domestically for residential uses, it is still used in industrial applications. Wood preservatives, especially CCA, accounted for most of the arsenic consumption in the United States until about 2004. As a result, a large quantity of arsenic-treated wood is currently in use and is present in significant amounts in construction and demolition ("C&D") wood waste. Its presence in the disposal sector is predicted to increase heavily in the near future.

No statewide standards for the content of C&D waste exist and most waste management firms rely on their own standards and specifications to remove the majority of the contaminants and non-burnables from the C&D waste. Limited test data from one facility indicate that concentrations of arsenic and dioxin are doubled and quadrupled, respectively, when burning 50 percent C&D wood compared to burning only forest biomass.[81] Due to concerns regarding the release of hazardous substances, several states have restricted or banned the use of C&D wood waste as fuel for biomass plants and other purposes. For example, New Hampshire has banned the use of C&D debris regardless of whether it is clean, unadulterated waste from construction sites or pressure-treated and painted wood, for example, from demolition activities. The State of Massachusetts has implemented a moratorium on use of C&D waste. The City of Portland, Oregon, prohibits any use, including combustion, of painted or pressure-treated woods except in "incidental"

---

[79] *See* Staff Report, p. IX-9.

[80] *See* Excerpts from Ellen Moyer, Ph.D., P.E., Should Construction and Demolition Wood Be Burned? An Evaluation of NESCAUM's May 2006 Report (attached hereto as **Attachment D**).

[81] *See id.*, at p. 23.

quantities.[82] The Maine Department of Environmental Protection has published detailed specifications limiting the permissible fraction of non-combustible materials, plastics, CCA-treated wood, fines, and asbestos in C&D wood waste and specifying fuel quality standards for arsenic, lead, and PCBs in blended biomass fuel.[83] The open burning of C&D waste also happens to be banned in the San Joaquin Valley Air District.[84]

At a minimum, the FED must identify the likely sources of agricultural wood waste and the likely types of agricultural materials that would be used as fuel. The FED must also analyze hazardous air pollutant ("HAP") emissions from the combustion of the amount of urban waste wood, including C&D waste, the Project is expected to use as fuel. Because the incineration of C&D waste may significantly increase HAP emissions, ARB must require the segregations of C&D waste to mitigate for the potentially significant adverse impacts of biomass combustion.

### B. ARB Failed to Analyze the Air Quality Impacts of Biomass Plants

ARB assumes that biomass facilities will not be concentrated in a particular air basin.[85] This major assumption is nowhere explained in the FED and, therefore, is not based on substantial evidence. Moreover, elsewhere in the Staff Report, ARB acknowledges that many biomass plants are located within the Sacramento and San Joaquin Valleys.[86] Contrary to the FED, biomass facilities occur in the vicinity of agricultural centers, where sources of biofuel are near and in abundance.[87] Currently, San Joaquin Valley, spanning San Joaquin, Stanislaus, Madera, Merced, Fresno, Tulare, Kings and Kern Counties, has the highest concentration of biomass facilities in the State. Fresno County, in particular, is the leading source of biomass fuel supply in the State, making it an attractive location for siting biomass

---

[82] *See* Ron Kotrba, The Politics of 'Dirty' Wood, Biomass Magazine, April 2009, available at: http://www.biomassmagazine.com/article.jsp?article_id=2539&q=&page=all (as of July 14, 2010) (attached hereto as **Attachment E**).

[83] Maine Department of Environmental Protection, Maine Solid Waste Management Rules: Chapter 418, Beneficial Use of Solid Wastes, June 16, 2006, pp. 13-14.

[84] District Rule 4103 § 5.1.

[85] Staff Report, pp. IX-16-17.

[86] Staff Report, p. V-4.

[87] *See* California Energy Commission website, http://www.energy.ca.gov/maps/power_plant.html

facilities.[88] This predominantly rural region of California also suffers from severe air pollution, ranking among the worst in the Nation.

The San Joaquin Valley Air Basin is designated "nonattainment" for fine particulate matter ("PM2.5") and "severe nonattainment" for ozone under the federal Clean Air Act.[89] In August 2009, the State requested that the U.S. Environmental Protection Agency classify the San Joaquin Valley as "extreme nonattainment" for ozone. The Valley was only recently designated in "attainment" of federal standards for PM10.

The siting of additional biomass combustion facilities in San Joaquin Valley could have disproportionate adverse air quality impacts on nearby communities. For example, *one* additional biomass combustion facility with a nominal capacity of 40 MW could emit approximately over 900 tons of criteria pollutants on an annual basis.[90] The emission of toxic air contaminants associated with a 40 MW biomass facility approximate significance thresholds for cancer risk.[91] Such a power plant would also emit over a million tons of GHGs per year.[92] As such, just one more utility scale biomass facility would be a major source of air pollution and a potential public health hazard for San Joaquin Valley. The FED fails to analyze the potentially significant air quality impacts of biomass facilities, and the potential for such facilities to have a disproportionate air quality impact in rural communities in the State. ARB must include this analysis, along with any necessary and feasible mitigation measures, in a revised FED.

### C. ARB Failed to Analyze the Land Use Impacts of Biomass Generation

---

[88] *See* Application for Certification for the San Joaquin Solar 1 & 2 Power Plant, In the Matter of the Application for Certification for the San Joaquin Solar 1 and 2 Hybrid Power Plant Project, California Energy Commission Docket No. 08-AFC-12, p. 3-5, *available at* http://www.energy.ca.gov/sitingcases/sjsolar/documents/applicant/afc/index.php (last visited 9/19/10).

[89] 75 Fed. Reg. 4,745, 4750-51 (Jan. 29, 2010).

[90] *See* Application for Certification for the San Joaquin Solar 1 & 2 Power Plant, In the Matter of the Application for Certification for the San Joaquin Solar 1 and 2 Hybrid Power Plant Project, California Energy Commission Docket No. 08-AFC-12, pp. 5.2-23-24, *available at* http://www.energy.ca.gov/sitingcases/sjsolar/documents/applicant/afc/index.php (last visited 9/19/10).

[91] *Id.* at pp. 5.16-14-5.16-16.

[92] *Id.* at p. 5.2-29.

The FED fails to differentiate among and discuss the disparate land use impacts of first generation and next generation biofuels.[93] First generation biofules are also commonly referred to as "conventional biofuels," and are produced primarily from major commercial crops such as corn, grain, and soybean. Second generation biofuels are produced from a variety of feedstocks and conversion technologies, including, but not limited to, solid municipal solid waste (e.g. tree trimmings, yard waste, paper products), forest residues and thinning, annual crop residues (e.g. corn stover), herbaceous perennial energy crops (e.g. native prairie grasses), and microalgae. Recent studies show that crop-based biofuels contribute to "deforestation and other damaging land conversion," potentially eliminating the benefits of this renewable energy sources.[94] "Traditional intensive corn-grain and soybean production practices are associated with rates of chemicals (e.g., fertilizer, pesticide) inputs, extensive water consumption in some regions, and many deleterious environmental effects such as soil erosion, surface water pollution, air pollution, and biodiversity losses."[95] There is consensus in the scientific community that such land use impacts of biomass generation are "real and significant."[96] ARB must revise the FED to include an analysis of the land use impacts of crop based fuels in and outside of California.

While second generation feedstocks are believed to be less taxing on the environment, significant uncertainty exists with respect to the land use impacts of these resources because they are not yet produced or collected on a commercial scale nationwide.[97] For example, "life-cycle GHG emissions from MSW [Municipal Solid Waste] –based ethanol are estimated to be approximately 60-80 percent less than that of conventional corn-grain ethanol."[98] However, "[i]t is currently unclear to what extent the allocation of potential upstream burdens associated with MSW (e.g. grass clippings produced from fertilized laws) might offset these GHG reductions."[99] The FED, however, fails to identify or analyze this uncertainty and the potentially

---

[93] Staff Report, Appendix E, p. E-51.
[94] Union of Concerned Scientists, *Land Use Changes and Biofuels Fact Sheet*, p. 2 ("Performance-based policies should reward reductions in global warming pollution over a fuel's full life cycle, based on the best available information and vetted in an open and transparent process.") (attached hereto as **Attachment B**); *see also* Williams, et al., *supra*, note 41 (attached hereto as **Attachment C**).
[95] *Id.*, at p. 4,763.
[96] Union of Concerned Scientists, *Land Use Changes and Biofuels Fact Sheet*, p. 2 (attached hereto as **Attachment B**).
[97] Williams, *supra* note 41, p. 4,765 (attached hereto as **Attachment C**).
[98] *Id.* at p. 4,765.
[99] *Id.*

significant adverse land use impacts of biomass generation in and outside of California.

### D. ARB Failed to Analyze the Indirect Land Use Impacts of Biomass Generation

ARB is required by CEQA to analyze the indirect physical changes in the environment which may be caused by the Project.[100] Even when a lead agency adopts regulations that ostensibly benefit the environment, CEQA requires an analysis of the regulation's possible unintended environmentally damaging side effects.[101] The use of traditionally unexploited biomass production systems, such as forests and prairies, is a foreseeable consequence of a regulatory program that incentivizes competition between biomass combustion facilities and other renewable energy technologies.[102] Forests and prairies "play an important role in supporting needed ecosystem services, including water purification, carbon sequestration, nutrient cycling, biodiversity, and recreation."[103] The FED does not discuss the Project's potentially significant adverse impacts on biomass production systems. ARB must include this analysis, along with any necessary and feasible mitigation measures, in a revised FED.

## VI. THE FED MUST BE REVISED AND RECIRCULATED FOR PUBLIC REVIEW AND COMMENT

ARB is required to revise the FED to adequately analyze and address the Project's impacts, and to recirculate the revised FED for public review and comment. CEQA requires recirculation when a draft environmental review document was so fundamentally and basically inadequate and conclusory in nature that meaningful public review and comment were precluded.[104] Recirculation is also required under CEQA when significant new information is added to the EIR following public review and before project certification.[105] The CEQA Guidelines

---

[100] CEQA Guidelines § 15064(d)

[101] *Dunn-Edwards Corporation v. Bay Area Air Quality Management District* (1992) 9 Cal. App.4th 644, 656.

[102] *See* Union of Concerned Scientists, *Land Use Changes and Biofuels Fact Sheet*, p. 2 (attached hereto as **Attachment B**).

[103] *Id.*

[104] CEQA Guidelines § 15088.5(a)(4).

[105] Pub. Resources Code § 21092.1; *see also* CEQA Guidelines § 15088.5.

clarify that new information is significant if "the EIR is changed in a way that deprives the public of a meaningful opportunity to comment upon a substantial adverse environmental effect of the project" including, for example, "a disclosure showing that … [a] new significant environmental impact would result from the project."[106] Here, ARB failed to identify the Project under review and to identify the potentially significant environmental impacts of its components, to establish a correct baseline for analyzing Project impacts, to identify and analyze the Project's potentially significant direct and indirect impacts, and to mitigate any such significant impacts to a level of insignificance. Because significant new information must be added to the FED to remedy these deficiencies, ARB must revise and recirculate the FED in accordance with CEQA.

## VII. CONCLUSION

Thank you for the opportunity to submit comments on the FED.

Sincerely,

/s/

Elizabeth Klebaner

EK:vs
Attachments

---

[106] CEQA Guidelines § 15088.5.

# ATTACHMENT A

Manomet Center for Conservation Sciences JUNE 2010 NCI-2010-03

NATURAL CAPITAL INITIATIVE AT MANOMET REPORT

# BIOMASS SUSTAINABILITY AND CARBON POLICY STUDY

### PREPARED FOR:

Commonwealth of Massachusetts
Department of Energy Resources
100 Cambridge Street
Boston, Massachusetts 02114

### PREPARED BY:

Manomet Center for Conservation Sciences
81 Stage Point Road
P.O. Box 1770
Manomet, Massachusetts 02345
Phone: (508) 224-6521

### CONTRIBUTORS:

Thomas Walker, Resource Economist (Study Team Leader)
Dr. Peter Cardellichio, Forest Economist
Andrea Colnes, Biomass Energy Resource Center
Dr. John Gunn, Manomet Center for Conservation Sciences
Brian Kittler, Pinchot Institute for Conservation
Bob Perschel, Forest Guild
Christopher Recchia, Biomass Energy Resource Center
Dr. David Saah, Spatial Informatics Group

### CONTACT INFORMATION FOR REPORT:

Manomet Center for Conservation Sciences
Natural Capital Initiative
14 Maine Street, Suite 305
Brunswick, Maine 04011
Phone: 207-721-9040
jgunn@manomet.org

Manomet Center for Conservation Sciences
14 Maine Street, Suite 305
Brunswick, ME 04011
Contact: 207-721-9040, jgunn@manomet.org

## ACKNOWLEDGEMENTS

This report was prepared for the Commonwealth of Massachusetts Department of Energy Resources in response to RFP ENE 2010-001.

Manomet Center for Conservation Sciences would like to acknowledge the thoughtful contributions to this study by our Advisory Panel: Dr. Clark Binkley (International Forestry Investment Advisors), Dr. David Foster (Harvard Forest), Mr. Paul Lemar, Jr. (Resource Dynamics Corporation), and Dr. Alaric Sample (Pinchot Institute for Conservation).

Also, additional staff at team members' organizations provided valuable input and technical support: John Hagan and Andrew Whitman (Manomet Center for Conservation Sciences); Adam Sherman and Kamalesh Doshi (Biomass Energy Resource Center); Zander Evans (Forest Guild); and Will Price (Pinchot Institute for Conservation).

Finally, we would like to thank Dr. Anne Perschel of Germane Consulting for skillfully organizing and leading the public meeting on December 17, 2009.

### SUGGESTED CITATION:

Manomet Center for Conservation Sciences. 2010. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Walker, T. (Ed.). Contributors: Cardellichio, P., Colnes, A., Gunn, J., Kittler, B., Perschel, R., Recchia, C., Saah, D., and Walker, T. Natural Capital Initiative Report NCI-2010-03. Brunswick, Maine.

## CONTENTS

# EXECUTIVE SUMMARY

# BIOMASS SUSTAINABILITY AND CARBON POLICY

## INTRODUCTION

This study addresses a wide array of scientific, economic and technological issues related to the use of forest biomass for generating energy in Massachusetts. The study team, assembled and directed by the Manomet Center for Conservation Sciences, was composed of experts in forest ecosystems management and policy; natural resource economics; and energy technology and policy. The Commonwealth of Massachusetts Department of Energy Resources (DOER) commissioned and funded the study.

The study provides analysis of three key energy and environmental policy questions that are being asked as the state develops its policies on the use of forest biomass.

1. What are the atmospheric greenhouse gas implications of shifting energy production from fossil fuel sources to forest biomass?
2. How much wood is available from forests to support biomass energy development in Massachusetts?
3. What are the potential ecological impacts of increased biomass harvests on forests in the Commonwealth, and what if any policies are needed to ensure these harvests are sustainable?

The goal of the report is to inform the development of DOER's biomass policies by providing up-to-date information and analysis on the scientific and economic issues raised by these questions. We have not been asked to propose specific policies except in the case where new approaches may be needed to protect the ecological functioning of forests. We do not consider non-forest sources of wood biomass (e.g., tree care and landscaping, mill residues, construction debris), which are potentially available in significant quantities but which have very different greenhouse gas (GHG) implications.

This Executive Summary highlights key results from our research and the implications for the development of biomass energy policies in Massachusetts. While certain of the study's insights are broadly applicable across the region (e.g., estimates of excess lifecycle emissions from combustion of biomass compared to fossil fuels), it is also important to recognize that many other conclusions are specific to the situation in Massachusetts—particularly greenhouse gas accounting outcomes that depend on the forest management practices of the state's landowners, which likely differ considerably from those in neighboring states. Nonetheless, the framework and approach that we have developed for assessing the impacts of wood biomass energy have wide applicability for other regions and countries.

## SUMMARY OF KEY FINDINGS

**Greenhouse Gases and Forest Biomass:** At the state, national, and international level, policies encouraging the development of forest biomass energy have generally adopted a view of biomass as a *carbon neutral* energy source because the carbon emissions were considered part of a natural cycle in which growing forests over time would re-capture the carbon emitted by wood-burning energy facilities. Beginning in the 1990s, however, researchers began conducting studies that reflect a more complex understanding of carbon cycle implications of biomass combustion. Our study, which is based on a comprehensive lifecycle carbon accounting framework, explores this more complex picture in the context of biomass energy development in Massachusetts.

The atmospheric greenhouse gas implications of burning forest biomass for energy vary depending on the characteristics of the bioenergy combustion technology, the fossil fuel technology it replaces, and the biophysical and forest management characteristics of the forests from which the biomass is harvested. Forest biomass generally emits more greenhouse gases than fossil fuels per unit of energy produced. We define these excess emissions as the biomass *carbon debt*. Over time, however, re-growth of the harvested forest removes this carbon from the atmosphere, reducing the carbon debt. After the point at which the debt is paid off, biomass begins yielding *carbon dividends* in the form of atmospheric greenhouse gas levels that are lower than would have occurred from the use of fossil fuels to produce the same amount of energy (Figure 1). The full recovery of the biomass carbon debt and the magnitude of the carbon dividend benefits also depend on future forest management actions and natural disturbance events allowing that recovery to occur.

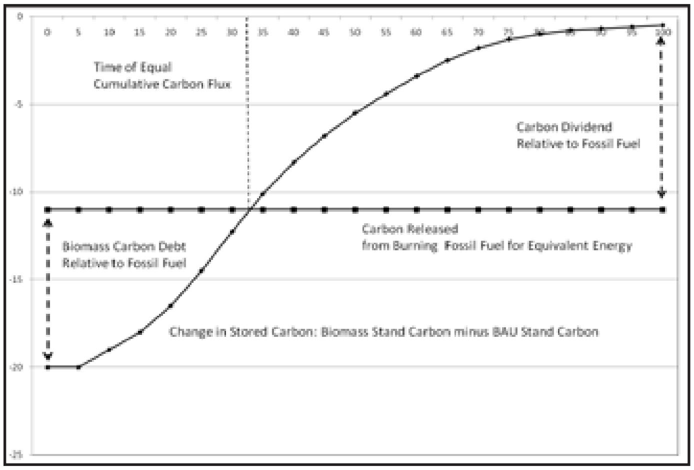


**Figure 1 (tonnes of carbon).** The schematic above represents the incremental carbon storage over time of a stand harvested for biomass energy wood relative to a typically harvested stand (BAU). The initial *carbon debt* (9 tonnes) is shown as the difference between the total carbon harvested for biomass (20 tonnes) and the carbon released by fossil fuel burning (11 tonnes) that produces an equivalent amount of energy. The *carbon dividend* is defined in the graph as the portion of the fossil fuel emissions (11 tonnes) that are offset by forest growth at a particular point in time. In the example, after the 9 tonnes biomass carbon debt is recovered by forest growth (year 32), atmospheric GHG levels fall below what they would have been had an equivalent amount of energy been generated from fossil fuels. This is the point at which the benefits of burning biomass begin to accrue, rising over time as the forest sequesters greater amounts of carbon relative to the typical harvest.

The initial level of the carbon debt is an important determinant of the desirability of producing energy from forest biomass. Figure 2 provides a summary of carbon debts, expressed as the percentage of total biomass emissions that are in excess of what would have been emitted from fossil fuel energy generation. Replacement of fossil fuels in thermal or combined heat and power (CHP) applications typically has lower initial carbon debts than is the case for utility-scale biomass electric plants because the thermal and CHP technologies achieve greater relative efficiency in converting biomass to useable energy. As a result, the time needed to pay off the carbon debt and begin accruing the benefits of biomass energy will be shorter for thermal and CHP technologies when the same forest management approaches are used in harvesting wood.

**Figure 2: Carbon Debt Summary Table**

| Excess Biomass Emissions as % of Total Biomass Emissions | | | | |
|---|---|---|---|---|
| **Scenarios** | **Coal** | **Oil (#6)** | **Oil (#2)** | **Natural Gas** |
| Electric | 31% | | | 66% |
| Thermal/ CHP | | 2%-8% | 9%-15% | 33%-37% |

The absolute magnitude and timing of the carbon debts and dividends, however, is sensitive to how landowners decide to manage their forests. Since future landowner responses to increased demand for forest biomass are highly uncertain, we modeled the recovery of carbon in growing forests under a number of alternative management scenarios.

For a scenario that results in relatively rapid realization of greenhouse gas benefits, the switch to biomass yields benefits within the first decade when oil-fired thermal and CHP capacity is replaced, and between 20 and 30 years when natural gas thermal is replaced (Figure 3). Under comparable forest management assumptions, dividends from biomass replacement of coal-fired electric capacity begin at approximately 20 years. When biomass is assumed to replace natural gas electric capacity, carbon debts are still not paid off after 90 years.

**Figure 3: Carbon Debt Payoff**

| Fossil Fuel Technology | Carbon Debt Payoff (yr) |
|---|---|
| Oil (#6), Thermal/CHP | 5 |
| Coal, Electric | 21 |
| Gas, Thermal | 24 |
| Gas, Electric | >90 |

Another way to consider greenhouse gas impacts of biomass energy is to evaluate at some future point in time the cumulative carbon emissions of biomass (net of forest recapture of carbon) relative to continued burning of fossil fuels. The Massachusetts Global Warming Solutions Act establishes 2050 as an important reference year for demonstrating progress in reducing greenhouse gas emissions. Figure 4, comparing 40 years of biomass emissions with 40 years of continued fossil fuel burning, shows that replacement of oil-fired thermal/CHP capacity with biomass thermal/CHP fully offsets the carbon debt and lowers greenhouse gas levels compared to what would have been the case if fossil fuels had been used over the same period—approximately 25% lower over the period under a rapid recovery scenario. For biomass replacement of coal-fired power plants, the net cumulative emissions in 2050 are approximately equal to what they would have been burning coal; and for replacement of natural gas cumulative total emissions are substantially higher with biomass electricity generation.

**Figure 4: Cumulative Carbon Dividends from Biomass Replacement of Fossil Fuel**

| Biomass Cumulative % Reduction in Carbon Emissions (Net of Forest Carbon Sequestration) | | | | |
|---|---|---|---|---|
| **Year** | **Oil (#6) Thermal/ CHP** | **Coal, Electric** | **Gas, Thermal** | **Gas, Electric** |
| **2050** | 25% | -3% | -13% | -110% |
| **2100** | 42% | 19% | 12% | -63% |

**Forest Biomass Supply:** Future new supplies of forest biomass available for energy generation in Massachusetts depend heavily on the prices that bioenergy facilities are able to pay for wood. At present, landowners in the region typically receive between $1 and $2 per green ton of biomass, resulting in delivered prices at large-scale electricity facilities of around $30 per green ton. Under current policies that are influenced by the competitive dynamics of the electricity sector, we do not expect that utility-scale purchasers of biomass will be able to significantly increase the prices paid to landowners for biomass. Consequently, if future forest biomass demand comes primarily from large-scale electric facilities, we estimate the total "new" biomass that could be harvested annually from forest lands in Massachusetts would be between 150,000 and 250,000 green tons—an amount sufficient to support 20 MW of electric power capacity—with these estimates potentially increasing by 50%–100% when out-of-state forest biomass sources are taken into account (these estimates do not include biomass from land clearing or other non-forest sources such as tree work and landscaping). This is the amount of incremental biomass that would be economically available and reflects the costs of harvesting, processing and transporting this material as well as our expectations about the area of land where harvest intensity is likely to increase. Thermal, CHP, and other bioenergy plants can also compete for this same wood—which could support 16 typically sized thermal facilities or 4 typical CHP plants—and have the ability to pay much higher prices on a delivered basis; thus, they have more options for harvesting and processing forest biomass and can outbid electric power if necessary.

Paying higher prices to landowners for forest biomass could potentially increase forest biomass supplies significantly. For this to occur, electricity prices would need to rise, due to substantially higher fossil fuel prices or significant policy shifts. Thermal, CHP, and pellet facilities can already pay much higher prices for biomass at current energy prices, and would remain competitive if prices paid to landowners were to rise significantly. If these prices were to increase to $20 per green ton, we estimate that supplies of forest biomass from combined in-state and out-of-state sources could be as high as 1.2 to 1.5 million green tons per year. However, this high-price scenario is unlikely given current expectations of fossil fuel prices and existing renewable energy incentives.

Figure 5 shows the potential bioenergy capacity that could be supported from these estimated volumes of "new" forest biomass in Massachusetts. The upper end of the range for Massachusetts forest biomass supplies under our high-price scenario is approximately 885,000 green tons per year—this is close to the annual quantity of biomass that can be harvested without exceeding the annual net growth of the forest on the operable private land base. If additional forest biomass supplies that would be potentially available from out-of-state sources are taken into account, the biomass quantity and number of bioenergy facilities that could be furnished would be 50%–100% higher than shown in this table.

**Figure 5: Potential Bioenergy Capacity from "New" Forest Biomass Sources in Massachusetts**

| | **Green Tons per Year** |
|---|---|
| Current Massachusetts Harvest * | 325,000 |
| Potential Forest Biomass Supply (Massachusetts only) ** | |
| Current Biomass Prices | 200,000 |
| High-Price Scenario | 800,000 |
| | **Number of Facilities** |
| Electric Power Capacity: Number of 50 MW Plants | |
| Current Biomass Prices | 0.4 |
| High-Price Scenario | 1.6 |
| Thermal Capacity: Number of 50 MMBtu/hr Plants *** | |
| Current Biomass Prices | 16 |
| High-Price Scenario | 62 |
| CHP Capacity: Number of 5 MW/34 MMBtu/hr Plants *** | |
| Current Biomass Prices | 4 |
| High-Price Scenario | 15 |

***Notes:*** ** Average of industrial roundwood for 2001–2009.*
*** Based on mid-point of the range of volumes estimated for new biomass in Massachusetts.*
**** Thermal plants are assumed to operate 1800 hours per year, while CHP plants operate 7200 hours per year.*

**Forest Sustainability and Biomass Harvests:** In Massachusetts, the possibility of increased harvesting of biomass for energy has raised a number of sustainability issues at both the landscape and stand levels. At the landscape scale, potential impacts to a broad range of societal values arise with increases in biomass harvesting. However, in our low-price scenario for biomass, we anticipate that harvested acreage will not increase from current levels—biomass will come from removal of logging residues and poor quality trees at sites that would be harvested for timber under a business-as-usual scenario. Furthermore, in this scenario the combined volume of timber and biomass harvests represents less than half of the annual net forest growth across the state's operable private forest land base. Under our high-price biomass supply scenario, although harvests still represent annual cutting on only about 1% of the forested lands in the state, the total harvest levels approach the total amount of wood grown each year on the operable private forest land base.

Under either price scenario, however, harvests for bioenergy facilities could have more significant local or regional impacts on the landscape. These might include aesthetic impacts of locally heavy harvesting as well as potential impacts on recreation and tourism and the longer-term health of the wood products sector of the economy. We have outlined four general options encompassing a wide range of non-regulatory and regulatory approaches that the state may wish to consider if it determines that further actions are needed to protect public values at the landscape scale.

- Option 1: Establish a transparent self-monitoring, self-reporting process for bioenergy facilities designed to foster sustainable wood procurement practices.
- Option 2: Require bioenergy facilities to purchase wood from forests with approved forest management plans.
- Option 3: Require bioenergy facilities to submit wood supply impact assessments.
- Option 4: Establish formal criteria for approval of wood supply impact assessments—possible criteria might include limits on the amount of harvests relative to anticipated forest growth in the wood basket zone.

At the stand level, the most significant sustainability concerns associated with increased biomass harvests are maintenance of soil productivity and biodiversity. Current Chapter 132 Massachusetts forest cutting practices regulations provide generally strong protection for Massachusetts forests, especially water quality; however, they are not currently adequate to ensure that biomass harvesting is protective of ecological values across the full range of site conditions in Massachusetts. Other states and countries have recently adopted biomass harvesting guidelines to address these types of concerns, typically through new standards that ensure (1) enough coarse woody debris is left on the ground, particularly at nutrient poor sites, to ensure continued soil productivity and (2) enough standing dead wildlife trees remain to promote biodiversity. While the scientific literature does not provide definitive advice on the appropriate practices for Massachusetts' forests, recent guidance from the Forest Guild and other states provides the State Forestry Committee with a useful starting point for developing additional stand level standards that ensure continued protection of ecological values in Massachusetts forests.

# CHAPTER 1

# INTERNATIONAL AND U.S. FOREST BIOMASS ENERGY POLICIES

## 1.1 OVERVIEW

International and U.S. domestic forest biomass energy policies form a critical backdrop to the analyses presented in this report. The purpose of this introductory chapter is to provide a general understanding of (1) the development of policies that have driven the growth of the biomass energy sector; (2) the key policy instruments that have been relied upon to promote this development; and (3) a summary of recent discussions about the greenhouse gas (GHG) implications of forest biomass energy.

The chapter is organized into two major sections. The first reviews international biomass energy policies—focusing on the historical development of these policies, discussing the policy instruments in place that promote biomass development, and summarizing recent concerns about the impact on GHG of emissions from biomass energy facilities. The second section provides a more detailed review of U.S. energy policies affecting forest biomass both at the federal and state levels, with a particular focus on policies in Massachusetts.

## 1.2 INTERNATIONAL FOREST BIOMASS ENERGY POLICIES

### 1.2.1 Historical Context

The late 20th century development of forest biomass energy facilities originated from energy security concerns triggered by the 1973–1974 oil crisis. The International Energy Agency (IEA) was founded at this time primarily to address the security issue.

> *Energy Security can be described as "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns." The need to increase "energy security" was the main objective underpinning the establishment of the IEA. With particular emphasis on oil security, the Agency was created in order to establish effective mechanisms for the implementation of policies on a broad spectrum of energy issues: mechanisms that were workable and reliable, and could be implemented on a co-operative basis (International Energy Agency, 2010).*

Although IEA's original founding agreements did not explicitly address forest biomass, the agency created IEA Bioenergy in 1978 with:

> *…the aim of improving cooperation and information exchange between countries that have national programmes in bioenergy research, development and deployment (IEA Bioenergy, 2010).*

Our review of available documents suggests that prior to IEA Bioenergy's 1998–2002 Strategic Plan (IEA Bioenergy, NA), the greenhouse gas implications of forest biomass combustion were not a primary area of research for the organization (IEA Bioenergy, 1995). Moreover, recent IEA policies have continued to reflect the view that biomass combustion is "close to carbon neutral in most instances" (International Energy Agency, 2007).

In fact, from a climate change perspective, the desirability of biomass energy appears to have been the prevailing wisdom of international bioenergy policies over most of the past ten or fifteen years. These policies have generally equated burning of biomass from renewable sources with "climate friendly" outcomes. The presumption has been that as long as the harvested areas grow back as forests, the emitted $CO_2$ emissions will be recaptured in the growing trees, resulting in lower net $CO_2$ emissions over time across the entire energy generation sector. For example, in a 2000 study of forestry and land use, the Intergovernmental Panel on Climate Change (IPCC), the lead international organization charged with assessing impacts of greenhouse gas emissions, stated that:

> *Biomass energy can be used to avoid greenhouse gas emissions from fossil fuels by providing equivalent energy services: electricity, transportation fuels, and heat. The avoided fossil fuel $CO_2$ emissions of a biomass energy system are equal to the fossil fuels substituted by biomass energy services minus the fossil fuels used in the biomass energy system. These quantities can be estimated with a full fuel-cycle analysis of the system. The net effect on fossil fuel $CO_2$ emissions is evident as a reduction in fossil fuel consumption (IPCC, 2000).*

In its most recent 2007 assessment, IPCC noted that:

> *In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit.*
>
> *For the purpose of this discussion, the options available to reduce emissions by sources and/or to increase removals by sinks in the forest sector are grouped into four general categories (1)…(4) increasing the use of biomass-derived energy to substitute fossil fuels (IPCC, 2007).*

European Union policies also promote the use of forest biomass energy, as embodied in the EU's 2006 Forest Action Plan:

> *The EU has adopted an ambitious energy and climate policy which aims by 2020 to reduce energy consumption by 20%, with a similar cut in $CO_2$ emissions, while raising the share of renewables in the EU's energy mix to 20%.*
>
> *More than half of the EU's renewable energy already comes from biomass, 80% of which is wood biomass. Wood can play an important role as a provider of biomass energy to offset fossil fuel emissions, and as an environmentally friendly material. There has recently been higher demand for wood from the energy sector in addition to*

> *rising demand from the established wood-processing industries. Many experts consider that significantly more wood could be mobilised from EU forests than is currently the case. However, the cost at which this can be done is the key factor (EU, 2006).*

In approving the Forest Action Plan, the Commission of European Communities identified a variety of key actions, including:

> *Key action 4: Promote the use of forest biomass for energy generation*
>
> *Using wood as an energy source can help to mitigate climate change by substituting fossil fuel, improving energy self-sufficiency, enhancing security of supply and providing job opportunities in rural areas.*
>
> *The Standing Forestry Committee will support the implementation of the Biomass Action Plan (Commission of European Communities, 2005) in particular concerning the development of markets for pellets and chips and information to forest owners about the opportunities of energy feedstock production.*
>
> *The Commission will facilitate investigation and dissemination of experience on mobilisation of low-value timber, small-sized wood and wood residues for energy production. The Member States will assess the availability of wood and wood residues and the feasibility of using them for energy production at national and regional levels, in order to consider further actions in support of the use of wood for energy generation. The 7th Research Framework Programme and the IEE-CIP provide the necessary possibilities to facilitate such activities.*
>
> *The Commission will continue to support research and development of technologies for the production of heat, cooling, electricity and fuels from forest resources in the energy theme of the 7th Research Framework Programme's cooperation specific programme, and to encourage the development of the biofuel technology platform and support the implementation of its research agenda through the 7th Research Framework Programme (Commission of European Communities, 2006).*

### 1.2.2 POLICY INSTRUMENTS

Energy policies for forest biomass are embedded in a broader system of policies promoting the development of renewable energy sources. These policies are typically implemented through incentive schemes such as feed-in tariffs that guarantee favorable purchase prices for renewables and through Renewable Portfolio Standards (RPS) requiring that renewable sources constitute a certain minimum percentage of energy generation. A 2009 status report from the Renewable Energy Policy Network for the 21st Century (REN21) provides summary data characterizing the renewable energy policies of countries around the globe. According to REN21:

> *By early 2009, policy targets existed in at least 73 countries, and at least 64 countries had policies to promote renewable power generation, including 45 countries and 18 states/provinces/territories with feed-in tariffs (many of these recently updated). The number of countries/states/provinces with renewable portfolio standards increased to 49. Policy targets for renewable energy were added, supplemented, revised, or clarified in a large number of countries in 2008 (Renewable Energy Policy Network for the 21st Century, 2009).*[1]

By allowing projects to qualify for feed-in tariffs and be counted towards RPS goals, designation of forest biomass as a renewable energy source has been an important driver of biomass energy project development. The REN21 status report indicates that by the end of 2008, 52 GW of biomass power capacity existed worldwide, about evenly split between developed and developing countries. The European Union and United States accounted for 15 GW and 8 GW of this capacity, respectively. About 2 GW of this total were added in 2008, an annual increase of approximately 4 percent.

Within the broad context of biomass energy policies, individual countries have emphasized different policy instruments. A variety of researchers have conducted assessments of country-specific impacts of biomass policies—for an excellent summary see (Junginger, 2007). Faaij (2006) points out that:

> *All EU-15 countries implemented policies for supporting bioenergy. These include the deployment of compensation schemes, tax deduction (in some cases specifically aimed at biofuels), feed-in tariffs, tax incentives, energy tax exemption, bidding schemes, CO2-tax and quota. Precise targets on the national level differ strongly however and are hard to compare because of differences in definitions and fuels in or excluded (such as MSW and peat).The same is true for the level of (financial) support provided through the various programs and instruments. The different countries clearly have chosen very different approaches in developing and deploying various bio-energy options. Partly this is caused by the natural conditions (type of resources and crops, climate) and the structure of the energy system, and also by the specific political priorities linked to the agricultural and forestry sectors in those countries.*

A general conclusion of these studies is that higher rates of biomass energy development are typically a function not of any single factor but instead result from the combined effects of a variety of policy instruments, in the context of a country's existing mix of energy sources and the degree of development of its forestry sector (Kautto, 2007; Junginger, 2007). For example, Sweden is one of the European countries that have most rapidly adopted biomass energy systems. Two key factors have been identified as

---

[1] For an extensive list of countries and their policies, see Table 2, pages 23–24, www.ren21.net/pdf/RE2007_Global_Status_Report.pdf, and pages 17–18 of www.ren21.net/pdf/RE_GSR_2009_Update.pdf

the basis for this growth. First is the presence of a large and well-developed forest products sector. Second, the design of Sweden's tax system has strongly encouraged biomass development through a range of mutually reinforcing policies.

> *Overall it appears that taxation has been a very effective policy instrument in increasing biomass utilisation in Sweden throughout the 1990's. This has particularly been the case in the heat sector, but, following market liberalisation, significant increases in the electricity sector have also been noted. It should be noted in this respect that the Swedish tax regime is long established and comprises multiple layers of VAT, energy and $CO_2$ taxes, increasing the effectiveness of tax increases. There is also a complex and frequently modified system of allocating rebates to certain industries that has enabled the tax to be augmented as required to encourage biomass use at the expense of fossil fuels, while maintaining competitive industrial advantage (Cooper & Thornley, 2007).*

On the other hand, Faaij (2006) points out that France's focus on biofuels and heat is primarily a function of excess capacity in its nuclear electricity production sector, making electrical generation from biomass unattractive.

The government policies of non-European countries also could dramatically increase biomass energy generation. For example, China has established a variety of policy goals that will promote biomass energy development (Roberts, 2010). By 2020, China is proposing to build 24 GW of biomass power capacity, equivalent to more than eight 25 MW plants per month over the next decade, although Roberts notes this is overly ambitious and likely to be downgraded to 10 GW. Although most of China's biomass appears to be based on agricultural wastes, plans do include increasing wood pellet production from two million tons per year in 2010 to 50 million tons per year by 2020 and developing 13.3 million hectares of forests to produce biomass feedstock. According to Roberts (2010), China has accounted for 23 percent of recent worldwide investment in biomass energy (compared with Europe's 44 percent share). Policies in large forested countries like Canada are also aimed at promoting biomass energy development, although Roberts notes that Canada has been slow in developing its bioenergy resources and that most "meaningful" biomass policies are being put in place at the provincial level, for example Ontario's feed-in tariffs and British Columbia's carbon tax.

Overall, growth of the biomass sector internationally could have important implications for the U.S. and Massachusetts. In Britain, two 300 MW biomass power plants are currently in the planning stages. These plants are projected to consume six million green tons of wood chips annually, purchased from around the globe, with New England identified as a possible source of woodchips (MGT Power, 2010). Given the potential for such increased international trade in biomass, Massachusetts forests could become suppliers of biomass regardless of whether any biomass plants are actually built in the state.

### 1.2.3 SUSTAINABILITY CONCERNS

Although mainstream policies continue to promote biomass as a renewable and carbon friendly fuel, the international policy framework is beginning to require more detailed assessments of the carbon implications of bioenergy development. This more sophisticated approach to understanding the greenhouse gas implications of climate policy dates from the 1990s when researchers began building formal models to explore the impacts of biomass combustion on greenhouse gas levels, for example studies by Marland and Schlamadinger (1995).[2] Work along these lines became a prominent feature of research conducted IEA Bioenergy Task 38, which is focused directly on the climate change implications of biomass combustion for energy. Researchers contributing to Task 38 have pointed out the difficulty of generalizing about the climate benefits of biomass combustion. This view was expressed in a December 2009 status report from IEA Bioenergy issued to coincide with the Copenhagen conference on climate change. This report provided a clearly articulated summary of the current, and in our view state-of-the-art, thinking on the impacts of forest biomass combustion on greenhouse gases.

> *Ranking of land use options based on their contribution to climate change mitigation is also complicated by the fact that the performance of the different options is site-specific and is determined by many parameters. Among the more critical parameters are:*
>
> - *Biomass productivity and the efficiency with which the harvested material is used—high productivity and efficiency in use favour the bioenergy option. Low productivity land may be better used for carbon sinks, given that this can be accomplished without displacing land users to other areas where their activities lead to indirect $CO_2$ emissions. Local acceptance is also a prerequisite for the long-term integrity of sink projects.*
> - *The fossil fuel system to be displaced—the GHG emissions reduction is for instance higher when bioenergy replaces coal that is used with low efficiency and lower when it replaces efficient natural gas-based electricity or gasoline/diesel for transport.*
> - *The initial state of the land converted to carbon sinks or bioenergy plantations (and of land elsewhere possibly impacted indirectly)—conversion of land with large carbon stocks in soils and vegetation can completely negate the climate benefit of the sink/bioenergy establishment.*
> - *The relative attractiveness of the bioenergy and carbon sink options is also dependent on the timescale that is used for the evaluation. A short timeframe (a few*

---

[2] For a more complete list of Task 38 background papers from the 1990s, see www.ieabioenergy-task38.org/publications/backgroundpapers/backgroundpapers.htm#marland1

> *decades) tends to favour the sink option, while a longer timeframe favours the bioenergy option. The reason is that the accumulation of carbon in forests and soils cannot continue endlessly—the forest eventually matures and reaches a steady state condition. This is also the case for soils. In contrast, bioenergy can be produced repeatedly and continue to deliver greenhouse gas emissions reduction by substituting fossil fuels.*
>
> *The bioenergy and carbon sink options obviously differ in their influence on the energy and transport systems. Bioenergy promotion induces system changes as the use of biofuels for heat, power, and transport increases. In contrast, the carbon sink option reduces the need for system change in relation to a given climate target since it has the same effect as shifting to a less ambitious climate target. The lock-in character of the sink option is one disadvantage: mature forests that have ceased to serve as carbon sinks can in principle be managed in a conventional manner to produce timber and other forest products, offering a relatively low GHG reduction per hectare. Alternatively, they could be converted to higher yielding energy plantations (or to food production) but this would involve the release of at least part of the carbon store created. On the other hand, carbon sinks can be viewed as a way to buy time for the advancement of climate-friendly energy technologies other than bioenergy. Thus, from an energy and transport systems transformation perspective, the merits of the two options are highly dependent on expectations about other energy technologies (IEA Bioenergy, 2009).*

Growing concerns about greenhouse gas impacts of forest biomass policies also surfaced recently in journal articles by Johnson (2008) and by Searchinger, et al. (2009). The Searchinger article, appearing in Science and titled "Fixing a Critical Climate Accounting Error," points out that rules for applying the Kyoto Protocol and national cap-and-trade laws contain a major flaw in that the $CO_2$ emissions from biomass energy are not properly taken into account because they embody the implicit assumption that all biomass energy is carbon neutral. Consistent with the recent IEA report discussed above, Searchinger's critique states:

> *The potential of bioenergy to reduce greenhouse gas emissions inherently depends on the source of the biomass and its net land-use effects. Replacing fossil fuels with bioenergy does not by itself reduce carbon emissions, because $CO_2$ released by tailpipes and smokestacks is roughly the same per unit of energy regardless of the source. Bioenergy therefore reduces greenhouse gases only if the growth and harvesting of the biomass for energy capture carbon above and beyond what would be sequestered anyway and thereby offset emissions from energy use. This additional carbon may result from land management changes that increase plant uptake or from the use of biomass that would otherwise decompose rapidly.*

In on-line supporting material for the Science article, Searchinger et al. note that:

> ***Use of forests for electricity on additional carbon:*** *Roughly a quarter of anthropogenic emissions of carbon dioxide are removed from the atmosphere by the terrestrial carbon sink, of which the re-growth of forests cut in previous decades plays a major role. Any gain in carbon stored in regenerating forests contributes to the sink, so activities that keep otherwise regenerating forests to constant levels of carbon reduces that sink relative to what would have occurred without those activities.*
>
> *The net effect of harvesting wood for bioenergy is complicated and requires more analysis. Each ton of wood consumed in a boiler instead of coal does not significantly alter combustion emissions. However, some of the wood in standing timber is typically not utilized and is left to decay in the forest or nearby, causing additional emissions. Much of the carbon in roots will also decompose. Replanting may accelerate release of carbon from forest soils. As the forest regenerates following cutting, it may sequester carbon faster or slower than would have occurred in the absence of the harvesting, depending on the previous forest's age, site quality and forest type. Over long periods, the carbon stocks of the forests with and without the harvest for biofuels may be equal. For this reason, how different emissions are valued over time plays an important role in estimating the net carbon effects of harvesting wood for use as a bioenergy.*

In Europe, policies towards biomass may be beginning to reflect this more complex view of potential greenhouse gas impacts. A 2009 EU policy directive recognizes the need to demonstrate the sustainability of biomass energy, and specifies that the European Commission complete such a study.

> *Section 75: The requirements for a sustainability scheme for energy uses of biomass, other than bioliquids and biofuels, should be analysed by the Commission in 2009, taking into account the need for biomass resources to be managed in a sustainable manner (European Parliament and Council, 2009).*

However, the results of this recently completed study of biomass sustainability take as a starting point the presumption of biomass carbon neutrality—adopting the long-term view that $CO_2$ emissions from combusted biomass eventually will be recaptured as long as the forests are regenerated. In this context, the report goes on to discuss a variety of recommended policy options including ones to ensure that all biomass is sourced from certified sustainable supplies. To the extent that this new report becomes the basis for future EU policies, such policies would appear to adopt a very long-term view of the relevant timeframe for biomass policies, one that does not place great emphasis on the potential for shorter term increases in $CO_2$ flux that likely result from forest biomass energy generation.

At the broader international level, the IPCC is also in the processing of preparing a new report on renewable energy that is expected to be published in 2011. Initial indications are that this report will provide more detailed considerations of the carbon issue for forest biomass.

## 1.3 U.S. FEDERAL FOREST BIOMASS ENERGY POLICIES

### 1.3.1 Most Significant Federal Programs & Incentives for Biomass Energy

Federal incentives for renewable energy (including forest biomass) have taken many forms over the past four decades. The focus of most of these programs has been on encouraging renewable electricity generation and, more recently, production of renewable transportation fuels, such as ethanol. The third area of energy use—thermal applications for heat, cooling and industrial process heat—has not been a focus of federal energy programs until very recently. A summary of the full scope of existing federal programs and incentives related to the development of biomass energy facilities is included as Appendix 1-A to this report.

Federal policy initially encouraged renewable electricity generation by requiring utilities to purchase electricity from renewable energy generators at a fixed cost through the Public Utility Regulatory Policy Act (PURPA). More recently, federal policy has shifted towards encouraging renewable energy through tax incentives and direct grants—with the primary focus on renewable transportation fuels and renewable electricity generation.

The thrust of current federal investment in renewable energy is summarized in a recent report by the Environmental Law Institute (Environmental Law Institute, 2009). From 2002 through 2008 the U.S. Government spent approximately $29 billion on renewable energy subsidies (compared to $72 billion spent on fossil fuels). Of this $29 billion, most was dedicated to transportation fuels or electricity generation through a combination of tax programs and direct grants and loans.

- **Transportation fuels** via corn-based ethanol production received more than half of the total subsidies ($16 billion), primarily through the Volumetric Ethanol Excise Tax Credit Program (VEETC) ($11 billion) and the corn-based ethanol grant program ($5 billion).
- **Renewable electricity generation** projects received approximately $6 billion in subsidies during this seven-year period, principally through the Production Tax Credit ($5 billion), the Investment Tax Credit ($250 million), the Modified Accelerated Cost Recovery System ($200 million), and the Clean Renewable Energy Bond program ($85 million).
- **Thermal energy** as a sector received no significant subsidies.

Within the electric power sector biomass facilities are eligible for funding under these four primary renewable electricity generation incentives (the Production Tax Credit, Investment Tax Credit, Modified Accelerated Cost Recovery System, and Clean Renewable Energy Bond program); however they have received a relatively small share of the total funding. The U.S. Energy Information Administration (EIA) estimates that in fiscal year 2007, open-loop biomass facilities received approximately $4 million in tax credits under the production tax credit program, compared to approximately $600 million for wind facilities. Funding for combined heat and power or purely thermal facilities is also negligible compared to expenditures on other renewable resources (EIA, 2008). And many of the biomass-specific grant programs have total annual allocations in the $1 to $5 million range, with individual projects often capped in the $50,000 to $500,000 range.

The primary federal subsidy or incentive to biomass electric power production is the Renewable Electricity Production Tax Credit which provides $0.011 per kWh or approximately $10 per MWh.[3] As discussed more fully below, while smaller in value than state Renewable Energy Credits (REC's), which currently average between $20–$35 per MWh, the PTC does provide a significant and stable incentive for the development of biomass power over time. The American Recovery and Reinvestment Act of 2009 allows taxpayers eligible for the federal renewable electricity production tax credit (PTC) to take the federal business energy investment tax credit (ITC) or to receive a grant from the U.S. Treasury Department instead of taking the PTC for new installations for up to 30% of capital costs following the beginning of commercial production. The new law also allows taxpayers eligible for the business ITC to receive a grant from the U.S. Treasury instead of taking the business ITC for new installations. Grants are available to eligible properties placed in service in 2009 or 2010, or if completed by 2013.

Within federal subsidies specific to biomass energy, there is an even greater emphasis on transportation fuels, a very limited focus on biomass power, and no historic public policy support for biomass thermal applications.

In addition to the federal Production Tax Credit, the Biomass Crop Assistance Program (BCAP) has provided significant subsidies over the past year to the biomass supply sector. However, it is considered unlikely that the current high level of subsidies will continue. Created in the 2008 Farm Bill, BCAP (sec. 9011) is an innovative program intended to support establishment and production of eligible crops for conversion to bio-energy, and to assist agricultural and forest landowners with collection, harvest, storage, and transportation (CHST) of these eligible materials to approved biomass conversion facilities (BCF).

---

[3] The federal renewable electricity production tax credit (PTC) is a per-kilowatt-hour tax credit for electricity generated by qualified energy resources and sold by the taxpayer to an unrelated person during the taxable year. Originally enacted in 1992, the PTC has been renewed and expanded numerous times, most recently by H.R. 1424 (Div. B, Sec. 101 & 102) in October 2008 and again by H.R. 1 (Div. B, Section 1101 & 1102) in February 2009. Efforts to again renew the PTC are currently underway in the US Congress.

The program pays for up to 75% of establishment costs of new energy crops. In addition, farmers participating in a selected BCAP project area surrounding a qualifying BCF can collect five years of payments (15 years for woody biomass) for the establishment of new energy crops. An additional matching payment of up to $45/ton (on a $1 to $1 basis) to assist with collection, harvest, storage and transportation (CHST) of an eligible material to a BCF will also be available for a period of two years.

The launch of this new program has resulted in a substantial new subsidy for the existing wood market with significant market impact. Large numbers of existing biomass conversion facilities (led by lumber, pellet and paper mills currently burning wood for their own energy use without a federal subsidy) submitted applications to USDA to be approved as qualifying facilities. Consequently, funds obligated (though not yet spent) for BCAP through the end of March 2010 soared to over $500 million, more than seven times BCAP's estimated budget of $70 million in the 2008 Farm Bill. The USDA now estimates BCAP costs at $2.1 billion on CHST from 2010 through 2013.

USDA has allocated $2.1 million to Massachusetts for BCAP payments and $500,000 has been dispersed to date. Despite broad outreach (11 public meetings and other efforts), BCAP enrollment has been limited in the state, probably due to the limited array of biomass facilities. In Massachusetts, there are two qualifying biomass conversion facilities (BCF): Pinetree Power (17 MW electric generation facility) and LaSalle Florists, a very small greenhouse operation (USDA, 2010). Pinetree Power has about 20–25 suppliers that are approved eligible material owners (EMO). Based on interviews with procurement personnel at the Pinetree facility, the long-term impact of BCAP is unknown at this point. Overall, it is perceived to have created instability in the supply sector, potentially cutting costs for the electric power industry, but increasing costs for other competing industries that are not enrolled in the program. In Pinetree's view, it also might encourage overcutting in response to the short-term subsidy to suppliers. The lack of forest management requirements for the program was also noted.[4]

Based on interviews with Cousineau Forest Products, a leader in the wood brokerage industry for pulp, chips and biomass supplies across New England and the east, approximately 50% of the BCAP subsidy is being passed onto qualifying facilities from suppliers in the form of lower prices paid for fuel. Consequently, as currently structured, the BCAP program is significantly lowering fuel costs for the biomass power sector. Where landholdings are small, such as in Massachusetts, these savings generally accrue to loggers and the biomass consumers. In areas with larger landholdings, more of these savings go to landowners.

The Commodity Credit Corporation (CCC) has issued a draft rule to implement BCAP specifying the requirements for eligible participants, biomass conversion facilities, and biomass crops and materials. Public comment on the draft rule closed on April 9, 2010. Comments on the rule address a diversity of issues ranging from overall support for the continuation of the program to concern that the initial focus on CHST payments has resulted in a substantial new subsidy for the existing woody-biomass market, creating market distortions and instability in the supply sector, cutting costs for some users (e.g., biomass power plants) and increasing costs for other competing industries (OSB manufacturers and other users of bark and chips). In addition, some comments have raised the issue of the absence of forest management requirements in BCAP could encourage overcutting in response to the short term subsidy to suppliers. Others have spoken to the need to focus BCAP on directing more resources towards the establishment and production of new energy crops, so the program can fulfill its purpose of expanding the amount of biomass available for alternative energy.

### 1.3.2 ENVIRONMENTAL PROTECTION AGENCY POSITION ON BIOMASS ENERGY AND CARBON ACCOUNTING[5]

As determined by the Environmental Protection Agency in their final rule on Mandatory Reporting of Greenhouse Gases, electric generation and thermal facilities are not required to count emissions associated with biomass combustion when determining whether they meet or exceed the threshold for reporting (emission of 25,000 metric tons per year for all aggregated sources at a facility). But if the threshold is exceeded, facilities are required to separately report emissions associated with the biomass combustion. Thus, facilities that rely primarily on biomass fuels are not be required to report under the rule (EPA, 2009).

This approach is consistent with IPCC Guidelines for National Greenhouse Gas Inventories, which require the separate reporting of $CO_2$ emissions from biomass combustion, and the approach taken in the U.S. Inventory of Greenhouse Gas Emissions and Sinks. Separate reporting of emissions from biomass combustion is also consistent with some State and regional GHG programs, such as California's mandatory GHG reporting program, the Western Climate Initiative, and The Climate Registry, all of which require reporting of biogenic emissions from stationary fuel combustion sources. While this reporting requirement does not imply whether emissions from combustion of biomass will or will not be regulated in the future, the data collected will improve EPA's understanding of the extent of biomass combustion and the sectors of the economy where biomass fuels are used. It will also allow EPA to improve methods for quantifying emissions through testing of biomass fuels.

---

[4] Pinetree Power information based on interviews with Tim Haley who prepared their BCAP application and Jamie Damman (M.S.) forester and wood buyer for North Country Procurement, consultant to Pinetree Power.

[5] Much of this section is drawn directly and/or quoted verbatim from the EPA's Response to Public Comments Volume No.: 1 Selection of Source Categories to Report and Level of Reporting, September 2009

This rule is based on the EPA's basic premise that burning biomass for energy is considered to be carbon-neutral when considered in the context of natural carbon cycling:

> *Although the burning of biomass also produces carbon dioxide, the primary greenhouse gas, it is considered to be part of the natural carbon cycle of the earth. The plants take up carbon dioxide from the air while they are growing and then return it to the air when they are burned, thereby causing no net increase. Biomass contains much less sulfur and nitrogen than coal; therefore, when biomass is co-fired with coal, sulfur dioxide and nitrogen oxides emissions are lower than when coal is burned alone. When the role of renewable biomass in the carbon cycle is considered, the carbon dioxide emissions that result from co-firing biomass with coal are lower than those from burning coal alone (EPA, 2010).*

Regarding consideration of life-cycle emissions, the EPA has stated that preparation of a complete life cycle analysis is beyond the scope of this rule:

> *With respect to emissions and sequestration from agricultural sources and other land uses, the rule does not require reporting of emissions or sequestration associated with deforestation, carbon storage in living biomass or harvested wood products. These categories were excluded because currently available, practical reporting methods to calculate facility-level emissions for these sources can be difficult to implement and can yield uncertain results. Currently, there are no direct GHG emission measurement methods available except for research methods that are very expensive and require sophisticated equipment (EPA, 2009).*

Regarding biomass-derived transportation fuels, the Energy Independence and Security Act of 2007 (EISA) (P.L. 110–140) required EPA to establish a rule for mandatory lifecycle GHG reduction thresholds for various renewable liquid transportation fuel production pathways, including those using wood as a feedstock. Each qualifying renewable fuel must demonstrate that net GHG emissions are less than the lifecycle GHG emissions of the 2005 baseline average for the fossil fuel that it replaces. For non-agricultural feedstocks, renewable fuel producers can comply with the regulation by: (1) collecting and maintaining appropriate records from their feedstock suppliers in order to demonstrate that feedstocks are produced in a manner that is consistent with the renewable biomass requirements outlined in the ruling, or (2) fund an independent third party to conduct annual renewable biomass quality-assurance audits based on an a framework approved by EPA.

### 1.3.3 PENDING FEDERAL CLIMATE AND ENERGY LEGISLATION

Pending federal climate and energy legislation continues to be in flux, with an uncertain future and significantly evolving content. Overall, these bills focus primarily on the production of renewable electricity and transportation fuels rather than production of thermal energy. In all of the various versions of these bills, energy produced from biomass is considered to be renewable and carbon neutral and generally excluded from proposed caps on carbon emissions and related proposals for carbon emission allowances. There is continuing debate about the definition of biomass from qualifying sources and various proposals to provide safeguards for natural resources on public and/or private lands. This debate also includes consideration of sustainability requirements or guidelines for biomass to qualify as a renewable fuel. There is concern that aggressive targets for increasing the use of biomass for production of renewable electricity and transportation fuels from the current Renewable Fuels Standard, a proposed Renewable Electricity Standard and a limit on carbon emissions would outstrip the capacity of our nation's forests to provide an economically and ecologically sustainable supply. To ensure sustainable harvesting levels and accurate accounting of carbon emissions and re-sequestration, there is discussion and debate about including emissions from renewable biomass energy under proposed carbon caps based on full lifecycle accounting. At this point, however, it is unclear what direction will emerge in this developing legislation.

## 1.4 MASSACHUSETTS FOREST BIOMASS ENERGY POLICIES

Massachusetts has implemented policies to increase the use of biomass to meet energy needs in the electricity sector, the transportation sector, and the building heating sector, although as is the case at the federal level, state policies have been focused primarily on using biomass to replace fossil fuels in the electricity and transportation sectors. Combined with the state's regulatory structure for implementing the Regional Greenhouse Gas Initiative (RGGI) (which sets an emissions cap on fossil fuel electrical generation systems of 25 megawatts or greater), this has created significant incentives driving the state towards greater reliance on biomass electric generation capacity. A recent exception to this trend is the Massachusetts Green Communities Act of 2008, which established new Renewable and Alternative Energy Portfolio Standards (RPS and APS) that allow eligible CHP units to receive credits for useful thermal energy. This program promotes the installation and effective operation of new CHP units for residential, commercial, industrial, and institutional applications. Overall, the bill significantly reforms the state's energy policy, and makes large new commitments to electric and natural gas energy efficiency programs, renewables, and clean fossil fuels like combined heat and power (Environment Northeast, 2008).

Massachusetts has two regulatory programs that directly impact the incentives for developing biomass-fueled electricity in the state. The first is the Massachusetts Renewable Portfolio Standard (RPS), which is administered by the Department of Energy Resources (DOER), and the second is the implementation of the state's membership in the Regional Greenhouse Gas Initiative (RGGI), which is administered by the Department of Environmental Protection (DEP).

### 1.4.1 MASSACHUSETTS RENEWABLE PORTFOLIO STANDARD

The Massachusetts RPS program currently mandates that all retail electricity suppliers must include minimum percentages of RPS Class I Renewable Generation, RPS Class II Renewable Generation, and RPS Class II Waste Energy in the retail electricity they sell to consumers. For 2010, the Class I requirement is 5%, the Class II Renewable requirement is 3.6%, and the Class II Waste requirement is 3.5%. The definition of "eligible biomass fuel" under the RPS program is:

> *Fuel sources including brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that are not mixed with other unsorted solid wastes; by-products or waste from animals or agricultural crops; food or vegetative material; energy crops; algae; organic refuse-derived fuel; anaerobic digester gas and other biogases that are derived from such resources; and neat Eligible Liquid Biofuel that is derived from such fuel sources.*

It is notable that this definition contains no "sustainability" requirement. The RGGI definition, by contrast, does contain such a requirement, though the criteria for sustainability in that definition are not fleshed out at this time. This definition also includes liquid biofuels, which are expressly excluded from the definition of "eligible biomass" for purposes of the Massachusetts RGGI program.

Biomass facilities may qualify as RPS Class I or Class II generation units as long as they are classified as "low-emission, advanced biomass Power Conversion Technologies using an Eligible Biomass Fuel." Both the Class I and Class II RPS regulations also allow generators that co-fire to qualify as RPS Renewable Generation as long as certain requirements are met. This provision in the RPS program is analogous to the biomass exemption from carbon dioxide emissions accounting in the RGGI program.

In 2008, the Massachusetts Green Communities Act established new Renewable and Alternative Energy Portfolio Standards (RPS and APS) allowing Combined Heat and Power facilities to be included as an eligible technology, provided the thermal output of a CHP unit is used in Massachusetts. APS eligible CHP units receive credits for the useful thermal energy of a CHP unit delivered to Massachusetts end-uses, subject to the formula included in the regulations. The DOER rules issued for this program will, for the first time in the Commonwealth, promote the installation of new CHP units for residential, commercial, industrial, and institutional applications.

A central component of the Massachusetts RPS program is the issuance of Renewable Energy Credits (REC's) for biomass-fueled electric power generation, providing a significant incentive and market driver for large-scale biomass electric power generation. While the market price for REC's varies significantly based on state RPS requirements, the available pool of qualifying renewable energy sources, and overall demand for electricity, they are a very significant factor in the economics of biomass power generation and a significant factor in negotiating Power Purchase Agreements. The current market price for REC's is between $20–$40 per MWh and the average monthly price for electricity in the ISO New England region from March 2003—February 2010 is $62/MWh (ISO New England, 2010). At these rates (which have been even higher in past years with REC's bringing up to $50/MWh) REC's are clearly a major, though variable, factor in a biomass power plant's return on investment.

### 1.4.2 MASSACHUSETTS RGGI IMPLEMENTATION

As a member of the Regional Greenhouse Gas Initiative (RGGI), Massachusetts has agreed with ten other states to cap carbon dioxide emissions from large (i.e. > 25 MWe) fossil fuel-fired electric power plants in the ten-state region, and to lower this cap over time. Each individual state has adopted regulations to create allowances corresponding to their share of the cap, and to implement accounting, trading, and monitoring regulations necessary to control emissions. Any allowance can be used for compliance with any state's RGGI regulation. The RGGI Model Rule provides a template on which all state regulations are based.

The RGGI Model Rule includes three provisions related to the combustion of biomass fuels. The first exempts facilities whose fuel composition is 95% or greater biomass from the program. The second allows projects that achieve emissions reductions by switching to certain biomass-derived fuels for heating to apply to create offset allowances. The third applies to regulated facilities that co-fire biomass fuels with fossil fuels, or switch completely from fossil to biomass fuel. In such cases, emissions that result from the combustion of "eligible biomass" fuels are not counted toward compliance obligations. Massachusetts' RGGI regulation includes all three of these provisions, but no power plant or offset project in the state has yet applied to take advantage of the co-firing or offset provisions. The definition of below is from Massachusetts' RGGI regulation:

> ***Eligible biomass.*** *Eligible biomass includes sustainably harvested woody and herbaceous fuel sources that are available on a renewable or recurring basis (excluding old-growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, unadulterated wood and wood residues, animal wastes, other clean organic wastes not mixed with other solid wastes, and biogas derived from such fuel sources. Liquid biofuels do not qualify as eligible biomass. Sustainably harvested shall be determined by the Department [of Environmental Protection].*

In addition to the complete exemption from the RGGI system for generators whose fuel composition is 95 percent or greater biomass, the RGGI Model Rule and all participating states except for Maine and Vermont provide partial exemptions for facilities that co-fire with smaller percentages of biomass. This partial exemption provides that any carbon dioxide emissions attributable to "eligible biomass" may be deducted from a facility's total carbon dioxide emissions when calculating whether the facility's emissions are within its carbon-allowance budget.

Regarding the impact of the Regional Greenhouse Gas Initiative (RGGI) as an incentive for biomass electric power generation, since RGGI defines biomass power as carbon neutral and exempt from participation in the carbon allowance program and categorically excludes biomass power from allowable offsets qualifying for carbon allowances, biomass energy receives no direct incentives through the carbon allowance auction program central to RGGI implementation. It might be incentivized, however, through state investments in clean energy from auction revenues allocated to consumer benefit and renewable energy and efficiency programs. In Massachusetts, these revenues are allocated to five uses, as follows, based on the recently passed 2008 Green Communities Act: promotion of energy efficiency and demand response (minimum of 80% of revenue); reimbursement of municipalities in which tax receipts decrease due to RGGI (limited to 3 years); green communities (not to exceed $10 million per year); zero-interest loans to some municipalities for efficiency projects; and, state administration of the cap and trade program (Green Communities Act, 2008).

In terms of the impact of the RGGI program on the development of biomass generating facilities, should auction prices rise sufficiently, they could provide an incentive for generating facilities to switch to biomass as a power source, or for the construction of new biomass-fired power plants. However, at current allowance prices of approximately $2 per ton of carbon dioxide, there is insufficient price pressure to incentivize such a shift at this time (RGGI, Inc, 2010).

A summary of the range of statutory and regulatory provisions that directly address biomass in Massachusetts, with an emphasis on biomass policy within the electricity sector, is included in Appendix 1-A to this report.

## 1.5 BIOMASS ENERGY POLICIES IN OTHER STATES

Based on a review of eleven states' policies regarding biomass (Arizona, California, Connecticut, Maryland, Minnesota, Missouri, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin), the thrust of state policies promoting biomass and/or biofuels is focused on electric generation and less so on transportation and thermal. All surveyed states have numerous policies, programs and/or incentives to promote electric generation from renewable sources of energy, including biomass. A few states have policies to support the use of biomass/biofuels for transportation (California, Minnesota, Oregon, Pennsylvania, Washington, and Wisconsin) and/or for thermal production (Arizona, Connecticut, Missouri, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin).

Typically, states include biomass as one of a number of sources of renewable energy in a variety of policies and programs aimed at increasing electric generation from renewable energy such as renewable portfolio standards. Other common state policies supportive of biomass electric generation are net metering programs; public benefits funds; other grant and/or loan programs; power purchasing programs at the state and/or local level; and a variety of tax incentives. [6]

States with large sources of biomass supply—Minnesota, Missouri, Oregon, Washington and Wisconsin—also tend to have biomass-specific policies or programs in addition to general programs such as renewable portfolio standards. These states are also likely to have biomass working groups or a biomass program (Connecticut, Minnesota, Oregon, Pennsylvania, and Vermont). Some have produced biomass reports, including woody biomass supply assessments. (Arizona, California, Minnesota, Oregon, Vermont, Washington, and Wisconsin). These reports typically focus more on biomass promotion and less on sustainability, and some discuss the linkage between biomass utilization and climate change. Finally, some states have produced woody biomass harvesting guidelines that focus on best management practices for harvesting woody biomass in an ecologically sensitive and sustainable manner (Minnesota, Missouri, Pennsylvania, and Wisconsin). All such harvesting guidelines are voluntary guidance only.

## 1.6 OVERALL STATE AND FEDERAL POLICY DRIVERS FOR BIOMASS POWER IN MASSACHUSETTS

While conclusive data on the cumulative amounts and impacts of the suite of state and federal policies relevant to biomass power are not available, interviews with plant managers and experts in the field of electric power regulation and development[7] and analyses of federal subsidies indicate that, generally, the most important federal subsidy is the Production Tax credit ($10 per MWh) and most important state incentives are Renewable Portfolio Standards and the related sale of Renewable Energy Credits (currently $25–$35 per MWh). While the value of a REC is higher, the price varies significantly in the marketplace with the cycling of RPS requirements, emergence of new technologies, construction of new renewable energy facilities, the state of the economy and demand for electric power. While less valuable at only $10/MWh, the federal PTC is a more stable source of income for biomass plants over time.

Overall, the economics of individual biomass power plants are determined by the Power Purchase Agreement (PPA), which defines a long-term contract for the purchase of power from a generating facility to utilities or other buyers in the electric power market. PPA's include some or all of the power produced by the generating facility and can also include some or all of the REC's held by a facility in long term contracts. Overall, banks and other investors need confidence in a credible investment stream stemming from a contract including an adequate price (for power and

---

[6] For a description of the range of tax incentive programs, see the public policy program appendix to this report

[7] Synapse Energy Economics, Cambridge, Massachusetts; Innovative Natural Resource Solutions, Portland, ME; Mc Neill Generating Station, Burlington VT; Schiller Station, Portsmouth, NH; Ryegate Power Station, East Ryegate, VT.

possibly REC's) over a sufficiently long period of time to satisfy the debt service for the facility. It is worth noting that only one new biomass power plant has been built in the region since the advent of REC's (Schiller) and that RECs are considered to be an important feature in its financial picture.

After the Power Purchase Agreement, the second largest cost variable involved in the finances of a biomass power plant is fuel supply and pricing. For example, the Ryegate plant in Vermont and Schiller plant in New Hampshire spend between 60% and 70% of their operating costs on fuel purchases and generally, costs in excess of $30–$35 per ton are considered the maximums if biomass power is to remain competitive with other fossil fuel capacity.[8] Given the relative importance of fuel purchases on operating costs, BCAP payments could play a significant role in incentivizing power plants over other non-energy biomass uses in Massachusetts if a continued high level of subsidy to suppliers of biomass to qualifying electric generation facilities lowers fuel supply costs for the power sector. However, given current Congressional review of the BCAP program and the USDA rulemaking process, it is considered unlikely that current levels of subsidies will continue.

Regarding relative incentives for the construction and location of biomass power plants in Massachusetts versus other New England states, it does not appear that there are significant subsidies or incentives in existing public policy that make Massachusetts more or less likely to attract new biomass power plant proposals. While Massachusetts does have a strong market for REC's due to their well-established and aggressive RPS program, this does not provide any particular incentive for building qualifying plants in Massachusetts versus surrounding states. Furthermore, Massachusetts is not unique in having a number of current biomass power plant proposals. Vermont currently has 5 to 8 proposals in varying stages of discussion; New Hampshire has two major projects that have come and gone over the past few years; etc.[9] To further illustrate the scale and scope of biomass power plant proposals across the region, over the past ten years, there have been 243 biomass power plant proposals in the ISO New England region, with only one new plant constructed Schiller Power Plant, NH).

Overall, federal and state policies and incentives are responsible for the trend within the biomass industry to propose large-scale electric generation facilities in Massachusetts and elsewhere in the country.

---

[8] $30–$35 per ton for wood purchase is the breaking point as reported in interviews with the Ryegate and Schiller power plants and is also consistent with independent research conducted by the Biomass Energy Resource Center.

[9] Recent Vermont biomass power plant proposals include: 20–25 MW plant in Ludlow, 20–30 MW plant in Rutland, two 20–30MW combined pellet mill/biomass plants in Pownal and Fair Haven, 20–30MW plant in North Springfield. Recent New Hampshire biomass power plant proposals include: 70MW power plant in Berlin, 50–70 MW power plant (in combination with a celluslosic ethanol plant) in Groveton.

## REFERENCES

Commission of European Communities. (2005). *Biomass Action Plan Communication from the Commission* . Retrieved from http://eur-lex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=COMfinal&an_doc=2005&nu_doc=628

Commission of European Communities. (2006). Communication from the Commission to the Council and the European Parliament on an EU Forest Action Plan. Brussels.

EU. (2006). *The EU Forest Action Plan.* European Commission on Agriculture and Rural Development 2007–2011.

Energy Information Administration. (2008). *Federal Financial Interventions and Subsidies in Energy Markets 2007.*

Environmental Law Institute. (2009). *Estimating US Government Subsidies to Energy Sources: 2002–2008*

Environment Northeast. (2008). *Summary of Massachusetts 2008 Energy Bill, An Act Relative to Green Communities, Senate Bill No. 2768, June 25, 2008*

European Parliament and Council. (2009). *Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.* Retrieved from http://eur-ex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!CELEXnumdoc&lg=EN&numdoc=32009L0028

EPA. 2009. *40 CFR 86, 87, 89 et. al. October 30, 2009.*

EPA. *2009. Federal Register / Vol. 74, No. 209 / Friday, October 30, 2009 / Rules and Regulations*

EPA. 2010. *Air Emissions.* Retrieved 2010 from EPA: http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html

Green Communities Act. (2008). Chapter 169 of the Acts of 2008, An Act Relative to Green Communities.

IEA Bioenergy. (2009). *Bioenergy—a Sustainable and Reliable Energy Source.* Energy Research Centre of the Netherlands, E4Tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht.

IEA Bioenergy. (NA). *IEA Bioenergy Strategic Plan 1998–2002.*

IEA Bioenergy. (1995). *Progress and Achievements 1992–1994.* Retrieved from IEA Bioenergy: www.ieabioenergy.com/DownLoad.aspx?DocId=1027

IEA Bioenergy. (2010). *What is IEA Bioenergy?* Retrieved 2010, from IEA Bioenergy: www.ieabioenergy.com/IEABionergy.aspx

International Energy Agency. (2010). *Energy Security.* Retrieved 2010, from IEA: www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4103

International Energy Agency. (2007). *Good Practice Guidelines: Bioenergy Project Development & Biomass Supply.* Paris: International Energy Agency.

IPCC. (2007). *Contribution of Working Group III to the Fourth Assessment Report.* Intergovernmental Panel on Climate Change.

IPCC. (2000). *Land Use, Land Use Change and Forestry.* Intergovernmental Panel on Climate Change.

ISO New England, Inc. (2010). *SMD Monthly, Daily LMP*

Johnson, E. (2008). Goodbye to carbon neutral: Getting biomass footprints right. *Environmental Impact Assessment Review*

Marland, G., & Schlamadinger, B. (1995). Biomass Fuels and Forest-Management Strategies: How do We Calculate the Greenhouse Gas Emission Benefits? *Energy—The international Journal , 20* (11), 1131–1140.

MGT Power. (2010). *MGT Projects.* Retrieved 2010, from MGT Power: http://www.mgtpower.com/projects.php

*Renewable Energy Policy Network for the 21st Century.* (2009). Renewables Global Status Report 2009 Update. Paris.

RGGI, Inc. (2010). *March 12, 2010 Press Release "RGGI CO2 Auctions Yield Millions for Investment in Clean Energy, Job Creation"*

Searchinger, T., Hamburg, S., Mellilo, J., Chameides, W., Havlik, P., Kammen, D., et al. (2009). Fixing a Critical Climate Accounting Error. *Science* , 326, 527–528.

USDA. (2010). *Farm Service Agency Biomass Crop Assistance Program* Retrieved 2010, from USDA http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap

# CHAPTER 2
# TECHNOLOGY PATHWAYS

## 2.1 INTRODUCTION TO TECHNOLOGY OPTIONS

Biomass in various forms can be used for a range of energy options, through a variety of technologies, to achieve various end purposes. In this chapter, we are looking at several pathways to give the reader an understanding of this range, but also to inform and model potential demand for fuel supply in the future (Chapter 3), and to understand the carbon implications for these choices (Chapter 6). This assessment looks exclusively at the use of existing low-grade forest resources in Massachusetts and surrounding counties in neighboring states, as opposed to agricultural crops or residues or plantation trees and crops which can also provide biomass for energy. Sources of non-forest based biomass, such as wood waste from construction debris, or other sources sometimes considered as biomass, such as municipal waste, were not considered.

With respect to the forest's low-grade wood resource potentially used for energy, the end products can be solid—such as cordwood, wood chips, or wood pellets—liquid, such as pyrolysis oil or cellulosic ethanol, or gas—synthetic or producer gas made through "gasification" and "bio-char" technologies. Finally, the end uses can range from residential to industrial applications, and fall into three general categories: electricity power production, thermal applications for heating (and cooling), or emerging technologies such as cellulosic ethanol or gasification. Between the first two categories, is combined heat and power (CHP), which in turn can be thermally led (optimizing heat production with some electricity produced) or electricity-led (sizing the plant for optimal electricity production and using some of the heat).

Some of these technologies and applications are well established and have been in place for years and others are pre-commercial or still under development. In the sections that follow, we describe two main currently available applications for electricity and thermal production, with CHP discussed in a subsequent section. This discussion focuses on those technologies and applications that are already well established, or are technologically available in the immediate future should policies wish to guide additional biomass in these directions. These are the applications most likely to place demands on Massachusetts' forest resources in the short term. Still, because of the amount of federal investment for research and development in some of the emerging technologies, which, if realized, have the potential to significantly affect demand for forest resources (such as cellulosic ethanol), a third category of applications is discussed in Section 2.5, entitled "Emerging Technologies." All of the liquid biofuels options for producing transportation fuels fall into this category, as does gasification and bio-char production.

Among these application areas, we selected 12 technology pathways to describe how biomass might be used, and compared them to their six fossil fuel equivalent applications. These are described in Appendix 2-A, and summarized in Appendix 2-B.

## 2.2 ELECTRICITY GENERATION

### 2.2.1 CURRENT SOURCES OF ELECTRICAL SUPPLY

Massachusetts uses about 55.8 million Megawatt hours (MWH) of electricity (Energy Information Administration—EIA, 2010) and produces about 47.1 million MWH (EIA, 2007). Massachusetts is a member of ISO New England, which is responsible for wheeling power throughout the region and bringing in power from other regions as needed. Of the power the state produces, renewables account for about two million MWH (4.3 percent), with biomass power generation accounting for 119,000 MWH, or six percent of the renewable portfolio and 0.3 percent of total production (EIA, 2007). Ten natural gas-fired power plants are now the state's leading power producers, accounting for over half of net generation. Coal, primarily from Colorado and West Virginia, is the state's second leading generation fuel; it is used in four plants and accounts for about 25 percent of net electricity production. Massachusetts also uses oil-fired systems (seven existing plants—although oil has been increasingly replaced by natural gas over the past decade) and nuclear from the Pilgrim plant to round out the remaining percentages of its profile. Of the renewables, landfill gas is the largest contributor, accounting for about 1.1 million MW followed by hydroelectric generation at 797,000 MWH (EIA, 2010).

The nuclear facility, all of the fossil fuel based power, and solid-fuel biomass power plants all use steam turbine technology, which has the common attribute of being approximately 25 to 32 percent efficient at converting the energy value of the fuel to electricity. Unused heat in these systems is released through cooling towers, or through heat exchanged in Cape Cod Bay in the case of the Pilgrim Nuclear facility (Entergy, 2008). The four coal facilities use 382,000 tons of coal each year (EIA, 2007), and the wood facilities[1], at full operation, would use approximately 215,000 green tons annually (INRS, 2007).

### 2.2.2 ELECTRICAL GENERATION PATHWAYS

Pathways 1–4 describe the range of power facilities used now, and for the foreseeable future, to produce electricity. Pathway #1 assumes a 50 MW biomass powered facility, and enables comparison to two fossil fuel options for coal (Pathway #3) and natural gas (Pathway #4) as well as a co-firing option where wood is substituted for 20 percent of the coal at a coal-fired unit (Pathway #2).

All pathways assume advanced pollution controls as needed to ensure the units are performing to meet expected pollution control objectives, but the efficiency is an average based on present performance of units in use today. Generally, this is 32 percent for coal, 20–25 percent for woody biomass, and 33 percent for natural gas (Appendix 2-B).

---

[1] There are two wood-fired electrical facilities in Massachusetts: Pinetree-Fitchburg (14 MW) which is operating and Ware Co-Gen (8.6 MW) which is idle (INRS at 40).

The following chart (Exhibit 2-1) presents the $CO_2$ emissions for the four electrical generation pathways.

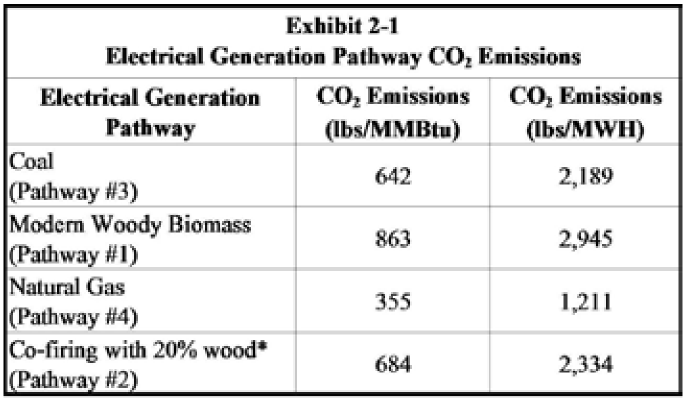


**Exhibit 2-1**
**Electrical Generation Pathway $CO_2$ Emissions**

| Electrical Generation Pathway | $CO_2$ Emissions (lbs/MMBtu) | $CO_2$ Emissions (lbs/MWH) |
|---|---|---|
| Coal (Pathway #3) | 642 | 2,189 |
| Modern Woody Biomass (Pathway #1) | 863 | 2,945 |
| Natural Gas (Pathway #4) | 355 | 1,211 |
| Co-firing with 20% wood* (Pathway #2) | 684 | 2,334 |

*Total emissions for coal and wood combined.

These pathways are used to evaluate and compare different scenarios for forest management and carbon impacts if policies are directing biomass use toward stand-alone electrical generation, and to enable comparison to the most likely fossil fuel alternatives. Of all the fuels considered, natural gas is the cleanest and the lowest carbon emitting due to its ability to generate power using a direct combustion turbine at higher efficiency than traditional steam turbine technologies, and the fact that it has less carbon per unit of energy.

## 2.3 THERMAL PRODUCTION

Roughly one-third of the nation's energy demands are thermal demands for heat, hot water, cooling, and industrial process heat (EIA,2008),. In the Northeast, this percentage is even higher, with the region using 82 percent of the nation's home heating oil (EIA, 2009). In Massachusetts, 42 percent of the households and businesses use #2 heating oil or propane as their primary source of heat (EIA, 2007).

At the residential and community scale, biomass can be an effective means of using local wood resources and displacing fossil fuels efficiently. Generally, these thermal systems are between 75 percent and 85 percent efficient (See Appendix 2-B).

### 2.3.1 CURRENT SOURCES OF THERMAL SUPPLY

### 2.3.1.1 Residential Biomass Forms and Uses

Biomass has been used to heat homes for millennia. The amount of biomass used to heat Massachusetts' homes is not known, but is estimated at between one and two million green tons annually (Personal Communications, MADOER, 2010). Residential applications use biomass in fireplaces; wood stoves, furnaces, and boilers[2]; pellet stoves furnaces and boilers; and outdoor wood boilers. These applications decrease in efficiency (California Air Resources Board-CARB, 2005) and increase in emissions as one moves from pellet stoves and boilers to wood stoves and boilers to outdoor wood boilers to fireplaces.

Exhibit 2-2 presents efficiency, particulate, and CO2 emissions associated with these residential applications.

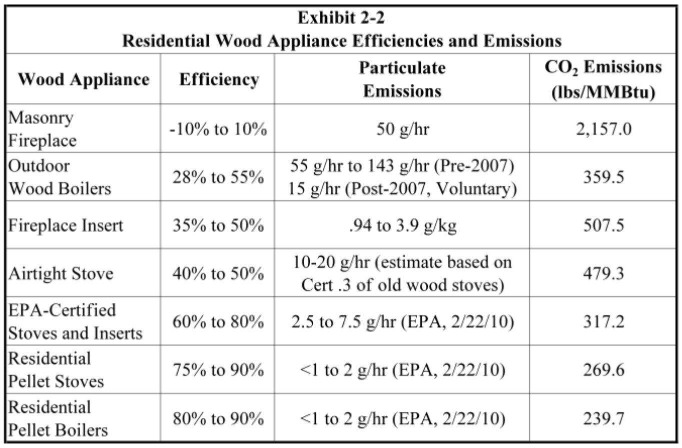


**Exhibit 2-2**
**Residential Wood Appliance Efficiencies and Emissions**

| Wood Appliance | Efficiency | Particulate Emissions | $CO_2$ Emissions (lbs/MMBtu) |
|---|---|---|---|
| Masonry Fireplace | -10% to 10% | 50 g/hr | 2,157.0 |
| Outdoor Wood Boilers | 28% to 55% | 55 g/hr to 143 g/hr (Pre-2007)<br>15 g/hr (Post-2007, Voluntary) | 359.5 |
| Fireplace Insert | 35% to 50% | .94 to 3.9 g/kg | 507.5 |
| Airtight Stove | 40% to 50% | 10-20 g/hr (estimate based on Cert .3 of old wood stoves) | 479.3 |
| EPA-Certified Stoves and Inserts | 60% to 80% | 2.5 to 7.5 g/hr (EPA, 2/22/10) | 317.2 |
| Residential Pellet Stoves | 75% to 90% | <1 to 2 g/hr (EPA, 2/22/10) | 269.6 |
| Residential Pellet Boilers | 80% to 90% | <1 to 2 g/hr (EPA, 2/22/10) | 239.7 |

### 2.3.1.2 Institutional Biomass Forms and Uses

Use of biomass for heat and hot water in community buildings, institutions, etc. has had limited application in Massachusetts. Two examples are: Quabbin Reservoir Administrative Building in Belchertown, and Mount Wachusett Community College in Gardner. The Quabbin system was installed in 2008 and uses 350 tons of wood per year to displace 22,000 gallons of #2 heating oil (Biomass Energy Resource Center-BERC, 2010). It is 2.0 MMBtu/hr in size. The Mount Wachusett system is 8.0 MMBtu/hr in size, was installed in 2002 and uses between 1,200 and 1,400 tons of wood each year (BERC, 2010). This system replaced electric heating, and the college estimates it has saved 30 million kWh of electricity in the eight years of operation (BERC, 2010). The technology for these systems uses centralized hot water-based boilers and underground insulated pipe distribution systems.

Other applications of this scale of system are used in several schools. Several colleges are considering conversion to biomass, including UMASS Amherst, and the VA hospital in Northampton.

### 2.3.2 THERMAL PRODUCTION PATHWAYS

Pathways 5–10 describe the range of applications that may be used for thermal production, beginning with cordwood systems that would serve a typical home (Pathways #5 and #6). These boilers represent small systems that, at 100,000 Btu/hr, would be used to serve a small business or residence. The difference between these two pathways is that Pathway #6 represents an EPA-certified boiler that is more efficient and therefore has fewer carbon emissions per energy output than Pathway #5.

Pathway #7 describes a pellet system, separated into two parts in order to compare effectively with other sources of thermal energy presented—pellet manufacturing is Pathway 7A and covers the process of using green wood chips to produce pellets, and Pathway 7B describes the use of these pellets in a typical commercial or institutional setting, sized at 5.0 MMBtu/hr. When considering pellets and comparing to other fuels with respect to harvesting needs and carbon impacts, it is important to consider both pathways.

---

[2] A stove is considered to be a stand-alone space-heating device, a furnace is a central hot air system, and a boiler is a central hydronic (hot water pipe and radiator) system.

Pathway #8 is a wood chip system sized at 50 MMBtu/hr, which would serve a community in a district energy system of the kind commonly used in Europe. Pathways #9 and #10 provide information about the fossil fuel equivalent versions of this system, using #6 heating oil and natural gas, respectively.

Exhibit 2-3 presents the $CO_2$ emissions from these thermal pathways[3]:

**Exhibit 2-3**
**Thermal Generation Pathway $CO_2$ Emissions**

| Thermal Generation Pathway | $CO_2$ Emissions (lbs/MMBtu) |
|---|---|
| Wood chip-fired District Energy (Pathway #8) | 288 |
| Non EPA-Certified Residential Wood Boiler (Pathway #5) | 360 |
| #6 Heating Oil (Pathway #9) | 217 |
| Natural Gas (Pathway #10) | 138 |

## 2.4 COMBINED HEAT AND POWER OPTIONS

All electrical production from combustion of fuels creates excess heat that is often wasted. In the case of power plants, excess heat is often released through cooling towers, as steam from the turbine is condensed and returns to the boiler. Combined heat and power systems (CHP) seek to utilize some or all of this excess heat. As this excess heat is made into useful energy, the efficiency of the generating system increases with the proportion of heat it uses. Generally, using conventional technology, for each unit of electricity produced, three units of thermal energy are released.

Electricity-led CHP is an option where power production is near a thermal demand. A 20 MW power plant produces enough heat to heat approximately 1,100 homes[4]. However, to date, the economics, incentives and siting preferences have not resulted in power plants choosing this route. As a result, regardless of the fuel source producing the electricity, approximately 75 percent of the energy value of the fuel has been wasted as lost heat. Taking advantage of this energy value requires planning, intentional siting, and either financial or regulatory incentives that promote power producers deciding to increase the complexity of their systems by the addition of steam or hot water as a salable output. This is not the business model that has been pursued to date. Recently, with the increased understanding of efficiency and concern about efficient use of resources, biomass power facilities are beginning to incorporate some CHP in their proposals, though because of the large amount of heat available relative to potential nearby uses, these projects often make use of only a small percentage of the available heat (10–15 percent).

Thermally led CHP maximizes the demand for heat, but produces relatively little electricity. At the community scale, a typical CHP facility might produce 1–5 MW of electricity while heating a college campus or small community district of 200–500 homes and businesses.

An important point to note is that the efficient scale of producing electricity alone leads to plants in the 20–50 MW size range. At this scale, it is more cost-effective to produce the power, and any CHP component is a complicating factor that tends to reduce the overall cost-effectiveness of the project under current policies. At smaller scale thermal-led CHP systems, the opposite is true—production of heat alone maximizes cost-effectiveness of the project, and adding an electrical component reduced the overall economics of the project, i.e. the savings in heat help subsidize the electrical generation components.

Conventional technology requires the production of steam to produce electricity, but European commercial technologies include gasification where the produced gas is combusted directly in a combustion turbine, or Organic Rankine Cycle (ORC) thermal oil technology which uses a thermal oil to gain temperature gradients necessary to produce electricity without steam, so that the thermal system can be designed around hot water, and at low pressure. The ORC system, while more easily incorporated into a hot-water based thermal application and therefore of greater potential in smaller CHP systems (see below), the ORC process is still only approximately 20% efficient on its own in the production of electricity, but would be expected to be between 75% and 85% efficient in heat-led applications. Heat-led gasification can be expected to be approximately 75% efficient. (See Appendix 2-B for sources of efficiency information).

### 2.4.1 CHP PATHWAYS

Pathways #11 and #12 describe moderate-sized CHP systems capable of producing 5.0 MW of electricity. The first uses conventional technology, producing steam to run a turbine, and fully utilizes the 34 MMBtu/hr of heat generated to heat facilities on the order of magnitude of a college campus, a hospital, or small community. As such, the overall efficiency is rated at 75 percent. The second pathway uses gasification technology, which is just an emerging technology here in the United States. Still, there is an example of a commercial system operating since 2000 in the Town of Harboøre, Jutland, Denmark that produces 1.6 MW of electricity and heats 900 homes (BERC, 2010). The efficiency rating for this system is also 75 percent.

Pathways #13 and #14 are the fossil fueled equivalent of the biomass CHP systems for oil and natural gas.

Exhibit 2-4 below presents $CO_2$ emissions for the four CHP pathways considered.

**Exhibit 2-4**
**CHP Generation Pathway $CO_2$ Emissions**

| CHP Generation Pathway | $CO_2$ Emissions (lbs/MMBtu) |
|---|---|
| Wood chip Steam System (Pathway #13) | 287 |
| Wood chip Gasifier (Pathway #14) | 287 |
| Oil System (Pathway #15) | 232 |
| Natural Gas System (Pathway #16) | 146 |

---

[3] As with the other exhibits which follow, the source of data for these charts is presented in Appendix 2-B

[4] 20 MW electric produces approximately 136 MMBtu/hr of heat. Residential heating typically uses 40 Btu's/sq ft. Based on a 3,000 square foot house, heating requirement is 120,000 Btu's/hr, or 1,137 homes.

## 2.5 EMERGING TECHNOLOGIES

There are several emerging technologies for using biomass that have the potential to change the demand for low-grade wood over time. Most of these are transportation sector related. The US Department of Energy has invested hundreds of millions of dollars over the last decade to augment the ethanol production of agricultural crops (corn primarily) with ethanol derived from woody-biomass sources (cellulosic ethanol). To date, they have sponsored both research and development, funding six pilot scale plants throughout the country. While not yet commercially viable, our transportation fuel demands are so high and this is another area, like heating oil, directly related to our importation of fossil fuels, that the issue is an important one to consider in the context of making policies to support the sustainable use of the low-grade wood resource. To put it in context, the Range Fuels plant near Soperton, Georgia will begin at pilot scale producing 20 million gallons of cellulosic ethanol a year, using 250,000 tons of wood. At its commercial scale of 100 million gallons per year, the wood demand will be over 1.2 million tons of green wood per year for this one plant (Range Fuels, 2010).

Smaller scale work in bio-oil (pyrolysis oil) and bio-char (torrefaction) are emerging technologies that can help with both transportation fuel alternatives to gasoline and diesel, as well as, in the case of bio-char, potentially sequester portions of the wood carbon for long periods of time (Laird, 2008). These systems are operational at very small scales at the moment, but have a potential to contribute positively to the biofuel equation.

There are other technologies of similar scale to the bio-oil that use biomass to produce a range of products, including fertilizers, plastics, and glues. All of these products are relatively limited in demand, so source material from forests will not be significant relative to energy demands or other forest product uses.

### 2.5.1 EMERGING TECHNOLOGY PATHWAYS

The emerging technologies represented here all use some of the heat for other aspects of their processes, so their efficiencies are generally in the 40–45 percent range. Pathway #15 provides an example of a commercial-scale cellulosic ethanol plant, making 100 million gallons of cellulosic ethanol per year. In this process, the cellulose in the wood is converted to sugars that are fermented into alcohol. The lignin part of the wood is combusted directly to produce steam and electricity. Pathway #18 is a variation on this whereby the by-product of pyrolysis is used to produce other products, such as plastics, glues, organic fertilizers, and fuel additives instead of electricity. Pathway #16 represents a bio-oil and bio-char system, producing 15 million gallons/year of bio-oil, and approximately 21,575 tons of bio-char (charcoal), having heating value of 11,000 btu/lb (dry basis), that can be used as a soil amendment for carbon storage. Pathway #17 is of similar size, producing a syngas that is used to make liquid fuels, with lignin used to produce steam-based electricity. The following chart summarizes the $CO_2$ implications of these pathways:

**Exhibit 2-5**
**Emerging Technology Pathway $CO_2$ Emissions**

| Emerging Technologies Pathway | $CO_2$ Emissions (lbs/MMBtu) |
|---|---|
| Cellulosic Ethanol (Pathways #15 and #18) | 255 |
| Bio-products Pathway (Pathways #16 and 17) | 119 |

## 2.6 GENERAL DISCUSSION AND SUMMARY

### 2.6.1 THE FUTURE ROLE OF BIOMASS UNDER PRESENT POLICIES

Electricity demand is expected to increase by approximately 1.2 percent annually, with a peak demand increase of 1.3 percent due to increased cooling demand in the summer (ISO New England Inc., 2009). Air pollution goals, as well as cost and projected supplies, will continue to drive new power production toward natural gas, but for the state's RPS. In an attempt to reach 15 percent by 2020, Massachusetts is looking to alternatives to fossil fuels to reach its goals. There are several significant wind projects in place and in planning, as well as solar projects, but as biomass power is "base load," the trend has been to look to it to supply an increased share of the electricity portfolio.

Over the next five to 10 years, barring a change in policy or incentives, or a dramatic change in the price of fossil fuel or electricity, we would expect the current pattern of incremental proposal and construction of stand-alone biomass power plants between 20 MW and 50 MW to continue to be the major focus of the use of biomass. As described elsewhere, the pattern has been for many to be proposed (214 throughout New England over the past decade, with one constructed), and there are currently four proposals in Massachusetts. In part, the low ratio of "proposed" to "constructed" reflects the marginal economics of constructing plants based on the present cost of electricity, and the desire for investors to recoup costs of capital investment within a relatively short period of time—most private investors look for a return on investment of 20 percent within two to five years[5].

Events that can speed this up are if the wholesale rates of electricity increase substantially while the policy direction for renewables is maintained. In 2008, Massachusetts paid an average of 16.27 cents/kWh retail for electricity, the fourth highest in the nation and highest in New England. It is doubtful that electricity prices will increase dramatically in the face of the downward regional and nationwide pressure on prices. If Renewable Electricity Credits (REC's) rise in value and are stabile over a period of several years, this too would encourage construction of more power plants.

---

[5] It also reflects the tendency for proposers to announce projects at a very early stage of project development as a relatively easy means of assessing public acceptance of a given project, so the public announcements are not a good gauge of projects that are truly in advanced development and are likely to be built.

Factors that can make power plant investment slow down are low value of REC's coupled with only an inflationary increase in the price of electricity. Also, if the availability of fuel supply is restricted, or if it is only available at a cost higher than what plants can afford to pay, biomass power will be discouraged. We consider this scenario to be possible, but unlikely in the immediate future.

While incentives and policies may promote biomass electric plant construction, the pace and penetration of biomass power plants are controlled most significantly by the fuel supply; it is such a large portion of the cost of operations that it is looked at very carefully by investors. This is why multiple proposals may be vetted at a given time, but if one is built, the others in the woodbasket are significantly adversely affected and are less likely to go forward. If there are reasonable harvesting and procurement standards in place regarding overall sustainability, this factor is likely to increase the due diligence on available fuel supply and prevent over-development of biomass power facilities.

If policies are changed to require CHP or a minimum annual net efficiency standard, as some states have done in certain circumstances and as DOE encouraged in recent procurements, more CHP can be expected. But under current conditions, siting constraints, the required scale for economically viable power production and lack of large centralized demand for thermal at the scale produced by a 20–50 MW power plant will all limit the desirability of power developers to include heat, as well as the amount of heat that can be effectively used by an electricity-led CHP system. We do not see electricity-led CHP as growing in the absence of policies or incentives to encourage that direction.

Residential conversions are very dependent on oil and propane prices. In the absence of policies that would encourage large-scale switchover to biomass in residences, such as a substantial increase in the residential tax credit, or a change in building codes or insurance standards (to not require a conventional fossil fuel-based system in the home), the trend is expected to remain about the same. Although the use of biomass for home heating is significant, and currently not well-quantified, dramatic changes in the trend are not expected, though as explained below, residences can react quickly to rapid oil and propane price increases.

At this scale, residential use will not be a significant driver in determining Massachusetts' forest resource capacity for increased biomass use or the overall sustainability of the resource. Accordingly, the analyses in subsequent sections of this report assume residential use (and all existing uses for that matter) remains about the same as they are. That said, things which weigh in on people's decisions to burn wood in the home primarily relate to cost of the fossil fuel alternative, and while this consideration may be at the forefront individual preferences regarding energy security and price stability, ease of operation and maintenance, degree of automation and convenience, cleanliness, availability of the wood fuel, heating effectiveness and comfort all play a role. Other factors such as emissions, environmental benefit, energy independence, space, and cumulative impacts are of lesser importance to the individual decision.

Biomass options in the home most closely able to substitute for oil are pellet boiler and furnace systems, and these systems are very popular in Europe and increasingly so here. The obstacles preventing large conversion of homes are primarily related to price. A conventional central heating system costs between $2,500 and $4,000 for a typical home. A comparable pellet system would be between $5,000 and $8,500. Even though the fuel is cheaper than oil, its availability in bulk is presently limited, and the cost disparity in systems cannot be made up for by the present 30 percent tax credit that has a cap of $1,500 per home.

If one wishes to promote advanced biomass technologies for the home, incentives such as tax credits, change-out programs, and programs that allow homeowners to offset the additional costs of choosing a biomass system either through credits or ability to finance costs through low or no cost options all work to overcome the cost implications. Proposals are pending in Congress to raise or eliminate the tax credit cap, and to develop a Homestar program that among other things supports pellet system installations. Similarly, New Hampshire and Maine each have programs to encourage an expanded residential market. A reliable bulk delivery option and convenient storage and automated delivery to the boiler or furnace are also necessary for the residential use of pellets to increase significantly and displace oil and propane.

Cordwood use is limited in growth to those capable of handling and tolerating the storage, handling, and messiness of cordwood. Outdoor wood boilers avoid some of the indoor mess of handling cordwood, but the low efficiency and high emissions from them are of increasing concern to states in the Northeast, even when compared to conventional wood stoves. Though they are improving, some of the cost-attractiveness of these systems will be lost as their technology improves.

One hears periodically about home-based CHP systems, but with regard to biomass systems these are not commercially available, and developing products are very expensive relative to either conventional fossil fuel or biomass thermal systems. There are some demonstration projects using a Stirling Engine design, but these are still experimental or unique applications (Obernberger, et. al, 2003). We conclude from this that electrical generation from wood at the residential scale is not commercially available.

With respect to residential heating, it is important to recognize the individual residential component and fuel price sensitivity of the cordwood market when considering net available low-grade wood for sustainable biomass use. Although each homeowner's use is relatively small—perhaps five to 10 tons per season (2-5 cords)—cumulatively, it can be significant, and often the hardest sector to quantify. In Vermont for example, cordwood is estimated to account for between 30 and 40 percent of all biomass use in the state (BERC, 2007). It increased by 20–30 percent in the single season of 2008 when oil approached $150/barrel.

There will also likely be small, incremental increase in thermal applications of biomass at colleges, institutions, and other facilities that have the capital to invest in longer-term payback projects, as the economics are compelling at current or slightly higher than current heating oil prices. These are not going to be common or numerous, as few institutions have the capital to make the changeover, and the payback period of generally between seven and 12 years is too long for private investment interest. To increase thermal applications dramatically, if that is a policy direction Massachusetts wishes to pursue, state and federal incentive programs to provide capital, such as through a revolving loan fund, would be needed .

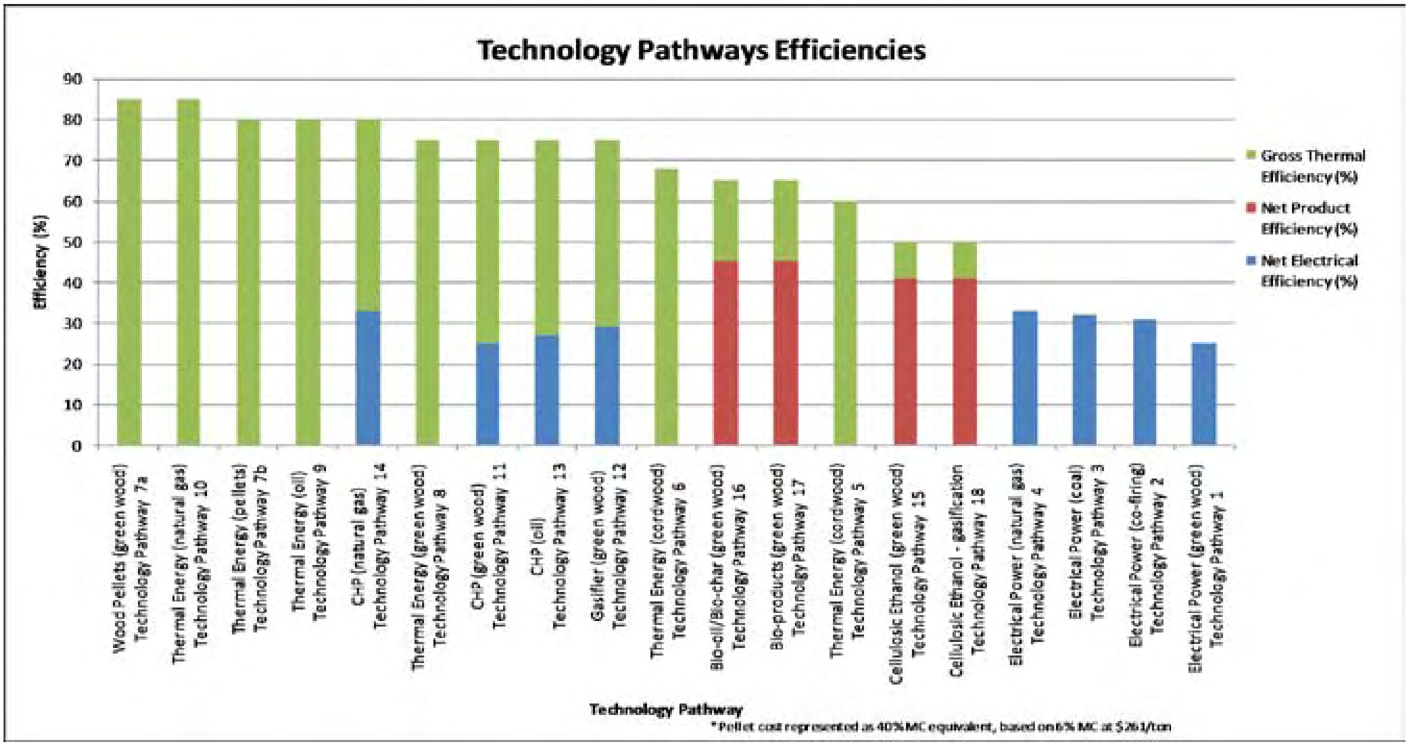
Finally, cellulosic ethanol production has the potential to completely usurp power production at a comparable scale if electricity prices remain low, and oil (gasoline) prices increase markedly. However, the pilot projects under way and supported by the US DOE must prove out, and as such, we consider this scenario to be worthy of watching, but unlikely—especially in the near five to 10 year timeframe.

## 2.6.2 EFFICIENCY

As has been discussed throughout, converting biomass into different energy pathways and products yields varying ranges of efficiency for extracting the energy value of that biomass resource. Exhibits 2-6 and 2-7 on the following pages show the range of efficiencies for the different applications and pathways selected from most efficient to least efficient.

It is important to recognize that what is presented is just the efficiency of the process to produce energy or fuel or product from the biomass. This does not include up-front processes to get the biomass to the facility, or additional losses incurred through the use of the end product. For example, for electricity, these efficiencies do not include line losses or the efficiency of a given appliance to turn remaining electricity into useful work. Similarly, for the transportation fuels, this does not include the relative inefficient (18 percent) ability of your car to take the energy value of the fuel and convert it into the work of moving you down the road. Finally, for the thermal applications, it does not include the loss of heat exchange from the thermal system to a home, or the efficiency of a home to retain heat. These examples show that further down the process more losses of the energy value of the original biomass will be incurred. They may be smaller or they may be quite large, depending on the end use.

**Exhibit 2-6: Graph of Efficiency of 18 Technology Pathway Options**[6]

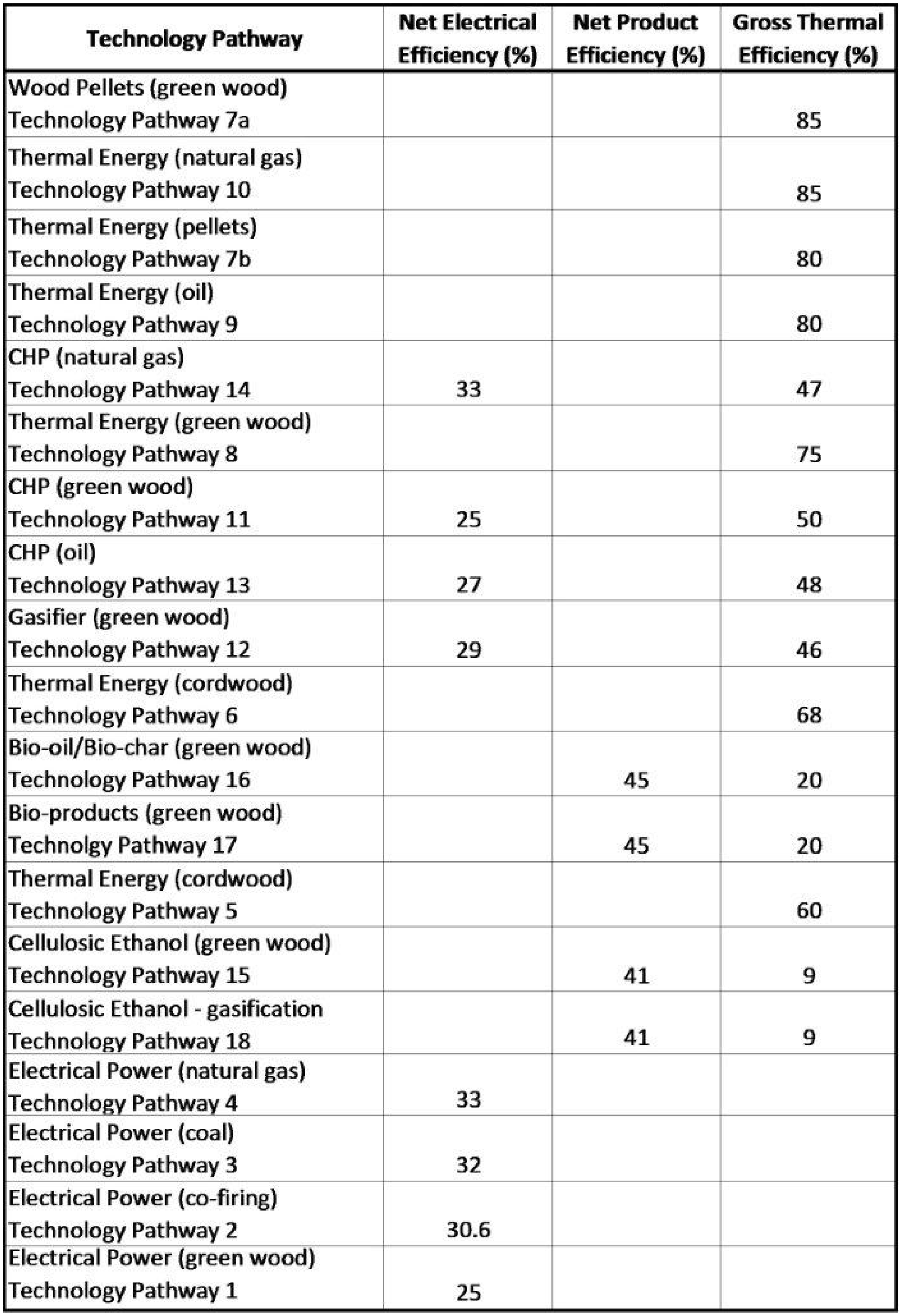


*Pellet cost represented as 40% MC equivalent, based on 6% MC at $261/ton

---

[6] Graph information is derived from Appendix 2-B. See that Appendix for data and sources.

**Exhibit 2-7: Chart of Efficiency of 18 Technology Pathway Options**[7]

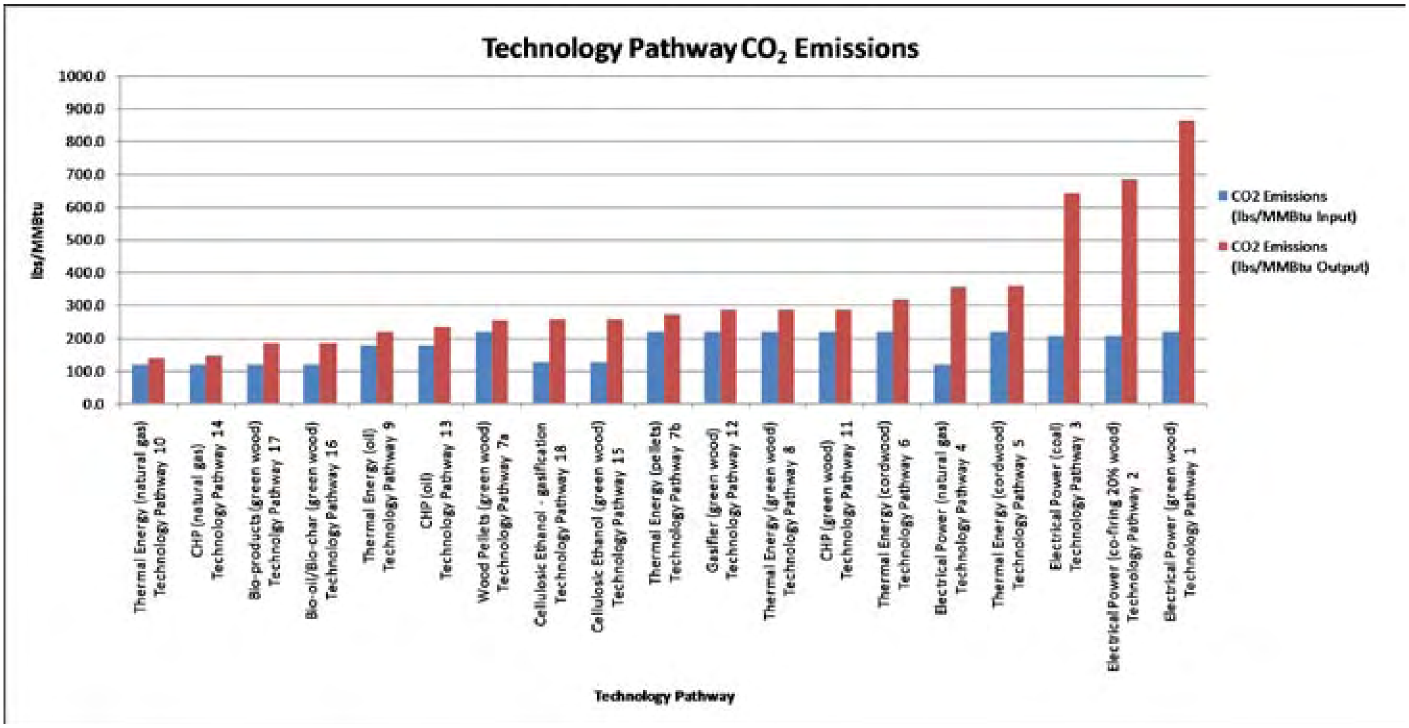


| Technology Pathway | Net Electrical Efficiency (%) | Net Product Efficiency (%) | Gross Thermal Efficiency (%) |
|---|---|---|---|
| Wood Pellets (green wood)<br>Technology Pathway 7a | | | 85 |
| Thermal Energy (natural gas)<br>Technology Pathway 10 | | | 85 |
| Thermal Energy (pellets)<br>Technology Pathway 7b | | | 80 |
| Thermal Energy (oil)<br>Technology Pathway 9 | | | 80 |
| CHP (natural gas)<br>Technology Pathway 14 | 33 | | 47 |
| Thermal Energy (green wood)<br>Technology Pathway 8 | | | 75 |
| CHP (green wood)<br>Technology Pathway 11 | 25 | | 50 |
| CHP (oil)<br>Technology Pathway 13 | 27 | | 48 |
| Gasifier (green wood)<br>Technology Pathway 12 | 29 | | 46 |
| Thermal Energy (cordwood)<br>Technology Pathway 6 | | | 68 |
| Bio-oil/Bio-char (green wood)<br>Technology Pathway 16 | | 45 | 20 |
| Bio-products (green wood)<br>Technolgy Pathway 17 | | 45 | 20 |
| Thermal Energy (cordwood)<br>Technology Pathway 5 | | | 60 |
| Cellulosic Ethanol (green wood)<br>Technology Pathway 15 | | 41 | 9 |
| Cellulosic Ethanol - gasification<br>Technology Pathway 18 | | 41 | 9 |
| Electrical Power (natural gas)<br>Technology Pathway 4 | 33 | | |
| Electrical Power (coal)<br>Technology Pathway 3 | 32 | | |
| Electrical Power (co-firing)<br>Technology Pathway 2 | 30.6 | | |
| Electrical Power (green wood)<br>Technology Pathway 1 | 25 | | |

---

[7] Chart information is derived from Appendix 2-B. See that Appendix for sources.

**Exhibit 2-8: Graph of $CO_2$ Emissions of 18 Technology Pathways[11]**



## 2.6.3 CARBON IMPACTS

The CO2 emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. Generally, the CO2 emissions expressed as "input" energy reflect the fuel the process is based on, and the CO2 emissions based on "output" energy reflect the efficiency of the biomass-product conversion, be that electricity, thermal, or fuel. Exhibits 2-8 and 2-9 on the following pages reflect the different pathways from least CO2 emissions based on energy output to the most emitting pathways.

As with the efficiency discussion, it is very important to note this is not a life-cycle analysis of these technology pathways. The carbon aspects of mining coal, harvesting biomass, or drilling and transporting natural gas or oil are not shown here. Nor, except for the electricity and thermal applications, are the emissions of the ultimate use accounted for—that is, the fuels combusted will further release $CO_2$ associated with that product. While full carbon life-cycle accounting for all pathways is beyond the scope of this work, lifecycle estimates of carbon emissions for the technological options considered in Chapter 6 are provided there.

**Exhibit 2-9: Chart of CO2 Emissions of 18 Technology Pathways[12]**

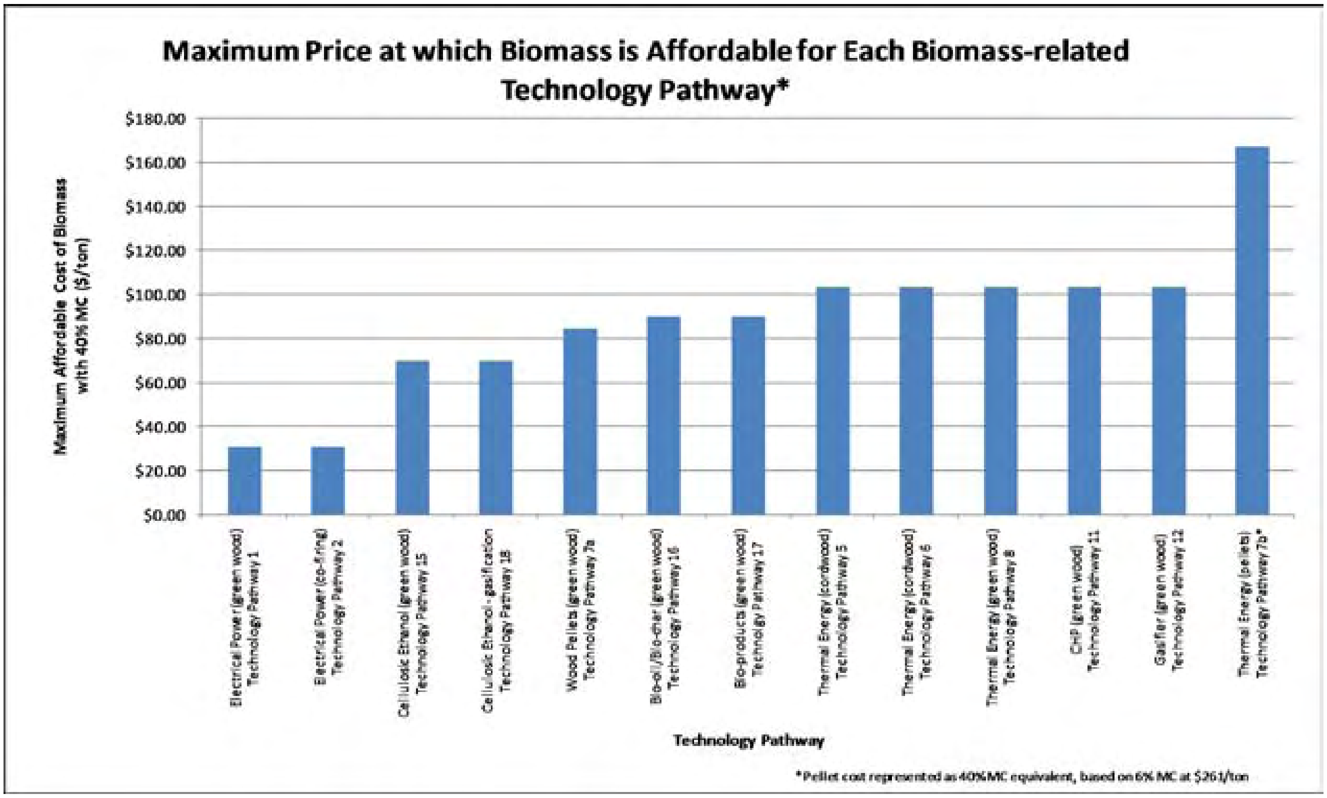
| Technology Pathway | $CO_2$ Emissions (lbs/MMBtu Input) | $CO_2$ Emissions (lbs/MMBtu Output) |
|---|---|---|
| Thermal Energy (natural gas)<br>Technology Pathway 10 | 117.0 | 137.6 |
| CHP (natural gas)<br>Technology Pathway 14 | 117.0 | 146.3 |
| Bio-products (green wood)<br>Technolgy Pathway 17 | 118.6 | 182.5 |
| Bio-oil/Bio-char (green wood)<br>Technology Pathway 16 | 118.6 | 182.5 |
| Thermal Energy (oil)<br>Technology Pathway 9 | 173.9 | 217.4 |
| CHP (oil)<br>Technology Pathway 13 | 173.9 | 231.9 |
| Wood Pellets (green wood)<br>Technology Pathway 7a | 215.7 | 253.7 |
| Cellulosic Ethanol - gasification<br>Technology Pathway 18 | 127.3 | 254.5 |
| Cellulosic Ethanol (green wood)<br>Technology Pathway 15 | 127.3 | 254.5 |
| Thermal Energy (pellets)<br>Technology Pathway 7b | 215.7 | 269.6 |
| Gasifier (green wood)<br>Technology Pathway 12 | 215.7 | 287.6 |
| Thermal Energy (green wood)<br>Technology Pathway 8 | 215.7 | 287.6 |
| CHP (green wood)<br>Technology Pathway 11 | 215.7 | 287.6 |
| Thermal Energy (cordwood)<br>Technology Pathway 6 | 215.7 | 317.2 |
| Electrical Power (natural gas)<br>Technology Pathway 4 | 117.0 | 354.5 |
| Thermal Energy (cordwood)<br>Technology Pathway 5 | 215.7 | 359.5 |
| Electrical Power (coal)<br>Technology Pathway 3 | 205.3 | 641.6 |
| Electrical Power (co-firing 20% wood)<br>Technology Pathway 2 | 207.4 | 684.3 |
| Electrical Power (green wood)<br>Technology Pathway 1 | 215.7 | 862.7 |

---

[8] Graph information is derived from Appendix 2-B. See that Appendix for data and sources.

[9] Chart information is derived from Appendix 2-B. See that Appendix for sources.

**Exhibit 2-10: (below) Maximum Price at which Biomass is Affordable for Each Biomass-Related Technology Pathway**[13]



## 2.6.4 AFFORDABLE COST FOR BIOMASS SOURCE MATERIAL

Finally, for the purposes of conducting sensitivity analyses of the demand for forest products and how demand might affect cost paid for biomass, and how, in turn, that affects harvesting methods, intensity and options, we have looked at what the maximum affordable price is for each pathway to pay for biomass from the forests. The following Exhibits 2-10 and 2-11 illustrate these prices.

The maximum affordable price for power generation has been calculated based on the wholesale price of 12.5 cents per kWh including REC benefits, the cost of biomass fuel as 33 percent of sale price, higher heating value of wood chips as 17 MMBtu/ton, and moisture content of wood chips as 40 percent. The maximum affordable price for thermal applications has been calculated based on the price of #2 oil as $3 per gallon, higher heating value of 138,000 Btu/gallon, combustion efficiency of 80 percent for oil boiler, affordable price of wood chips as percent of price of oil on $/MMBtu basis as 50 percent and the combustion efficiency of wood chips boiler as 75 percent. The maximum affordable price of wood pellets for thermal energy has been calculated based on e f wood pellets with six percent moisture content as percent of price of oil on $/MMBtu basis as 75 percent and the combustion efficiency of wood pellet boiler at 80 percent. The maximum affordable price of wood chips for manufacturing wood pellets have been calculated based on maximum affordable price of wood pellets for thermal energy at $261 per ton, efficiency of conversion of wood chips to wood pellets as 85 percent, requirements of wood chips per ton of wood pellets as 1.575 tons, and the affordable price of wood chips as 60 percent of the price of wood pellets. The maximum affordable price for other technology pathways has been estimated in proportion of the net efficiencies for the products.

The maximum affordable price is important as the price one is willing and able to pay for biomass determines the type of equipment and treatments that can be applied to the forest, and which uses may get preference over others with respect to biomass product. Higher affordable prices may enable better management, landowner commitment to sustainable forestry, and enhancement of logging infrastructure and methods. The pathways constraining the electricity related biomass prices are based on an electricity wholesale price of 12.5 cents/ kWh, which assumes a wholesale price to the grid plus any value of REC's. Thermal applications are based on a $3.00 per gallon oil equivalent. Obviously, if the price of either goes up, then the ability to pay more for biomass (and still have the project "break even") goes up as well. All of the assumptions for this and the other analyses are shown in the attached Appendix 2-C.

---

[10] Graph information is derived from Appendix 2-B. See that appendix for data and sources. Methodology for calculations is presented in Section 2.6.4.

**Exhibit 2-11: Maximum Price at which Biomass is Affordable for Each Biomass-Related Technology Pathway**[11]

| Technology Pathway | Maximum Affordable Cost of Biomass with 40% MC ($/ton) |
|---|---|
| Electrical Power (green wood)<br>Technology Pathway 1 | $31.00 |
| Electrical Power (co-firing)<br>Technology Pathway 2 | $31.00 |
| Cellulosic Ethanol (green wood)<br>Technology Pathway 15 | $70.00 |
| Cellulosic Ethanol - gasification<br>Technology Pathway 18 | $70.00 |
| Wood Pellets (green wood)<br>Technology Pathway 7a | $85.00 |
| Bio-oil/Bio-char (green wood)<br>Technology Pathway 16 | $90.00 |
| Bio-products (green wood)<br>Technolgy Pathway 17 | $90.00 |
| Thermal Energy (cordwood)<br>Technology Pathway 5 | $104.00 |
| Thermal Energy (cordwood)<br>Technology Pathway 6 | $104.00 |
| Thermal Energy (green wood)<br>Technology Pathway 8 | $104.00 |
| CHP (green wood)<br>Technology Pathway 11 | $104.00 |
| Gasifier (green wood)<br>Technology Pathway 12 | $104.00 |
| Thermal Energy (pellets)<br>Technology Pathway 7b* | $167.00 |

## REFERENCES

Biomass Energy Resource Center, 2007. Vermont Wood Fuel Supply Study: An Examination of the Availability and Reliability of Wood Fuel for Biomass Energy in Vermont,
url: http://www.biomasscenter.org/resources/publications.html

Biomass Energy Resource Center. 2010. College Chip System Smoothly Generates Cost Savings.
url: http://www.biomasscenter.org/resources/case-studies/campuses/200-mt-wachusett.html

Biomass Energy Resource Center. 2010. On the Coast of Denmark, a Quietly High-Performing Woodchip Gasifier Is Producing District Heat and Power.
url: http://www.biomasscenter.org/resources/case-studies/communityde/214-harboore.html

Biomass Energy Resource Center. 2010. Woodchip System at Quabbin Ignites Interest in Massachusetts.
url: http://www.biomasscenter.org/resources/case-studies/govt-facilities/165-quabbin.html

Bituminous Coal. 2010.
url: http://en.wikipedia.org/wiki/Bituminous_coal

California Air Resources Board. 2005. Wood Burning Handbook – Protecting the Environment and Saving Money, (14 pp)
url: http://www.cabq.gov/airquality/pdf/arbwoodburninghandbook.pdf

Department of Energy (DOE). 2000. Carbon Dioxide Emissions from the Generation of Electric Power in the United States.
url: http://www.eia.doe.gov/electricity/page/co2_report/co2report.html

Energy Efficiency & Renewable Energy (ERRE), US Department of Energy. 2009. ABC's of Biofuels.
url: http://www1.eere.energy.gov/biomass/abcs_biofuels.html

Energy Information Administration (EIA), US Department of Energy. Energy Kids: Energy Units Basics.
url: http://tonto.eia.doe.gov/kids/energy.cfm?page=about_energy_units-basics

Energy Information Administration (EIA), US Department of Energy. 2008. Annual Energy Review
http://tonto.eia.doe.gov/energy_in_brief/major_energy_sources_and_users.cfm

Energy Information Administration (EIA). US Department of Energy, 2009. Fuel and Kerosene Sales, 2008
http://www.eia.doe.gov/energyexplained/index.cfm?page=heating_oil_use

Energy Information Administration (EIA), US Department of Energy. 2007. Massachusetts Renewable Electricity Profile.
url: http://www.eia.doe.gov/cneaf/solar.renewables/page/state_profiles/massachusetts.html

Energy Information Administration (EIA), US Department of Energy. 2010. Massachusetts State Energy Profile.
url: http://tonto.eia.doe.gov/state/state_energy_profiles.cfm?sid=MA

Engineering Toolbox. 2005. Fuel Oil and Combustion Values.
url: http://www.engineeringtoolbox.com/fuel-oil-combustion-values-d_509.html

---

[11] Chart information is derived from Appendix 2-B. See that appendix for sources.

Entergy. 2008. Pilgrim Station & the Local Environment.
url: http://www.pilgrimpower.com/local-environment.html

Innovative Natural Resource Solutions. 2004. New Hampshire Bio-oil Opportunity Analysis.
url: http://www.inrsllc.com/download/NH_bio_oil_analysis.pdf

Innovative Natural Resource Solutions (INRS) LLC. Biomass Availability Analysis—Five Counties of western Massachusetts. Prepared for DOER, January, 2007. (55 pp.)

ISO New England Inc. 2009. 2009 Regional System Plan.
url: http://www.iso-ne.com/trans/rsp/2009/rsp09_final.pdf

Kerr, Dawn R., Mann, Margaret K., Spath, Pamela L. 1999. Life Cycle Assessment of Coal-fired Power Plants. National Renewable Energy Lab (NREL).
url: http://www.nrel.gov/docs/fy99osti/25119.pdf

Laird, David A. 2008. The Charcoal Vision: A Win–Win–Win Scenario for Simultaneously Producing Bioenergy, Permanently Sequestering Carbon, while Improving Soil and Water Quality Agronomy Journal 100: 178-181.

Obernberger, I. et al. 2003. State of the Art and Future Developments regarding Small Scale Biomass CHP Systems with a special focus on ORC and Stirling Engine Technologies. International Nordic Bioenergy Conference (2003).

Range Fuels. 2010. Biomass to Energy: Renewable, Sustainable, Low Carbon Biofuels and Clean Energy. url: http://www.rangefuels.com/

# CHAPTER 3
# FOREST BIOMASS SUPPLY

## 3.1 INTRODUCTION AND MAJOR FINDINGS

Massachusetts has attracted the attention of bioenergy proponents and investors, in part due to a substantial rise in timber inventories over the last several decades. Recent studies on the availability of biomass to support new bioenergy plants have focused on incremental forest growth—implicitly treating inventory accumulation as potential supply—and confirmed expectations that inventories will continue to rise significantly. These studies thus concluded that available biomass is more than adequate to furnish several large-scale electric power plants without reducing timber inventories below current levels.

At this juncture, state policymakers require a better understanding of biomass supply, looking at factors beyond forest growth. Policymakers need to know whether the objectives of different energy policies are consistent with available wood supply, and how forest biomass harvests might respond to different economic realities that may be driven policy choices. With this perspective, we have crafted this analysis of forest biomass supplies in 2010–2025 around two central questions:

- How much forest biomass would be supplied at current biomass stumpage prices if there is an increase in demand from bioenergy plants?
- How much would forest biomass supplies increase if bioenergy plants pay higher prices for wood?

Another goal of this supply analysis is to better understand the implications of potential biomass harvest levels for forest health and forest harvesting guidelines.

### 3.1.1 CONCEPTUAL FRAMEWORK FOR FOREST BIOMASS SUPPLY ANALYSIS

**Key Study Features**

Our approach focuses on economic issues and landowner behavior and has been developed with an eye toward the availability and quality of relevant data. Unlike previous forest-growth-based studies,[1] this study of forest biomass supply in Massachusetts has several features that are different: 1) it is explicitly linked to energy prices; 2) it incorporates data on biomass harvesting and production costs; 3) it provides a detailed analysis of historical harvesting patterns on private lands, thus recognizing landowner willingness to harvest along with harvest intensity; 4) it considers the effect of stumpage prices and per-acre income on landowner behavior; 5) it is closely linked to available timber inventory in terms of accessible areas, mature volumes on private lands, and stocks of low-value trees; 6) it treats public lands separately and utilizes information on historical harvest levels, new Forest Resource Management Plans, and the Forest Futures Visioning Process; and 7) it incorporates sustainability criteria that have been developed and presented in Chapter 4.

We define forest biomass as wood supplied from forest management activities on private lands and public lands. These two ownership categories are considered separately in our analysis because they differ in several important ways: 1) the factors that determine the decision to harvest; 2) forest management objectives on private and public lands, and thus silvicultural prescriptions and harvesting techniques; and 3) harvest intensity and timber yields. In terms of area harvested in Massachusetts each year, private lands dominate with an average of about 22,000 acres harvested annually in 2000–2009.[2] In contrast, only about 4,000 acres of public land were harvested annually in the same time period. Note that we do not include land clearing as a source of forest biomass, because it is not a forest management activity and there are issues related to definitions of renewability. Nevertheless, it is the source of a substantial volume of wood (the average area of land cleared for development in 1999–2005 was estimated to be almost 5,000 acres per year) and so we have provided a separate section on potential biomass volumes from this source.

**Incremental Biomass Production**

The purpose of this supply study is to evaluate how much forest biomass would be available to furnish the potential expansion of bioenergy capacity and production in Massachusetts. For this reason, our analysis and projections are focused on incremental biomass production, not total production. The volume of biomass chips that has been produced from forest sources historically is considered to be "utilized" and, since this wood is already accounted for, it is not available to meet the demand from new bioenergy plants. We sometimes refer to this incremental production as "new" biomass.

**Two Biomass Price Scenarios Linked to Energy Prices**

We have developed two biomass price scenarios—linked to energy prices—that are intended to provide DOER with guidance as to how much wood may be available to furnish new bioenergy plants. These scenarios recognize the importance of stumpage prices and income in influencing landowner behavior, and the important relationship between delivered biomass prices and harvesting systems/logging costs. This section discusses these scenarios with respect to electricity prices; thermal and CHP

---

[1] Recent studies using the forest-growth approach to assess biomass availability in Massachusetts are reviewed in Appendix 3-A. While these studies provide useful information on how much wood could be harvested on an ongoing basis without reducing inventories below current levels, they do not address the complex economic and social factors that will determine how much of this biomass would actually be available to furnish new biomass facilities. We have developed estimates of biomass availability using a forest-growth approach in Section 3.2.5 so that they may be compared with the results of the approach that we have developed.

[2] The data and information provided in this section are summarized from the main body of this chapter. Sources and references are contained in the relevant sections.

are addressed in the following section. Note that this assessment is intended to provide estimates of forest biomass potential over the medium term; in the near term, logging and infrastructure constraints (not addressed in this study) could be significant obstacles to harvest increases.

Our starting point is to estimate the potential of forest biomass to supply electric power plants in Massachusetts. This is an area of immediate concern for DOER given that they are now considering proposals for several facilities and the adequacy of wood supplies to furnish these plants is a central issue. In this scenario, our assumptions have been developed to reflect the current pricing environment for electricity and biomass: real electricity prices are assumed to remain near recent levels as are the price of renewable energy credits.[3, 4] Consistent with this assumption, real biomass prices are also assumed to remain near recent levels: delivered wood prices at power plants would be about $30 per green ton, and biomass stumpage prices would average $1–$2 per green ton. We refer to this scenario as the "Low-Price Biomass" scenario.

Our second scenario is intended to provide perspective on the upper bound for forest biomass production if bioenergy demand and prices increase beyond the level established in the Low-Price Biomass scenario. It is not reasonable to specify an absolute maximum for biomass supply since supply is an economic concept which depends on timber prices (and a host of other factors). Thus, we need to specify a "high" biomass stumpage price, and then consider how private landowner harvests might respond to this price level. Forest biomass volumes could still increase beyond this level, but it would be increasingly difficult to due to biophysical, economic, and social constraints and increasingly unlikely due to macroeconomic and energy constraints. We refer to this future outlook as the "High-Price Biomass" scenario.

How high should the biomass stumpage price be in this "limiting"case? For increased demand from new wood-fired electric power capacity, we have developed an upper-range electric price scenario that leads to real biomass stumpage prices of about $20 per green ton.[5] The significant increase in real electricity prices needed for power plants to purchase wood in this scenario could be triggered by either macroeconomic or policy shifts.[6] Also, policy initiatives (such as REC's) that provide higher income for utilities could be compatible with this level of biomass stumpage prices.[7] We should note that we think that the high level of electricity prices that would drive this scenario is unlikely on the basis of macroeconomic trends and projections of future escalation in coal and natural gas prices. Significant changes in government policies would probably be necessary for this scenario to unfold and could take the form of greater incentives for electric power, or policies that spur substantial investment in thermal, CHP plants, and pellet plants.

How much forest biomass would landowners be willing to supply in response to higher prices? As demand and prices increase, more wood can be supplied from private lands by increasing removals of low-value wood from sites that are already under harvest, diverting wood from other end-use markets (such as pulpwood) to biomass, and increasing the number of acres being harvested. The standard and most direct approach to answering this question would be to estimate the effect of price changes on harvest volumes directly (that is, the timber supply elasticity). We have presented some results from our analysis of this relationship in Massachusetts, but they are merely suggestive due to the poor quality of the data on both harvest volumes and prices.

A second approach would be to rely on the literature for estimates of timber supply elasticities that have been developed in other regions. Available studies generally show that timber supply is very inelastic (that is, price changes have little or no influence harvest volumes).[8] However, these results are not necessarily relevant in evaluating the biomass supply situation in Massachusetts because the characteristics of the landowners, timber inventory, and forest products industry are very different. Importantly, there are two issues not addressed in previous research that are likely to have a significant effect on forest biomass supply behavior in Massachusetts and call for an alternative approach.

The first issue relates to biomass prices and per-acre incomes. Studies which examine the relationship between harvests and prices generally focus on sawtimber prices (and sometimes pulpwood) because these dominate the value of a harvest in most regions.

---

[3] Reference case (or base case) forecasts of electricity prices suggest that real prices will remain relatively flat over the next 15 years, as they play off a projected declining trend in real natural gas prices and a slightly increasing trend in real coal prices (see for example, Annual Energy Outlook 2010: U.S. Energy Information Administration, 2009).

[4] The assumption about REC's is important since they provide a significant share of revenue for wood-fired power plants and they can be modified by state policy.

[5] The delivered wood and electricity prices consistent with this scenario are discussed later in this report.

[6] There are numerous policies under consideration that could lead to such changes (see U.S. Environmental Protection Agency, 2009: EPA Analysis of the American Clean Energy and Security Act of 2009).

[7] If electric power plant demand for wood increases but there are no increases in electricity prices that would allow power producers to pay the higher prices needed to generate more wood supply, then direct payments to landowners would be another policy that could lead to more biomass production.

[8] There are many issues with these studies that raise concerns, perhaps the most serious being data limitations and errors in measuring price and harvest variables. In addition, many studies estimate binary choice models and only address the question of whether or not price has an effect, not the magnitude of that effect.

However, if biomass prices rise significantly, they can make an important contribution to income and influence landowner decisions.[9] The second issue is the age structure of the inventory in Massachusetts. Many empirical studies consider inventory levels in a broad sense, but none directly consider the age structure of the inventory. A large percentage of the private forests in Massachusetts are now over 60 years old and are ready—if not overdue—to be thinned for landowners interested in commercial timber production[10]; financial incentives could have an important effect on the decisions of these landowners.

These concerns have led us to an approach for the High-Price Biomass scenario that recognizes landowner characteristics, the age structure of the inventory, and the importance of per-acre income levels. While we believe this method provides a better estimate of forest biomass supply than traditional economic approaches, a good deal of uncertainty concerning landowner responses cannot be eliminated since we are considering behavior that is well beyond our historical experience. As demand and prices increase, the confidence intervals grow wider and it is important to recognize and acknowledge this uncertainty.

### Biomass Supplies for Thermal and CHP Plants

It is relatively straightforward to extend the above scenarios to evaluate the availability of forest biomass supplies for wood-fired thermal and CHP plants. The cost structure of thermal and CHP plants and their competition with facilities that use oil and natural gas allow them to pay much higher prices for wood than electric power plants. For example, in current markets (assuming oil prices of $3 per gallon), thermal and CHP plants could pay up to $85–$95 per green ton of wood (45% moisture content) and still cover their full cost of capital (based on the analysis in Chapter 2).

In terms of wood supply, one important difference between electric power and thermal/CHP plants is that the latter prefer higher-quality chips that are uniform in size and shape and have low ash content (Maker, 2004; P Squared Group and Biomass Energy Resource Center, 2008). Clean chips and chip specifications in general may add about $10–$15 per green ton to the cost of chip production. Thus, thermal and CHP plants would need to pay $40–$45 per delivered green ton compared to $30 for an electric power plants.[11] Importantly, in the same woodshed, thermal and CHP plants can pay this difference—and much more if necessary—and remain profitable.

At the high end of the supply curve, if the market price of delivered wood for electric power plants is $50–$60 per green ton, thermal and CHP plants would face wood prices in the range of $65–$75 per green ton. This price level is still below the range that these plants could afford to pay today and cover their full costs. Of course, if electric power prices increase due to macroeconomic factors and fuel costs, it is a safe bet that oil prices would be much higher as well; in fact, most forecasts indicate that oil prices will increase faster than electricity prices (which are tied more closely to the cost of coal and natural gas).

In sum, higher-quality chip specifications for thermal and CHP plants shift the supply curve for delivered wood chips upward relative to that of electric power plants. Under reasonable energy price scenarios, when these plants compete for the same wood supply, thermal and CHP plants will be able to outbid electric power plants due to their production economics and the competitive environment of the energy markets in which they operate.

### Harvesting Systems and Logging Costs

We have conducted our assessment of wood biomass supply in Massachusetts with and without the harvesting restrictions—particularly with respect to the removal of tops and limbs—that are provided by the guidelines in Chapter 4 of this report.

Our assessment of biomass supply in Massachusetts suggests that if demand increases due to the expansion of electric power plants, it will almost certainly be accompanied by increases in whole-tree harvesting due to the limited supply of other forest biomass and the cost advantages of whole-tree methods. Generally, we assume that whole-tree harvesting can be used on private lands as long as it meets the forest practices standards required by the state. Given the uncertainty regarding the acceptance of whole-tree harvesting (particularly mechanical systems) in Massachusetts, our supply projections allow for the fact that many landowners, foresters, and loggers will still favor alternative harvesting methods.

Thermal and CHP plants are not constrained to use whole-tree harvesting methods because of their ability to pay higher prices for delivered wood chips. These facilities could buy wood procured with log-length methods, in which trees are delimbed and bucked at the stump and the logs are forwarded or skidded to the landing. Log-length methods may be selected over whole-tree methods if management plans call for leaving tops and limbs scattered on the site and/or there is concern about damage to soils or to the

---

[9] Landowners may also respond differently to an equivalent amount of income from harvesting biomass and sawtimber because the removal of low-value biomass may have a different impact on the value of non-timber amenities than the removal of large trees.

[10] Kelty et al. (2008) reference silvicultural research that indicates that 50 years is the recommended age for first thinning (cited from Hibbs and Bentley, 1983), but indicate that first thinnings in Massachusetts are commonly delayed until stands reach 70 years of age.

[11] While thermal and CHP plants will compete for bole chips, electric power plants can use whole-tree chips from tops and limbs. However, given the wood supply situation in Massachusetts, it appears that electric power plants would need to obtain most of their wood from whole trees and thus could face the prospect of competing directly with thermal and CHP plants for bolewood when operating in the same woodshed.

residual stand (Fight et al., 2006). As noted earlier, our estimates indicate that log-length harvesting methods would add about $10–$15 to the cost of a green ton of chips.

## 3.1.2 MAJOR FINDINGS AND CONCLUSIONS

Here we summarize the major findings of our wood supply assessment:

**Forest Biomass Supply Available in Massachusetts with Low-Price Stumpage**

- At current prices for biomass stumpage, we estimate that about 150,000–250,000 green tons of "new" biomass could be harvested annually from forest lands in Massachusetts.[12] Most of this material would be sourced from standing trees due to the small size of the forest industry in Massachusetts, and hence the limited supply of logging residues and limited opportunities for log merchandizing. This wood would be available to electric power, thermal, CHP or other bioenergy plants; however, if the wood is harvested as feedstock for electric power plants, whole-tree harvesting would be necessary to produce chips at $30 per delivered green ton.

- We estimate that virtually all of the "new" forest biomass supply would be harvested from private lands. Given the low price of stumpage in this scenario, biomass producers would have economic access only to low-value wood and it would be harvested almost exclusively on sites that are already being harvested for sawtimber. If whole-tree harvesting operations are established for biomass production, it would also become economical to remove sawtimber logging residues from those same sites. Applying the ecological guidelines provided in Chapter 4 of this report, our projection shows that tops and limbs from industrial roundwood would account for about 15%–20% of the "new" biomass harvest from private lands.

- We find that there would likely be little or no increase in biomass production from public lands. Our review of Forest Resource Management Plans and anticipated forest policies leads us to conclude that the total volume of wood harvested on public lands in 2010–2025 will be about the same level that we have observed during the past decade. We have assumed that biomass fuel will not be diverted from other end uses (such as pulpwood) in this scenario. Logging residues are not projected to contribute to supply because of ecological restrictions and poor economics.

**Forest Biomass Supply Available in Massachusetts with High-Price Stumpage**

- Higher biomass stumpage prices could dramatically affect the supply of biomass by providing economic incentives that bring more private land into timber production, increase the harvest intensity on all lands that are harvested, and divert wood from pulpwood and other end-use markets to biomass. With our scenario of biomass stumpage prices at $20 per green ton, per-acre income from wood sales could double and we estimate that about 685,000–885,000 green tons of "new" forest biomass could be produced annually in Massachusetts.

- Increased prices would not be expected to lead to higher harvest levels on public lands. However, at these higher stumpage prices, biomass supplies would increase as wood from public lands would likely be diverted from pulpwood to bioenergy plants. The volumes would be small, however, and would account for only about 5% of "new" statewide forest biomass production.

- We have estimated a "sustainable" level of biomass supply using the criteria that harvests do not exceed net growth and that biomass harvests can be maintained at the same level for the foreseeable future. Based on our estimates of operable private land area and our growth estimates in Chapter 5, we have calculated that average annual biomass supply could be 900,000 green tons per year. Thus, the high end of the range that we derived using our approach (885,000 green tons) would be considered "sustainable" by this definition. In addition, our analysis suggests that the "supply" estimates developed using forest-growth approaches would only be consistent with very high biomass stumpage prices.

**Forest Biomass Supply Available from the Border Counties**

- We evaluated supplies in the border counties (NH, VT, NY, CT, and RI) by considering timberland area, timber inventory, growth rates, ownership characteristics, and forest products production. There is no simple scheme to weight these factors, but our best estimate is that incremental forest biomass production in the border counties would be about 50% greater than that of Massachusetts. The logic of our two scenarios still applies: at low biomass stumpage prices, "new" volumes would be limited because they come primarily from the additional harvest of low-value wood on sites already being logged for other commercial timber; at high biomass stumpage prices, the harvested land base would increase considerably, as would the harvest intensity on these sites.

- Biomass produced in the border region could be consumed in the "local" market, shipped to Massachusetts, or shipped to the next ring of bordering counties and beyond. The eventual destination for this wood will depend on the location and timing of new capacity investment throughout the region and a variety of other factors such as transportation costs, infrastructure, and supply logistics. While this is a complex problem with a high degree of uncertainty, we think that as a general planning guide it would be prudent to assume that Massachusetts could successfully purchase only half of the available wood. Thus, in the Low-Price Biomass scenario, "new" forest biomass available from the border counties to

---

[12] The major uncertainty that accounts for this range is the average volume of biomass material removed from an acre. It is also possible that some pulpwood could be diverted to biomass fuel at relatively low biomass stumpage prices, but we have not introduced this potential shift in the Low-Price Biomass scenario.

furnish bioenergy plants in Massachusetts would be about 110,000–190,000 green tons per year. With the assumption of high biomass stumpage prices, forest biomass supplies from adjacent counties would increase to about 515,000–665,000 green tons annually.

Our projections for incremental forest biomass production in Massachusetts and the border counties are summarized in Exhibit 3-1. Although we have provided a range of estimates in this table, there are, of course, a wider set of possible outcomes for these scenarios. This uncertainty is largely due to our limited historical experience with biomass harvesting in Massachusetts, and this becomes a greater concern when we analyze the impact of much higher biomass prices. We have conducted sensitivity analysis of some of our key assumptions within this chapter. Perhaps the most significant source of uncertainty is how private landowners will respond to the prospect of earning higher income from biomass harvests. Another general issue is the acceptance and adoption of whole-tree harvesting by landowners, foresters, and loggers in Massachusetts—this is particularly important in scenarios involving electric power expansion since whole-tree harvesting would likely be necessary due to cost considerations. For the border counties, it is more difficult to address the issue of confidence intervals because our estimates were established relative to Massachusetts, and then scaled down to recognize that facilities outside of Massachusetts would compete in this same woodshed.

**Exhibit 3-1: Summary of Forest Biomass Fuel Supplies for 2010–2025**

| Low- and High-Price Biomass Scenarios<br>000 Green Tons per Year | | |
|---|---|---|
| | **Low-Price** | **High-Price** |
| **Massachusetts** | | |
| **Private Lands** | 150–250 | 650–850 |
| **Public Lands** | 0 | 35 |
| **Total** | 150–250 | 685–885 |
| **Border Counties** | 110–190 | 515–665 |
| **Combined Total** | 260–440 | 1,200–1,550 |

*Note: Estimates have been rounded for this table.*

We have focused on two price scenarios for forest biomass supply, with the high-price scenario intending to provide an approximate upper bound for incremental biomass harvests. Clearly, these two price levels represent only two points on a supply curve that embodies many price-harvest combinations. A few comments on the shape of this curve are appropriate. At current/low price levels, the supply curve for private owners is presumed to be flat suggesting that any volume of forest biomass up to the range of 150,000–250,000 green tons per year could be procured at these prices. At high-end prices, we would expect that the slope of the curve would be relatively steep reflecting landowner resistance to harvesting additional acres due to the greater value that owners at the margin may place on non-timber amenities. This nonlinearity suggests that if bioenergy capacity increases in Massachusetts, it may not be difficult to procure wood at affordable prices in the early stages of expansion, but it could become more problematic as prices rise nearer to the levels assumed in the High-Price Biomass scenario.

## 3.1.3 POTENTIAL WOOD BIOMASS SUPPLIES FROM OTHER SOURCES

This assessment has focused on the core issue of biomass production from forest sources. It is important to recognize that there are other biomass sources that could potentially make a substantial contribution to the supply of wood available for new bioenergy facilities in Massachusetts. These can be classified into three major categories: 1) wood from land clearing; 2) wood from mill residues and tree care/landscaping sources; and, 3) wood grown in short-rotation plantations.

### Wood From Land Clearing

There is a high degree of uncertainty in estimating the area of land that is cleared each year in Massachusetts, the amount of wood removed from that land, and the current disposition of that wood. As a result, it is difficult to estimate the volume of incremental biomass supplies that could be generated from land clearing over the next 15 years. Holding the area of land cleared annually constant, we have calculated that a 10% increase in the recovery rate[13] would yield an additional 30,000 green tons per year of biomass that could furnish an expansion in bioenergy plants. Given current disposal costs for cleared wood and current potential uses for that wood, it would seem that an increase in recovery rates from 30% to 70% (at high biomass stumpage prices) would provide reasonable bounds for the potential supply from this source. This translates to a maximum volume of 120,000 green tons of "new" biomass given our assumptions on the area of land cleared and the expected diversion of high-quality wood to other end-use markets.

### Wood Biomass From Mill Residues and Tree Care/Landscaping Sources

Among these other sources, the most significant is wood from tree care/landscaping sources. This wood is often referred to as "urban wood" which is somewhat of a misnomer because it includes wood not only from tree care in urban areas, but also wood from tree care from sources such as county parks and recreation areas and maintenance of electric power lines. The term can also be confusing because it is not always clear whether it includes "urban waste" such as construction debris.

A literature review conducted in 2002 indicated that tree care/landscaping sources accounted for 1.0 million tons (42%) out the total available supply of 2.5 million tons of non-forest wood biomass in Massachusetts (Fallon and Breger, 2002). However, given the difficulties in estimating this volume (noted in the report), this estimate is perhaps best used to suggest that the potential from

---

[13] We define the recovery rate as the percentage of wood cleared that is used for industrial roundwood products or industrial and residential fuelwood.

these sources may be substantial and worthy of further investigation (importantly, the carbon profile of this material is generally similar to logging residues and thus very favorable compared to that of harvesting standing trees).

Two other important sources of wood biomass that should be noted are mill residues and urban waste (municipal solid waste, and construction and demolition debris). Although mill residues can be a valuable source because they are clean, dry and easily accessed, they are generally fully utilized. Moreover, mill residue supplies in Massachusetts have been declining in parallel with the contraction in lumber production. On the other hand, solid waste and C&D debris may be considered under-utilized, but are expensive to sort and can be difficult to recover due to contamination issues.

**Short-Rotation Wood Plantations**

DOER and DCR commissioned a study that included an evaluation of the potential of growing short-rotation willow crops in Massachusetts for bioenergy use (Timmons et al., 2008). In light of our forest biomass supply assessment, there are three reasons that the potential of this supply source on marginal agricultural lands may deserve more attention if DOER wishes to promote bioenergy development. First, our economic analysis has shown that the potential to produce forest biomass chips in the current pricing environment and with current policy incentives is significantly less than suggested by previous studies that were focused on forest growth. Second, although BCAP policies are now undergoing revision, the proposed rules offer significant subsidies for the establishment and development of wood energy crops (see policy review in Chapter 1). Third, if carbon emissions are an important consideration in state energy policies, closed-loop short-rotation crops have some obvious advantages when compared to natural forest biomass sources.

### 3.1.4 REPORT ORGANIZATION

This report is organized as follows. Section 3.2 provides an in-depth analysis of biomass supplies from private lands in Massachusetts. We begin with a review of historical levels of timber harvesting since we believe this is fundamental to understanding future biomass supplies—biomass production often makes economic sense only when integrated with sawtimber harvests. The forecast for low-price biomass supply requires the review of three important topics: 1) costs of whole-tree harvesting; 2) low-value wood supply in sawtimber stands; 3) landowner willingness to increase harvest intensity. In order to generate a forecast of high-price biomass supplies, the discussion is extended to include: 1) the size of the operable land base after adjusting for biophysical factors and landowner characteristics; 2) landowner response to higher wood prices and higher per-acre income levels.

Section 3.3 discusses the potential for harvesting "new" biomass supply from public lands, and covers both historical harvest levels and projections of wood harvests. Our forecasts for forest biomass supplies in Massachusetts are summarized by source for our two biomass stumpage price scenarios in Section 3.4. Section 3.5 reviews potential biomass production from other sources, including land clearing and conversion.

In Section 3.6, we present our assessment of biomass supply from nearby states by evaluating their potential relative to Massachusetts. Key topics covered include timberland area, timber inventory, timber growth, forest products industry status and associated harvesting levels, and landowner characteristics. After developing estimates of potential additional biomass production in the border region, we conclude by discussing some of the factors that determine where this wood might eventually be consumed.

Some of our work and analysis has been presented in several Appendices, which include the following topics: 1) a review of results of previous studies on forest biomass availability in Massachusetts (Appendix 3-A); 2) logging residue data and methods for estimation (Appendix 3-B); 3) firewood production and consumption in Massachusetts (Appendix 3-C); 4) an analysis of biomass potential in southern New Hampshire (Appendix 3-D).

## 3.2 BIOMASS SUPPLY FROM PRIVATE LANDS IN MASSACHUSETTS

Private timberlands in Massachusetts are by far the most important source of "new" or incremental forest biomass production because of their size and the ability of landowners to adjust their harvest decisions in response to changes in market conditions. The analysis in this section is organized as follows: 1) historical estimates of timber harvests; 2) review of potential supplies from logging residues; 3) projection of biomass supplies in the Low-Price Biomass scenario; and 4) projection of biomass supplies in the High-Price Biomass scenario. Our projections include a review of harvesting costs, and examine the important role of stumpage prices in influencing production volumes.

### 3.2.1 HISTORICAL ESTIMATES OF TIMBER HARVESTS ON PRIVATE TIMBERLAND

The economics of forest biomass production are generally most favorable when biomass harvests are integrated with sawtimber harvests. In this section, we provide a detailed analysis of historical patterns of timber harvests in Massachusetts to lay the groundwork for our projections of sawtimber and other industrial roundwood harvests. Unless income incentives increase substantially under some scenarios that are described under our High-Price Biomass scenario, the harvesting footprint with biomass is likely to be very similar to that for industrial roundwood alone. Biomass production will then come from increasing the harvest intensity on these lands, by taking tops, limbs, and low-value standing trees.

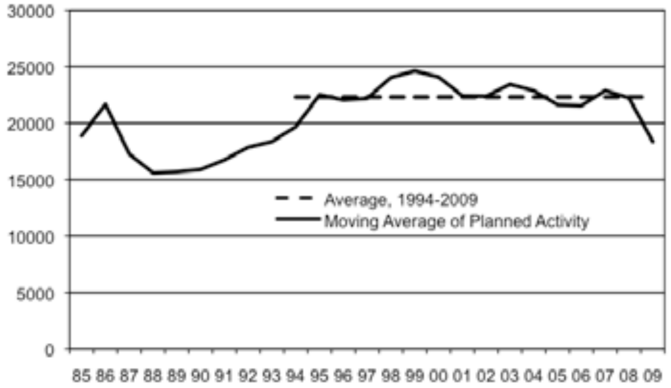
Unlike several states in the Northeast region, Massachusetts does not track and collect data on annual harvest levels. Thus, this analysis relies on forest cutting plans (FCPs) that are required by the state under the Forest Practices Act. Although FCPs have several important limitations with regard to coverage and timing[14], they are the best data source available to identify important long-term trends in harvesting activity in Massachusetts. We have obtained these data for 2001–2009 from the Massachusetts Department of Conservation and Recreation, and for 1984–2000 from research at the Harvard Forest (Kittredge et al., 2009).

The FCP data indicate that the average annual volume of wood "harvested" from private lands in 2001–2009 was 323,000 green tons.[15] Average volumes by end-use market according to these plans were 224,000 green tons of sawtimber, 84,000 green tons of "pulpwood," and 16,000 green tons of fuelwood. However, one must be cautious in interpreting these data because wood that is classified as pulpwood may actually be consumed for fuel, either in residential or industrial uses—wood classifications and conversions to green tons are discussed in more detail later in this section.

In order to analyze these data, we first consider acres harvested on all private lands, which are shown in Exhibit 3-2. Harvested acres dropped sharply in the late 1980s, but rebounded by the mid-1990s and have been relatively flat since that time. In fact, the stability of the private land area harvested over the past 15 years is remarkable given the number of factors that influence this trend, including overall demand levels for wood products, and harvest volumes supplied from public lands and land clearing activity. We should note that forest industry lands are only a small portion of the private land base in Massachusetts (harvests on industrial lands account for only about 5% of acreage as well as 5% of volume removed); thus, we have not disaggregated private lands into industrial and non-industrial components as is commonly done in timber supply analysis.

This "stable" trend is more interesting in light of the fact that the area of private timberland in Massachusetts has declined by 20% during this period, from 2.5 million acres in 1985 to 2.0 million acres in 2008 according to FIA data[16] (these data suggest that this shift was primarily due to a transfer of timberlands from private to public ownerships, with land conversion playing a much less important role[17]). While the stability in area harvested is open to various interpretations, the most probable explanation would relate to the small share of land that is harvested. Thus, in spite of the increasing fragmentation of the land base and the small average parcel size of ownership, the data suggest that much of the harvesting in Massachusetts may take place on an operable land base that may not have changed much over this period of time.

**Exhibit 3-2: Acres Harvested on All Private Lands, 1985–2009**



*Note: Derived from Forest Cutting Plans assuming 95% of plans are completed.*

As noted above, sawtimber demand is the key driver of harvesting activity on Massachusetts timberland and thus critical to the analysis of potential biomass supply. Over the historical time period, the sawtimber harvest on a per-acre basis has ranged from a low of about 1,600 board feet (International ¼" log rule) in 1991 to a high of 2,200 board feet in 2006 (Exhibit 3-3). The average in 1994–2009 was 2,000 board feet per acre.[18]

The stability in the volume of sawtimber harvested on private lands in 1994–2009 contrasts markedly with the large decline in lumber production during this period. Lumber production in Massachusetts was just over 100 million board feet in 1993 and

---

[14] Important limitations include: 1) they are pre-harvest plans and thus the volume to be harvested is only an estimate of what was actually cut; 2) once filed, the plans can be implemented over the following two years and there may be extensions (for two additional years); in addition, those who file may choose not to harvest at all; 3) they are only required for wood harvests greater than 50 cords or 25,000 board feet; 4) they are only required if the land remains in forest use and thus do not include land clearing. These issues are discussed in Ch. 132 of the Massachusetts Forest Cutting Practices Act and by Kittredge et al., 2009.

[15] Although these data are pre-harvest levels as stated in the Forest Cutting Plans, we refer to them as though they are "actuals," partly for convenience, but also because we have adjusted them, reducing the levels by 5% (based on information reported by Kittredge et al., 2009) and using a distributed lag function to allocate harvests over multiple years to account for the fact that those who file plans have up to two years to harvest with the possibility of extensions.

[16] Reference to FIA data is made frequently throughout this report. FIA refers to the Forest Inventory and Analysis National Program which provides detailed data on forests and forestland based on surveys by the U.S. Forest Service.

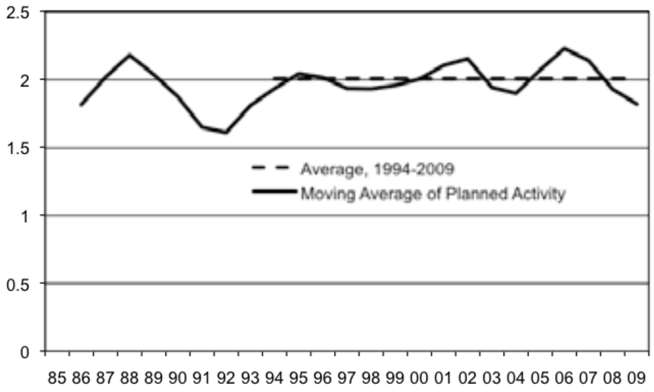
[17] It should be noted that it is difficult to quantify accurately the magnitude of these land shifts and different data sources can lead to different conclusions. For example, using the same FIA database and considering forestland in Massachusetts (forestland area is about 5% greater than timberland area) suggests larger losses in the private land base, smaller gains in the public land base, and a much higher share of land lost to conversion. Data that provide direct measurements of land conversion in Massachusetts are discussed later, but these data also have numerous problems and are not consistent with the FIA trends.

[18] It is interesting to note that Kelty et al., 2008 report that a 50% overstory thinning on average private lands in Massachusetts would yield 2 MBF (International ¼" log rule) per acre.

edged higher to 104 million board feet in 1996; however, production was estimated to have been only 69 million board feet in 2001 and 49 million board feet 2005 (Damery et al., 2006). On public lands, sawtimber harvests were also flat over the past 15 years according to FCP data. One interpretation of these trends would be that the contraction in lumber production was less a function of final demand than of the competitive position of sawmills in Massachusetts, and high-quality sawlogs continued to be cut and shipped out of state to be processed elsewhere. Another factor that needs to be considered is that it appears that land clearing dropped sharply over this time frame; thus, a potentially important source of sawlogs declined substantially and may have increased the demand for sawlogs from private lands.

Most importantly for this study, in spite of major changes in local processing capacity and demand and some significant price swings, acres harvested and sawtimber harvests have remained relatively stable. These trends provide the basis for our projections of future harvest levels in Massachusetts.

**Exhibit 3-3: Average Sawtimber Harvest Intensity on All Private Lands, 1985–2009 (000 board feet, International ¼" log rule per acre)**

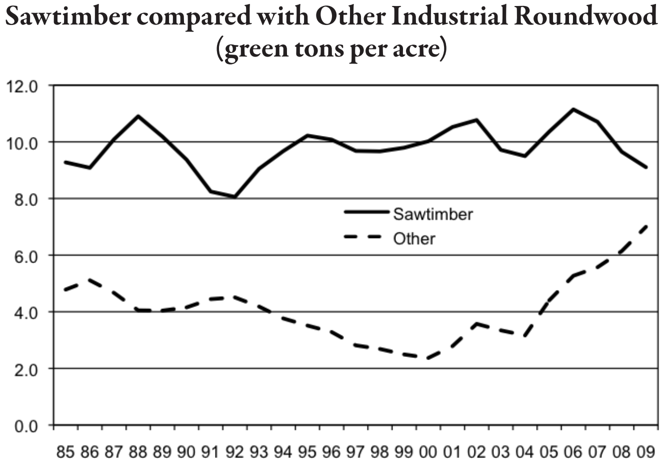


*Note: Derived from Forest Cutting Plans assuming 95% of plans are completed.*

In order to project forest biomass supply, it is also important to consider the volume of timber that is being harvested for other end uses. These calculations provide insight into other demands on the resource base, harvest intensities on timberland, and the potential for additional harvests of biomass. In order to compare the harvest volumes reported on the FCPs, we converted sawtimber (MBF, International ¼" log rule), pulpwood (reported as 128 cubic-foot cords), and fuelwood (reported as green tons) to common units (green tons in this case). Harvest intensity for sawtimber in green tons per acre is contrasted with the other industrial roundwood uses in Exhibit 3-4.[19] Other industrial roundwood fell from about 4 green tons per acre in the early 1990s to only about 2 green tons per acre in 2000. Since that time, other industrial roundwood harvests have climbed sharply, reaching 7 green tons per acre in 2009 (according to plan data, this consists of 5 green tons of pulpwood and 2 green tons of fuelwood).

We should also note that our analysis of historical timber harvests includes only a small percentage of the total volume of firewood that is cut and consumed in Massachusetts. FCPs are required only for harvests that exceed 50 cords and it appears that most firewood is produced in much smaller operations. This is consistent with Massachusetts landowner surveys that suggest that many owners of small parcels are interested in firewood harvests, but not harvests of industrial roundwood.

**Exhibit 3-4: Average Harvest Intensity on All Private Lands, 1985–2009**



*Note: Derived from Forest Cutting Plans assuming 95% of plans are completed.*

For this study, we have assumed that residential fuelwood harvests do not have a significant impact on the potential for forest biomass supply since most of the biomass for industrial use is likely to come from larger harvesting operations. However, there is an interface between the two sectors as some residential fuelwood does get cut during industrial roundwood harvests, and sometimes in follow-up harvests if crews move in to remove smaller wood or standing dead wood. This area may deserve additional study because of the large volume of firewood production in Massachusetts, which we estimate may be two-to-three times the volume of industrial roundwood harvested (see Appendix 3-C).

## 3.2.2 LOGGING RESIDUES

Most studies of potential forest biomass availability start with logging residues because: 1) they represent a substantial volume of wood (4.5 billion cubic feet in the U.S. in 2006, which compares with 15.0 billion cubic feet of roundwood harvested for all products (Smith et al., 2009); 2) their removal has been considered integral to forest and ecological health in many situations due to potential fire hazard and insect damage; 3) they are perceived to be underutilized and have additional value as product output;

---

[19] We have combined pulpwood and fuelwood into "other industrial roundwood" because the two classifications are not reliable indicators of their end-use markets. Some pulpwood—perhaps more appropriately referred to as cordwood—can be cut and split for firewood, and may be chipped for biomass. Fuelwood is comprised of roundwood that is processed for residential firewood, and also wood that is chipped for industrial biomass use.

4) they are assumed to be the most easily procured—and thus the least costly—source of biomass supply from forests. Logging residues have been a central focus of many studies (for example, the "Billion-Ton-Study," Perlak et al., 2005) and are considered a key source of forest biomass fuel.

### 3.2.2.1 LOGGING RESIDUE GENERATION

Here we consider the potential volume of forest biomass supplies from logging residues in Massachusetts. The primary source of logging residue data in most studies is the Timber Products Output (TPO) reports from the U.S. Forest Service. These data could not be used directly for Massachusetts due to problems in the underlying database (see Appendix 3-B for a full discussion of the logging residue data). In addition, the TPO methodology tends to overstate the volume of logging residues available for biomass fuel because the data include a significant volume attributable to breakage and residual stand damage.

For these reasons, we have devised an alternative approach in which we estimate the volume of tops and limbs associated with harvesting trees of varying diameter classes (the derivation of these estimates is provided in 3-B). When these percentages of top and limb material are applied to recent industrial roundwood harvest levels, they suggest that the total volume of "logging residues" generated on private lands in Massachusetts is on the order of 100,000 green tons per year.[20]

### 3.2.2.2 LOGGING RESIDUE RECOVERY

Most studies that evaluate the availability of logging residues make the assumption (sometimes implicitly) that the bulk of logging residues are delivered to a landing as part of normal harvesting operations. In these logging operations, a tree is assumed to be delivered to the landing for the value of the sawlog and pulpwood, while the "wastewood" is assumed to be a by-product of the operation with zero costs for "delivery" to a landing. With these assumptions, the portion of the tree that could be considered biomass fuel is inexpensive and available for the cost of chipping and transport to a bioenergy facility. While this may be true in many regions, it is generally not the case in Massachusetts where logging operations commonly consist of manual felling, bucking into logs in the field at the stump, and cable skidding or forwarding; thus, most tops and limbs remain on the ground where the trees are felled.

While it may be feasible to recover scattered logging residues in some circumstances, it seems fair to conclude that biomass supply from logging residues in Massachusetts would be minimal without some modifications to existing harvesting operations. Although these logging residues do have the advantage of having been felled at no cost to the biomass producer, the high cost of collection and delivery to a central location would generally be prohibitively expensive.

In order to produce biomass competitively from tops and limbs, whole-tree harvesting operations would likely be necessary to reduce the costs of landed residue material. Rather than topping and limbing felled trees at the stump, trees could be skidded to a landing with some portion of the top and limbs remaining intact. Tops and limbs could then be removed at the landing and chipped there. If biomass is produced in this manner, the primary costs would be chipping (about $6–$7 per green ton for slash) and transport from the landing to a bioenergy plant (directly dependent on distance, but averaging about $8–$12 per green ton).[21] Thus, total delivered costs would be $14–$19 per green ton.[22]

### 3.2.2.3 FORECAST OF FOREST BIOMASS SUPPLY FROM LOGGING RESIDUES ON PRIVATE LANDS

In order to project biomass supplies that can be used to meet potential demand from new bioenergy plants, we have assumed that 65% of the tops and limbs from harvested trees can be recovered on acres where silvicultural prescriptions include whole-tree biomass harvests. This percentage was selected for two reasons: 1) it leaves behind more than enough material to conform to the ecological guidelines that have been spelled out in Chapter 4; 2) it recognizes that a significant share of tops and limbs remain uneconomic due to timber breakage, small pieces, and small branches. Some issues, such as difficulties in handling large hardwood crowns, encompass both ecological and economic concerns.

Harvests of logging residues have been considered in conjunction with harvests of standing forest biomass in the following sections. We did not consider it useful to develop a separate biomass supply scenario for only logging residues. Biomass production from logging residues would be widely dispersed and given historical harvest levels, it would amount to only about 2–3 green tons on an average acre. It may be feasible to economically recover this material in some locations with small chippers and chip vans. However, in the broader context of biomass markets, the economic case for producing forest biomass makes more sense when more volume is produced on a per-acre basis. Thus, our projections of biomass supplies from logging residues are combined with harvests of other low-value standing trees and these projections are discussed below.

## 3.2.3 LOW-PRICE BIOMASS FROM PRIVATE TIMBERLANDS

---

[20] One shortcoming of this approach is that it is not possible to estimate how much of this topwood and limbwood may already be utilized for products (due to differing utilization standards), or harvested for firewood.

[21] These data are based on the combination of a literature review and informal survey of industry professionals.

[22] Although we have assumed that tops and limbs are free at the landing in this case, increased competition for this material in response to higher biomass demand would likely cause the value of the wood to be bid higher, thus raising the cost of delivered wood. There are also some additional logging costs associated with piling or "putting up' the material at the landing.

At this stage of the analysis, we remain focused on biomass supplies from acres that are already under harvest for sawtimber and other industrial roundwood products. We restrict the potential for forest biomass to this footprint because of our assumption that biomass stumpage prices remain near recent levels. As shown in Exhibit 3-5, stumpage prices for forest biomass chips averaged only \$1–\$2 per green ton in southern New Hampshire in 2008 and 2009. Prices were lower than this in western Massachusetts, but higher in Maine. At these price levels, there will be little incentive for landowners to bring additional acres into production. Historically (at least for the past several decades), timber harvests in Massachusetts have been driven by the demand for sawtimber[23] and in this scenario, this continues to be the case.

**Exhibit 3-5: Average Cost of Fuel Grade Chips in Southern New Hampshire**

| | Dollars per Green Ton | | |
|---|---|---|---|
| | **Delivered** | **Stumpage** | **Difference** |
| **2005** | \$18 | \$0.8 | \$17 |
| **2006** | \$23 | \$0.8 | \$22 |
| **2007** | \$22 | \$0.9 | \$21 |
| **2008** | \$32 | \$1.2 | \$31 |
| **2009** | \$30 | \$1.6 | \$28 |

*Source: Compiled from average quarterly prices as reported by the New Hampshire Timberland Owners Association's Market Pulse and reported in the Timber Crier magazine.*

If the demand for biomass fuel increases in response to an expansion in bioenergy plants, how much "new" biomass could be harvested economically from areas already under harvest for sawtimber in Massachusetts? There are three analytical tasks involved in this projection. First, we address the issue of harvesting costs in Massachusetts: if new biomass demand originates from electric power plants, it would almost certainly be accompanied by an increase in whole-tree harvesting; thus, we start with an analysis of these costs. As shown in Exhibit 3-5, delivered prices for fuel grade chips were about \$30 per green ton in 2008–2009 and we are assuming that biomass producers must be close to that target for electric power plants. If new biomass demand originates from thermal and CHP plants, they can pay higher prices for wood chips and thus have the option of using alternative logging methods; in addition, they will be competing for bolewood because of their need for higher-quality chips. Second, we consider the issue of how much low-value timber (that is, timber with low stumpage prices) is available on typical stands that are being harvested for sawtimber? Once we have established how much low-value wood is available and the cost of harvesting it, we then consider whether landowners would be amenable to these higher harvest levels. Using this information, we conclude this section with a projection of how much forest biomass supply would be available at current energy prices.

### 3.2.3.1 Costs of Whole-Tree Harvesting

In whole-tree harvesting systems, trees are felled by either mechanical or manual means and moved to a landing with most or all of their tops and branches. For our analysis, the costs of whole-tree harvesting in Massachusetts are important because low-value trees that are cut only for biomass chips have to bear the full variable costs of the harvest. If a logging operation is arranged to include biomass chip production, some portion of the cost of getting equipment to the site and setting up operations should also be covered by biomass. These fixed costs are one reason that production volume is an important economic variable in determining the profitability of biomass harvests.

In order to estimate the costs of whole-tree harvesting in Massachusetts, we have conducted a large number of simulations with the Fuel Reduction Cost Simulator.[24] Our main interest in this analysis is to understand the relationship between tree size and the chip production costs because it commonly stated that pre-commercial thinnings and small trees can make a significant contribution to forest biomass supply. This model can also be used to analyze the relationship between chip production costs and a host of other factors such as block size and skidding distance. [25]

We designed this analysis to determine the cost of producing 25 green tons of wood chips on one acre (this volume is based on our analysis of availability in the next section) using different combinations of the size and number of trees.[26, 27] The results are presented in Exhibit 3-6. Although these parameters will

---

[23] According to Forest Cutting Plan reports for 1984–2003, 95% of harvests included sawtimber.

[24] The Fuel Reduction Cost Simulator (FRCS) was developed by the U.S. Forest Service (Fight et al., 2006) to estimate the costs associated with fuel reduction treatments in harvests of whole trees, logs, and chips with a variety of harvesting systems. Although originally developed for forests in the Northwest, the model has been subsequently expanded to other regions (including the Northeast) by Dennis Dykstra and is available on the U.S. Forest Service website at: www.fs.fed.us/pnw/data/frcs/frcs.shtml

[25] Our analysis in Task 5 has also utilized this model as a key source in developing estimates of diesel consumption as a component of the life-cycle analysis.

[26] Assumptions made so that conditions would be representative of average conditions of Massachusetts include: a) harvest block size of 50 acres, and thus an average skidding distance of 600 feet; b) terrain sloped 5%; c) species mix evenly distributed between softwood and hardwood.

[27] We also assumed no move-in costs simply to avoid the issue of how these costs should be shared with sawtimber operations. Move-in costs depend directly on the total tons produced from a given logging operation. In our simulations, producing 25 green tons on 50 acres (1250 tons total) results in move-in costs of \$1-\$2 per green ton (assuming a 15-mile move) if there is no complementary sawtimber/pulpwood harvest to share the expense. If 25 green tons are produced on 25 acres, then move-in costs per green ton remain about the same because the doubling in fixed costs is approximately offset by the reduction in skidding costs due to shorter hauls.

differ by individual site, logging equipment, harvest layout and many other factors, we believe our general conclusions are robust.

**Exhibit 3-6: The Influence of Tree Size on the Cost of Chips ($/GT, FOB Truck, at Landing) Using Mechanical and Manual Whole-Tree Harvesting**

| DBH, in | Height, ft | # Trees* | GT/Tree | Mech WT | Man WT |
|---|---|---|---|---|---|
| 3.0 | 25 | 980 | 0.03 | $92 | $160 |
| 5.0 | 35 | 287 | 0.09 | $51 | $63 |
| 7.0 | 45 | 92 | 0.27 | $26 | $28 |
| 9.0 | 55 | 46 | 0.54 | $19 | $21 |
| 11.0 | 60 | 30 | 0.85 | $16 | $17 |
| 13.0 | 65 | 21 | 1.22 | $14 | $13 |
| 15.0 | 70 | 15 | 1.63 | $13 | $11 |

*Notes: * "# Trees" denotes the number of trees at each diameter and height that are required to yield 25 green tons of chips.*

*In these calculations, mechanical harvesting uses a drive-to-tree feller-buncher and grapple skidder. Manual harvesting uses chainsaw felling in combination with chokers and cables to skid unbunched trees.*

The model suggests that the minimum size threshold for whole-tree harvesting in Massachusetts is in the range of 7.0–9.0 inches DBH if the economic objective is to deliver chips to a bioenergy plant at a cost of about $30 (or less) per green ton. In addition to harvesting costs, this estimate allows for: 1) $1–$2 per green ton for biomass stumpage; 2) $8–$12 per green ton for truck transport to the bioenergy plant; 3) recognition of the potential range in model estimates due to site-specific factors and modeling errors.[28] It is important to note that these estimates include machinery and equipment costs. While lower delivered prices may not attract new investment in machinery and equipment, those who already have equipment may choose to operate if they are able to cover only their variable costs of production.

Costs rise exponentially when tree sizes decrease below this level because of the exponential relationship between tree diameter and weight. For example, it would take about 40 trees that are 3-inches DBH to produce one ton of green chips, and thus it would take almost 1000 trees to generate 25 tons of green chips. The number of trees required for 25 green tons could be reduced to about 100 at 7-inches DBH and to only 10 trees if tree DBH was 18 inches.

We also tried to estimate the costs of such logging operations on the basis of a literature review. Available studies show wide variation in costs due to factors such as species, size, quality, terrain, and harvesting equipment: the range extends from about $20-to-$50 per green ton. However, without information that links harvesting costs to timber size, it is not possible to put these estimates in our context. It seems that pre-commercial thinnings and small trees should be excluded as part of the biomass resource in Massachusetts—as one logger in Maine told us anecdotally, "the fastest way to go broke in the biomass business is to harvest 2-to-6 inch trees."

These model results clearly demonstrate the critical importance of tree size and handling costs in the economics of whole-tree harvesting: whole-tree harvesting appears to be cost prohibitive for sapling-size trees. In addition, manual harvesting is much more expensive than mechanical in the small-diameter classes primarily due to the high costs of gathering and skidding unbunched trees. However, the cost curves for these two whole-tree systems converge (and eventually cross) as tree diameter increases. This may be important for management plans on some forests because the two systems will have different impacts on soils and harvest sites.

There are a variety of other harvesting systems that could be employed in removing forest biomass. Thermal and CHP plants often demand higher-quality chips than electric power plants and can pay more for delivered wood; thus, more harvesting options are available for procuring their wood supply. Log-length methods may be selected instead of whole-tree methods if the manager or operator wishes to leave tops and limbs scattered on the site and/or is concerned about residual stand damage (to both soils and standing trees). Two common log-length methods that could be used are cut-to-length (in which mechanized harvesters are used to fell, delimb, and buck trees at the stump) and manual systems (in which chainsaws are used to fell, delimb, and buck trees at the stump) (Fight et al., 2006). Logs can then be debarked and chipped at the landing, or transported to a plant and processed there. Using the FRCS model, we have estimated that these harvesting systems will add about $10–$15 per green ton to the cost of delivered chips.

In future decisions regarding the choice between mechanical and manual harvesting systems, labor issues also are an important consideration. As labor costs rise and the labor force ages, there will be a preference for mechanized harvesting to reduce overall labor costs (including improving safety and reducing insurance premiums for health, liability, and worker's compensation). Labor costs have been identified as having an important role in increasing mechanized harvesting—both whole-tree and cut-to-length—in some regions.

### 3.2.3.2 THE AVAILABILITY OF LOW-VALUE WOOD IN MASSACHUSETTS FORESTS

The Low-Price Biomass scenario assumes that biomass stumpage will be available for $1–$2 per green ton, which is generally the price we see throughout markets in New England. Here we provide

---

[28] Modeling errors can arise from many sources. For example, on the fixed cost side, key areas of concern would be the choice of equipment and the calculation of ownership costs for situations in Massachusetts. On the variable cost side, wage costs and diesel costs are important parameters that may vary significantly over time and for different operations.

a broad overview of the volume of wood in Massachusetts forests that might be available at such low prices.

Approximately 65% of the standing trees on Massachusetts timberland are 1"–5" DBH; however, in spite of their large numbers, these sapling-size trees represent only 5% of the timber volume on a tonnage basis (FIA Statistics for 2008). It would be cost prohibitive to harvest trees in this size class based on our analysis. In order to be competitive in current markets, biomass producers would need to harvest trees with low stumpage value that are greater than 5" DBH.

As discussed earlier, sawtimber harvests are crucial in opening timber stands to biomass production. In Massachusetts, sawtimber harvests will typically take place in stands that are 60-to-100 years old, and FIA data for 2008 indicate that these stands account for 80% of total growing stock volume. Thus, these age classes are by far the most important in identifying the availability of low-cost wood.

Exhibit 3-7 presents the total volume and volume per acre for timber stands classified in the 61–100 year age class in Massachusetts.[29] The key groups that are potential sources of biomass potential are: 1) rough cull trees, with 8% of the average stand volume; 2) grade 4 & 5 trees, with 16% of the volume; and 3) pulpwood trees,[30] with 21% of the volume. As reported in this table, the combination of these three groups totals 59 green tons per acre.

**Exhibit 3-7: Timber Volume by Tree Grade, Age Classes 61–100 Years in Massachusetts (All Timberland) 000 Acres and Million Green Tons, 2008**

| | Quantities | Share | GT / Acre |
|---|---|---|---|
| **Acres (000's)** | 2,120 | | |
| **Total Volume (millions)** | 273.2 | 100% | 129 |
| **Grades 1 & 2** | 76.4 | 28% | 36 |
| **Grade 3** | 67.9 | 25% | 32 |
| **Grades 4 & 5** | 44.7 | 16% | 21 |
| **Pulpwood** | 57.8 | 21% | 27 |
| **Rough Cull** | 23.0 | 8% | 11 |
| **Rotten Cull** | 3.5 | 1% | 2 |

*Note: FIA data; include all live volume (merchantable volume, tops, limbs, and stumps) in trees ≥ 5 inches DBH.*

These data provide only a starting point and need several adjustments before they can serve as a useful upper bound for potential biomass supply. About 30% of grade 4 & 5 trees are greater than 25" DBH; it is not practical to harvest these trees with standard equipment. On the opposite end of the spectrum, about 20% of the pulpwood trees are less than 7" DBH and we exclude half of these (those that may be in the 5"–6" range) because of their higher harvesting costs. Finally, as discussed earlier, some poletimber-size trees are already being harvested for pulpwood/fuelwood end uses; these total about 10 green tons per acre (when adjusted to a comparable basis with the inclusion of tops and limbs).

With these adjustments, the availability of grade 4 & 5 trees is reduced from 21 to 15 green tons per acre; pulpwood is reduced from 27 to 12 tons per acre; and rough cull remains at 11 tons per acre; hence, the revised total of available biomass is 37 green tons per acre. At the risk of appearing overly precise, we should recognize that this timber will continue to grow: if we assume the volume increases by an average net annual growth rate of 2% per year for 7½ years to reflect the average availability in 2010–2025, timber availability rises to 43 green tons per acre.[31]

This review characterizes the potential availability of biomass in broad terms of value and economic accessibility, but there is still a good deal of uncertainty in defining what share of this volume would be available at very low stumpage prices. At this level of aggregation, there is no straightforward way to address this, but it would be reasonable to assume that not more than half of low-grade sawtimber and poletimber could be purchased and harvested at low stumpage prices. This would reduce available supply to the range of 20–25 green tons per acre. On the basis of the information and assumptions presented above, we think that 15 green tons per acre is a good "ballpark" estimate of incremental whole-tree biomass potential—we also consider 20 green tons per acre as a potential upper bound.

### 3.2.3.3 LANDOWNER WILLINGNESS TO HARVEST

We have identified a significant volume of low-value wood in Massachusetts that could be harvested at low cost, at least with whole-tree harvesting systems. The question that remains is: if the demand for forest biomass from private timberlands in Massachusetts increases (from bioenergy plants established in Massachusetts, nearby states, or overseas), what is the likelihood that we would see increased biomass harvests in conjunction with sawtimber operations? Would landowners be receptive to these changes? In many cases, there could be strong economic incentives, even though they would not be the result of direct, immediate income in the Low-Price Biomass scenario.

While there is a tendency to use landowner surveys to highlight the lack of interest in timber production in Massachusetts, there is a flip side to this viewpoint. Every year, an average of 22,300 acres of private timberland in Massachusetts is harvested,

---

[29] These volumes represent total tree biomass, not just bole volumes. Since we are not interested in total volumes for individual ownerships, we have combined the data for private and public lands to obtain more accurate estimates of grade shares and per-acre volumes.

[30] Pulpwood is defined as 5"–9" DBH for softwood trees, and 5"–11" DBH for hardwoods.

[31] Increasing the available volume for growth has the same effect as the inventory variable in standard economic models of timber supply.

primarily for sawtimber. More than half of the private acreage in Massachusetts (1.2 million acres) is held in parcels that are 50 acres or larger (Butler, 2008).[32, 33] Owners of 40% of the family forest land (about 650,000 acres) reported that a commercial harvest—sawlogs, veneer logs, or pulpwood—occurred since they acquired the land.[34] The large majority of these owners stated that they harvested trees because the trees were mature and/or they wished to improve the quality of the remaining trees. Suffice to say, while timber production is certainly not the number one priority on most private forest land in Massachusetts, there is a significant component of the forest land base in Massachusetts that is used to generate timber income and would likely be available for more aggressive forest management under the right circumstances.

There are landowners who would like to pursue forest management practices that will enhance the growth of their forest for future commercial timber production. With no market for biomass, these owners need to pay loggers for the cost of harvesting and collecting low-value wood and then may have an additional cash outlay for slash disposal. This could be a substantial investment with a return not seen for many years. However, with a "new" market for biomass fuel, the prices for delivered biomass may be sufficient to cover logging costs and may go beyond break-even to generate positive stumpage values for this material. Thus, harvesting of forest biomass could open the door for alternative forest management practices that are focused on improving sawtimber growth and value.

### 3.2.3.4 A Forecast of Forest Biomass Supply in Massachusetts with Low-Price Biomass Stumpage

Here we combine the information above to forecast how much "new" forest biomass could be supplied if demand from bioenergy facilities increases while real biomass stumpage prices remain at recent levels. The forecast is intended as an upper limit in the sense that any volume less than this could be produced to meet the demand from bioenergy plants at similar prices.

This projection is predicated on several key assumptions:

- The total land area harvested remains at the historical average.
- One half of this area is managed as it has been in recent years. The same volume of sawtimber and other industrial roundwood will be harvested and no logging residues are harvested for biomass because such operations are not justified by the economics (due to scattered material which is costly to harvest and low volumes per acre). Due to the low level of pulpwood stumpage prices, it is possible that some of this material could be diverted to biomass fuel, but we have not included this potential shift as part of the Low-Price Biomass scenario.
- The other half of the land area harvested receives silvicultural treatments that include whole-tree biomass harvesting.[35] While many landowners will find this management option suitable for their objectives, many others will not look favorably upon heavier logging of their woodlots.
- On the acres that are harvested more intensively with whole-tree methods, 65% of tops and limbs removed for industrial roundwood production are harvested for biomass. (As noted above, pulpwood is assumed not to be diverted to biomass in this scenario.)
- For whole-tree biomass harvests, 15 green tons are cut per acre. Of this volume, 10% is left on the harvest site for ecological reasons (this is equivalent to 1/3 of tops and limbs).

Projections for this biomass harvest scenario are shown in Exhibit 3-8. Land is classified as "½ Current" (land harvested as in recent years) and "½ WT" (land harvested with whole-tree harvesting). Removals per acre average 21.8 green tons in "½ Current," compared to 36.8 green tons in "½ WT," so the removals per acre average 29.3 green tons statewide (compared to 21.8 tons with no additional biomass harvesting). Total forest biomass fuel harvested averages 16.5 green tons per acre in "½ WT," and 8.3 green tons per acre for all private lands in Massachusetts. On the acres where biomass is harvested, 13.5 green tons come from whole trees, while 3.0 green tons consist of residues from sawtimber/pulpwood harvests.

As shown in Exhibit 3-8, this scenario results in 184,000 green tons of additional biomass produced for bioenergy on private lands in Massachusetts. If we increase the biomass removal rate to 20 green tons per acre, the biomass harvest increases to 235,000 green tons. The availability of low-value stumpage (timber that will be sold for only $1–$2 per green ton) and the implications

---

[32] Landowner survey results show that only 43% of the 1.7 million acres that are family owned are 50 acres or larger; however, 88% of the remaining 0.4 million acres held by private owners belong to this size class.

[33] The National Woodland Owner Survey provides a substantial of information intended to characterize the behavior of private forest owners in the United States. The main report summarizing these data is Family Forest Owners of the United States, 2006 (Butler, 2008). An on-line version—NWOS Table Maker Ver 1.01—provides users with the ability to create their own customized tables for individual states.

[34] Among survey respondents, 25–30 years seems like a reasonable approximation of the average ownership tenure for family-owned land (measured by area, not number of owners): the ownership tenure was 25–49 years for about 40% of the family-owned acreage and 10–24 years for about 30% of the acreage.

[35] This assumption is consistent with an electric power demand scenario. It can be easily modified for thermal or CHP demand. We would assume that stumpage prices remain at the same level—thermal and CHP could pay more for stumpage but there is no reason to do so unless competing for higher-value timber. The main difference would be that if loggers do not use whole-tree methods, then tops and limbs would be excluded from the harvest volumes.

for removal rates is one of the key assumptions in this scenario. Further analysis of these removal rates is provided below.

The share of land assumed to be harvested using whole-tree methods is also a critical assumption in this scenario. The relationship between biomass production and this share is linear in our formulation since we are working with "average" acres. Thus, if whole-tree harvesting and increased harvesting intensity were used on only one-quarter of all private lands being harvested commercially, production of biomass for bioenergy would be reduced to 92,000 green tons; similarly, if these practices were extended to all commercial harvests on private lands, biomass production would increase to 368,000 green tons.

In the next section, we review related data from nearby states to provide some perspective on these estimates of forest biomass production for Massachusetts. The data from nearby states give us some confidence that our forecasts are in the appropriate range; however, it is difficult to say for sure without more detailed analysis of timber sales and more experience with biomass harvesting in Massachusetts.

### 3.2.3.5 The Experience in Nearby States

It is useful to consider this outlook for whole-tree harvesting with respect to other states in New England where whole-tree harvesting is now more extensive than in Massachusetts and has a much longer history, and thus might be considered to be in a mature phase. Maine and New Hampshire, with relatively large forest products industries and well-developed wood-fired power plant sectors, may represent the potential for whole-tree harvesting when the industry pursues more aggressive harvest yields with mechanization. State harvest reports indicate the following: in Maine (Maine Forest Service, 2009), forest biomass chips comprised 23% of the total harvest of roundwood products in 2008 (3 million green tons out of a total harvest of 13 million green tons); in New Hampshire (New Hampshire Report of Cut, 2008), the comparable share was 24% in 2000–2006 (790,000 green tons out of a total harvest of 3.2 million green tons, on average). Whole-tree harvesting is not practiced to the same extent in Vermont (Vermont Forest Resource Harvest Summary, various years), where forest biomass chips represented an average of 13% in 2000–2006 (200,000 green tons out of a total harvest of 1.5 million green tons, on average).

**Exhibit 3-8: Biomass Supplies Available from Massachusetts Private Lands under the Low-Price Biomass Scenario**

| **Annual Rates, 2010–2025 (Green Tons and Acres)** | | | | |
|---|---|---|---|---|
| | **Current** | **Low Biomass Price** | | |
| | **Harvest** | **½ Current** | **½ WT** | **Total** |
| **Area Harvested (acres)** | 22,300 | 11,150 | 11,150 | 22,300 |
| **Wood Removals** | **Green Tons per Acre** | | | |
| Industrial Removals | 21.8 | 21.8 | 21.8 | 21.8 |
| Roundwood Harvest | 17.1 | 17.1 | 17.1 | 17.1 |
| Logging Residues Generated | 4.7 | 4.7 | 4.7 | 4.7 |
| Left on Site | 4.7 | 4.7 | 1.6 | 3.2 |
| Harvested for Biomass Fuel | 0.0 | 0.0 | 3.0 | 1.5 |
| Whole-Tree Biomass Removals | 0.0 | 0.0 | 15.0 | 7.5 |
| Whole-Tree Harvest | 0.0 | 0.0 | 13.5 | 6.8 |
| Logging Residues Left on Site | 0.0 | 0.0 | 1.5 | 0.7 |
| Total Removals | 21.8 | 21.8 | 36.8 | 29.3 |
| Total Biomass Harvest | 0.0 | 0.0 | 16.5 | 8.3 |
| **Wood Removals** | **000's of Green Tons** | | | |
| Industrial Removals | 485 | 243 | 243 | 485 |
| Roundwood Harvest | 381 | 191 | 191 | 381 |
| Logging Residues Generated | 104 | 52 | 52 | 104 |
| Left on Site | 104 | 52 | 18 | 70 |
| Harvested for Biomass Fuel | 0 | 0 | 34 | 34 |
| **Whole-Tree Biomass Removals** | 0 | 0 | 167 | 167 |
| Whole-Tree Harvest | 0 | 0 | 151 | 151 |
| Logging Residues Left on Site | 0 | 0 | 17 | 17 |
| **Total Removals** | 485 | 243 | 410 | 652 |
| **Total Biomass Harvest** | 0 | 0 | 184 | 184 |

*Notes: "Current Harvest" is a projection assuming that commercial harvests continue at average levels of the past several years and there is no additional harvesting for biomass. With the increased harvest in the Low-Price Biomass scenario, one half of acres are assumed to be managed in the same way as in the Current Harvest Projection ("½ Current"), and one half of acres are assumed to be managed more intensively using whole-tree harvesting techniques ("½ WT").*

For Massachusetts, our Low-Price Biomass scenario (assuming removal of 15 green tons in silvicultural treatments with biomass) yields a harvest share for forest biomass chips of about 33% (this figure includes whole-tree chips from tops and limbs produced in harvesting industrial roundwood). Thus, relative to the northern New England experience, it appears that our scenario would represent a reasonable upper bound for expected outcomes. With assumed biomass removal rates of 20 green tons per acre, the forest biomass harvest share in Massachusetts would increase to 38%, which would seem high, particularly when considered in the context of differences in parcel size, attitudes, and social factors among the states. However, this share will depend on other factors that could favor a higher share in Massachusetts including: the availability of low-value timber on forest stands that are being harvested; and, the extent of alternative outlets for pulpwood along with the relative strength of demand and prices for pulpwood and biomass fuel. Given these uncertainties, we have reported the likely biomass harvest as a range from 150,000 to 250,000 green tons per year, thus spanning the estimates (184,000 and 235,000 tons) provided above.

### 3.2.4 HIGH-PRICE BIOMASS FROM PRIVATE TIMBERLANDS

How much would forest biomass supplies increase if bioenergy plants could pay higher prices for stumpage? As demand and prices increase, more wood can be supplied from private lands by increasing the volume of wood removed from sites that are already under harvest for industrial roundwood, diverting wood from other end-use markets (such as pulpwood) to biomass, and increasing the number of acres being harvested. This scenario is intended to provide perspective on the upper bound for forest biomass production if bioenergy demand and prices increase beyond the level established in the Low-Price Biomass scenario. It is not reasonable to specify an absolute maximum for biomass supply since supply is an economic concept that depends on timber prices (and a host of other factors). Thus, we need to specify a “high” biomass stumpage price, and then consider how private landowner harvests might respond to this price level. Forest biomass volumes could still increase beyond this level, but it would be increasingly difficult to due to biophysical, economic, and social constraints and increasingly unlikely due to macroeconomic and energy constraints.

The amount that bioenergy plants can afford to pay for wood is a function of the prices they receive for their output. In order to determine a biomass stumpage price in this limiting case, we have assumed that the increase in demand for biomass comes from an expansion in electric power capacity (this assumption does not, however, restrict the usefulness of these results for other types of bioenergy). We have considered several electric price scenarios and selected $20 per green ton as the real biomass stumpage price that would reflect the high end of projections for electricity prices.

A biomass stumpage price of $20 per green ton would be consistent with a significant increase in the price of electricity. Although we have not modeled the dynamics of the harvesting and transport sector, it would be reasonable to assume that these costs would also increase in the near term due to the limited supply of loggers, foresters, machinery, and equipment; thus, delivered wood prices would likely rise well above $50 per green ton. However, we would anticipate that harvesting and transport costs would subsequently retreat with increasing competition and new investment in harvesting machinery and equipment. If these increases in wood costs were fully incorporated into the price of electricity, the impact would be as follows: a $20 per green ton increase in delivered wood prices (from $30 currently to $50) would equate to an increase of 3.2 cents per Kwh; delivered wood prices of $60 per green ton would translate to an increase of 4.8 cents per Kwh; and $70 per green ton would equate to an extra 6.4 cents per Kwh.

There are a variety of other scenarios that could lead to the production of much higher volumes of forest biomass fuel supplies. A key factor distinguishing these scenarios are those in which exogenous factors affect biomass demand directly (examples would be increasing energy production or high export demand for biomass fuel) and those that stimulate other commercial timber production (examples would be housing policy or local product promotion) and increase biomass production as by-product. Generally, biomass prices will rise in cases where there is direct demand stimulus; however, if biomass production rises as a by-product of expanded sawtimber production, biomass prices will remain low. We have assumed that higher biomass demand drives this scenario for two reasons: 1) we are primarily interested in energy policy, and whether forest biomass supplies would be adequate to support an expansion of bioenergy capacity; and 2) the probability of a substantial increase in sawtimber production seems fairly remote.[36]

There are several issues that need to be considered in gaining an appreciation for how much biomass could be harvested from private lands in Massachusetts if biomass stumpage prices were to rise substantially. These include:

- How large is the operable land base, or in other words, how much land should be excluded from potential harvesting due to biophysical constraints or lack of landowner interest in timber production?

---

[36] Although lumber production is likely to recover from the recent downturn, we are aware of no studies that project the lumber industry in this region (or in the U.S. North in general) to move above the trend levels of the past decade. Although the sawtimber inventory is rising in Massachusetts, there appear to be few other competitive advantages that would promote an expansion of the sawmilling industry: 1) maturing timber has not resulted in increasing sawtimber harvests in the past two decades; 2) sawmills are closing in Massachusetts, not expanding, and lumber capacity has contracted sharply over the past decade; 3) there are questions about sawtimber quality due to age and years of partial cutting for sawtimber production; 4) there is plenty of “cheap” timber in competing areas of North America and the world and this is especially true over the coming decade due to delays in timber harvesting that have occurred as the result of the housing debacle of 2007–2010.

- What is an appropriate harvest schedule for these lands, or over what period might we expect initial harvests to begin and for these lands to be brought under management?
- What share of this land is likely to be drawn into production at different price levels? Harvesting these lands is not an all or nothing proposition, so here we consider how landowners may respond to higher biomass prices and the higher income they may receive from such harvests.

After discussing each of these factors, we provide a forecast of biomass supplies at much higher demand and price levels. We then review some key areas of uncertainty and provide some sensitivity analysis for important assumptions.

### 3.2.4.1 ESTIMATION OF THE SIZE OF THE OPERABLE PRIVATE FOREST LAND BASE IN MASSACHUSETTS

As shown earlier, the area of private land harvested in Massachusetts has been very stable over the past 15 years, and has not exceeded 25,000 acres during the 25 years for which we have data. This sort of stability would be consistent with a regulated forest where each age class has the same number of acres. However, this is far from the case in Massachusetts, which would be better described as an even-aged forest due to the high concentration of timber in a few age classes: Exhibit 3-9 indicates that about 50% of the acreage on private lands in Massachusetts is in the 61–80 year stand-age grouping (according to Kelty et al., 2008, this is about the age that the first partial thinning is done by most owners interested in harvesting timber). Much of the standing timber inventory in Massachusetts can be considered already mature or approaching maturity; in fact, natural mortality exceeds removals according to the FIA data for 2008.[37] These age-class data suggest that with higher demand and higher prices, harvesting activity could increase and break out of the stable pattern seen historically.

**Exhibit 3-9: Number of Timberland Acres by Age Class, Private Land Owners, 000's (2004–2008)**

| Age Class | Acres | Percent |
|---|---|---|
| 0–20 | 24 | 1% |
| 21–40 | 69 | 3% |
| 41–50 | 142 | 7% |
| 51–60 | 202 | 10% |
| 61–70 | 529 | 26% |
| 71–80 | 507 | 25% |
| 81–90 | 373 | 18% |
| 91–100 | 101 | 5% |
| 100–120 | 60 | 3% |
| 120+ | 18 | 1% |
| TOTAL | 2,026 | 100% |

*Source: FIA data.*

In order to estimate the size of the operable land base on private lands, we rely on a variety of studies and a growing body of research on landowner behavior and factors that affect willingness to harvest. Our general approach, which has become fairly standard, is to reduce the total land area to account for: 1) physical land attributes that limit logging access; 2) small parcels that have a low probability of being harvested due to economic and social factors; and 3) lack of landowner interest in producing timber due to the higher value of nontimber benefits.[38]

Physical factors appear to be relatively unimportant in limiting harvesting activity in Massachusetts. A study by Butler et al. (2010) indicated that 6% of the land in family-forest ownership should be considered unavailable due to biophysical restrictions (primarily slope and hydric physiographic class). Kelty et al. (2008) assumed 7% of forest land was off limits to logging based on a review of forest plans for the Quabbin state forest. For our scenarios, we have reduced the private land area by 5% to account for these factors, and have done so assuming that the restrictions are distributed equally across all groups and size classes.

Our next step is to eliminate parcels of small size. The rationale for their removal is twofold: 1) the attitudes of owners holding small parcels, who tend to be focused on forest benefits other than timber income; and 2) the relatively high costs of wood production on small parcels, which becomes much more important when whole-tree harvesting of biomass fuel is considered. The distribution of acres across ownership size classes is presented in Exhibit 3-10.

**Exhibit 3-10: Number of Acres Held by Size of Holdings, Private Land Owners, 000's (2002–2006)**

| Acre Class | Family | Other | Total | Percent | #Owners |
|---|---|---|---|---|---|
| 1–9 | 562 | 0 | 562 | 26% | 261 |
| 10–19 | 208 | 0 | 208 | 10% | 17 |
| 20–49 | 187 | 61 | 248 | 11% | 8 |
| 50–99 | 250 | 62 | 312 | 14% | 4 |
| 100+ | 479 | 370 | 849 | 39% | 3 |
| TOTAL | 1,686 | 493 | 2,179 | 100% | 293 |

*Notes: Data are from Family Forest Owners of the United States, 2006 (Butler, 2008). Family owners are defined as "families, individuals, trusts, estates, family partnerships, and other unincorporated groups of individuals that own forest land." Other private owners are industry, corporations, clubs, and associations.*

---

[37] Although these differences are not statistically significant given the large sampling errors associated with both removals and mortality.

[38] We should note that we have not adjusted the total land area for land clearing and conversion. If forest land clearing continues at recent historical rates (which we discuss in more detail in Section 3.5.1), this would mean a reduction of about 70,000 acres of private forest land (only 3% of the total) over the next 15 years. However, as noted earlier, this number could be much larger historically (and going forward), but it is difficult to measure the magnitude of the shift accurately and to document the exact causes of land use changes. However, this shift clearly becomes of greater consequence over a longer time horizon. In addition, land clearing is linked to trends in land fragmentation which has important implications for wood supply.

Analysis of landowner attitudes leads to the conclusion that interest in timber production is highly correlated with size of forest holdings, and most owners of small parcels choose to own forest land for reasons other than wood harvesting (although they are often interested in obtaining fuelwood for their own use). For example, for the land held in parcels less than 10 acres, a large majority of the land would not be logged or there would be "minimal activity to maintain forest land" during the next five years, while all respondents said they would not harvest sawlogs or pulpwood.[39]

Butler et al. (2010) suggest that the minimum operable size for timber harvesting may now be about 15 acres, and might be increasing into the range of 30 acres, based on studies that have evaluated the economies of scale associated with modern harvesting equipment. Surveys of minimum economical scale for whole-tree harvesting in Vermont among different stakeholder groups provided responses that were concentrated around 800 green tons per logging operation (Sherman, 2007). Average responses by group were: foresters, 27 acres at 12 cords per acres (810 green tons); logging contractors, 23 acres at 14 cords per acre (805 green tons); chipping contractors, 15 acres at 21 cords per acre (788 green tons). These data suggest that removing an average of 25 green tons of the wood on an acre would require a logging site of at least 30 acres.

Using the information on both landowner attitudes and economies of scale, we have excluded parcels less than 20 acres from the operable land base. While there seems to be evidence that the harvest threshold may now be above this level, we have tried to be conservative in an effort to establish an upper bound to the operable harvest base. In addition, this lower level allows for the use of current equipment and harvesting methods that may be suitable for smaller-scale production for thermal and CHP plants.

Another reason that this threshold is likely to be "conservative" and tend to overstate the amount of land available for harvesting and biomass production is that we have not attempted to project changes in the distribution of land ownership by parcel size in the future. There have been significant reductions in average parcel size historically (Kittredge, 2009). Perhaps more importantly for our analysis, projections suggest that there are likely to be significant increases in private forest land development in central and southeastern Massachusetts from 2000 to 2030 (Harvard Forest, 2010). However, as noted with land clearing, it is difficult to quantify these developments and they are more critical for long-term projections than over the next 15 years.

The final adjustment to the land base relates to landowner attitudes of those who hold parcels that are greater than our threshold of 20 acres. Surveys of family forest owners indicate that those who hold parcels greater than 50 acres also place high value on benefits other than commercial timber production. For example, when asked about their management intentions for the next five years, owners of 56% of the land said they would do nothing or engage in minimal activity as compared to 43% who planned to harvest sawlogs. In response to their reason for owning their land, 71% (again, based on acreage) said for beauty and scenery, 51% said for privacy, and only 34% said to produce sawlogs or pulpwood. At the same time, although timber income is not a primary motivation for owning land, it is still important as owners of 66% of the land reported having a commercial harvest on some portion of their land during their tenure. (All data are from the National Woodland Ownership Survey, on-line data, Butler et al., 2008.)

Based on these survey data, we have reduced the available area of family-owned forest parcels that are greater (or equal to) 20 acres by 20%, which believe is conservative. We have assumed the same adjustment is appropriate for landowners in the "other private" category.

A summary of the results from our process of netting down the private land area to obtain the operable land base is shown in Exhibit 3-11. Our methodology and assumptions reduce the total private land base by 51%, thus leaving 1,071,000 acres of private land available for harvesting in Massachusetts. It is interesting to compare these results with two other studies for Massachusetts that use similar methods, but different assumptions. Kelty et al. (2008) provides two scenarios of private land availability: the higher has 1,072,000 operable acres when 10 acres is used as a parcel size threshold (and other constraints are introduced) [40]; a second scenario with a 100-acre threshold shows only 379,000 acres available (which seems somewhat extreme compared to our calculations). Butler et al. (2010) estimate that biophysical and social constraints on private lands might reduce the wood available from family-owned forests by 68% (we show a 59% reduction for the family-forest category). That study also uses a 20-acre threshold, but assumes a much larger reduction due to social constraints.

**Exhibit 3-11: Private Land Area Available for Timber Harvesting in Massachusetts, After Deductions for Biophysical and Social Constraints 000 Acres**

| | Family Owners | Other Private | Total |
|---|---|---|---|
| **Total Timberland Area** | 1,686 | 493 | 2,179 |
| **Reduce for Physical Constraints (5%)** | 1,602 | 468 | 2,070 |
| **Reduce for Small Parcels (< 20 Acres)** | 870 | 468 | 1,339 |
| **Reduce for Other Social Factors (20%)** | 696 | 375 | 1,071 |
| **Percentage Available** | 41% | 76% | 49% |

### 3.2.4.2 HARVEST SCHEDULE FOR THE OPERABLE LAND BASE

The above analysis provides an estimate the *total* size of the operable land base. The 22,300 acres that are already being harvested

---

[39] The rationale for eliminating these parcels from biomass harvesting becomes more obvious when one considers that the average parcel size in the 1–9 acre size class is only 2 acres.

[40] It is tempting to consider the nearly identical results as confirmation of the validity of one or both approaches. The two approaches are different, and the fact that the results are almost identical is coincidental.

each year in Massachusetts (and in our Low-Price Biomass scenario) are assumed to be part of this land area. In this new scenario, higher biomass stumpage prices encourage more of the landowners in the operable land base to harvest timber in any given year. How many more acres would be harvested annually? Or, put another way, what would be a reasonable time frame over which to enter these stands and initiate forest management?

We have assumed that 25 years would be a reasonable period over which bring these stands into production. The most important factor is the age structure of these stands. As shown earlier (Exhibit 3-9), the majority of the timber on private lands in Massachusetts has reached the age where it is appropriate to begin thinning based on silvicultural and economic considerations. Another important factor is that the harvest is "scheduled" to accommodate the life expectancy of electric power and other bioenergy plants—the facilities will need some assurance that wood supplies will be adequate on an ongoing basis in order to attract capital for large-scale investments.

If we assume that 1,071,000 acres are available among the private land base in Massachusetts, and that partial harvests will occur on these lands over a 25-year period, then 42,800 acres would be potentially available for harvest each year.

### 3.2.4.3 The Supply Curve for Landowner's Who Harvest Timber

Our analysis so far has attempted to determine the maximum operable land base, which we have defined as the land that would be harvested at much higher prices. In order to provide more perspective on how much of this land might be accessed, we need to incorporate the assumptions of our High-Price Biomass scenario (biomass stumpage prices averaging $20 per green ton). How do these owners value their nontimber amenities and at what prices would they be willing to become active players in the timber market? Would these price levels be sufficiently compelling to bring all of these lands into production?

The prices required to increase harvests significantly on private lands in Massachusetts are outside the range of recent historical experience. This is obvious from the remarkable stability in harvest levels that we have seen in Massachusetts over the past two decades. In order to assess whether this harvest stability is simply the result of limited price variation or the fact that landowners are insensitive to price swings, we have examined the relationship between timber prices (a weighted index of real red oak and white pine sawtimber stumpage prices) and harvest volumes (sawtimber harvests according to FCPs).

From 1994 to 2005, observations on prices and volumes are tightly clustered and somewhat random: the average absolute deviation from the mean is only 5% for prices and 6% for volumes. However, a much different story emerges over the last few years. From the average of 2003–2005 to 2009, planned sawtimber "harvests" fell about 30%, while real prices dropped 60%. This would suggest a price elasticity of timber supply of about 0.5, a result that is consistent with the conventional wisdom that short-run timber supply is inelastic. Of course, this calculation is merely suggestive of ownership behavior because of the quality of the data and the limited sample size.[41] Furthermore, there is no possibility to consider asymmetric behavior and to evaluate whether landowners would respond in a similar fashion if prices rose sharply.

While this result is interesting, one must also be cautious in extrapolating the conclusions much beyond the historical range: in this scenario, we are considering prices and potential landowner income that is far above historical levels. Over the 2000–2006 period, an average harvest on private lands generated about $400 per acre.[42] If we assume that 20 tons of biomass are harvested on an acre with stumpage prices of $1 per green ton, then per-acre income would rise by $20, or by only about 5%. However, if biomass prices jump to $20 per green ton, landowners could now earn an additional $400 per acre, thus doubling their income on a per-acre basis.

As biomass stumpage prices increase, we would expect that many of the owners in the operable land base would move to take advantage of the opportunity to earn more income. However, landowners possess a complex set of objectives and it is difficult to say how high prices would need to rise to induce all landowners in the operable land base to harvest biomass. It seems likely that the response would be mixed at $20 per green ton: the financial incentives would likely be too compelling for many to ignore; on the other hand, they are probably not adequate to attract many landowners who place high value on the nontimber benefits of owning forests and are not focused on timber revenue.

A final consideration in making a realistic assessment of the response in biomass harvests to higher prices, particularly in the near term, is the limitations of the labor and logging infrastructure. These would need to expand dramatically to achieve much higher harvest levels and this is another development that would be at odds with recent trends. In assessing the ramifications of this from the perspective of biomass supply, the concern is that harvesting costs may need to rise sharply to attract investment in this sector: this could mean reduced stumpage prices that would mitigate the supply response, or an increase in delivered wood prices that would choke off demand. We would anticipate that harvesting and transport costs would subsequently retreat with increasing competition and new investment in harvesting machinery and equipment.

### 3.2.4.4 A Forecast of Forest Biomass Supply with Higher Biomass Stumpage Prices

This outlook assumes that biomass stumpage prices rise to $20 per green ton as a result of higher demand from bioenergy plants. A

---

[41] We should underscore this point by recalling that the FCP data report only planned harvests, not actual harvest volumes.

[42] We calculated this value by assuming a harvest of 2 MBF and using a weighted average of median red oak and white pine stumpage prices for western Massachusetts from 2000–2006 (University of Massachusetts Amherst, 2008).

substantial increase in landowner income brings more land into production. Forest biomass fuel becomes a primary timber product, much as pulpwood is today, and we assume that bioenergy plants can outbid their competitors for pulpwood and low-grade sawlogs and that this material is harvested more intensively as well. It is worth noting that $20 per green ton is equivalent to prices of about $50 per cord and $100 per MBF (International ¼" log rule).

While is a good deal of uncertainty associated with many of the assumptions in this analysis, we believe that developing this forecast provides useful guidance while demonstrating many of the important factors at work. Following the presentation of the results, we provide some sensitivity analysis to key assumptions along with some discussion of the conclusions.

This projection is predicated on the following key assumptions:

- One half of the original harvest footprint of 22,300 acres continues to be managed as it has been in recent years. The same volume of sawtimber and other industrial roundwood will be harvested and no logging residues are harvested for biomass because the economics do not justify such low-volume operations. (As in the previous scenario, the pulpwood produced in this "original" share of the harvest is still assumed to be consumed in this end-use market, although it could easily be diverted to biomass fuel at the assumed price levels.)
- One half of the "original" 22,300 acres receive silvicultural treatments that include whole-tree biomass harvesting.[43] With the introduction of whole-tree harvesting on these acres, trees formerly harvested for other industrial markets are now chipped for biomass. Sixty-five percent of sawtimber tops and limbs are harvested for biomass.
- Of the remaining acreage available annually (20,500 acres, or 42,800 minus 22,300), one half is assumed to be drawn into production for whole-tree biomass harvests. The same amount of sawtimber is removed as on other lands, but all other roundwood harvested is used for biomass.
- For whole-tree biomass harvests, 25 green tons are cut per acre as higher prices increase the harvest intensity of "lower-value" wood. Of this volume, 10% of all material is left on the site for ecological reasons (equivalent to 1/3 of tops and limbs).

Projections for this High-Price Biomass scenario are shown in Exhibit 3-12, with the land classified as "½ Current" (land harvested as in recent years) and "Bal WT" (the balance of land harvested with whole-tree harvesting). Removals per acre average 21.8 green tons in ½ Current, compared to 46.8 green tons in Bal WT; removals per acre average 38.2 green tons statewide, as more acres are brought into production and harvested more intensively than in the Low-Price Biomass scenario. Total forest biomass fuel harvested averages 32.4 green tons per acre in Bal WT, resulting in an average of 21.3 green tons per acre for all private lands in Massachusetts. On the acres where biomass is harvested, 31.0 green tons come from whole trees, while only 1.4 green tons consist of residues from sawtimber harvests.

As shown in Exhibit 3-12, this scenario results in 694,000 green tons of additional biomass produced for bioenergy from private lands in Massachusetts. This represents an increase of about 510,000 green tons from our Low-Price Biomass scenario: approximately 1/3 of the additional material comes from increased harvesting of "low-value" timber and the diversion of wood formerly harvested for non-sawtimber industrial uses to biomass; the remaining 2/3's comes from new land that is brought into production. This estimate is intended to represent an upper limit for biomass fuel production in Massachusetts, given the biophysical availability of wood and our assessment of how landowners might respond in a situation with much higher biomass prices. We think this scenario provides a reasonable representation of biomass supply over the medium term with biomass stumpage prices near $20 per green ton (as noted earlier, this analysis does not account for logging and infrastructure constraints that may restrict harvesting in the near term).

There are, of course, many uncertainties in this scenario and thus some sensitivity analysis to key assumptions is important. One crucial assumption is the harvest intensity with higher stumpage prices. Our scenario shows total timber removals averaging 47 green tons an acre for harvested acres that include biomass production. This is more than twice the current average harvest of about 22 green tons per acre. Nevertheless, with biomass stumpage prices of $20 per green ton, bioenergy plants could compete for most timber on a typical stand and could probably consistently outbid lumber producers for Grade 3 sawtimber. If we raise per-acre biomass removals from 35 green tons to 50 green tons (total removals increase to 62 green tons per acre), then the biomass harvest would increase from 0.7 million tons to 1.0 million tons. A further biomass increase to 60 green tons per acre would increase the forest biomass harvest to 1.2 million tons.

Another important assumption is the percentage of operable area that is harvested at higher prices. If we increase the additional area that is brought into production from one-half to two-thirds (from 10,250 acres to 13,667 acres), then the total biomass harvest would increase to about 800,000 green tons. On the other hand, if all acres were brought into production (20,500 additional acres), then the total biomass harvest from private lands would increase to 1.0 million green tons.

Relaxing some of our assumptions increases harvest estimates to 800,000 tons and above. In order to acknowledge these key uncertainties, we have summarized our results as a range from 650,000 to 850,000 green tons. Estimation of the upper end of this range is not scientific, but simply reflects our judgment of the uncertainty in these estimates and the likelihood that harvests could be higher. Importantly, it is a reminder to use caution in using these harvest levels as point estimates.

---

[43] As noted in our previous scenario, this assumption is consistent with an electric power demand scenario and can be easily modified for thermal or CHP demand. The main difference would be that if loggers do not use whole-tree methods, then tops and limbs would be excluded from the harvest volumes.

**Exhibit 3-12: Biomass Supplies Available from Massachusetts Private Lands under the High-Price Biomass Scenario**

| Annual Rates, 2010–2025 (Green Tons and Acres) | | | | |
|---|---|---|---|---|
| | Current | High Biomass Prices | | |
| | Harvest | ½ Current | Bal WT | Total |
| Area Harvested (acres) | 22,300 | 11,150 | 21,400 | 32,550 |
| Wood Removals | Green Tons per Acre | | | |
| Industrial Removals | 21.8 | 21.8 | 12.3 | 15.5 |
| Roundwood Harvest | 17.1 | 17.1 | 10.1 | 12.5 |
| Logging Residues Generated | 4.7 | 4.7 | 2.2 | 3.1 |
| Left on Site | 4.7 | 4.7 | 0.8 | 2.1 |
| Harvested for Biomass Fuel | 0.0 | 0.0 | 1.4 | 0.9 |
| Whole-Tree Biomass Removals | 0.0 | 0.0 | 34.5 | 22.6 |
| Whole-Tree Harvest | 0.0 | 0.0 | 31.0 | 20.4 |
| Logging Residues Left on Site | 0.0 | 0.0 | 3.4 | 2.3 |
| Total Removals | 21.8 | 21.8 | 46.8 | 38.2 |
| Total Biomass Harvest | 0.0 | 0.0 | 32.4 | 21.3 |
| Wood Removals | 000's of Green Tons | | | |
| Industrial Removals | 485 | 243 | 263 | 506 |
| Roundwood Harvest | 381 | 191 | 216 | 406 |
| Logging Residues Generated | 104 | 52 | 48 | 100 |
| Left on Site | 104 | 52 | 17 | 69 |
| Harvested for Biomass Fuel | 0 | 0 | 31 | 31 |
| Whole-Tree Biomass Removals | 0 | 0 | 737 | 737 |
| Whole-Tree Harvest | 0 | 0 | 664 | 664 |
| Logging Residues Left on Site | 0 | 0 | 74 | 74 |
| Total Removals | 485 | 243 | 1,001 | 1,243 |
| Total Biomass Harvest | 0 | 0 | 694 | 694 |

*Notes: “Current Harvest”’ is a projection assuming that commercial harvests continue at average levels of the past several years and there is no additional harvesting for biomass. With the High-Price Biomass scenario, one half of acres of the “original” footprint are assumed to be managed in the same way as in the Current Harvest Projection (“½ Current”), and balance of the acres are assumed to be managed more intensively using whole-tree harvesting techniques (“Bal WT”).*

To put these results in perspective, we have looked to the literature for estimates that may provide useful comparisons of the timber supply response. The response of harvest levels to prices is commonly measured as the timber supply elasticity. For statistical reasons, harvest response to income is not comparable to harvest response to prices. Nevertheless, a few comments on timber supply elasticities are useful. Most econometric studies have found timber supply to be very inelastic for non-industrial private ownerships. In fact, a meta-analysis indicated that of the 19 relevant studies that were reviewed, seven did not find a significant relationship between harvests and prices, that is, prices do not affect harvest decisions (Beach et al., 2003). The study also concluded that there often was not enough information in this research to compute supply elasticities (some were binary choice models). In spite of all the work and research that has been done over the past two decades on this topic, the default value for the supply elasticity that frequently appears for non-industrial private landowners is 0.3, which seems to date from Adams and Haynes (1996).

In our scenario, we have assumed that biomass stumpage prices increase to $20 per green ton. With our price and harvest assumptions, per-acre incomes about double. The High-Price Biomass scenario also shows a 50% increase in acres harvested. If we consider the landowner decision variable to be how many acres to harvest, then our results suggest that a 1% increase in income results in a 0.5% increase in harvest activity. As we have said, this “elasticity” cannot be directly compared with the timber supply elasticity; however, in terms of first-order approximations, both are inelastic suggesting that the behavior assumed for Massachusetts landowners is not inconsistent with previous research.

### 3.2.5 POTENTIAL BIOMASS SUPPLY BASED ON FOREST GROWTH

Previous studies of potential biomass supply in Massachusetts (reviewed in Appendix 3-A) have considered supply to be the maximum volume of low-value wood that could be harvested without reducing timber inventories below current levels. It is useful to compute this estimate to see how it compares with our estimate of biomass supply in the High-Price Biomass scenario. This also provides information as to whether our estimate is "sustainable" when using the criteria that harvests do not exceed net growth and that biomass harvests can be maintained at the same level for the foreseeable future.

The calculation of the total "sustainable" volume of biomass that can be harvested in Massachusetts depends critically on how the land area is defined and how net growth is estimated. While there are a variety of ways to make these calculations, here we follow the methodology used by Kelty et al. (2008). We define the land area as the size of the operable land base on private lands, which we have derived to be 1,071,000 acres in the previous section. For the growth rate, we use data from Chapter 5 on the average annual growth of unmanaged "mature" stands in all cover types. The average annual increase in the volume of above-ground live trees over the next 50 years is 1.3 green tons per acre. Thus, the long-term average annual growth (net of mortality) in Massachusetts would be 1.4 million green tons per year. Finally, if we reduce this estimate by 36% to account for timber that would be expected to be consumed as sawtimber (again following Kelty et al., 2008), average annual biomass availability would be 900,000 green tons per year.[44]

The upper end of our estimate of biomass supply of 850,000 green tons per year in the High-Price Biomass scenario is within the range of what would be considered "sustainable" based on the rule of harvest not exceeding growth, and thus would not result in a reduction of timber inventories across the operable land base. However, our sensitivity analysis of biomass supplies showed some projections as high as 1.2 million green tons per year which would exceed "sustainable" annual volumes as we have defined them here.

The discussion of sustainability in this context raises two important theoretical issues. One issue concerns the approach of calculating "sustainable" growth rates using initial inventory levels and fixing the time horizon in the future.[45] The majority of the timber inventory in Massachusetts is over 60 years old, and given the shape of the timber yield curves, average timber growth rates are decelerating over time. As a result, the longer the future time span that is selected, the lower the average "sustainable" growth rate. We have selected 50 years in parallel with the analysis by Kelty et al. (2008). However, the simple fact that our starting year is 2010—compared to the base year 2000 used by Kelty et al. (2008)—changes the growth trajectory enough to reduce our "sustainable" growth levels compared to their results.

The second theoretical issue concerns scale: there is no simple answer to the question of how to define the appropriate land base. If all forest land in Massachusetts were included, the total land area would jump to about 3.0 million acres and average timber growth would be about 4.0 million green tons per year. Using this theoretical approach, it would be feasible to harvest wood much more aggressively on operable private lands due to the ongoing increase in timber inventories on public lands and private lands that are not being harvested.

## 3.3 BIOMASS SUPPLY FROM PUBLIC LANDS IN MASSACHUSETTS

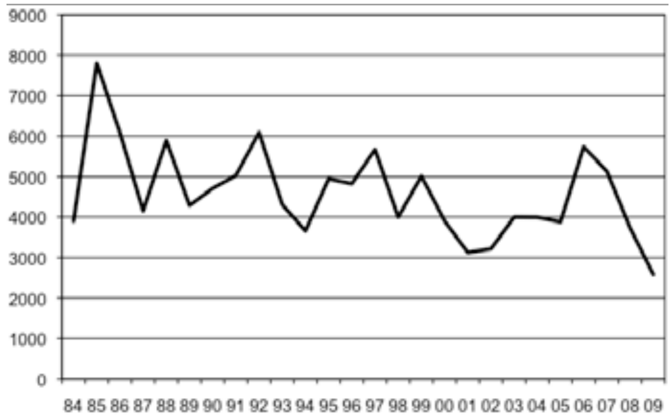
This section considers the availability of forest biomass supply from harvesting on public lands in Massachusetts. We first review estimates of historical harvest levels on all public lands and then explore these in more detail by major agency. These trends are then used to develop projections of commercial timber harvests for public lands for 2010–2025.

Using this background and perspective, we provide two forecasts of biomass supply from public lands that are consistent with our Low-Price Biomass and High-Price Biomass scenarios. As discussed previously, these are projections of incremental biomass production and do not include biomass chips that may already be counted in historical wood production totals.

### 3.3.1 HISTORICAL HARVEST ESTIMATES

As noted earlier, we have obtained data on Forest Cutting Plans (FCPs) for public sector lands for the period from 1984 to 2009. Exhibit 3-13 shows the number of acres targeted for harvest on public lands according to these plans. There is a general downward trend in these data: the annual average for 2005–2009 was 4,300 acres, significantly less than the average of 5,600 acres in 1984–1988.

**Exhibit 3-13: Acres Planned for Harvest on All Public Lands, 1984–2009**



---

[44] Note that this approach provides a "ballpark" estimate and does not attempt to adjust for logging residues and similar details. Estimates of biomass availability from previous studies using the "forest-growth" approach are discussed in Appendix 3-A.

[45] Another approach that is commonly used but beyond the scope of this study is to evaluate the volume of wood that could be produced if the forests of Massachusetts were brought into fully regulated management under optimal rotation ages. Such an approach would likely lead to a higher estimate of long-term timber and biomass supply.

We have assembled planned harvest data by public agency for 2001–2009 in several tables that follow. Exhibit 3-14 provides annual averages of the number of acres to be harvested, along with timber harvests of sawtimber (MBF, International ¼" rule), pulpwood (cords), and fuelwood (tons).[46] During this nine-year period, state lands accounted for an annual average of 3,092 acres, or 79% of the public area to be harvested. City and town lands accounted for 811 acres per year, or 21% of the total. The "Other" category was less than 1% of the total and consists of occasional harvests by the University of Massachusetts and the Army Corps of Engineers.

**Exhibit 3-14: Summary of Forest Cutting Plans for Public Lands in Massachusetts**

| Area and Volumes, Annual Averages, 2001–2009 | | | | |
|---|---|---|---|---|
| | Acres | MBF | Cords | Tons |
| DCR, State Parks & Recreation | 1,490 | 4,884 | 4,030 | 2,470 |
| DCR, Water Supply Protection | 1,454 | 4,873 | 5,069 | 6,766 |
| Fisheries & Wildlife | 148 | 465 | 502 | 450 |
| Cities & Towns | 811 | 2,789 | 2,033 | 1,804 |
| Other | 30 | 137 | 75 | 388 |
| Total Public Lands | 3,933 | 13,148 | 11,709 | 11,877 |

Harvest rates on a per-acre basis are presented in Exhibit 3-15. Among the major groups, the harvest intensity for sawtimber was very consistent, ranging from 3.2-to-3.4 MBF per acre; these compare with harvest rates of 2.0 MBF per acre on private lands. "Pulpwood" harvests averaged 3.0 cords per acre and "fuelwood" harvests averaged 2.9 green tons per acre.

**Exhibit 3-15: Summary of Forest Cutting Plans for Public Lands in Massachusetts**

| Harvest per Acre, Annual Averages, 2001–2009 | | | |
|---|---|---|---|
| | MBF | Cords | Tons |
| DCR, State Parks & Recreation | 3.3 | 2.7 | 1.7 |
| DCR, Water Supply Protection | 3.4 | 3.5 | 4.7 |
| Fisheries & Wildlife | 3.2 | 3.4 | 3.0 |
| Cities & Towns | 3.4 | 2.5 | 2.2 |
| Other | 4.5 | 2.5 | 12.8 |
| Average, All Public Lands | 3.3 | 3.0 | 3.0 |

Per-acre harvest rates have all been converted to a green ton basis in Exhibit 3-16. Excluding the "Other" group, sawtimber harvests average 17 green tons per acre, while the total harvest per acre ranges from 25-to-30 green tons. Thus, sawtimber has accounted for 56% to 67% of the wood harvested from public lands.

**Exhibit 3-16: Summary of Forest Cutting Plans for Public Lands in Massachusetts**

| Harvest in Green Tons per Acre, Annual Averages, 2001–2009 | | | | |
|---|---|---|---|---|
| | Sawtimber | Pulpwood | Fuelwood | Total |
| DCR, State Parks & Recreation | 16 | 7 | 2 | 25 |
| DCR, Water Supply Protection | 17 | 9 | 5 | 30 |
| Fisheries & Wildlife | 16 | 9 | 3 | 27 |
| Cities & Towns | 17 | 6 | 2 | 26 |
| Other | 23 | 6 | 13 | 42 |
| Average, All Public Lands | 17 | 7 | 3 | 27 |

## 3.3.2 TIMBER HARVEST PROJECTIONS FOR 2010—2025

As with timber harvest projections for private lands, historical trends provide the starting point for this assessment. Our next step was to review the 15-year Forest Resource Management Plans for state forests, several of which have already been approved. Finally, we contacted representatives from each of the three main state divisions—State Parks & Recreation, Water Supply Protection, and Fisheries and Wildlife—to review historical cutting levels and discuss their expectations for harvests in the future.

On the basis of our review and discussions, it appears that historical averages for 2001–2009 probably provide the best estimate of acres to be treated and timber harvest volumes over the next 15 years. Information from some of the individual Forest Plans suggest that acres and harvests could be higher than we have observed historically, but it seems more likely that there will be some downward adjustments to reflect the recommendations of the Forest Futures Visioning Process (2010). There will, no doubt, be other adjustments to harvest areas and to harvest intensity and silvicultural treatments, but we do not anticipate that these will be significant enough to alter our assessment of future biomass potential.

With regard to the issue of biomass harvesting, there are at least two key factors that distinguish our analysis of potential supplies from private versus public lands. First, private landowners have the flexibility to be much more responsive to market forces and can adjust the acreages they choose to harvest as well as their silvicultural treatments. In contrast, public lands are subject to a wider array of objectives and planning issues and it is more difficult for these plans to be modified in response to changes in market demand and prices. Second, the harvest of tops and limbs will not

---

[46] As noted earlier, "pulpwood" is sometimes referred to as "cordwood" and likely contains a combination of wood that will be shipped to pulp mills and processed for fuelwood. Fuelwood includes both residential fuelwood that will be cut and split and wood that will be processed into biomass chips.

be permitted from public lands if new management guidelines suggested by the Forest Futures Visioning Process are adopted.

Thus, once management plans have been established on public lands, undergone public scrutiny, and been officially approved by the responsible agency, it is more difficult to increase harvests in response to potential new demand from bioenergy plants. However, while the volume of wood to be harvested may be pre-determined, the ultimate disposition of the wood is not—planned harvests of pulpwood and residential fuelwood might be diverted to biomass fuel depending on demand conditions and relative prices.

### 3.3.3 LOW-PRICE BIOMASS SCENARIO

The economics of biomass production on private lands in Massachusetts suggest that in order to obtain sufficient volumes to furnish bioenergy plants and make logging operations profitable, it is necessary to harvest some combination of cull material, small trees, and low-grade sawtimber: the harvest of whole trees generates the volume that makes it economic to enter the stand for biomass production. Once that process is underway, then tops and limbs from industrial roundwood harvests can also be harvested for biomass.

Given the various constraints associated with harvests on public lands, we find that there is not likely to be any increase in biomass production above the levels that are already being produced for the market. (There are no estimates of the volume of biomass chips produced from public lands historically, but it is known that whole-tree biomass chips account for much of the “fuelwood” volume that is reported in tons on the FCPs.) There are several key reasons for our assessment: 1) we are not anticipating an increase in the total volume of wood harvested on public lands; on average, future annual harvest levels are projected to be about the same as during 2001–2009; 2) we are not anticipating any diversion from previous end-use markets (pulpwood, for example) because of the assumed low-price levels for biomass stumpage; 3) restrictions on the removal of tops and limbs mean that logging residues from industrial roundwood harvesting will not be available.

Thus, while there is already some production of chips on public lands, we do not project any significant increase in biomass supplies beyond recent levels.

### 3.3.4 HIGH-PRICE BIOMASS SCENARIO

It is likely that biomass supplies from public lands would become significant in response to a large increase in biomass stumpage prices. In this scenario, biomass stumpage prices are assumed to increase to $20 per green ton in response to higher demand from bioenergy plants. As we have noted, if the higher demand originates from electric power plants, higher electricity prices will be needed for wood-fired utilities to remain in operation. For thermal and CHP plants, it is likely they could afford wood at these prices and remain profitable.

The main vehicle for achieving the increased biomass production on public lands will be the diversion of wood from other end uses: at the projected price levels for biomass stumpage, bioenergy plants will be able to outbid their competitors for low-grade sawtimber, pulpwood, and residential fuelwood. We do not expect that forest management plans on public lands would be modified to increase the total volume of material that could be harvested on designated logging sites.

In this scenario, incremental biomass production from public lands is estimated as follows: 1) about 4,000 acres will be harvested each year; 2) all of the pulpwood harvested—7 green tons per acre—will now be chipped for biomass; 3) half of the fuelwood harvested—1.5 green tons per acre—will also be chipped for biomass (it is known that much of the reported fuelwood volume is already consumed for biomass fuel so we have assumed half simply to recognize this phenomenon). Thus, “new” biomass supplies from public lands would total 34,000 green tons per year (4,000 acres x 8.5 tons/acre).

We have assumed that the removal of tops and limbs will not be acceptable under new silvicultural guidelines for state lands. We should note that if the removal of logging residues were permissible, this would further increase biomass supplies by about 17,000 green tons, thus bringing the total from public lands to approximately 50,000 green tons per year.

We should point out that our scenarios reflect relatively light harvests on state lands relative to the volume of timber grown each year. In these scenarios, timber inventories on state lands continue to rise, resulting in rising levels of carbon storage. If the political winds on harvesting shift, these policies could be modified so that much more biomass is harvested from state lands. However, we think that such a scenario would have low probability because of the state’s mandate to balance a wide array of timber and nontimber objectives.

## 3.4 SUMMARY OF FOREST BIOMASS SUPPLIES IN MASSACHUSETTS

The volumes of biomass available from private lands and public lands for our two scenarios are summarized in Exhibit 3-17. Importantly, we should re-emphasize that these data represent the incremental volumes of biomass that we project could be supplied in response to expanded demand from new bioenergy plants, and thus would be available to furnish these facilities.

Our Low-Price Biomass scenario was designed to evaluate the potential supplies of forest biomass that might be produced if there was an expansion in demand from bioenergy plants. This analysis was motivated by the assumption that if the increase for demand originates from wood-fired electric power plants, they will not likely be able to pay much more than the current price of $30 per green ton without significant increases in real electricity prices; thus, given the harvesting and transport costs, there is little value left for stumpage. This same volume of wood could be utilized by thermal and CHP plants—they could pay more for stumpage than the $1–$2 per green ton that we have assumed, but would not need to until demand increases to higher levels.[47] On private lands, income from biomass production is not adequate to justify bringing more land into production and biomass volumes will be limited to increasing the harvest intensity on sites already being logged for sawtimber. On public lands, we do not anticipate an increase in the incremental volume of biomass production: planned harvest volumes are not likely to be modified in response to increased biomass demand, and low biomass stumpage prices will not provide the economic incentives to divert timber from current uses to biomass chips.

**Exhibit 3-17: Summary of Forest Biomass Fuel Supplies for 2010–2025**

| Low- and High-Price Biomass Scenarios<br>000 Green Tons per Year | | |
|---|---|---|
| | Low-Price | High-Price |
| Private Lands | 150–250 | 650–850 |
| Public Lands | 0 | 35 |
| TOTAL | 150–250 | 685–885 |

*Note: Some estimates are rounded for this table.*

In our High-Price Biomass scenario, total "new" forest biomass supply increases from 150,000–250,000 green tons per year to about 650,000–850,000 green tons per year. We have postulated that increases in demand from bioenergy plants drive biomass stumpage prices up to $20 per green ton, and prices in energy markets are high enough so that electric power, thermal, and CHP plants can compete for this wood. The large volume increase from private lands occurs primarily because much higher income levels provide incentives to bring more timberland into production. Public lands are also assumed to yield more biomass as relative prices cause timber to be diverted from pulpwood markets to biomass markets.

## 3.5 BIOMASS SUPPLY FROM NON-FOREST SOURCES IN MASSACHUSETTS

Our study has focused on biomass supplies from forest biomass sources, which include the harvesting of whole trees (including thinnings, cull, pulpwood, and low-grade sawtimber) and logging residues. These are sometimes classified as primary sources (see, for example, the *Billion-Ton Study*, Perlak et al., 2005). Wood from land clearing from development is also considered to be a primary source of wood biomass fuel in the taxonomy of the *Billion-Ton Study*. The potential volume from this source is evaluated below.

There are two other important general sources of non-forest biomass material that should be mentioned. Secondary sources ("mill residues") include any wood residues generated in the processing of logs (mill residues from sawmills, veneer mills, etc.) or lumber (manufacturing residues, from furniture, pallets, etc.). It appears that most secondary-source material is already being fully utilized in Massachusetts, and this is consistent with recent trends that show significant inflation in their prices. Tertiary sources (often referred to as "urban wood") include all other wood material and consists mainly of municipal solid waste, construction and demolition debris, and wood from landscaping and tree care. Tertiary material may potentially be a source of substantial volumes of biomass that could provide feedstock for new bioenergy plants and this source is briefly discussed below.

### 3.5.1 LAND CLEARING AND CONVERSION

According to a report by Mass Audubon (2009), forest land clearing and conversion averaged 4,700 acres per year from 1999 to 2005. Forest land clearing and conversion was reported at much higher levels in the previous three decades, but there are numerous inconsistencies between these data and independent data on building and construction. In addition, the new techniques and methods used in the 2005 survey (involving computer imaging and digitization) provide much finer resolution and greater accuracy in measuring land areas cleared. Given that average building permits in 1999–2005 were similar to the average levels of the past 20 years, we have assumed that recent levels of land clearing and conversion represent a reasonable estimate of land clearing for 2010–2025.

We have not been able to identify any information that would allow us to track the volume and disposition of the wood removed from these lands. It is probably safe to assume that higher-value sawtimber material is cut and sold, whereas the fate of the low-value material is much harder to predict.

Given the lack of information on these land clearing and conversion operations, it is not feasible to provide a rigorous quantitative projection of biomass supply from these sources. However, we can provide a framework for understanding the important parameters in evaluating this supply—this framework can then be used to demonstrate the biomass potential from land clearing. The potential increase in biomass supply from this source over the next 15 years will depend on: 1) the relative size of the land area cleared (future versus history); and 2) the relative rates of biomass recovery between the two periods. As noted above, we have assumed that land clearing will remain at the recent historical level of 4,700 acres per year. Thus, any increase in biomass production will require an increase in biomass recovery rates.

In order to demonstrate the potential biomass supply from land clearing, two important assumptions are necessary. The first concerns removals of sawtimber and other high-value timber for industrial products: we assume that the economics always justify harvesting this material first and for this example we assume that it accounts for an average of 36% of standing timber volume. The second assumption is the initial stocking levels of lands to be cleared and we assume that an average acre has 100 green tons of wood (this is less than the average shown in Exhibit 3-7 which applies only to stands of mature timber). Thus, the maximum volume of wood that could have been harvested for biomass in each year of

---

[47] There are several reasons (including administrative, logistical, and transport costs) that may lead some facilities to pay higher prices for biomass stumpage in their own timbershed, rather than purchase biomass from other locations where stumpage may be available at lower cost.

the historical period—as well as in the forecast period—would be about 300,000 green tons (4,700 acres x 64 tons/acre).

At this stage, it is easy to see the importance of the recovery rate. If biomass demand increases due to the expansion of bioenergy plants, then we would expect that there would be an increase in the percentage of material from land clearing that would be chipped and used for biomass fuel. Although it is not possible to quantify historical recovery rates, we can demonstrate the potential magnitude of this biomass source by considering the impact of different recovery rates. A recovery rate of 30% would imply that 90,000 green tons of material was collected and utilized. Each increase of 10% in the recovery rate would add an additional 30,000 green tons to the supply base, so at 70%, the total volume of supply available would be 210,000 green tons.

While the disposition of wood from land clearing sources is not known in 2000–2005[48], it is highly probable that if demand increases significantly for bioenergy uses, a greater share of this wood would be recovered and shipped to these markets. Logistics and economics will govern how much biomass can be recovered from land clearing. The kinds of machinery used, the harvesting methods, and the end-use markets for this wood will vary depending on the size of the parcel being cleared and other site-specific factors. The price of biomass delivered to a bioenergy plant will also be a critical factor in determining how much biomass is actually recovered, as will transport costs and tipping fees when the option is sending the material to a landfill.

The potential volume of wood that could be generated from land clearing in 2010–2025 will depend critically on the current disposition of this wood. If current recovery and utilization are low, the incremental volumes available in the future could be substantial. At the extreme, one might consider the increase in volume to be as much as 120,000 green tons if recovery rates were to increase from 30% to 70%. Conversely, if current recovery rates are higher due to tipping fees and competing uses, "new" biomass from these sources in the future would be reduced accordingly. A final consideration is the possibility that this material in being "underutilized" in current markets. That is, if wood is chipped and used in landscaping primarily because it is a good economic option compared to disposal, it is possible that some of this wood could be diverted to bioenergy in situations where that might become a higher value use.

### 3.5.2 TREE CARE AND LANDSCAPING SOURCES

Among the tertiary sources mentioned above, the most significant is wood from tree care and landscaping sources. This wood is often referred to as "urban wood" which is somewhat of a misnomer because it includes wood not only from tree care in urban areas, but also wood from tree care from sources such as county parks and recreation areas and maintenance of electric power lines. The term can also be confusing because it is not always clear whether it includes "urban waste" such as construction debris.

A literature review conducted in 2002 indicated that tree care/landscaping sources accounted for 1.0 million tons (42%) out the total available supply of 2.5 million tons of non-forest wood biomass in Massachusetts (Fallon and Breger, 2002). However, given the difficulties in estimating this volume (noted in the report), this estimate is perhaps best used to suggest that the potential from these sources may be substantial and worthy of further investigation (importantly, the carbon profile of this material is generally similar to logging residues and thus very favorable compared to that of harvesting standing trees). Problems in measuring supplies from these sources may be attributed to: 1) the actual generation of this material is difficult to estimate; 2) it appears that wood from land clearing may be included in this estimate; 3) little is known about the current disposition of these materials, although some broad generalizations are possible such as more than half of the material in the Northeast is "managed on-site"; and 4) the economics of recovering this material are quite variable due to the wide variety of sources from which it is generated.

## 3.6 BIOMASS SUPPLY FROM NEARBY STATES

The outlook for how much wood is available to furnish an expansion of bioenergy capacity in Massachusetts is certainly not complete without considering potential wood supply and demand from the surrounding region. State boundaries mean little in the wood biomass market, as demand, supply, and prices are determined on a regional basis. New bioenergy facilities in Massachusetts would have access to wood from nearby states, while, at the same time, new bioenergy facilities in nearby states would have access to wood supplies in Massachusetts.

There are a number of ways to gain some insights into this issue. Our strategy is as follows. Given the objectives of this study, we have focused most of our effort on a detailed analysis of forest biomass fuel supplies within Massachusetts. It is not possible to use the same approach for the Massachusetts timbershed, so we assess the potential of this region by putting it in perspective relative to Massachusetts. Among the key features that we compare are: timberland areas, timberland inventory, timber growth rates, landowner characteristics, and forest products output. We have defined the timbershed as the counties which border Massachusetts: the distance across these counties is similar to the maximum that biomass could be economically transported to bioenergy plants located in Massachusetts.

Once estimates of "new" biomass supply potential are developed for the border counties, the question remains as to where this wood will be consumed. This will depend on many factors including local demand, permitting requirements for new energy facilities, who builds first, transportation costs and infrastructure. In the last section, we discuss the implications of these factors for future wood flows to—and from—Massachusetts.

---

[48] The startup of the Schiller plant in Portsmouth, New Hampshire in 2006 makes the comparisons going forward more problematic. The plant consumes about 500,000 green tons of wood per year and has ready access to wood from land clearing in eastern Massachusetts (where most land clearing in the state occurs).

This section thus addresses two central questions:

- How much incremental biomass supply is available in the border counties?
- How much of this supply is likely to be shipped to new bioenergy plants in Massachusetts?

## 3.6.1 TIMBERLAND AREA AND TIMBER INVENTORY

Timber inventory is an obvious place to start in considering the border counties' potential contribution in meeting future demand from Massachusetts bioenergy plants. In Exhibit 3-18, we show the timberland areas and timber growing stock inventories in Massachusetts and in the major counties that border Massachusetts.[49] These FIA data indicate that timberland areas in the border counties are nearly 30% greater than those of Massachusetts. The conclusion is the same using the growing stock data.

Also noteworthy is that Massachusetts has a much higher share of public land (30%) than the border counties (an average of 19%, ranging from 28% in the Vermont and Connecticut sub-regions to only 5% in New York's three counties). Thus, when private lands only are considered, timberland areas and timber volumes in the border counties are about 50% greater than those in Massachusetts. This distinction is important because harvesting regulations for biomass fuel are generally more restrictive on public lands than on private; for example, in New Hampshire, whole-tree harvesting is prohibited on National Forest lands.

**Exhibit 3-18: Timberland Area and Growing Stock Inventory in Massachusetts Timbershed, 000 Acres and Million Green Tons; 2008**

| | Area | | | Inventory | | |
|---|---|---|---|---|---|---|
| | Total | Private | Public | Total | Private | Public |
| **Massachusetts** | 2,895 | 2,026 | 869 | 207 | 146 | 62 |
| **Border County Total** | 3,712 | 3,018 | 694 | 262 | 212 | 50 |
| New Hampshire (3 counties) | 1,075 | 938 | 137 | 81 | 70 | 11 |
| Vermont (2 counties) | 755 | 543 | 212 | 57 | 43 | 15 |
| New York (3 counties) | 747 | 708 | 38 | 46 | 43 | 3 |
| Connecticut (4 counties) | 983 | 709 | 274 | 69 | 49 | 19 |
| Rhode Island (1 county) | 152 | 120 | 33 | 10 | 8 | 2 |
| Combined Total | 6,607 | 5,044 | 1,563 | 470 | 358 | 112 |
| Border Counties ÷ Mass. | 1.28 | 1.49 | 0.80 | 1.27 | 1.46 | 0.81 |

*Source: FIA On-line; volumes converted from original units assuming 30 green tons per 1000 cubic feet. Note that 2008 is the nominal date for the survey data, but the data were compiled from annualized surveys and thus reflect an average of data collected over the period 2004–2008. County List: New Hampshire: Cheshire, Hillsborough, Rockingham; Vermont: Bennington, Windham; New York: Rensselaer, Columbia, Dutchess; Connecticut: Litchfield, Hartford, Tolland, Windham; Rhode Island: Providence*

## 3.6.2 TIMBER GROWTH

When interpreted strictly from a biophysical standpoint, there is a large volume of "excess" wood available in both Massachusetts and the border region in the sense that forests are growing more wood than is being removed through harvesting and mortality. Here we compare the potential of the border counties to Massachusetts on the basis of relative rates of timber growth. We should emphasize that relationship between net growth and removals is not a measure of supply; it only speaks to how much timber could be harvested without reducing inventory levels.[50]

There are a number of ways of measuring and evaluating timber growth. Ultimately, the key variable of interest is how much additional wood will become available in different regions. As noted above, we are primarily interested in private inventories because biomass harvesting is subject to fewer restrictions and owners tend to be more responsive to market forces.

Most often, this growth has been evaluated by comparing net growth (gross growth less mortality) and removals. This relationship would be an excellent metric (it essentially defines inventory accumulation at any point in time) were it not for the poor quality of the data on removals. Furthermore, issues of data accuracy have become more of a concern in recent years due to the new annualized survey procedures that have been adopted by the Forest Service. For example, the sampling error for removals in 2008 is 45% in Massachusetts and 31% in New Hampshire. At the county level, the sampling error for removals is so large as to make these data effectively meaningless.[51]

Although any approach will encounter problems with accuracy due to sample size and sample frequency issues, we believe that comparing inventory levels over time is a better method for

---

[49] Data on growing stock volumes significantly understate the volume of biomass available because of the availability of wood from non-growing stock sources, notably cull trees, tops and limbs. However, our analysis is focused on relative levels—not absolute volumes—and this omission has little effect on our conclusions.

[50] Even if a forest is not adding new wood each year, it still has the potential to contribute to biomass production; biomass supplies can come out of existing stocks, not growth. From a carbon standpoint, a forest that has matured to the point that the yield curve has leveled off (net growth = mortality) may be a preferred source of material.

[51] Data for 2008 for timber removals in 12 Massachusetts counties show: no removals recorded in 7 counties, sampling errors of 100% or greater for 3 counties. For the 13 selected counties that are adjacent to Massachusetts, there were no removals recorded in 2 counties, sampling errors of 100% or greater for 4 counties, and the minimum sampling error for the remaining 7 counties was 53%. The reason for the poor accuracy is that removals are a rare event given the sampling methodology; for example, in Massachusetts, about 120 plots were re-measured in 2008 (20% of the 600 plots in the sample) and with about one percent of timberlands harvested in Massachusetts each year, that means that one would expect to find, on average, only about six plots with harvest activity every five years.

evaluating growth trends. The primary reason is statistical in that standing inventory can be measured on each plot that is surveyed each year. Likewise, with regard to components of change in the FIA data, net growth is much more reliable than data on removals. Since we are interested in small areas, we have also combined private and public inventories for this comparison because sampling errors for areas and inventories increase significantly for separate ownerships.

### 3.6.2.1 Growth per Acre

When all lands (private and public) are considered together, timber growth rates in Massachusetts are similar to the border region on per-acre basis. In Exhibit 3-19, average stocking levels are shown along with two sets of growth rates. The data on net growth per acre (gross growth less mortality) are derived by dividing net growth (as reported directly by FIA data) by the area in each region. The data indicate that growing stock timber inventories in Massachusetts are increasing at an average rate of 1.6 green tons per acre. The average growth rate in the border counties is essentially the same (1.5 green tons per acre), spanning a range of 1.2–1.8 green tons per acre.

The second set of growth data is derived by calculating the annual rate of change in per-acre stocking levels using FIA data between the 2004–2008 inventory/area surveys and the surveys from 10-to-15 years ago. This is a more inclusive measure of timber accumulation on an average acre by accounting for not only net growth and mortality, but also removals. These data also show very little difference between Massachusetts and the border counties—timber inventory volume is increasing at an average of about 0.8–0.9 green tons per acre, and with the exception of Rhode Island, the border counties are clustered around this number.

According to the above data, timber volume per acre is increasing at very similar rates throughout the area we have defined as the Massachusetts timbershed. These similarities reinforce the idea of using relative land areas as a measure of potential supply. Thus, if timberland use and ownership were to remain the same over the next 15 years, the potential contribution of the border counties areas—from a growth perspective—would be about 50% greater than Massachusetts (based on the private timberland area).

**Exhibit 3-19 Stocking Levels and Inventory Growth for Growing Stock**

| All Timberlands (Private + Public), Green Tons per Acre | | | |
|---|---|---|---|
| | **Stocking** | **Net G** | **Inv Δ** |
| **Massachusetts** | 71.7 | 1.6 | 0.8 |
| **Border County Total** | 70.7 | 1.5 | 0.9 |
| New Hampshire (3 counties) | 74.9 | 1.3 | 0.7 |
| Vermont (2 counties) | 76.1 | 1.2 | 0.7 |
| New York (3 counties) | 61.1 | 1.8 | 1.0 |
| Connecticut (4 counties) | 70.0 | 1.8 | 1.0 |
| Rhode Island (1 county) | 65.9 | 1.2 | 2.4 |

*Notes: See Exhibit 3-18 for county definitions. Net G is net growth per acre: the net growth volumes are taken directly from FIA data for 2008 and divided by area for 2004–2008 (Exhibit 3-18). Inv Δ is a more inclusive measure of volume change on an average acre and accounts for net growth, removals and mortality; it is calculated as the change in stocking levels over the last 10-to-15 years (depending on the date of the previous inventory).*

### 3.6.2.2 Total Volume Growth

Does the conclusion change when we adjust overall inventory growth for historical land use changes? There are two aspects of land-use change to consider: 1) shifts in total timberland area over time; 2) shifts from private to public ownership. For the border counties as a whole, the change in total timberland area has been negligible (a decrease of less than 1% from the earlier inventory years). However, over this same time frame, there has been a large shift from public to private ownership: approximately 20,000-to-25,000 acres per year have shifted into public ownership according to FIA data (as noted earlier, there are inconsistencies in these data due to measurement errors and sampling errors and their accuracy has been disputed). Thus, while the total increase in timber inventory was about 2.6 million green tons per year in the border zone, the increase in *private* timber inventories was only 0.9 million green tons per year, while inventories on *public* lands increased by 1.7 million green tons per year.

When measured on a comparable basis, private timber inventory volume in Massachusetts has increased at a rate of about 1.1 million green tons per year. Thus, in the important area of private timber inventory growth, the data suggest that inventories in Massachusetts are increasing at rates similar to those in the surrounding counties. From this perspective, the border countries lose the 50% advantage that we observed when considering growth rates on a per-acre basis.

Of course, there is no *a priori* reason to assume that land use changes will continue at the same rates as in the recent past. Good arguments can be made that future shifts from private to public lands could accelerate or proceed more slowly. In any case, it does seem clear that a serious assessment of biomass fuel availability in the border counties should consider an in-depth analysis of land-use changes in the region. To the extent that significant reductions in private timberland will continue, this would likely have an important influence on potential supplies from the surrounding region.

## 3.6.3 THE FOREST PRODUCTS INDUSTRY AND REGIONAL HARVESTING

Another possibility for assessing the relative importance of the border counties is to consider harvesting levels given that the greatest potential for biomass (at least in the near term) comes from integrated harvesting with higher-value industrial roundwood. Logging residues—generally considered to be a prime source of biomass fuel—will be directly proportional to the amount of industrial roundwood harvested. Perhaps more importantly, areas that already have a significant forest industry may be good candidates for biomass fuel harvests through additional cutting of low-value timber, or possibly because forest industry intensity is a good indicator of timber availability and underlying landowner attitudes.

For this overview, we have used TPO data because they have the appropriate concepts at the county level (Exhibit 3-20). These data indicate that production in the border counties is about three times that in Massachusetts; thus, from the vantage point of current harvesting activity, the border counties show a lot more promise as a source of biomass than Massachusetts. The table also shows an index which compares the intensity of harvests in the different areas—this is calculated as roundwood harvests divided by total timberland acres, and is indexed to Massachusetts = 1.0.

**Exhibit 3-20: Industrial Roundwood Harvests in Massachusetts Timbershed, 000 Green Tons and Index; 2006**

| | Sawlogs | Pulpwood | All Ind. | Cut/Acre |
|---|---|---|---|---|
| Massachusetts | 217 | 33 | 254 | 1.0 |
| Border County Total | 605 | 174 | 819 | 2.5 |
| New Hampshire (3 counties) | 252 | 111 | 387 | 4.1 |
| Vermont (2 counties) | 142 | 28 | 170 | 2.6 |
| New York (3 counties) | 92 | 30 | 137 | 2.1 |
| Connecticut (4 counties) | 101 | 6 | 107 | 1.2 |
| Rhode Island (1 county) | 17 | 0 | 17 | 1.3 |

*Source: Harvest data from TPO. All Ind. is "All Industrial" and, in addition to sawlogs and pulpwood, includes veneer logs, composite products, posts, poles, piling, and miscellaneous. Cut/Acre is an index (Massachusetts = 1.0), measured as All Ind./Timberland Acres. See Exhibit 3-18 for county definitions.*

## 3.6.4 LANDOWNER CHARACTERISTICS IN THE REGION

Ownership characteristics provide another perspective on future wood biomass fuel availability in the border counties for at least three reasons: 1) the size of forest holdings is generally considered to be highly correlated with the landowner's propensity to harvest timber; 2) the size of forest holdings is of particular importance for biomass fuel because of economies of scale in whole-tree harvesting; and 3) landowner attitudes are important in the decision of whether or not to use their land for commercial timber production.

In Exhibit 3-21, data that address the above issues are presented at the state level.[52] In Massachusetts, the average parcel size for family-owned forest land is 6 acres, while Rhode Island is also 6 acres and Connecticut averages 9 acres per owner. Forest holdings are much larger in New Hampshire and Vermont, where the average owner has 19 acres and 36 acres, respectively (although it is likely to be the case that parcel sizes in the border counties are more similar to those in Massachusetts than the state averages would imply). Notably, a significant area of New Hampshire's private forest land (1.3 million acres) is held by non-family owners (average forest holdings of owners in this group are substantially larger). According to these survey data, only 43% of the family forest land area in Massachusetts is held in parcels that are 50 acres or larger. New Hampshire and Vermont are much higher at 64% and 75%, while Connecticut is 48% and Rhode Island is 33%. Importantly, New Hampshire has twice as much family-owned land as Massachusetts in 50+ acre parcels, while Vermont has three times as much land; however, we do not have data on the relative areas for the border county region.

**Exhibit 3-21: Attributes of Family Forest Landowners**

| | MA | NH | VT | CT | RI |
|---|---|---|---|---|---|
| Private Lands (000 acres) | 2,179 | 3,646 | 3,864 | 1,383 | 303 |
| Family Forest Owners (000 acres) | 1,686 | 2,358 | 3,109 | 898 | 204 |
| Family Forests, 50 acres or more | 729 | 1,514 | 2,343 | 434 | 68 |
| % of Family Forests, 50 acres or more | 43% | 64% | 75% | 48% | 33% |
| Average Size, Family (acres per parcel) | 5.8 | 19.0 | 35.7 | 8.9 | 5.5 |
| Timber production is important* | 20% | 21% | 29% | 12% | 11% |
| Commercial harvest in past 5 years | 40% | 59% | 68% | 39% | 26% |
| Commercial harvest in next 5 years | 20% | 29% | 39% | 9% | 11% |
| % of family forests available given constraints* | 32% | 43% | 57% | 20% | 21% |

*Source: National Woodland Ownership Survey, Butler et al., 2008; on-line data.*

*Notes: 1) Data are state level, not for county sub-regions.*

*2) The survey asks landowners to rank the importance of producing commercial timber on a 7-point scale from "very important" to "not important." These data show the percentage that ranked production as '1' or '2' on this scale.*

*3) "% of family forest available given constraints" is taken from Butler et al. (2010) and reflects reductions for biophysical and social constraints, including parcel size and landowner attitudes and preferences.*

With respect to timber production, probably the three most important questions asked in the National Woodland Ownership Survey are: 1) how important is timber production?; 2) did you conduct a commercial harvest in the past five years?; and, 3) do you plan to conduct a commercial harvest in the next five years? The results shown in Exhibit 3-21 are much as one might expect: Vermont and New Hampshire owners gave answers that

---

[52] We evaluated these data at the survey unit level in New Hampshire and Vermont to focus more directly on the sub-regions of concern. However, there were no obvious differences within the states, particularly given the large sampling errors associated with this survey. We did not consider the data for New York because the three-county area accounts for such a small share of the state's total forest land.

most favored timber production, Massachusetts was ranked in the middle of this group, and Connecticut and Rhode Island owners were least oriented toward timber production.

There appears to be a fairly high degree of correlation between parcel size and landowner interest and willingness to pursue commercial timber harvests. A recent study by Butler et al. (2010) developed a methodology to combine these factors in a manner to eliminate double counting in the presence of multiple constraints. Harvest "participation rates" from this study are shown on the last line of Exhibit 3-21: Vermont had 57% of family forest land available for harvest (ranking the highest of all 20 northern states); New Hampshire was second of this group with 43% available; Massachusetts had only 32% of land available; Connecticut and Rhode Island were the lowest with only about 20% of land available (and ranked among the lowest of the 20 northern states).

Some question the validity and usefulness of landowner surveys, so it is useful to have additional information from other sources. Participation rates in current use programs provide further insights into the level of interest in forest management and related income incentives. The Chapter 61-61A-61B program in Massachusetts has had limited success relative to its counterparts in New Hampshire and Vermont. In Massachusetts, about 15% of private forest lands were enrolled in this program in 2009 (Massachusetts Department of Conservation, 2009). This is in stark contrast to New Hampshire where about 27,000 landowners participate in the current use program, covering nearly 3 million acres (New Hampshire Timberland Owners Association, 2010). In Vermont, more than 1.6 million acres of forest land were enrolled in their current use program in 2009 (Vermont Department of Taxes, 2010).

Ownership attributes clearly reinforce the patterns shown earlier on the basis of area, inventory and harvesting. The potential for forest biomass fuel from border counties in Connecticut and Rhode Island appears limited. On the other hand, the border counties of New Hampshire, Vermont, and New York are similar in size to Massachusetts (on the basis of timberland area, inventory, and growth) and their forest products industry and industrial roundwood harvests are significantly higher. Furthermore, landowner surveys for New Hampshire and Vermont show family owners in these states to be more supportive of timber harvesting.

### 3.6.5 SUMMARY OF FOREST BIOMASS SUPPLY POTENTIAL IN BORDER COUNTIES

In order to assess potential forest biomass supplies from the counties surrounding Massachusetts, we have looked at several key measures relative to Massachusetts. The general conclusion from our analysis of timberland area, timber inventory, and timber growth is that private lands in the border counties have the ability to supply about 50% more biomass than Massachusetts.

When the analysis is expanded to account for landowner characteristics and the development of the forest products industry, the potential biomass contribution of border counties becomes more difficult to evaluate. It is certainly the case that New Hampshire, Vermont, and New York would be much more conducive to increased harvesting than Massachusetts based on landowner attitudes and the distribution of ownership by parcel size. This already manifests itself in a much larger forest industry and much higher roundwood production. Thus we are faced we this analytical dilemma: these regions may be more attractive for timber harvesting, but given that more harvesting is now taking place, how much further expansion is likely? Has investment to date put the production in these regions in equilibrium relative to Massachusetts? Are there still more promising opportunities in the border counties? Or are they already approaching production levels that make it more difficult to expand further? Whole-tree harvesting already has a long history in southern New Hampshire for example, suggesting that future increases might be more difficult to achieve and come only at higher cost.

While this issue will not be settled in this analysis, we have made an effort to better understand the situation in southern New Hampshire: it has been suggested that New Hampshire has the most potential for increasing supplies of forest biomass because of its inventory, harvest rates, and favorable stance toward timber production. Our evaluation of recent harvest relationships and price trends is provided in Appendix 3-D. We did not find any obvious pockets of opportunity or expansion possibilities in the southern counties, nor any evidence to support claims that southern New Hampshire may be in an advantageous position to produce more biomass compared to neighboring areas.

Since we have considered the availability of biomass from border counties in relation to supplies from Massachusetts, it is important that we consider these supplies in the context of our two scenarios for Massachusetts. In our Low-Price Biomass scenario, we expect that biomass supplies in Massachusetts will increase as a result of more intensive harvesting using whole-tree harvesting. Given the development that has already taken place in some of the border areas, we would not expect that increased biomass demand at current biomass prices would spur additional harvesting to the same extent that we might see in Massachusetts. However, in our High-Price Biomass scenario, more land is harvested and more timber is harvested from that land. We would expect that this will cause a substantial response in the border counties, just as we expect in Massachusetts. Given landowner characteristics in the region, one might argue that the response in border counties might be greater than in Massachusetts.

Mindful of the numerous uncertainties involved in projecting the potential supply of biomass in the counties bordering Massachusetts, we consider a reasonable "guesstimate" to be 50% more than can be produced within this state. In our Low-Price Biomass scenario, this would suggest the border counties could produce an additional 225,000–375,000 green tons of forest biomass annually. If the High-Price Biomass scenario unfolds, border county supply would jump to an annual average of 1.0–1.3 million green tons.

## 3.6.6 INTER-REGIONAL TRADE AND IMPLICATIONS FOR BIOMASS SUPPLIES FOR FUTURE BIOENERGY PLANTS IN MASSACHUSETTS

Understanding potential wood biomass supplies in the counties that surround Massachusetts is critically important in estimating biomass availability for bioenergy plants that may get built in Massachusetts. But where will this wood be consumed? It is crucial to consider future demand outside of Massachusetts and possibilities for biomass trade. Biomass produced in the border counties could stay within its home zone for local use, it could flow between sub-regions (from New Hampshire to Vermont, for example), it could flow to the northern areas, or it could flow to Massachusetts. Likewise, wood in Massachusetts is not limited to home use; in fact, with few outlets for wood biomass in Massachusetts currently, biomass chips are now being shipped to bioenergy facilities in New Hampshire.

### 3.6.6.1 Historical Wood Products Trade

Recent patterns in wood products trade in this region provide some perspective on trade possibilities. Data available on wood trade for New Hampshire, Vermont, Maine, and New York show that the four-state region is a net importer of wood, purchasing 195,000 green tons in 2005. (We caution that the data are for only one year and they do not indicate specifically what is happening with Massachusetts.)

Data for Vermont (Northeast State Foresters Association, 2007b) indicate that Vermont consumed about 400,000 green tons of biomass chips in 2005. Of this total, about 300,000 green tons were imported from other states, while at the same time, Vermont exported 75,000 green tons; thus, net imports were just over half of wood chip consumption.

Based on the limited data that we have on Massachusetts wood trade, it appears that trade between Massachusetts and Vermont has been one-directional, with Massachusetts exporting a small volume of sawlogs to mills in Vermont.

**Exhibit 3-22: Wood Trade Among Northeast States, 2005 (000 green tons; does not include international trade)**

| | Import | Export | Net Imports |
|---|---|---|---|
| **New Hampshire** | 353 | 820 | -468 |
| **Vermont** | 508 | 630 | -123 |
| **Maine** | 1,115 | 363 | 753 |
| **New York** | 838 | 805 | 33 |
| **TOTAL** | 2,813 | 2,618 | 195 |

*Source: Northeast State Foresters Association, 2007a. Original data in cords; converted to green tons assuming 2.5 green tons per cord.*

### 3.6.6.2 Potential Future Trade in Forest Biomass Fuel

One of the advantages of Massachusetts size and shape is that it has access to a large horseshoe of wood as part of its timbershed. However, it is important to recognize that an even larger horseshoe envelops this timbershed, which means that wood available from that area may provide incentives to build bioenergy facilities in the border region, or that wood could flow from Massachusetts to feed plants in that area. Exhibit 3-23 provides a list of facilities that—if built—might potentially compete for the same wood that could provide feedstock to proposed plants in Massachusetts. Plans and proposals change frequently and this list is intended only to be suggestive of some of the facilities—and their size—that are now under consideration in this region. This list does not include facilities that are located overseas, but there is always the possibility that biomass produced in this region could be directed to export markets.

**Exhibit 3-23: Proposed Bioenergy Plants that Could Influence Biomass Availability for Massachusetts (Wood Use in Green Tons per Year)**

| State | Company | Location | Size | Wood Use |
|---|---|---|---|---|
| **MA** | Russell Biomass | Russell | 50 MW | 550,000 |
| | Greenfield Biomass | Greenfield | 50 MW | 550,000 |
| | Tamarack Energy | Pittsfield | 30 MW | 350,000 |
| | Palmer Renewable | Springfield | 30 MW | *235,000 |
| **NH** | Clean Power Development | Berlin | 29 MW, CHP | 340,000 |
| | Clean Power Development | Winchester | 15 MW | 150,000 |
| | Alexandria Power | Alexandria | 16 MW (re-start) | 200,000 |
| | Greenova Wood Pellets | Berlin | pellets | 400,000 |
| | Laidlaw Energy | Berlin | 40 MW | 400,000 |
| **VT** | Vermont Biomass Energy | Island Pond | pellets | 200,000 |
| | Brattleboro District Heat | Brattleboro | | |
| **CT** | Decker International | Plainfield | 30 MW | 400,000 |
| | Tamarack Energy | Watertown | 30 MW | 400,000 |

*Notes: *plan calls for construction and demolition debris as feedstock.*

Two important strategic issues in siting large-scale bioenergy facilities are relevant to this discussion. One is that transportation costs are a significant component of delivered biomass costs and so the location of new facilities should be optimized so that they have access to the most wood within short distances. Thus, plants should be built where there are ample supplies of wood in the "home" area. This could be analyzed with mathematical optimization models, but the results would probably be of little use due to the large number of other factors that affect plant location, many of which are specific to individual locations and facilities.

A second strategic issue is what has been termed “first-mover advantage,” which suggests that the facility that starts up first will have a competitive advantage in establishing its network and logistics for wood supply. In addition, the first mover may discourage future investments that would need to access the same timbershed. However, being first does not rule out the possibility that other new facilities that may start later: they may be willing to compete for the same wood due to proximity or the belief that they will be more efficient and thus able to pay more for their fiber.

### 3.6.6.3 Wood Supplies Available for Massachusetts

How much in the border counties would be available for new bioenergy facilities in Massachusetts? This will depend on how the bioenergy industry in the region evolves and depends on the following:

- How many new facilities will be built and how large will they be?
- Where will they be built?
- When will they be built?

In order to provide some general guidelines, such an analysis might proceed as follows. For economic reasons, it would seem most likely that the majority of wood produced would remain in its home market: it might be reasonable to assign that a 50% probability. The remaining 50% could be shipped to Massachusetts or shipped “outside” to the facilities in the next ring of border counties. Thus, in this example, the supply of biomass being shipped to Massachusetts from the border region would be 25% of the total available. If the amount of wood available in Massachusetts is X, and the amount available from outside is 1.5X, then Massachusetts could plan on increasing its supplies by 0.375X (or 0.25 * 1.5X).

These numbers can be adjusted to develop some insights into what might represent a reasonable upper bound. Suppose we make the assumption that the amount of “new” biomass available in the border counties is actually twice that available in Massachusetts (call this 2X). Furthermore, suppose that Massachusetts is able to purchase half of that wood by virtue of location or the timing of establishing new plants and their supply infrastructure. In this case, Massachusetts could increase its supply by X (or 0.5 * 2X), thus doubling the amount available only within the state.

In order to provide some general guidance and indication of the volumes of biomass that could be available from the border counties to supply new bioenergy facilities in Massachusetts, we have assumed that Massachusetts could successfully purchase 50% of the potential incremental production. In our Low-Price Biomass scenario, this would suggest that 110,000–190,000 green tons of forest biomass from border counties could augment the supplies available within Massachusetts. Supplies available from border counties increase to 515,000–665,000 green tons in the High-Price Biomass scenario.

Suffice to say, there is no simple answer to the question of how much biomass might be available from the border counties to furnish new bioenergy facilities in Massachusetts. However, it would seem prudent that each new facility (particularly those with large annual wood consumption) conduct its own feasibility study and carefully establish that the supplies it needs are available and not destined for other bioenergy plants.

## REFERENCES

Adams D.M. and Haynes R.W. 1996. The 1993 Timber Assessment Market Model: Structure, Projections and Policy Siumulations. U.S. Department of Agriculture, Forest Service. General Technical Report PNW-GTR-368.

Beach R.H., Pattanayak S.K., Yang J., Murray B.C., and Abt R.C. 2003. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Policy and Economics 7 (2005) 261-281.

Butler, B.J. 2008. Family Forest Owners of the United States. 2006. Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. www.treesearch.fs.fed.us/pubs/15758.

Butler B.J., Ma Z., Kittredge D.B., and Catanzaro P. 2010. Social Versus Biophysical Availability of Wood in the Northern United States. Accepted for publication in Northern Journal of Applied Forestry.

Butler B.J., Miles P., and Hansen M. 2008. National Woodland Owner Survey Table Maker web-application version 1.0. U.S. Department of Agriculture, Forest Service, Northern Research Station, Amherst, MA. Available only on internet: http://fiatools.fs.fed.us/NWOS/tablemaker.jsp].

Damery D.T., Bellemer C, and Boyce G. 2006. Massachusetts Directory of Sawmills & Dry Kilns – 2006.

Fallon M. and Breger D. 2002. The Woody Biomass Supply in Massachusetts: A Literature-Based Estimate.

Fight R.D., Hartsough B.R. and Noordijk P. 2006. Users Guide for FRCS: Fuel Reduction Cost Simulator Software. U.S. Department of Agriculture, Forest Service. General Technical Report PNW-GTR-668.

Forest Futures Visioning Process. 2010. Recommendations of the Technical Steering Committee. Final Report (April 21, 2010). Massachusetts Department of Conservation and Recreation.

Harvard Forest. 2010 (May). Wildlands and Woodlands: A Vision for the New England Landscape. Harvard Forest, Harvard University. Petersham, Massachusetts.

Innovative Natural Resource Solutions LLC. 2007. Biomass Availability Analysis—Five Counties of Western Massachusetts.

Kelty M.J., D’Amato A.W., and Barten P.K. 2008. Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts. Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA.

Kittredge, D. 2009 (May). Ownership and use of Massachusetts forests (presentation). Natural Resources Conservation, Umass-Amherst, Harvard Forest.

Kittredge D, Foster D, McDonald R. 2009. Massachusetts Timber Harvesting Study. Harvard Forest Data Archive: HF080.

Maine Forest Service, Department of Conservation, Forest Policy and Management Division. 2009. 2008 Wood Processor Report, Including Import and Export Information.

Maker, T.M. 2004. Wood-Chip Heating Systems: A Guide for Institutional and Biomass Heating Systems. Original 1994, revised in 2004 by Biomass Energy Resource Center, Montpelier, Vermont.

Mass Audubon. 2009. Losing Ground: Beyond the Footprint.

Massachusetts Department of Conservation and Recreation, Bureau of Forest Fire Control and Forestry, 2008 Annual Forestry Stakeholder Report: Promoting Stewardship of Our Forest for a Safe and Healthy Environment, Economy, and Society. 2009.

New Hampshire Report of Cut. 2008. Summary data generated by Matt Tansey, New Hampshire Division of Forest & Lands.

New Hampshire Timberland Owner's Association. Timber Crier. Various issues.

New Hampshire Timberland Owner's Association. 2010. Website: www.nhtoa.org.

Northeast State Foresters Association. 2007a. The Economic Importance and Wood Flows from the Forests of Maine, New Hampshire, Vermont and New York, 2007.

Northeast State Foresters Association. 2007b. The Economic Importance and Wood Flows from Vermont's Forests, 2007.

P Squared Group, LLC and Biomass Energy Resource Center. 2008 (February). Heating with Biomass: A Feasibility Study of Wisconsin Schools Heated with Wood.

Perlak R.D., Wright L.L., Turhollow A.F., Graham R.L., Stokes B.J., and Erbach D.C. 2005 (April). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.

Sherman, A.R. 2007. Vermont Wood Fuel Supply Study: An Examination of the Availability and Reliability of Wood Fuel for Biomass Energy in Vermont. BERC (Biomass Energy Resource Center).

Timmons D, Allen G, Damery D. 2008. Biomass Energy Crops: Massachusetts' Potential. University of Massachusetts, Department of Resource Economics.

University of Massachusetts Amherst. 2008. Southern New England Stumpage Price Report. MassWoods, maintained by Paul Catanzaro. www.masswoods.net/sne_stumpage/

U.S. Department of Agriculture, Forest Service. Forest Inventory and Analysis National Program. Forest Inventory Data Online: www.fia.fs.fed.us/tools-data.

U.S. Department of Agriculture, Forest Service. Forest Resources of the United States, 2007. A Technical Document Supporting the Forest Service 2010 RPA Assessment. Smith W.B., Miles P.D., Perry C.H., and Pugh S.A. 2009. Gen. Tech. Rep. WO-78.

U.S. Department of Agriculture, Forest Service. Forest Resources of the United States, 2002. A Technical Document Supporting the USDA Forest Service 2005 Update of the RPA Assessment. Smith W.B., Miles P.D., Vissage J.S., and Pugh S.A.

U.S. Department of Agriculture, Forest Service. Timber Product Output Mapmaker Version 1.0. On-line software for the Timber Product Output Database Retrieval System (TPO). www.fia.fs.fed.us/tools-data/other/

U.S. Energy Information Administration. 2009. Annual Energy Outlook 2010 Early Release Overview. Report #:DOE/EIA-0383(2010).

U.S. Environmental Protection Agency, Office of Atmospheric Programs. 2009. EPA Analysis of the American Clean Energy and Security Act of 2009, H.R. 2454 in the 111th Congress (6/23/09).

Vermont Department of Taxes. 2010. Annual Report. Division of Property Valuation and Review.

Vermont Forest Resource Harvest Summary. Various years. Vermont Department of Forests, Parks & Recreation.

# CHAPTER 4
# FOREST SUSTAINABILITY AND BIOMASS HARVESTING IN MASSACHUSETTS

## 4.1 INTRODUCTION

The objective of this task of the Biomass Sustainability and Carbon Policy study is to evaluate the potential impacts posed by increased biomass harvesting in the forests of Massachusetts and offer recommendations for mitigating any negative outcomes that are identified. Although biomass harvesting offers opportunities to enhance silvicultural treatments and produce greater quantities and quality of traditional forest products such as sawlogs these economic impacts are not the focus of this chapter. This chapter reviews indicators of forest sustainability for Massachusetts forests and gauges the impact of increased biomass harvesting on forest ecosystem sustainability. It also suggests options for policies, guidelines, or regulations that might be needed to protect ecological values while producing a forest based energy supply and realizing the economic benefits from increased silvicultural productivity.

The concept of forest sustainability requires consideration of what is being sustained, over what time period, and at what landscape scale. Section 2 addresses these issues at the stand-level, focusing on the localized ecological impacts of biomass harvesting. These stand-level considerations are most readily observed and quantifiable. The stand-level analysis discusses the potential impacts to ecological systems and processes and then reviews the biomass harvesting guidelines used by other states and political entities to minimize any impacts at the stand level. Then the adequacy of Massachusetts' current forest management regulations and guidelines are evaluated. Section 3 considers a broader set of sustainability factors at the landscape rather than the stand level. This discussion includes socio-economic indicators that go beyond stand-level ecological effects and have the potential to alter the provision of forest ecosystem services at a regional scale. The chapter concludes with a discussion of policy options that the state may want to consider for addressing these potential stand- and landscape-scale impacts.

To help answer questions about the potential impact of increased biomass harvests on forest sustainability at both stand and landscape scales, this report draws heavily on information from three separate but related reports that were developed or updated for this study by the Forest Guild. These documents are included as appendices to this report. *Ecology of Dead Wood in the Northeast* consists of a literature review of important topics relevant to biomass harvesting in forest types common to Massachusetts. Excerpts from this report and implications for Massachusetts policies are included in Section 2. *An Assessment of Biomass Harvesting Guidelines* (2009) was revised for this study, and the unpublished revised version is included. Finally, *Forest Biomass Retention and Harvesting Guidelines for the Northeast* is a complete set of recommendations to protect Massachusetts forest types that was developed in a parallel process by Forest Guild members and staff.[1] These guidelines provide a useful starting point for the development of state-specific guidelines for Massachusetts.

These reports provide more detailed background information and a richer exploration of the underlying science and issues. Overviews of each of these reports and their implications for policies addressing increased biomass harvests in Massachusetts are included in Section 2 with the stand-level discussion.

## 4.2 STAND-LEVEL IMPACTS TO FOREST HEALTH RESULTING FROM INCREASED BIOMASS DEMAND

As we learned from the analysis in Chapter 3, woody biomass generated solely from logging debris (tops and branches) will contribute minimally to commercial-scale biomass facilities. This implies that the only way to meet higher demand would be to increase the annual forest harvest, i.e., cut more trees per acre or harvest additional acreage. Increasing harvest levels does not automatically mean an unsustainable forest ecosystem. As noted in Chapter 3, timber inventories have been increasing in Massachusetts for many decades and harvests can potentially be increased without reducing future wood supplies. The challenge with increased harvests is to provide assurances that forest ecosystem health would be preserved. There are three main areas where forest ecosystem sustainability might be affected. These issues are relevant to any harvesting operation, but become of greater concern if additional wood is removed for biomass:

- Impact on hydrology and water quality
- Impact on soils and site productivity
- Impact on habitat and biodiversity

### 4.2.1. INTRODUCTION

Hydrology and water quality are already covered with existing Best Management Practices (BMPs) in Massachusetts (reference to BMPs). Increasing the harvest levels to meet biomass demands should therefore not compromise water resources because of the protections already in place. It is not clear that protections are in place for soils and productivity, or biodiversity, and therefore we focus on these issues in this Task.

Many of the possible impacts related to biomass harvesting relate to the removal and retention of woody material. This is true for soil protection as well as wildlife and biodiversity. Although dead wood and declining trees have traditionally had little commercial value, they do have substantial ecological value. For this reason, we focus our analysis on the ecology and benchmarks for retention of this material.

---

[1] The three Forest Guild reports mentioned here are included in the Appendices.

*Ecology of Dead Wood in the Northeast* was prepared to provide background information for this study as well as to policymakers and foresters involved in biomass harvest issues elsewhere.

The paper reviews the scientific literature to provide information about the amount of dead wood retention necessary for forest health in the forest types of the northeastern U.S. Establishing the ecological requirements for dead wood and other previously low-value material is important because expanded biomass markets may cause more of this material to be removed, potentially reducing the forest's ability to support wildlife, provide clean water, and regenerate a diverse suite of vegetation. The paper covers the topics of dead wood, soil compaction, nutrient conservation, and wildlife habitat in temperate forests generally as well as in specific forest types of the Northeast. The sections that follow include excerpts from the report that cover the relevant major research findings and then summarize the implications for policies in Massachusetts.

## 4.2.2. IMPACTS ON SOILS AND PRODUCTIVITY

Biomass harvesting can affect chemical, physical, and biological attributes of soils. The silvicultural choices of what to harvest, the amount of material harvested, and the way the material is harvested are all factors that need to be considered, and sometimes mitigated, to protect soils. This section covers issues related to soil nutrients and productivity.

### 4.2.2.1 Definition of Downed Woody Material

Woody material is sometimes divided into coarse woody material (CWM), fine woody material (FWM), and large woody material. The U.S. Forest Service defines CWM as down dead wood with a small-end diameter of at least 3 inches and a length of at least 3 feet and FWM as having a diameter of less than 3 inches (Woodall and Monleon 2008). FWM tends to have a higher concentration of nutrients than CWM. Large downed woody material, such as logs greater than 12 inches in diameter, are particularly important for wildlife. Fine woody material is critical to nutrient cycles. In this report, we use the term **downed woody material (DWM)** to encompass all three of these size classes, but in some circumstances we discuss a specific size of material where the piece size is particularly important.

**Implications for Massachusetts Policies:** In order to avoid confusion, it will be important for Massachusetts to settle on definitions and terminology that are most helpful to discussions of native forest types and associated concerns.

### 4.2.2.2 DWM: Stand Development and Harvesting

The process of dead wood accumulation in a forest stand consists of the shift from live tree to snag to DWM, unless a disturbance has felled live trees, shifting them directly to DWM. During stand development following a clear cut, there is a large amount of DWM. The DWM remaining from the initial harvest decomposes rapidly in the first 25 years and continues to decline to age 40. The young stand produces large numbers of trees, and the intense competition produces an increasing number of snags. As the trees grow larger, more snags of larger sizes begin to appear. From age 40 to 100 years, DWM increases as small snags fall. Then larger snags begin to contribute to DWM. Very few large pieces of DWM are produced. Large DWM often results from wind or other disturbances that topple large trees in the old-growth stage. Thus, large dead wood tends to accumulate periodically from these disturbance pulses, whereas small pieces of DWM accumulate in a more predictable pattern throughout all stages of stand development.

Implications for Massachusetts Policies: The patterns of DWM development indicate the importance of retaining large live trees and large snags at the time of harvest. As the stand moves through the younger stages of development, it creates minor amounts of DWM of larger sizes. Retaining larger-diameter trees in all stages can provide larger size classes of DWM.

The concern at the stand level is that increased biomass harvests in Massachusetts might alter natural patterns of DWM accumulation and cause ecological damage. This can occur in stands that have not previously been harvested or by adding the additional removal of biomass to any kind of previous harvest. With new biomass markets becoming available, all sizes of woody material might be removed. Harvests that include taking material for biomass energy could lead to the removal of most or all of the dead or dying standing material, as well as low-quality trees that would eventually enter this class. Regeneration harvests, cuttings that are intended to establish new seedlings, might be helped by the ability to remove cull material that hinders new regeneration, but if the biomass removals are too heavy and too consistent, the amount of DWM could be reduced to insufficient levels. In some cases, increased prices for biomass, coupled with under-utilized equipment and logging contractors looking for work, might persuade a landowner to do a more intensive harvest than under a pre-biomass market scenario. Without guidelines for DWM retention, these heavier harvests might, in some cases, pose a greater risk for soils by depleting the structures—FWM, and to a lesser extent CWM and large woody material—that store and release nutrients back into the mineral soil.

### 4.2.2.3 DWM: Soil Productivity

DWM plays an important physical role in forests and riparian systems. DWM adds to erosion protection by reducing overland flow (McIver and Starr 2001, Jia-bing et al. 2005). DWM also has substantial water-holding capacity (Fraver et al. 2002).

In many ecosystems, DWM decomposes much more slowly than foliage and fine twigs, making it a long-term source of nutrients (Harmon et al. 1986, Greenberg 2002) (Johnson and Curtis 2001, Mahendrappa et al. 2006). While there is great variation across ecosystems and individual pieces of DWM, log fragmentation generally appears to occur over 25 to 85 years in the U.S. (Harmon et al. 1986, Ganjegunte et al. 2004, Campbell and Laroque 2007).

In some ecosystems, CWM represents a large pool of nutrients and is an important contributor to soil organic material (Graham and Cromack Jr. 1982, Harvey et al. 1987). However, a review of CWM in Northern coniferous forests suggested that it may play a small role in nutrient cycling in those forests (Laiho and Prescott 2004).

A review of scientific data suggests that nutrient capital can be protected when both sensitive sites (including low-nutrient) and clearcutting with whole-tree removal are avoided (see also Hacker 2005). However, there is no scientific consensus on this point because of the range of treatments and experimental sites (Grigal 2000). A study of an aspen/mixed-hardwood forest showed that even with a clear-cut system, calcium (Ca) stocks would be replenished in 54 years (Boyle et al. 1973). Minnesota's biomass guidelines present data that showed soil nutrient capital to be replenished in less than 50 years even under a whole-tree harvesting scenario (Grigal 2004, MFRC 2007). Whole-tree clearcutting and whole-tree thinning (Nord-Larsen 2002) did not greatly reduce amounts of soil carbon or nitrogen (N) in some studies (Hendrickson 1988, Huntington and Ryan 1990, Olsson et al. 1996, Johnson and Todd 1998). Lack of significant reduction in carbon and N may be due to soil mixing by harvesting equipment (Huntington and Ryan 1990). However, intensive cutting, such as clear-cutting with whole-tree removal, can result in significant nutrient losses (Hendrickson 1988, Federer et al. 1989, Hornbeck et al. 1990, Martin et al. 2000, Watmough and Dillon 2003)—in one case, an initial 13% loss of Ca site capital (Tritton et al. 1987).

Overall, the impact of biomass harvesting on soil nutrients is site dependent. Low-nutrient sites are much more likely to be damaged by intensive biomass removal than sites with greater nutrient capital or more rapid nutrient inputs, which is one reason scientific studies on the nutrient effects of whole-tree harvesting may yield different results.

Low-impact logging techniques that reduce soil disturbance can help protect nutrient capital (Hallett and Hornbeck 2000). Harvesting during the winter after leaf fall can reduce nutrient loss from 10 to 20% (Boyle et al. 1973, Hallett and Hornbeck 2000). Alternatively, if logging occurs during spring or summer, leaving tree tops on site would aid in nutrient conservation. Nordic countries have demonstrated that leaving cut trees on the ground in the harvest area until their needles have dropped (one growing season) can also reduce nutrient loss (Nord-Larsen 2002, Richardson et al. 2002).

**Implications for Massachusetts Policies:** The scientific literature makes clear that DWM plays a critical role in ensuring continued soil health and productivity. Modeling indicates that biomass harvests have the potential to reduce soil nutrient capital and cause long-term productivity declines (Janowiak 2010) at some sites; but other studies identify cases where soil nutrient capital is replaced in reasonable time periods even under whole-tree harvesting scenarios.

A recent report, *Silvicultural and Ecological Considerations of Forest Biomass Harvesting In Massachusetts*, suggested that with partial removals (i.e., a combination of crown thinning and low thinning that removes all small trees for biomass and generates from 9 to 25 dry t/ac or 20 to 56 Mg/ha) stocks of Ca, the nutrient of greatest concern, could be replenished in 71 years (Kelty et al. 2008). The Massachusetts study was based on previous research with similar results from Connecticut (Tritton et al. 1987, Hornbeck et al. 1990).

During the Forest Guild's working group discussions of soil productivity, the Kelty study was investigated thoroughly as it raised serious questions of long-term sustainability. As general cautionary context for soil productivity, it should be noted that leaching, particularly of Ca due to acidic precipitation, can reduce the nutrients available to forests even without harvests (Pierce et al. 1993). In the case of Ca and the Connecticut research there are important questions as to whether the input rates from natural weathering were accurate. Other researchers believe the weathering rates are much higher and the Ca-phosphorus mineral apatite may provide more sustainable supplies of Ca to forests growing in young soils formed in granitoid parent materials (Yanai et al. 2005). For example, a recent study using long-term data from Hubbard Brook Ecosystem Study indicated that "the whole-tree harvest had little effect on the total pool of exchangeable calcium" after 15 years (Campbell et al. 2007).

Consequently, the analysis provided in the Kelty study does not provide sufficient scientific justification to generalize about Ca depletion. The bottom line is that even while some available studies suggest that soil capital should be protected by avoiding sensitive sites and prohibiting clearcutting with whole-tree removals, there is no scientific basis for concluding that avoiding clearcutting or whole-tree harvesting are necessary at all sites to maintain productivity. Sensitive soil types should be determined and appropriate guidelines applied. We recommend a conservative approach that includes the retention of some DWM in all harvests. The Forest Guild Biomass Retention and Harvesting Guidelines deal directly with these issues and are summarized in this report.

### 4.2.2.4 QUANTITIES OF DEAD WOOD

Site productivity and the rate of decomposition help determine the amount of dead wood in a given stand (Campbell and Laroque 2007, Brin et al. 2008). As mentioned above, DWM decomposition varies greatly but generally occurs over 25–85 years in the U.S. (Harmon et al. 1986, Ganjegunte et al. 2004, Campbell and Laroque 2007). All mortality agents including wind, ice, fire, drought, disease, insects, competition, and senescence create dead wood (Jia-bing et al. 2005). These mortality agents often act synergistically.

A review of 21 reports of quantitative measures of DWM in Eastern forest types shows great variability across forest types and stand-development stages (Roskoski 1980, Gore and Patterson 1986, Mattson et al. 1987, McCarthy and Bailey 1994, Duvall and Grigal 1999, Idol et al. 2001, Currie and Nadelhoffer 2002). The reports ranged from 3 to 61 t/ac (7 to 137 Mg/ha) with a median of 11 t/ac (24 Mg/ha) and a mean of 15 t/ac (33 Mg/ha). Measurements of old forests (>80 years old), had a median of 11 t/ac (24 Mg/ha) and a mean of 13 t/ac (29 Mg/ha) in DWM.

In contrast, a study of U.S. Forest Service inventory plots found a mean of 3.7 t/ac (8.3 Mg/ha) and a median of 2.9 t/ac (6.5 Mg/ha) of DWM across 229 plots in the Northeast (Chojnacky et al. 2004 see Figure 2). This low level of DWM across the landscape may be due to widespread clearcutting in the 1880-1930 periods.

**Implications for Massachusetts Policies:** The amount of dead wood varies across forest types and stand ages. In order to determine appropriate benchmarks that correlate with forest health, more data by stand and age is required than current research provides. However, we find there is sufficient data to construct some initial, but likely conservative, guidelines. These are detailed in the Forest Guild's Biomass Retention and Harvesting Guidelines and summarized in Section 4.5.2 of this report.

### 4.2.2.5 SOILS AND PRODUCTIVITY ISSUES BY FOREST TYPE

*Northern Hardwood Forests*: In general, the amount of DWM in Northern hardwood forests follows the 'U' pattern mentioned above. Young stands have large quantities of DWM (usually due to a harvest); mature stands have less; older or uncut stands have more. For example, a study in New Hampshire measured 38 t/ac (86 Mg/ha) of DWM in a young stand, 14 t/ac (32 Mg/ha) in mature stands, 20 t/ac (54 Mg/ha) in old stand, and 19 t/ac (42 Mg/ha) in an uncut stand (Gore and Patterson 1986). Gore and Patterson (1986) also note that stands under a selection system had lower quantities of DWM, i.e., 16 t/ac (35 Mg/ha). A review of other studies identified similar temporal patterns and quantities of DWM (Roskoski 1977, Gore and Patterson 1986, McCarthy and Bailey 1994, McGee et al. 1999, Bradford et al. 2009).

Estimates of the volume of down dead wood in Maine's northern hardwood forests are 598 ft$^3$/ac (42 m$^3$/ha) or 9 t/ac (20.5 Mg/ha) (Heath and Chojnacky 2001). Keeton (2006) estimates a volume of 600 ft$^3$/ac (42 m$^3$/ha) of DWM in a multi-aged northern hardwood forest.

*Transitional Hardwoods*: As with the other forest types discussed, DWM density tends to follow a 'U' shape in oak-hickory forests. For example, Idol and colleagues (2001) found 61 t/ac (137 Mg/ha) in a one-year post-harvest stand, 18 t/ac (40 Mg/ha) in a 31–year-old stand, and 26 t/ac (59 Mg/ha) in a 100-year-old stand. Tritton and colleagues (1987) measured 5.8 t/ac (13 Mg/ha) in an 80-year-old stand in Connecticut.

Estimates of the volume of down dead wood in Maine's oak-hickory forests are 244 ft$^3$/ac (17 m$^3$/ha) or 0.7 (1.5 Mg/ha) (Heath and Chojnacky 2001). Wilson and McComb (2005) estimated the volume of downed logs in a western Massachusetts forest at 143 ft3/ac (10 m$^3$/ha).

A study in Appalachian oak-hickory forests showed that the decomposing residues left after a saw log harvest increased concentration of Ca, potassium (K), and magnesium in foliage and soils after 15 years in comparison to a whole-tree harvest (Johnson and Todd 1998). However, the study found no impacts on soil carbon, vegetation biomass, species composition, vegetation N or P concentration, soil bulk density, or soil N because of the whole-tree harvest (Johnson and Todd 1998).'

*White Pine and Red Pine Forests*: Estimates of the volume of down dead wood in Maine's pine forests are 255 ft3/ac (18 m$^3$/ha) or 1.6 t/ac (3.5 Mg/ha) (Heath and Chojnacky 2001). A review of research on DWM in the red pine forests of the Great Lakes area showed that there were 50 t/ac (113 Mg/ha) of DWM in an unmanaged forest at stand initiation and 4.5 t/ac (10 Mg/ha) in a 90-year-old stand (Duvall and Grigal 1999). In comparison, the managed stand Duvall and Grigal (1999) studied had less DWM at both initiation 8.9 t/ac (20 Mg/ha) and at 90 years 2.9 t/ac (6.6 Mg/ha). The same review showed the unmanaged stand had 30 snags per ac (74 per ha) while the managed forest had 6.9 per ac (17 per ha) (Duvall and Grigal 1999). Red and white pine that fall to the ground at time of death will become substantially decayed (decay class IV of V) within 60 years (Vanderwel et al. 2006).

While not a recognized forest type, stands with a mix of oak, other hardwoods, white pine, and hemlock are common. Many of the red oak and white pine stands on sandy outwash sites are susceptible to nutrient losses because of a combination of low-nutrient capital and past nutrient depletion (Hallett and Hornbeck 2000).

**Implications for Massachusetts Policies:** The amount of DWM and natural patterns of decay and soil replenishment vary by forest type in unmanaged stands. Ideally, DWM retention targets would also vary by forest type; but presently there are not enough data across forest types and ages to set specific targets. The Forest Guild Retention and Harvesting Guidelines for the Northeast include examples of DWM ranges by forest types.

**Exhibit 4.1: DWM Ranges by Forest Type**

| | Northern HW | Spruce-Fir | Oak-Hickory | White and Red Pine |
|---|---|---|---|---|
| Tons of DWM per acre* | 8–16 | 5–20 | 6–18 | 2–50 |

**Includes existing DWM and additional material left during harvesting to meet this target measured in dry tons per acre.*

The Forest Guild's guidelines also include general targets for retaining logging residues to protect soil nutrient capital. Over time, Massachusetts and other state guidelines may be able to hone in on specific targets by forest type.

### 4.2.2.6 IMPACTS FROM CHANGING HARVESTING TECHNOLOGY CAUSED BY INCREASED BIOMASS HARVESTING

All harvesting practices disturb forest sites, but the overall impact on soil structure and nutrients depends on the site, operator skill, and conditions of operation. A comprehensive study of site impacts in Maine (Benjamin 2010) reviewed the literature regarding soil compaction and erosion from logging. A comparison of nine related studies (Martin, 1988) concluded "the percentage of disturbance per area has increased over time with changes in equipment (tracked to wheeled machines, chain saws to harvesters) and harvest methods (partial cuts to clearcuts to whole-tree clearcuts)." However, the research also suggests that biomass harvesting will not contribute to or create additional physical impacts on the soil productivity as compared to conventional harvesting as long as BMPs are followed (Shepard 2006)

The supply scenarios developed in the Chapter 3 Forest Biomass Supply analysis indicate that "if biomass demand increases due to the expansion of electric power plants, it will almost certainly be accompanied by increases in whole-tree harvesting due to the limited supply of other forest biomass and the cost advantages of whole-tree methods." The concerns for physical soil structure and erosion revolve around the equipment that will likely be introduced on harvesting operations. Whole-tree harvesting systems come in a variety of designs that rely on different pieces of equipment. In Massachusetts, the most common whole-tree logging systems employ a feller/buncher, one or more grapple skidders, and some kind of loader at the landing. This equipment can be larger and heavier than traditional harvesting equipment and has the potential to magnify adverse effects on soil. Also, many biomass harvests use a two-pass system in which one piece of equipment cuts trees and stacks them and another piece eventually picks them up for transportation to the landing. Repeated equipment passes can cause greater degrees of soil compaction, resulting in increased soil strength, which can (1) slow root penetration and reduce the regeneration and tree growth (Greacen and Sands, 1980; Miller et al., 1996); and (2) reduce soil infiltration rates, thereby increasing the potential for erosion through changes in landscape hydrology (Harr et al.1979).

The extent of impacts on soil properties and site productivity will depend on the degree current best management practices (BMPs) and new guidelines are followed. Current BMPs include fundamental approaches that apply to biomass harvests as well as traditional harvests. They include anticipating site conditions, controlling water flow and minimizing and stabilizing exposed mineral soil. These guidelines should be re-emphasized and implemented in biomass harvests. Additional guidelines related to the retention and use of woody biomass will be helpful especially on skid trails and stream approaches. For example, research shows that spreading tops and limbs along skid trails and other operating areas and driving the equipment on this buffer can reduce soil impacts. In order to have this material available for these purposes it must be retained in place or brought back to the operating area. There are competing values of biomass that pit the desire to remove the material as a renewable fuel and to mitigate the global effects of climate change on forest ecology versus its onsite ecological benefits.

## 4.2.3 IMPACTS ON HABITAT AND BIODIVERSITY

Increasing harvests to include greater biomass removal will have two primary effects on habitat and biodiversity. First, a greater volume of wood will be removed from many harvest operations to meet the biomass demand. This will initially result in a more open residual stand than would have occurred otherwise and can range from stands with slightly lower residual stocking all the way to clearcuts. Habitat will change on individual parcels providing opportunities for new species and eliminating them for others. The other potential impact is on dead wood. Both standing snags and fallen logs (DWM) are important habitat features for many forest species. Dead wood is a part of a healthy forest. Forests that are intensively managed for forest products may eliminate important dead and dying structural components which could result in a lack of habitat and species on those managed landscapes. To ensure forest health for biodiversity, safeguards will be needed to ensure that dead wood remains a component of the forest ecosystem.

### 4.2.3.1 DWM: WILDLIFE AND BIODIVERSITY

Dead wood is a central element of wildlife habitat in forests (Freedman et al. 1996). Many forest floor vertebrates have benefited or depended on DWM (Butts and McComb 2000). In New England, De Graaf and colleagues (1992) catalogued at least 40 species that rely on DWM.

Some examples from the Northeast of relationships between animals and DWM include a study showing that low densities of highly decayed logs (less than one highly decayed log/ha ) had a negative impact on red-back voles (*Clethrionomys gapperi*) in a northern hardwoods forest in New Brunswick, Canada (Bowman et al. 2000). DWM retention increased spotted salamander (*Ambystoma maculatum*) populations in a Maine study (Patrick et al. 2006).

In aquatic environments, DWM provides a crucial refuge from predation (Angermeier and Karr 1984, Everett and Ruiz 1993). Logs that fall in the water formed a critical component of aquatic habitat by ponding water, aerating streams, and storing sediments (Gurnell et al. 1995, Sass 2009). In fact, removal of large woody material from streams and rivers had an overwhelming and detrimental effect on salmonids (Mellina and Hinch 2009).

DWM is a key element in maintaining habitat for saproxylic (live and feed on dead wood) insects (Grove 2002). For example, some specialist litter-dwelling fauna that depend on DWM appear to have been extirpated from some managed forests (Kappes et al. 2009). Extensive removal of DWM could reduce species richness of ground-active beetles at a local scale (Gunnarsson et al. 2004). More generally, a minimum of 286 $ft^3$/ac (20 $m^3$/ha) of DWM has been suggested to protect litter-dwelling fauna in Europe (Kappes et al. 2009).

Dead logs serve as a seedbed for tree and plant species (McGee 2001, Weaver et al. 2009). Slash could be beneficial to seedling regeneration after harvest (Grisez, McInnis and Roberts 1994). Fungi, mosses, and liverworts depend on dead wood for nutrients and moisture, and in turn, many trees are reliant on mutualistic relationships with ectomycorrhizal fungi (Hagan and Grove 1999, Åström et al. 2005). In general, small trees and branches host more species of fungus-per-volume unit than larger trees and logs; however, larger dead logs may be necessary to ensure the survival of specialized fungus species such as heart-rot agents (Kruys and Jonsson 1999, Bate et al. 2004).

**Implications for Massachusetts Policies:** It is clear that dead wood is a central contributor to biodiversity in our forests and that many species are dependent on sufficient quantities and sizes. This requires retention of DWM, standing cull trees and live trees that will eventually create these structures.

### 4.2.3.2 Habitat and Biodiversity Issues by Forest Type

*Northern Hardwood Forests*: The number of dead trees in five hemlock-yellow birch forests range from 16 to 45 per ac (40 to 112 per ha) or from 3 to14% of the basal area (Tritton and Siccama 1990). The 14 sugar maple-beech-yellow birch stands survey ranged from 14 to 99 dead trees per ac (35 to 245 per ha) or 5 to 34% of basal area (Tritton and Siccama 1990). Other estimates of snag densities in northern hardwood forests include 5 per ac (11 per ha) (Kenefic and Nyland 2007), 15 per ac (38 per ha) (Goodburn and Lorimer 1998), and 17 per ac (43 per ha) (McGee et al. 1999).

The number of cavity trees is another important habitat element in northern hardwood forests that is reduced by harvest. For example, studies in northern hardwood forests have shown a reduction from 25 cavity tree per acre (62 per ha) before harvest and to 11 (27 per ha) afterward (Kenefic and Nyland 2007). Another study measured 7 cavity trees per ac (18 per ha) in old growth, 4 per ac (11 per ha) in even-aged stand, and 5 per ac (13 per ha) in a stand in selection system (Goodburn and Lorimer 1998).

*Transitional Hardwoods*: Out of seven oak stands in Connecticut, the number of dead trees ranged from 19 to 44 per ac (46 to 109 per ha) or 5 to 15% of basal area (Tritton and Siccama 1990). The decadal fall rates of snags in a Massachusetts study varied from 52 to 82% (Wilson and McComb 2005). Snags, particularly large-diameter snags, provide important nesting and foraging sites for birds (Brawn et al. 1982, Gunn and Hagan 2000). In general, wildlife habitat requirements for dead wood are poorly documented, but it is clear that some wildlife species rely on dead wood in oak-hickory forests (Kluyver 1961, DeGraaf et al. 1992).

**Implications for Massachusetts Policies:** The number of standing dead trees varies by forest type in unmanaged stands. Ideally, biomass retention targets would also vary by forest type; but presently there are not enough data across forest types and ages to set specific targets for standing dead trees by forest type. The Forest Guild Retention and Harvesting Guidelines for the Northeast include guidelines with targets for retaining standing live and dead trees that are general for all forest types in Massachusetts. Over time Massachusetts and other state guidelines may be able to hone in on specific targets by forest type.

## 4.3 LESSONS FROM OTHER INITIATIVES: PROTECTING STAND LEVEL ECOLOGICAL VALUES THROUGH BIOMASS HARVEST GUIDELINES

States from Maine to Missouri, Canada, and some European countries have addressed or are addressing stand-level ecological concerns by developing guidelines for harvesting woody biomass from forests. To inform the Massachusetts process, we have expanded on the Forest Guild's report *An Assessment of Biomass Harvesting Guidelines* to provide updates, include additional states in New England, and give a thorough assessment of northern European initiatives. This section begins with an overview of the Guild report highlighting key points relevant to Massachusetts. It concludes with a brief review of the harvesting regulations and BMPs in Massachusetts and the gaps in those directives that indicate that a new set of guidelines is needed.

### 4.3.1 OVERVIEW OF REGULATORY FRAMEWORKS

In the U.S., forestry on private and state lands is regulated primarily at the state level. At least 276 state agencies across the country have some oversight of forestry activities, including agencies focused on forestry and others concerned with wildlife or environment protection policies (Ellefson et al. 2006). All 50 states have BMPs. In general, BMPs originally focused on water quality and did not anticipate the increased removal of biomass. Consequently, BMPs historically have offered little or no specific guidance on the amount of removal that is healthy for ecosystems or how much biomass should be retained. However, this situation is changing. Pennsylvania's old BMPs encouraged operators "to use as much of the harvested wood as possible to minimize debris," while more recent guidelines recommend leaving "15 to 30% of harvestable biomass as coarse woody debris."

Woody biomass is usually considered to be logging slash, small-diameter trees, tops, limbs, or trees that cannot be sold as higher-value products. Depending upon prevailing market conditions, however, material meeting pulp or pallet specifications may also be used in biomass energy facilities. Reasons for biomass harvesting guidelines are likely to mirror the reasons forestry is regulated in general, which include (Ellefson and Cheng 1994):

- general public anxiety over environmental protection,
- the obligation to correct misapplied forestry practices,
- the need for greater accountability,
- growth of local ordinances,
- landscape-level concerns, and
- following the lead of others.

Biomass harvesting guidelines are designed to fill the gaps where existing BMPs may not be sufficient to protect forest resources under new biomass harvesting regimes. In other words, BMPs were developed to address forest management issues at a particular point in time; as new issues emerge, new guidelines may be necessary. State BMP manuals usually include sections on timber harvesting, site preparation, reforestation, stream crossings, riparian management zones, prescribed burning and fire lines, road construction and maintenance, pesticides and fertilizers, and wetlands. These programs are routinely monitored, and literature suggests that when these BMPs are properly implemented they do protect water quality (Shepard, 2006).

U.S. federal law requires states to address non-point source pollution of waterways. State programs vary with some states prescribing mandatory practices while others rely on voluntary BMPs and education and outreach programs. These programs can be categorized in three ways: non-regulatory with enforcement, regulatory, and combination of regulatory and non-regulatory. In the Northeast, Massachusetts and Connecticut are considered regulated; Vermont and New Hampshire are non-regulated with enforcement; and Rhode Island, New York, and Maine use a combination of approaches.

Over time BMPs for water quality have expanded to include aesthetics, wildlife, and other resources. A survey in 2000 noted that nine states had extended their BMPs in such fashion, three of those from the Northeast (NASF Edwards and Stuart). This indicates a precedent for expanding BMPs to include issues such as increased biomass harvesting. In fact, some of the BMPs developed for water quality and conventional forestry already contain guidelines that would serve to protect water quality during increased biomass harvests. When these guidelines were developed, however, they were designed to specifically and solely address the issue of water pollution. Full implementation of these guidelines is necessary for protection of water quality. As harvests become more intense, other ecological issues, such as soil nutrient protection and wildlife habitat, come into play; previous BMPs likely do not account for them.

Although in many cases BMPs are voluntary, water pollution control requirements are not, and therefore landowners are compelled by law to adopt water quality BMPs to avoid legal penalties. This may explain the relatively high rates reported for national compliance (86%) and in the Northeast (82%) (Edwards 2002). Biomass harvesting standards must address several management criteria such as protection and maintenance of forest structure for wildlife habitat, soil nutrient protection, and forest-stand productivity. These criteria, unlike those for water quality, typically have no legal foundation to compel compliance.

The recently updated Forest Guild report, *An Assessment of Biomass Harvesting Guidelines*, reviews the biomass harvesting or retention guidelines from New York and New England, other states with specific biomass guidance, parts of Canada, northern European counties, and other organizations including the U.S. federal government and certification groups. We have grouped New York and the New England states together to offer a snapshot of the current situation in states geographically near Massachusetts. Maryland, Minnesota, Missouri, Michigan, Pennsylvania, Wisconsin, and California are also covered because of their forest practices guidance on biomass harvest and retention.

Entities interested in addressing concerns about biomass removal have taken at least three different approaches. One is to verify that existing forest practice regulations cover the issues raised by biomass harvests, obviating the need for new guidelines. Second, in instances where existing rules or recommendations are found to be insufficient, some entities—including Minnesota, Missouri, Pennsylvania, Wisconsin, and Maine—have taken a different approach and chosen to craft separate biomass guidelines that augment existing forest practice guidance. In the third case, standards-setting entities, such as the Forest Stewardship Council (FSC), have chosen to address concerns particular to biomass harvests in a revision of existing rules or recommendations. The examples in this report detail the status of rules and recommendations for removing biomass from forests.

The existing guidelines cover topics such as dead wood, wildlife and biodiversity, water quality and riparian zones, soil productivity, silviculture, and disturbance. *An Assessment of Biomass Harvesting Guidelines* lists the commonly used subtopics for each and identifies which are covered in a given set of guidelines. In some cases, a subtopic is noted as covered because it appears in another set of forestry practice rules or recommendations instead of that state's biomass guidelines. The list of subtopics was developed from section headings of the existing guidelines and is similar to other criteria for sustainable production and harvest of forest biomass for energy (Lattimore et al. 2009).

### 4.3.2 KEY FINDINGS FROM *AN ASSESSMENT OF BIOMASS HARVESTING GUIDELINES (REVISED)*

*An Assessment of Biomass Harvesting Guidelines* reveals a number of approaches to the development of biomass guidelines that provide useful insights for Massachusetts. While not necessarily directly applicable to the ecological conditions in Massachusetts, these approaches illustrate the general types of measures that have been adopted by other states and government entities. Three important questions are addressed:

**Do other guidelines offer specific targets backed by scientific research, or are they more general and open to further interpretation?**

The ability to assure the public that sustainable forestry is being practiced is often confounded by vagueness and generalities in forestry BMPs or guidelines. Foresters are leery of prescribing targets that are expected to be carried out on every acre of forestland. Each forest stand is subject to different ecological factors, historical trends, disturbance patterns, landscape context, and management intent and should be treated as unique. Despite these difficulties, it is important for the profession to define targets and a system of monitoring to win public confidence and retain what has been called a "social contract" to practice forestry. The struggle between the need to set specific measurable targets and the realities of on-the-ground forestry is now being played out as states and others entities attempt to set biomass harvesting guidelines.

In Maine, the earlier drafts of voluntary guidelines provided specific numeric targets, but the final version is more general (Benjamin 2010). Although background materials refer to specific targets recommended in an important multi-stakeholder report on biodiversity in Maine, targets were not incorporated in the final draft. The final guidelines call for leaving "some wildlife trees" without incorporating the numbers of trees per acre suggested in the report. Also, these guidelines call for leaving "as much fine woody material as possible" without specific requirements for top retention found in other states. Similarly, the Forest Stewardship Council's standards for the U.S. require the maintenance of habitat structure and well-distributed DWM, but are not specific about the amount that should be left on site.

**How do other guidelines address the concern over the depletion of soil nutrients?**

As noted above, some biomass harvest guidelines call for sufficient material to be retained to protect ecological functions such as soil nutrient cycles but offer no targets. A number of guideline documents, however, do offer targets in this category. The following is a sampling of the various ways retention of DWM has been approached.

- **Alabama**: Enough logging slash should be left and scattered across the area to maintain site productivity.
- **Maine**: Where possible and practical retain and scatter tops and branches across the harvest area.
- **Michigan**: retention of 17% to 33% of the residue less than four inches in diameter.
- **Minnesota**: tops and limbs from 20% of trees harvested.
- **Missouri**: 33% of harvest residue.
- **New Hampshire**: "Use bole-only harvesting (leaving branches and limbs in the woods) on low-fertility soils, or where fertility is unknown."
- **Pennsylvania**: 15 to 30% of "harvestable biomass."
- **Wisconsin**: tops and limbs from 10% of the trees in the general harvest area with a goal of at least 5 tons of FWM per acre.
- **Sweden**: 20% of all slash must be left on site.
- **Finland**: 30% of residues should remain and be distributed evenly over the site.

**How do other guidelines address the concern over retention of forest structure and wildlife habitat?**

The literature confirms that forest structure is important for wildlife habitat. Existing BMPs and new biomass harvesting guidelines use both general and specific approaches to address this issue. The following samples provide a snapshot of the range of approaches.

- **Maine**: leave some wildlife trees; retain live cavity trees on site; vary the amount of snags, down logs and wildlife trees; and leave as much FWM as possible.
- **New Hampshire**: Under uneven-aged management, retain a minimum of 6 secure cavity and/or cavity trees per acre with one exceeding 18 inches diameter at breast height (DBH) and 3 exceeding 12 inches DBH.
- **California**: retain all snags except where specific safety, fire hazard, or disease conditions require they be felled.
- **Minnesota**: on non-clear cut sites, leave a minimum of 6 cavity trees, potential cavity trees, and/or snags per acre. Create at least 2-5 bark-on down logs greater than 12 inches in diameter per acre.

## 4.3.3 ADEQUACY OF MASSACHUSETTS BMPS FOR INCREASED BIOMASS HARVESTS

The situation in Massachusetts is very similar to that in other states: current regulations and guidelines were developed for protection of water quality and did not anticipate the intensification of biomass harvesting. In Massachusetts, current regulations require a cutting plan that describes the harvest and the approaches to mitigate water-quality problems such as erosion and sedimentation.

Current regulations and BMPs, however, do not direct silvicultural or harvesting activities to sustain all the ecological values that might be negatively affected by increased biomass harvesting. There are no retention rules or guidelines that would prevent the harvest of every cull tree or den tree on a property, a situation that could take place with or without an expanded biomass market. Similarly, there are no harvesting guidelines that would prevent the scouring of DWM. Our literature review reveals these activities have the potential to degrade wildlife habitat, biodiversity, and soil nutrient levels. In addition, the current cutting plan process does not require sound silvicultural practice and the ecological safeguards that these proven practices offer in comparison to undisciplined harvesting. Finally, the introduction of larger, heavier whole-tree harvesting equipment presents new challenges and opportunities. Larger equipment can damage forest soils through soil compaction and increase residual stem damage because of their size. However, in some cases, new forest equipment can reduce soil impacts because they can provide less pressure per inch and reduce stand damage because of their longer harvesting reach. In practice, some of these impacts are and will be mitigated through good decisions by landowners, foresters and loggers, and the influence of supervising foresters through the cutting plan process. In most situations, however, there are no regulatory or voluntary guidelines in place that compel compliance.

The assessment of guidelines in other states and countries reveals a number of additional approaches that can be tailored to state forest types and conditions to prevent ecological damage from biomass harvesting. We recommend that a similar set of guidelines be developed in Massachusetts and integrated into the cutting plan process. The newly developed *Forest Guild Biomass Retention and Harvesting Guidelines* for the Northeast utilize the best thinking and approaches from other states to develop a set of guidelines for northeastern forest types. These should be directly applicable to Massachusetts and provide a starting point for developing guidelines tailored to the regional ecology and forest types of the Commonwealth.

## 4.4 FOREST SUSTAINABILITY INDICATORS AND LANDSCAPE LEVEL EFFECTS OF BIOMASS HARVESTING

### 4.4.1 INTRODUCTION

Beyond stand-level impacts, biomass harvesting has the potential to affect the provision of a broad suite of ecosystem services at larger regional or statewide scales. In this context, we are adopting the ecosystem services definitions used in the recent Forest Futures Visioning Process conducted by the Massachusetts Department of Conservation and Recreation (DCR). These include ecological, socio-economic and cultural values provided by forests—essentially the term ecosystem services refers to all the public and private values provided by our forests. The sustainability of this broad suite of ecosystem services across the landscape is not primarily a scientific problem; instead it involves balancing a complex set of public values that go far beyond simply ensuring that biomass harvests leave a well-functioning ecosystem in place on harvested sites.

Landscape ecological processes operate at varying spatial scales (e.g., across multiple stands, within a watershed, or an entire ecoregion). In the case of forests, the spatial arrangement and relative amounts of cover types and age classes become the ecological drivers on the landscape. The two most relevant ecological processes of interest in Massachusetts' forests include facilitating or blocking movement of organisms and loss of "interior" habitat because of smaller patch sizes. Pure habitat loss is not necessarily a landscape ecological issue until it reaches a threshold where it influences the spatial pattern of habitats. At that time, which will vary by species, the spatial pattern can drive impacts beyond the effects of pure habitat loss. For most species (including plants, invertebrates, and vertebrates), we do not know where this threshold exists (Andren 1994, Fahrig 2003, Lindenmeyer & Fischer 2006). In the discussion below, effects at the "landscape scale" generally refer to loss of habitat at different scales (e.g., watershed, statewide) and we do not attempt to address ecological processes that are influenced by the spatial arrangement of habitats.

The wood supply analysis in Chapter 3 suggests that absent very significant changes in energy prices, we do not expect dramatic increases over the next 15 years in harvest acreage across the state. But that analysis is really focused on overall supplies, and has not attempted to define more localized spatial impacts of these harvests. Moreover, although we do not foresee major changes in electricity pricing that would provide incentives for much heavier harvests, we cannot rule out such an occurrence in the event of a major energy price shock or a change in energy policies that significantly raises long-term prices. Consequently, for any specific bioenergy facility, we cannot rule out that forest impacts are potentially more dramatic within the "wood basket" of the facility than would occur on average across forests in the state. Such localized, wood basket effects could take the form of rapid reduction or change in the quality of forest cover if many landowners respond to the demand from a new biomass facility by cutting more heavily on acres they would have harvested for timber anyway or by increasing the acreage they decide to harvest. From the ecosystem services perspective, such an increase in cutting could have a variety of effects. First, if enough landowners decide to conduct relatively heavy biomass harvests, we might see a reduction in older forest habitat and a shift to plant and animal species that prefer younger forests. Second, heavier or geographically concentrated cutting by private landowners could have broad aesthetic impacts that might be unacceptable to the public, potentially having negative impacts on other ecosystem services like forest-based recreation or tourism. Third, at a regional scale, increased harvest area or intensity may have long-term implications for the local timber and wood products economy if stands are harvested in a manner that results in a reduction in long-term supplies of high-quality timber. These various effects are discussed below in greater detail.

### 4.4.2 POTENTIAL ECOLOGICAL IMPACTS OF BIOMASS HARVESTS

The ecological impacts from differing harvest scenarios can be considered at different scales. At the broadest scale—the forested land base of Massachusetts—a total harvest of 32,500 acres per year is approximately 1% of the total land base. This rate of harvest is unlikely to cause statewide ecological changes. The state's forestland is on a trajectory to be comprised of older age classes, and harvests on 32,500 acres will not alter that trajectory significantly other than to provide the opportunity to make small shifts toward younger successional forests. The harvest intensities predicted at the stand level are close to historical ranges, and the total volume of removal is far below growth rates. Other factors such as climate change, rapid land conversion, large-scale disturbance from insect, disease, or hurricanes could all play a cumulative role to cause landscape-wide ecological disturbance, but the harvest scenarios are not widespread enough to have this broad effect alone.

However, landowner response to increased demand from bioenergy facilities could create more significant changes at smaller landscape scales. It is possible that several adjacent landowners or a significant number of landowners in a watershed or viewshed independent of each other could all respond to biomass markets with regeneration cuts over a short time period. Although this cannot be ruled out, the historical trends and landowner attitudes predict otherwise. Historically, rising prices at local sawmills do not appear to have stimulated widespread harvests of sawtimber for parcels nearby. Varying landowner attitudes and goals for their properties apparently work at even the smaller scale to mitigate a mass movement in any one direction of harvest or management, and we expect this to hold for biomass markets as well.

The public's major landscape ecological concern focuses on wildlife habitat and the potential risks to individual or groups of species. The fact is, the abundance of any given species will wax and wane as forest age classes change and as those age classes shift across the landscape. The challenge, whether biomass harvesting becomes prevalent or not, is to make sure that no species declines to a level where it is at risk of being extirpated from the landscape as a result of forest harvesting. Once again, the number of different private landowners and varying nature of private landowner attitudes and behaviors serves to insulate forest landscapes from trends in harvesting strong enough to cause anything other than slight landscape scale changes in habitat or species composition.

Wildlife habitat could potentially be affected at smaller landscape scales (such as a watershed) if many landowners in the wood basket of a power plant suddenly change their historical cutting patterns. If clearcutting or acceleration of regeneration harvests in even-aged stands are used, this could create a loss of mature, interior habitat (depending on the spatial level of harvesting) and species associated with that habitat. Although these species would likely shift elsewhere and still maintain viable populations across broader landscape scales, they might not exist in certain sub-regions for periods of time. Our scenarios do not predict broad-scale clear cutting, and it is more likely that habitat could be affected by practices that are more acceptable to landowners such as more intensive thinnings. One possible scenario for landowners would be to use the new markets for biomass to combine a partial thinning of the dominant trees with a low thinning to remove understory vegetation. If poorly managed, these practices could eliminate certain structural layers from the forest or deplete the forest of the dead and dying material necessary for certain species. The importance of dead wood has been covered elsewhere in the report. The lower forest structure provides important habitat as well. For example birds, particularly long-distance migrants prefer stands with an understory component (Nemi and Hanowski 1984, DeGraaf et al 1998).

In order to gauge the effect that increased biomass harvesting could have on the amount of habitat at the landscape scale, it is instructive to consider neighboring regions. Maine and New Hampshire have a longer history with markets for low-grade material and the introduction of whole tree harvesting and clearcutting for pulp and biomass. How well these landscapes have fared in an ecological sense depends on perspective. If one compares these landscapes to an old growth ideal, they fall resoundingly short. However, a recent review of the ecological literature (Jenkins 2008) for the Northern Forest region indicates the difficulty in quantifying landscape-wide ecological damage.

Jerry Jenkins, a scientist with the Wildlife Conservation Society, reviewed the scientific literature on ecological factors in the intensively managed Northern Forest region for the Open Space Institute. The subsequent report, *Conservation Easements and Biodiversity in the Northern Forest Region*, includes sections on Northern Forest biodiversity and the effects of logging on biodiversity. Although the conclusions of this review are debated in the Northern Forest region, his introduction is helpful in understanding the different perspectives in evaluating landscape ecology. The "pragmatic" approach is to maintain the biodiversity that exists at present. The "idealistic" approach is to restore the forest to a more natural state. Jenkins notes that the pragmatists point to the literature which suggests "there have been almost no losses of vertebrates or higher plants from the working forests and that overall levels of biodiversity in clearcuts and managed forests often exceed those of old, undisturbed forests." The idealists "see the working forest as a conservation failure, and while they grudgingly accept it has considerable biodiversity, they argue that it is the wrong kind." They draw on the general literature of biodiversity and landscape ecology to suggest that our current forests are fragile and impoverished or will become so when the "extinction debt" induced by dissection and fragmentation is finally "paid." These proponents however, have not able to come up with good lists of the species that have actually been lost from managed forests.

The history of the intensively managed industrial landscape of northern New England and New York is far different than Massachusetts. The low harvest rates of the last century have allowed the Massachusetts forests to mature. The current forest landscape of the state offers management possibilities for the pragmatist and the creation of old growth for the idealists. The lessons from the Northern Forest indicate that even in regions with much heavier harvesting the debate over the impacts of changing habitat patterns across the landscape continues unresolved. We can certainly expect this debate to continue in Massachusetts as we try to understand a dynamic and shifting land cover that is resilient but faces a number of pressures. While the number of landowners and their attitudes and behaviors seem to ameliorate the possibility of widespread harvests, there still remains the possibility of localized habitat loss within a watershed as well as stand-level effects. For this reason, in a concluding section we suggest a number of policy options that Massachusetts officials could consider if they wish to assure a greater degree of protection for these ecological values.

### 4.4.3 POTENTIAL IMPACTS OF BIOMASS HARVESTS ON LANDSCAPE AESTHETICS

The forests of Massachusetts play a number of supporting roles in the socio-economic framework. They are the predominant natural land type and form the backdrop for most communities and many economic enterprises, including tourism and recreation. The forest landscape is integral to the way of life of Massachusetts residents and shapes the image of Massachusetts for visitors and employers locating businesses there. Although historically these forests have been heavily cut, and at one time reduced to 20% of the landscape, the current perception is one of dense unmanaged forests covering most of the landscape. At the more localized or regional scale, biomass harvesting could potentially alter this forest landscape. The heavily harvested forest landscape of northern Maine is one extreme example of what a forested landscape can look like when subject to available markets for low-grade material and landowners willing to harvest using clearcutting and short rotations. From the level of public reaction and media attention paid to clearcutting on public lands in the past, it is expected that broad scale clearcutting on private lands would likely have severe socio-economic impacts for Massachusetts.

While the harvest scenarios do not anticipate broad scale clearcutting, reactions to aesthetic landscape changes are difficult to quantify. The view-shed of most forested areas of Massachusetts now consists of rolling acres of consistent overstory. Even a small amount of clearcutting, consistently repeated across the landscape would dramatically alter these views and probably create a different and negative reaction from tourists or residents. Therefore, any significant increase in clearcutting methods as a form of forest management could have potentially dramatic impacts on recreation and tourism and face significant challenges from residents accustomed to a maturing forest. The quantification of these effects is beyond the scope of this study.

Fortunately, alternative forms of forest management are available including uneven-aged management that maintains a continuous overstory, and forms of even-aged management that delay final harvests until sizable regeneration has occurred. These alternative methods would mitigate the landscape-scale aesthetic effects on tourism and recreation and likely be more acceptable to residents.

### 4.4.4 POTENTIAL IMPACTS OF BIOMASS HARVESTING ON ECONOMIC PRODUCTIVITY OF FORESTS

Massachusetts forests have historically supported a vibrant forest products industry that has declined dramatically in the last two decades. Although harvest rates of sawtimber remain steady, the number of Massachusetts sawmills and wood product businesses has declined. More of the current harvest leaves the state for processing. The future of this industry is directly connected to a continuing availability of high-quality forest products. The growth and harvest of these higher-quality forest products could be either enhanced or diminished by increased biomass harvesting.

As demand and price for biomass rises, the number and choice of trees removed in harvests change. Trees that previously had no value and were left behind can now be removed profitably or at no cost. We expect that increased demand for biomass will lead to the introduction of whole-tree harvesting equipment on a wider scale, which will enable smaller trees to be harvested more economically. One positive effect of these new markets is to make it possible for foresters to remove portions of the stand that have little future economic value and thus provide growing space for trees with better potential. Without a biomass market, such improvement operations cost money and are typically not possible to perform.

However, new biomass markets may cause the harvest of trees that would eventually develop into valuable crop trees if left to grow. A straight, healthy 10" oak tree that would someday grow to be an 18" high-value veneer log might be removed too early in order to capture its much lower biomass value today. The misuse of low thinnings to remove biomass could also remove the future sawtimber crop as well as the forest structure referred to earlier. Whole tree harvesting equipment may make such removals more profitable, but these trees can also be added to the harvest in conventional operations that use skidders and chain saws. Whether these negative scenarios play out depends on whether the stand is managed with a silvicultural prescription, and that in turn depends on landowner intentions and state regulations for forest management.

### 4.4.5 EXISTING APPROACHES TO MANAGING LANDSCAPE LEVEL IMPACTS IN MASSACHUSETTS

Historically, Massachusetts has not had programs to manage silviculture and forest harvesting at the landscape (i.e., multi-owner) level. This may be a function of the historical fact that over the last century Massachusetts forests have been recovering from heavy harvesting and deforestation from a prior period when much of the landscape was in agricultural use. In addition, the statewide harvest has been limited in number of acres and intensity. The advent of increased biomass harvesting, the continued loss of forestland to development and the effects of climate change may change the perception of an expanding healthy forest and need for greater oversight of harvesting at the landscape level. While the state does limit the size of individual clearcuts and requires adequate regeneration from harvests and in some cases regulates harvesting in concern for endangered species, nothing in current regulations or guidance limits the ability of private landowners to independently decide to harvest their forests, even if this results in very heavy and rapid cutting in a relatively small area. Furthermore, under the existing regulations, it is theoretically possible for an individual landowner to legally harvest an entire standing forest within a relatively short timeframe (5–10 years) by using a combination of clearcutting and shelterwood harvests.[2]

There are many historical reasons why forest regulatory policy has been implemented at the stand level rather than the landscape level. The focus of existing regulations has generally been aimed at protecting *public* rather than *private* ecosystem services values. For example, BMPs came into existence to protect water quality, which is clearly an ecosystem service that affects the public good—either through off-site contamination of drinking water supplies or damage to public recreational resources. Proposed policies that assert control over ecosystem services that are viewed as purely private in nature have been much more controversial. The recent proposed changes to introduce better silviculture into the Forest Cutting Practices regulations are a case in point where the State Forestry Committee wrestled with these issues and ultimately agreed on an approach that would require sound silviculture practices across all harvests. The practice of silviculture was determined to be a public value and worthy of addressing in the cutting plans. But again, the only controls on forest harvesting now are at the stand level and focused on protecting values that are traditionally considered in the greater public's interest, such as clean water, rare species, adequate forest regeneration, and fire protection. Landscape aesthetics, for example, are not captured by any existing regulation. Voluntary programs, such as land

---

[2] Shelterwood harvest are heavier cuttings that are intended to regenerate the forest with seedlings but leave a sheltering mix of larger trees that are removed shortly after the regeneration is established.

purchases for conservation through land trusts and the state, have been the mechanism to achieve landscape objectives.

A second hypothesis for the lack of landscape-level forest management policies is a purely practical one. How such controls might be implemented is a difficult question. For example, what type of system would be put in place to decide who can harvest their land and when? Suppose a landowner needs short-term income for a medical emergency or college tuition. It will be difficult for the state to assume too much control over an individual's rights when a widely held public value is not being obviously compromised.

Finally, in the past 50 to 75 years, we generally have not had a forest landscape "problem" caused by over-cutting that the public believed needed to be addressed. Forests have been increasing in both area and wood volume for many years as abandoned farmland has returned to woodland. However, that trend may be changing as urbanization and other land-use changes begin to reduce the amount of forestland in the Eastern U.S. (Drummond and Loveland 2010).

From this discussion, it should be clear that the sustainability of ecosystem services at the landscape level raises a wide array of complex issues involving public values. Forest ecology and science can help inform decisions about the need for an approach to ensuring biomass harvests do not compromise ecosystem services at a landscape scale. But ultimately, public policy on this issue will be a value-based exercise. As a result, our recommendations on this issue, included in the final section of this chapter, focus on options that could be considered as part of a broader process of assessing public perceptions about what would be unacceptable impacts at the landscape level.

## 4.5 RECOMMENDATIONS FOR ADDRESSING STAND AND LANDSCAPE LEVEL IMPACTS OF INCREASED BIOMASS HARVESTING

### 4.5.1 STAND LEVEL RECOMMENDATIONS

The science underlying our understanding of the potential impacts posed by increased biomass harvests and the efficacy of policies to minimize these impacts is currently far from providing definitive guidance. While it is clear that DWM is fundamental to nutrient cycling and soil properties, there appears to be little or no consensus on the amount of woody debris that should be maintained. In fact, the literature generally suggests that minimum retention levels will differ based both on underlying site productivity as well as with the volume of material harvested and the anticipated amount of time the stand will have to recover before the next harvest. DWM is also essential for maintaining habitat and biodiversity; but again the scientific studies do not provide a definitive answer to the question of how much DWM should be left after a harvest. The impacts of logging equipment on soils are also likely to depend on site-specific conditions.

Fundamentally, in the face of imperfect scientific information, the choice of policies for protecting ecosystem functions at the stand level must factor in public values regarding how conservative biomass retention policies should be. In addition, it may be important to understand the public's views on the extent to which biomass standards should rely on voluntary or mandatory standards. This likely will depend on the extent to which the public believes the proposed harvest practices are needed to protect public versus private values.

In light of these considerations, Massachusetts may find it useful to utilize the State Forestry Committee to convene an appropriate public process to establish biomass harvesting retention and harvesting guidelines for Massachusetts. The scientific data we reviewed in Section 3 provide a starting point for these public discussions. One approach other states have used is to create a panel of experts from across the spectrum of forestry interests to come up with recommendations which are then reviewed and commented on by stakeholders. The revision of Chapter 132 regulations could easily fit this format by using the State Forestry Committee as the expert panel.

Embedded within our process recommendation is a second broad recommendation that the State Forestry Committee use the *Forest Guild's Forest Biomass Retention and Harvesting Guidelines* for the Northeast as a starting point for the substantive discussion of the options for ensuring biomass harvesting does not result in diminished ecosystem function at the stand level. The Forest Guild's proposed guidelines are readily adaptable to the Commonwealth and cover the major Massachusetts forest types. The Forest Guild Biomass working group consisted of 23 Forest Guild members representing field foresters, academic researchers, and members of the region's and country's major environmental organizations. The process was led by Forest Guild staff and was supported by the previously referenced reports *Ecology of Dead Wood* in the Northeast (Evans and Kelty 2010) and *An Assessment of Biomass Harvesting Guidelines* (Evans and Perschel 2009a).

Wherever possible the Forest Guild based its recommendations on peer-reviewed science. As noted above, however, in many cases available research was inadequate to connect practices, stand level outcomes, and ecological goals. Where this was the case, the Forest Guild relied on field observation and professional experience. The guidelines are meant to provide general guidance and where possible offer specific targets that are indicators of forest health and can be measured and monitored. They are not intended to be applied on every acre. Forests vary across the landscape due to site differences, natural disturbances, forest management, and landowner's goals. All of these elements need to be taken into consideration when applying the guidelines. These guidelines should be revisited frequently, perhaps on a three-year cycle, and altered as new scientific information and results of field implementation of the guidelines becomes available.

In the following section, the Forest Guild's stand-level recommendations for ensuring biomass harvests do not damage ecosystems are examined in. six major categories.

### 4.5.1.1 FOREST GUILD BIOMASS HARVEST GUIDELINES

**Site Considerations to Protect Rare Forests and Species**

Biomass harvests should be avoided in critically imperiled or imperiled forest types that can be determined through the State National Heritage Program. Biomass harvesting on sensitive sites may be appropriate to control invasive species, but they should only be done for restorative purposes and not to provide a long-term wood supply. Old-growth forest should be protected from harvesting. In Massachusetts, old growth exists exclusively on public lands.

**Retention of Coarse Woody Material**

A review of scientific literature reveals a limited number of studies that address the biomass and nutrient retention issue. Some studies suggest that biomass harvesting is unlikely to cause nutrient problems when both sensitive sites (including low-nutrient sites) and clearcutting and whole-tree harvesting are avoided. However, there is no scientific consensus on this point because of the wide array of treatments and types of sites that have not yet been studied. Given this lack of consensus, the Guild's recommendations adopt a conservative approach on this issue. They direct harvesting away from nutrient-limited sites. On sites with operable soils, we recommend that between 25% and 33% of tops and limbs be retained in harvests where 1/3 of the basal area is being removed on 15 to 20 year cycles. When harvests remove more trees or harvests are more frequent, greater retention of tops and limbs may be necessary. Similarly, where the nutrient capital is less rich or the nutrient status is unknown, greater retention of tops, branches, needles, and leaves is recommended. Conversely, if the harvest removes a lower percentage of basal area, if entries are less frequent, or if the site is known to have high nutrient levels, then fewer tops and limbs need to be left on site.

In Massachusetts it will be important to identify the soils where there are concerns regarding current nutrient status as well as those soils that could be degraded with repeated biomass harvests. Much of the current harvesting activity falls into the low-frequency and low-removal categories and will require lower levels of retention. It is difficult in most operations to remove all the tops and limbs even if the operator is attempting to do so. In these cases, the retention guidelines may not call for a significant change in operations. If whole-tree harvesting becomes more commonplace, the guidelines would become more important and the balance of acceptable retention and the frequency of harvests and removal intensities a greater issue. Whole-tree operations in some jurisdictions have dealt with retention targets for tops and limbs by cutting and leaving some whole trees that would otherwise have been designated for removal or transporting and scattering a certain percentage of the material back to the woodlot from the landing during return trips to remove additional material.

**Retention of Forest Structures for Wildlife and Biodiversity**

The Forest Guild recommends a number of approaches for retaining forest structure. All live decaying trees and dead standing trees greater than 10 inches should be left. In areas under even-aged management, we suggest leaving an uncut patch for every 10 acres of regeneration harvest, with patches totaling 5% to 15% of the area. These guidelines also call for maintaining vegetation layers (from the over-story canopy to the mid-story), shrub, and ground vegetation layers to benefit wildlife and plant species diversity. There are targets for retention of downed woody material by weight and forest type. In addition, there are specific targets by forest types for snags, cavity trees, and large downed logs.

In Massachusetts, there has been an awareness of the importance of forest structure for wildlife but no specific guidelines that broadly influence the retention of this material. The targets recommended here can be readily integrated into forest inventories, tree selection, and forest cutting plans.

**Water Quality and Riparian Zones**

In general, water quality and riparian concerns do not change with the addition of biomass removals. Massachusetts State BMPs currently cover these issues, and habitat management guidelines are available for additional protections for streams, vernal, pools, and other water bodies. These can be integrated into a set of guidelines tailored to Massachusetts.

**Silviculture and Harvesting Operations**

Most concerns about the operational aspects of biomass harvesting are very similar to all forestry operations. However, some key points are worth mentioning for Massachusetts forestlands:

- Integrate biomass harvesting with other forest operations to avoid re-entering a site and increasing site impacts such as soil compaction.
- Use low-impact logging techniques such as piling slash to protect soil from rutting and compaction.
- Use appropriate equipment matched to the silvicultural intention and the site.

**Forest Types**

Different forest types naturally develop different densities of snags, DWM, and large downed logs. Currently, available science leaves uncertainty around the exact retention targets for specific forest type and does not provide enough data to provide detailed guidance on each structure for every forest type. The Forest Guild guidelines, however, do discuss the relevant science that is available by forest type. Massachusetts can take that information and augment it with more localized research or prompt new research on specific topics. This information can be used to establish minimum retention targets for Massachusetts forest types. Wherever possible, targets should be exceeded as a buffer against the limitations of current research.

### 4.5.1.2 IMPROVED SILVICULTURAL REQUIREMENTS FOR FOREST ECOSYSTEM MANAGEMENT

Finally, we would like to note that Massachusetts has for a number of years been considering changes to the forest cutting plan regulations. In our view, putting these improved silvicultural guidelines in place, while not directly aimed at biomass harvests, will provide greater assurance that Massachusetts forests are managed to maintain ecosystem functions at the stand level. The remainder of this section discusses the current regulatory context and the changes that have been proposed.

### Existing Regulatory Framework

Regulations for harvesting forest growth in Massachusetts are guided by intent to promote sound forestry practices and the maintenance of the health and productivity of the forest base. The licensing of foresters in Massachusetts is a recognition of their unique professional education, skills, and experience to practice forestry. One of the keystones of forestry is the practice of silviculture, the art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis. Therefore, the argument has been made that all harvesting in the state should adhere to an acceptable form of silviculture and be performed by a licensed professional forester.

The state requires an approved harvesting plan for any harvest over 25,000 board feet. Any harvest is subject to oversight by Natural Heritage and Endangered Speices Program which imposes "life zones" around vernal pools and limits harvesting to certain months of the year in turtle habitat. But most harvested acres are ultimately subject only to requirements indicated in the state approved cutting plan for the property. Unfortunately, the current harvesting plan does not need to be filled out by a licensed forester, nor does it need to follow any accepted form of silvicultural practice.

On the cutting plan, landowners are offered a choice of long-term management and short-term management. A long-term management choice "employs the science and art of forestry." However, the short-term option does not and is characterized as follows:

> *Harvest of trees with the main intention of producing short-term income with minimum consideration given to improving the future forest condition ... [and] the selection of trees for cutting based on the economic value of individual trees which commonly results in a residual forest stand dominated by poor-quality trees and low-value species. While this strategy produces immediate income and meets the minimum standards of the act, it does little to improve the future condition of the forest.*

DCR takes the position that long-term management is the preferred option and warns that the short-term harvests retain slower-growing and poor-quality trees which can limit management options. Still, the short-term option is acceptable and used by 20% of current harvests. This means that aside from restrictions on some harvest areas through the Natural Heritage and Endangered Species Program the door remains open for virtually any kind of harvest as long as it protects water quality and assures adequate regeneration of some kind of tree species- a near certainty in Massachusetts forest conditions. The current system is not designed to assure protection and oversight of a number of ecological and socio-economic sustainability indicators that could be affected by increased biomass harvesting.

### Proposed Changes to the Cutting Plan Process

In 2006 the Massachusetts Forestry Committee ended a three-year process where regular public committee meetings were held to completely revise the Chapter 132 Forest Cutting Regulations. By statute, the Committee involves representatives from the key stakeholder interests, and each meeting included a number of public members from various stakeholder groups. The process also involved work in several sub-committees and data analysis from the DCR. The process ended in the spring of 2006 with the Committee completing its voting on a complete package of revisions to the Regulations. The result, supported by the majority of members, was forwarded to DCR in anticipation of public hearings on the Regulations.

Two of the proposed changes are directly related to ensuring that biomass harvesting protects ecological and socio economic values.

- A requirement that all forest cutting be based in silviculture, regardless of the owner's intent, and allowing state foresters to require that trees of high-timber quality be left distributed across the stand after thinning or intermediate cuttings.

- A requirement for marking all trees either to be cut or to be left, regardless of value or cost.

The committee was considering using the silvicultural requirement as a way of getting around opposition to a third suggestion that would mandate that only licensed foresters could fill out a harvesting plan. We recommend that when the Chapter 132 review process begins again, these proposed changes be resurrected in light of the interest in increasing the biomass harvest.

The requirement that all cutting plans be based on silviculture would help assure that biomass harvesting would be ecologically sound and aligned with the long-term economic productivity of the stand. In our view, the requirement for marking trees will also promote good silviculture and ecological practices. However, it may not be necessary in every case, and some flexibility should be considered. These changes would ensure the engagement of professional foresters, require that the harvest be silviculturally sound, and refine the decision making process for selecting trees for harvest by requiring the marking of trees in most cases.

## 4.5.2 LANDSCAPE LEVEL RECOMMENDATIONS

To determine the need for and nature of approaches to minimizing ecosystem service losses at the landscape-scale as a result of forest biomass harvests, we recommend a public process-based approach. A broad-based and legitimate public process is necessary for addressing landscape-scale impacts of biomass harvesting, particularly because the scientific literature has much less to offer at the landscape scale than it does at the stand level. A key driver of public concerns about diminished ecosystem services at the landscape level is uncertainty about the local and regional impacts of specific bioenergy facilities. Resolving these uncertainties requires gaining a better understanding of the spatial dimensions of harvests for specific proposed facilities. These uncertainties depend on facility size, wood demand, and the extent to which the facility relies on forest versus other biomass. Another uncertainty relates to future energy prices. While landowner reaction to price trends is difficult to predict with accuracy, the likelihood of increased harvests and the concern over landscape-scale impacts increases if policies result in greater use of bioenergy technologies that can afford to pay more for wood (e.g., thermal, CHP, cellulosic ethanol).

Uncertainty, however, will not be the only driver of public preferences. Equally important is how the public perceives and values possible impacts to competing ecosystem services (e.g., renewable energy production versus biodiversity across the landscape), and how risk averse the public is to potential negative impacts of biomass harvesting. Only through a legitimate public process will it be possible to gauge the public's desire for some landscape-level controls on biomass.

With these issues in mind, we have developed some options that could form the basis for a public dialogue on the need for and desirability of policies addressing landscape-scale impacts of biomass harvesting. These range from non-regulatory, information-based approaches to more stringent and enforceable regulatory processes. In general, it may be easier for an individual bioenergy facility to implement voluntary sustainable guidelines for the procurement of their biomass than for a state to implement the same sort of policies. Four possible options are discussed briefly below.

**Option 1: Establish a transparent self-monitoring, self-reporting process for bioenergy facilities that includes a commitment towards continual improvement.**

Bioenergy facilities could report their procurement status on a year-to-year basis. The report could include a report card that indicated where the supply came from according to a number of assurance criteria. Examples of these criteria can be found in the Forest Guild's A*ssurance of Sustainability in Working Forest Conservation Easements* and the Biomass Energy Resource Center's *Wood Fuel Procurement Strategies for the Harwood Union High School* report. Using a licensed forester or a management plan would be at one end of the assurance of sustainability spectrum. Compliance with the Forest Guild's biomass harvesting and retention guidelines might be in the middle of the spectrum and receiving supply from forest certified by FSC could be one of the highest assurances. Each year the facility would be expected to show improvement.

**Option 2: Require bioenergy facilities to purchase wood from forests with approved management plans**

If bioenergy facilities were allowed to purchase wood only from landowners with approved forest management plans approved by licensed foresters, there would exist a base level of assurance that biomass energy supplies would be harvested in a manner that would not result in damage, at least at the stand level. Vermont and New York require their biomass power producers to obtain their supply from forests with approved forest management plans. Such a requirement would be a start for Massachusetts facilities, but the harvests should also be certified as having been conducted under an acceptable set of biomass harvesting and retention guidelines. The Forest Guild guidelines or other state guidelines could be used where deemed sufficient, or enrollment in one of the existing forest certification programs that incorporate biomass retention guidelines could work as well.

One wood pellet manufacturer in New York State is supplied by 100% FSC-certified lands. Historically, certification has not been a practical option for a diverse, small forest-ownership land base such as Massachusetts. To the extent that aggregation of land ownerships into certification systems becomes more common, this may become feasible. In addition, the state has recently developed a new program that will allow small owners who seek Chapter 61 property tax exemption for their forest land to prepare "stewardship plans" that will automatically confer third-party certification status on their lands. The biomass facility would periodically report and be evaluated on the ecological and socioeconomic sustainability of the supply. This kind of transparent reporting has proven effective in the toxic waste sector and is applicable to biomass supply.

Another level of assurance is to require the biomass facilities that receive subsidies or incentives to monitor, verify, and report on the sustainability of their supply, including an annual geographic analysis of the facility's geographic wood basket. Some of the supply may come from other states; so the biomass facilities will need to account for supply not produced under the various safeguards that may be instituted in Massachusetts.

Overall, while these approaches improve the likelihood that bioenergy facilities are supporting good forestry practices, they may not be sufficient to fully protect against over harvesting at the local or regional scales.

**Option 3: Require bioenergy facilities to submit wood supply impact assessments**

This option would require that a facility submit information on its anticipated wood supply impacts as part of the facility siting and permitting process. The facility would identify the area from which it anticipates sourcing most of its forest biomass and would present information on the level of the cut across this region over the life of the facility. As conceived here, this is purely an informational requirement and would not be used as the basis for a positive or negative determination on a permit. But requiring information from a developer on the long-term impacts of their operation on wood supplies within the wood basket of the facility, may result in greater public accountability for the facility and a better understanding of the likely impact on forests. Similar informational programs, such as requiring manufacturing companies to submit information on toxic chemical use, have created positive incentives for improved environmental outcomes.

### Option 4: Establish formal criteria for approval of wood supply impact assessments

This option differs from Option 3 in that the state would establish criteria that would have to be met in order for a facility to receive approval for its wood supply impact assessment. For example, possible approval criteria might be based on limits on the amount of harvests relative to anticipated forest growth in the wood basket zone. These could take a variety of forms. For example, the state could require a demonstration that biomass harvests could be conducted without reducing future harvest levels in the wood basket zone (i.e., a non-declining even flow) or other types of limits on how much forest inventories in the wood basket could be reduced over the life of the facility. Once approved, the facility might also be required to submit annual comparisons of actual wood supplies with those included in the approved wood supply impact assessment. Measures could also be put in place requiring corrective actions to be taken by a facility if impacts exceed those anticipated in the impact assessment. Such an approach is more regulatory in nature and likely will be more expensive for facilities but it would give added assurance to the public that local and regional harvests would not diminish broader forest-based ecosystem services.

## REFERENCES

Andrén, H. 1994. Effects of Habitat Fragmentation on Birds and Mammals in Landscapes with Different Proportions of Suitable Habitat: A Review. Oikos 71:355-366

Angermeier, P. l., and J. r. Karr. 1984. Relationships between Woody Debris and Fish Habitat in a Small Warmwater Stream. *Transactions of the American Fisheries Society* 113(6):716-726.

Åström, M., M. Dynesius, K. Hylander, and C. Nilsson. 2005. Effects of Slash Harvest on Bryophytes and Vascular Plants in Southern Boreal Forest Clear-Cuts. *Journal of Applied Ecology* 42(6):1194-1202.

Bate, L. J., T. R. Torgersen, M. J. Wisdom, and E. O. Garton. 2004. Performance of Sampling Methods to Estimate Log Characteristics for Wildlife. *Forest Ecology and Management* 199(1):83-102.

Benjamin, J.G. Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine. Maine Agricultural and Forest Experiment Station, Orono, ME. Miscellaneous Publication 761

Bowman, J. C., D. Sleep, G. J. Forbes, and M. Edwards. 2000. The Association of Small Mammals with Coarse Woody Debris at Log and Stand Scales. *Forest Ecology and Management* 129(1-3):119-124.

Boyle, J. R., J. J. Phillips, and A. R. Ek. 1973. “Whole Tree” Harvesting: Nutrient Budget Evaluation. *Journal of Forestry* 71(12):760-762.

Bradford, J., P. Weishampel, M.-L. Smith, R. Kolka, R. A. Birdsey, S. V. Ollinger, and M. G. Ryan. 2009. Detrital Carbon Pools in Temperate Forests: Magnitude and Potential for Landscape-Scale Assessment. *Canadian Journal of Forest Research 39(4): 802–813 (2009) | doi:10.1139/X09-010.*

Brawn, J. D., W. H. Elder, and K. E. Evans. 1982. Winter Foraging by Cavity Nesting Birds in an Oak-Hickory Forest. *Wildlife Society Bulletin* 10(3):271-275.

Brin, A., C. Meredieu, D. Piou, H. Brustel, and H. Jactel. 2008. Changes in Quantitative Patterns of Dead Wood in Maritime Pine Plantations over Time. *Forest Ecology and Management* 256(5):913-921.

Butts, S. R., and W. C. McComb. 2000. Associations of Forest-Floor Vertebrates with Coarse Woody Debris in Managed Forests of Western Oregon. *The Journal of Wildlife Management* 64(1):95-104.

Campbell, J. L., C. T. Driscoll, C. Eagar, G. E. Likens, T. G. Siccama, C. E. Johnson, T. J. Fahey, S. P. Hamburg, R. T. Holmes, A. S. Bailey, and D. C. Buso. 2007. Long-term trends from ecosystem research at the Hubbard Brook Experimental Forest. GTR-NRS-17, U.S. Forest Service, Northern Research Station, Newtown Square, PA.

Campbell, L. J., and C. P. Laroque. 2007. Decay Progression and Classification in Two Old-Growth Forests in Atlantic Canada. *Forest Ecology and Management* 238(1-3):293-301.

Chojnacky, D. C., R. A. Mickler, L. S. Heath, and C. W. Woodall. 2004. Estimates of Down Woody Materials in Eastern Us Forests. *Environmental Management* 33:S44-S55.

Currie, W. S., and K. J. Nadelhoffer. 2002. The Imprint of Land-Use History: Patterns of Carbon and Nitrogen in Downed Woody Debris at the Harvard Forest. *Ecosystems* 5(5):446-460.

DeGraaf, R. M., J. B. Hestbeck, and M. Yamasaki. 1998. Associations between Breeding Bird Abundance and Stand Structure in the White Mountains, New Hampshire and Maine, USA. *Forest Ecology and Management* 103(2-3):217-233.

DeGraaf, R. M., M. Yamasaki, W. B. Leak, and J. W. Lanier. 1992. New England Wildlife: Management Forested Habitats. General Technical Report NE-144, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Drummond M.A.,and Loveland T.R. 2010. Land Use Pressure and a Transition to Forest Loss in the Eastern United States. *BioScience* 60(4):286-298

Duvall, M. D., and D. F. Grigal. 1999. Effects of Timber Harvesting on Coarse Woody Debris in Red Pine Forests across the Great Lakes States , USA. (29):1926-1934.

Edwards, P.J., and G.W. Stuart. 2002. State Survey of Silviculture Nonpoint Source Programs: A Comparison of the 2000 Northeastern and National Results. Northern Journal of Applied Forestry 19(3): 122-127

Ellefson, P. V., and A. S. Cheng. 1994. State Forest Practice Programs: Regulation of Private Forestry Comes of Age. *Journal of Forestry* 92:34-37.

Ellefson, P. V., M. A. Kilgore, and J. E. Granskog. 2006. State Government Regulation of Forestry Practices Applied to Nonfederal Forests: Extent and Intensity of Agency Involvement. *Journal of Forestry* 104:401-406.

Evans, A.M. 2008. Synthesis of Knowledge from Woody Biomass Removal Case Studies. Forest Guild. Santa Fe, NM.

Evans, A. M., and M. J. Kelty. 2010. The Ecology of Dead Wood in the Northeast. Forest Guild, Santa Fe, NM.

Evans, A. M., and G. McKinley. 2007. An Evaluation of Fuel Reduction Projects and the Healthy Forests Initiative. Forest Guild, Santa Fe, NM.

Evans, A. M., and R. T. Perschel. 2009a. An Assessment of Biomass Harvesting Guidelines. The Forest Guild, Santa Fe, NM.

Evans, A. M., and R. T. Perschel. 2009b. A Review of Forestry Mitigation and Adaptation Strategies in the Northeast U.S. *Climatic Change* 96(1-2):167-183.

Everett, R. A., and G. M. Ruiz. 1993. Coarse Woody Debris as a Refuge from Predation in Aquatic Communities. *Oecologia* 93(4):475-486.

Fahrig, L. 2003. Effects of Habitat Fragmentation on Biodiversity. Annual Review of Ecology, Evolution, and Systematics 34:487-515.

Federer, C. A., J. W. Hornbeck, L. M. Tritton, C. W. Martin, R. S. Pierce, and C. T. Smith. 1989. Long-Term Depletion of Calcium and Other Nutrients in Eastern Us Forests. *Environmental Management* 13(5):593-601.

Fraver, S., R. G. Wagner, and M. Day. 2002. Dynamics of Coarse Woody Debris Following Gap Harvesting in the Acadian Forest of Central Maine, U.S.A. *Canadian Journal of Forest Research* 32(12):2094-2105.

Freedman, B., V. Zelazny, D. Beaudette, T. Fleming, G. Johnson, S. Flemming, J. S. Gerrow, G. Forbes, and S. Woodley. 1996. Biodiversity Implications of Changes in the Quantity of Dead Organic Matter in Managed Forests. *Environmental Reviews* 4(3):238–265.

Ganjegunte, G. K., L. M. Condron, P. W. Clinton, M. R. Davis, and N. Mahieu. 2004. Decomposition and Nutrient Release from Radiata Pine (Pinus Radiata) Coarse Woody Debris. *Forest Ecology and Management* 187(2-3):197-211.

Goodburn, J. M., and C. G. Lorimer. 1998. Cavity Trees and Coarse Woody Debris in Old Growth and Managed Northern Hardwood Forests in Wisconsin and Michigan. *Canadian Journal of Forest Reseach* 28:427–438.

Gore, J. A., and W. A. Patterson, III,. 1986. Mass of Downed Wood in Northern Hardwood Forests in New Hampshire: Potential Effects of Forest Management. *Canadian Journal of Forest Research* 16(2):335-339.

Graham, R. L., and K. Cromack Jr. 1982. Mass, Nutrient Content, and Decay Rate of Dead Boles in Rain Forests of Olympic National Park. *Canadian Journal of Forest Research* 12(3):511–521.

Greenberg, C. H. 2002. Response of White-Footed Mice (Peromyscus Leucopus) to Coarse Woody Debris and Microsite Use in Southern Appalachian Treefall Gaps. *Forest Ecology and Management* 164(1-3):57-66.

Grigal, D. F. 2000. Effects of Extensive Forest Management on Soil Productivity. *Forest Ecology and Management* 138(1-3):167-185.

Grigal, D. F. 2004. An Update of Forest Soils. A Technical Paper for a Generic Environmental Impact Statement on Timber Harvesting and Forest Management in Minnesota. Laurentian Energy Agency, Virginia, MN.

Grisez, T. J. 1960. Slash Helps Protect Seedlings from Deer Browsing. *Journal of Forestry* 58(5):385-387.

Grove, S. J. 2002. Saproxylic Insect Ecology and the Sustainable Management of Forests. *Annual Review of Ecology and Systematics* 33(1):1-23.

Gunn, J.S., and J.M. Hagan. 2000. Woodpecker abundance and tree use in uneven-aged managed, and unmanaged, forest in northern Maine. *Forest Ecology and Management* 126:1-12.

Gunnarsson, B., K. Nittérus, and P. Wirdenäs. 2004. Effects of Logging Residue Removal on Ground-Active Beetles in Temperate Forests. *Forest Ecology and Management* 201(2-3):229-239.

Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. The Role of Coarse Woody Debris in Forest Aquatic Habitats: Implications for Management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5(2):143-166.

Hacker, J. J. 2005. Effects of Logging Residue Removal on Forest Sites: A Literature Review. Resource Analytics and West Central Wisconsin Regional Planning Commission, Eau Claire, WI.

Hagan, J. M., and S. L. Grove. 1999. Coarse Woody Debris: Humans and Nature Competing for Trees. *Journal of Forestry* 97(1):6-11.

Hallett, R. A., and J. W. Hornbeck. 2000. Managing Oak and Pine Stands on Outwash Sands: Protecting Plant Nutrients. *Northern Journal of Applied Forestry* 17(2):57-61.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack Jr., and K. W. Cummins. 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems Advances in Ecological Research. Pages 133-302 *in* A. MacFadyen and E. D. Ford, editors. *Advances in Ecological Research*. Academic Press, London, UK.

Harr, R., R.L. Fredrickson, J. Rothacker. 1979. Changes in Streamflow Following Timber Harvest in Southwestern Oregon. PNW-RP-249.Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Harvey, A. E., M. F. Jurgensen, M. J. Larsen, and R. T. Graham. 1987. Decaying Organic Materials and Soil Quality in the Inland Northwest: A Management Opportunity. GTR-INT-225, US Forest Service, Intermountain Research Station., Ogden, UT.

Heath, L. S., and D. C. Chojnacky. 2001. Down Dead Wood Statistics for Maine Timberlands, 1995. RB-NE-150, Forest Service, Northeastern Research Station, Newtown Square, PA.

Hendrickson, O. Q. 1988. Biomass and Nutrients in Regenerating Woody Vegetation Following Whole-Tree and Conventional Harvest in a Northern Mixed Forest. *Canadian Journal of Forest Research* 18(11):1427–1436.

Hornbeck, J. W., C. T. Smith, Q. W. Martin, L. M. Tritton, and R. S. Pierce. 1990. Effects of Intensive Harvesting on Nutrient Capitals of Three Forest Types in New England. *Forest Ecology and Management* 30(1-4):55-64.

Huntington, T. G., and D. F. Ryan. 1990. Whole-Tree-Harvesting Effects on Soil Nitrogen and Carbon. *Forest Ecology and Management* 31(4):193-204.

Idol, T. W., R. A. Figler, P. E. Pope, and F. Ponder. 2001. Characterization of Coarse Woody Debris across a 100 Year Chronosequence of Upland Oak-Hickory Forests. *Forest Ecology and Management* 149(1-3):153-161.

Janowiak, M.K., and C.R. Webster. 2010. Promoting Ecological Sustainability in Woody Biomass Harvesting. *Journal of Forestry* 108(1):16-23

Jenkins, J., Conservation Easements and Biodiversity in the Northern Forest Region. 2008. Open Space Institute and Wildlife Conservation Society, New York, NY.

Jia-bing, W., G. De-xin, H. Shi-jie, Z. Mi, and J. Chang-jie. 2005. Ecological Functions of Coarse Woody Debris in Forest Ecosystem. *Journal of Forestry Research* 16(3):247-252.

Johnson, D. W., and P. S. Curtis. 2001. Effects of Forest Management on Soil C and N Storage: Meta Analysis. *Forest Ecology and Management* 140(2-3):227-238.

Johnson, D. W., and D. E. Todd, Jr. 1998. Harvesting Effects on Long-Term Changes in Nutrient Pools of Mixed Oak Forest. *Soil Science Society of America Journal* 62(6):1725-1735.

Kappes, H., M. Jabin, J. Kulfan, P. Zach, and W. Topp. 2009. Spatial Patterns of Litter-Dwelling Taxa in Relation to the Amounts of Coarse Woody Debris in European Temperate Deciduous Forests. *Forest Ecology and Management* 257(4):1255-1260.

Keeton, W. S. 2006. Managing for Late-Successional/Old-Growth Characteristics in Northern Hardwood-Conifer Forests. *Forest Ecology and Management* 235(1-3):129-142.

Kelty, M. J., A. W. D'Amato, and P. K. Barten. 2008. Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts. Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA.

Kenefic, L. S., and R. D. Nyland. 2007. Cavity Trees, Snags, and Selection Cutting: A Northern Hardwood Case Study. *Northern Journal of Applied Forestry* 24(3):192-196.

Kluyver, H. N. 1961. Food Consumption in Relation to Habitat in Breeding Chickadees. The Auk 78(4):532-550.

Kruys, N., and B. G. Jonsson. 1999. Fine Woody Debris Is Important for Species Richness on Logs in Managed Boreal Spruce Forests of Northern Sweden. *Canadian Journal of Forest Research* 29(8):1295–1299.

Laiho, R., and C. E. Prescott. 2004. Decay and Nutrient Dynamics of Coarse Woody Debris in Northern Coniferous Forests: A Synthesis. *Canadian Journal of Forest Research* 34(4):763-777.

Lattimore, B., C. T. Smith, B. D. Titus, I. Stupak, and G. Egnell. 2009. Environmental Factors in Woodfuel Production: Opportunities, Risks, and Criteria and Indicators for Sustainable Practices. *Biomass and Bioenergy* 33(10):1321-1342.

Lindenmayer, D. B., and J. Fischer. 2006. Habitat fragmentation and landscape change: An ecological and conservation synthesis. Island Press: Washington, D.C. 328 pp.

Mahendrappa, M. K., C. M. Pitt, D. G. O. Kingston, and T. Morehouse. 2006. Environmental Impacts of Harvesting White Spruce on Prince Edward Island. *Biomass and Bioenergy* 30(4):363-369.

Martin, C., J. Hornbeck, G. Likens, and D. Buso. 2000. Impacts of Intensive Harvesting on Hydrology and Nutrient Dynamics of Northern Hardwood Forests. *Canadian Journal of Fisheries and Aquatic Sciences* 57(S2):19-29.

Mattson, K. G., W. T. Swank, and J. B. Waide. 1987. Decomposition of Woody Debris in a Regenerating, Clear-Cut Forest in the Southern Appalachians. *Canadian Journal of Forest Research* 17(7):712–721.

McCarthy, B. C., and R. R. Bailey. 1994. Distribution and Abundance of Coarse Woody Debris in a Managed Forest Landscape of the Central Appalachians. *Canadian Journal of Forest Research* 24(7):1317–1329.

McGee, G. G. 2001. Stand-Level Effects on the Role of Decaying Logs as Vascular Plant Habitat in Adirondack Northern Hardwood Forests. *The Journal of the Torrey Botanical Society* 128(4):370-380.

McGee, G. G., D. J. Leopold, and R. D. Nyland. 1999. Structural Characteristics of Old-Growth, Maturing, and Partially Cut Northern Hardwood Forests. *Ecological Applications* 9(4):1316-1329 CR - Copyright &#1169; 1999 Ecological Society of America.

McInnis, B. G., and M. R. Roberts. 1994. The Effects of Full-Tree and Tree-Length Harvests on Natural Regeneration. *Northern Journal of Applied Forestry* 11(4):131-137.

McIver, J. D., and L. Starr. 2001. A Literature Review on the Environmental Effects of Postfire Logging. *Western Journal of Applied Forestry* 16(4):159-168.

Mellina, E., and S. G. Hinch. 2009. Influences of Riparian Logging and in-Stream Large Wood Removal on Pool Habitat and Salmonid Density and Biomass: A Meta-Analysis. *Canadian Journal of Forest Research* 39(7):1280–1301.

MFRC. 2007. Biomass Harvest Guidelines. Minnesota Forest Resources Council, St. Paul, MN.

Niemi, G. J., and J. M. Hanowski. 1984. Relationships of Breeding Birds to Habitat Characteristics in Logged Areas. The Journal of Wildlife Management 48(2):438-443.

Nord-Larsen, T. 2002. Stand and Site Productivity Response Following Whole-Tree Harvesting in Early Thinnings of Norway Spruce (Picea Abies (L.) Karst.). *Biomass and Bioenergy* 23(1):1-12.

Olsson, B. A., H. Staaf, H. Lundkvist, J. Bengtsson, and R. Kaj. 1996. Carbon and Nitrogen in Coniferous Forest Soils after Clear-Felling and Harvests of Different Intensity. *Forest Ecology and Management* 82(1-3):19-32.

Patrick, D. A., J. Hunter, Malcolm L., and A. J. K. Calhoun. 2006. Effects of Experimental Forestry Treatments on a Maine Amphibian Community. *Forest Ecology and Management* 234(1-3):323-332.

Pierce, R. S., J. W. Hornbeck, W. C. Martin, L. M. Tritton, T. C. Smith, A. C. Federer, and H. W. Yawney. 1993. Whole-Tree Clear cutting in New England: Manager's Guide to Impacts on Soils, Streams, and Regeneration. GTR-NE-172, Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Perschel, R.T. 2006. Ensuring Sustainable Forestry Through Working Forest Conservation Easements. Forest Guild. Santa Fe, NM.

Perschel, R.T.,A.M.Evans, M.J.Summers. 2007. Climate Change, Carbon, and the Forests of the Northeast. Forest Guild, Santa Fe, NM

Richardson, J., R. Björheden, P. Hakkila, A. T. Lowe, and C. T. Smith, editors. 2002. *Bioenergy from Sustainable Forestry: Guiding Principles and Practice*. Kluwer Academic Publishers, Hingham, MA.

Roskoski, J. 1980. Nitrogen Fixation in Hardwood Forests of the Northeastern United States. *Plant and Soil* 54(1):33-44.

Roskoski, J. P. 1977. *Nitrogen Fixation in Northern Hardwoods Forests*. Yale University, New Haven, CT.

Sass, G. G. 2009. Coarse Woody Debris in Lakes and Streams. Pages 60-69 in G. E. Likens, editor. *Encyclopedia of Inland Waters*. Academic Press, Oxford.

Searchinger, T. D., S. P. Hamburg, J. Melillo, W. Chameides, P. Havlik, D. M. Kammen, G. E. Likens, R. N. Lubowski, M. Obersteiner, M. Oppenheimer, G. Philip Robertson, W. H. Schlesinger, and G. David Tilman. 2009. Fixing a Critical Climate Accounting Error. Science 326(5952):527-528.

Shepard, J. P. 2006. Water Quality Protection in Bioenergy Production: The Us System of Forestry Best Management Practices. *Biomass and Bioenergy* 30:378–384.

Tritton, L. M., C. W. Martin, J. W. Hornbeck, and R. S. Pierce. 1987. Biomass and Nutrient Removals from Commercial Thinning and Whole-Tree Clear cutting of Central Hardwoods. *Environmental Management* 11(5):659-666.

Tritton, L. M., and T. G. Siccama. 1990. What Proportion of Standing Trees in Forests of the Northeast Are Dead? *Bulletin of the Torrey Botanical Club* 117(2):163-166.

Vanderwel, M. C., J. R. Malcolm, and S. M. Smith. 2006. An Integrated Model for Snag and Downed Woody Debris Decay Class Transitions. *Forest Ecology and Management* 234(1-3):48-59.

Watmough, S. A., and P. J. Dillon. 2003. Base Cation and Nitrogen Budgets for Seven Forested Catchments in Central Ontario, 1983-1999. *Forest Ecology and Management* 177(1-3):155-177.

Weaver, J. K., L. S. Kenefic, R. S. Seymour, and J. C. Brissette. 2009. Decaying Wood and Tree Regeneration in the Acadian Forest of Maine, USA. *Forest Ecology and Management* 257(7):1623-1628.

Wilson, B. F., and B. C. McComb. 2005. Dynamics of Dead Wood over 20 Years in a New England Oak Forest. *Canadian Journal of Forest Research* 35:682–692.

Woodall, C. W., and V. J. Monleon. 2008. Sampling Protocol, Estimation, and Analysis Procedures for the Down Woody Materials Indicator of the Fia Program. NRS-GTR-22, U.S. Forest Service, Newtown Square, PA.

World Commission on Environment and Development. 1987. Our Common Future. Oxford University Press, Oxford, England.

Yanai, R. D., J. D. Blum, S. P. Hamburg, M. A. Arthur, C. A. Nezat, and T. G. Siccama. 2005. New Insights into Calcium Depletion in Northeastern Forests. *Journal of Forestry* 103(1):14-20.

# CHAPTER 5

# FOREST CARBON MODELING: STAND-LEVEL CARBON DYNAMICS AND IMPLICATIONS OF HARVESTING FOR CARBON ACCUMULATION

We evaluated the carbon dynamics of five common forest cover types throughout Massachusetts (Mixed Oak, White Pine, Northern Hardwoods, Hemlock, Mixed Hardwood). We had two primary objectives with this task: (1) to achieve an understanding of Massachusetts forest carbon dynamics and implications of different harvest intensities at the stand level; and (2) to support the forest carbon life cycle accounting analysis (Chapter 6) by providing data on the total carbon recovery rates of forest stands following harvests of varying intensity. Below we summarize the methods used to evaluate forest carbon dynamics and discuss the implications of varying harvest intensities on the carbon volume response by forest stands in Massachusetts.

## 5.1 FOREST MANAGEMENT AND CARBON SEQUESTRATION

Practices that increase the amount of biomass retained on a given acre over time can be seen as having a carbon benefit. This is particularly true when the removal of the retained biomass (e.g., for pulp wood for paper making) would have generated carbon emissions in a relatively short period of time or emit methane when ultimately disposed. Increased stand-level retention practices consistent with an ecological forestry approach are considered an appropriate mitigation strategy as well. Also appropriate are reduced impact logging practices that minimize soil disturbance and residual damage to stands, thereby reducing mortality and maintaining stand vigor. Under such approaches, late-successional forest structures are seen as beneficial to forest health and resiliency, as well as achieving the biomass levels needed to yield carbon benefits (NCSSF 2008). The relative value of extending rotations is being debated, but there is evidence accumulating that older forests continue to sequester carbon well beyond stand ages we are likely to see in the northeastern forests any time soon (Massachusetts: Urbanski et al., 2007; Globally: Luyssaert et al., 2008). Extending rotation lengths serves to enhance structural complexity, thereby accumulating more biomass on a given acre (Foley et al., 2009). This strategy could also serve to sequester more carbon offsite in long-lived wood products through the production of larger diameter trees suitable for use in these products. However, Nunery and Keeton (2010) showed that even when offsite storage was considered in Northern Hardwood stands, the unmanaged stands still accumulated more carbon over a 160 year time frame. Perez-Garcia et al. (2005) also concluded that offsite storage could not surpass onsite storage unless product substitution was considered. The assumptions made around product conversion efficiencies, decay rates, and the certainty around substitution effects will drive the conclusions about the significance of offsite carbon as a long-term sink associated with forest harvesting (e.g., Van Deusen, in press).

Our modeling of forest carbon dynamics only includes estimates of onsite storage. Chapter 6 incorporates a more complete carbon life cycle accounting of the substitution implications associated with using wood for energy. The role of offsite storage in products is minimal when you consider that only 3.5% of hardwood sawlogs are estimated to be still in use after 100 years in the Northeast (Smith et al., 2006). A significant amount of hardwood sawlogs (28%) is estimated to remain in landfills after 100 years (Smith et al., 2006), but without methane capture technologies in place emissions associated with landfill storage would far exceed the benefits of other offsite storage. Landfill emissions are especially problematic since methane has a Global Warming Potential 25 times worse than carbon dioxide (IPCC, 2007). Without a comprehensive life cycle assessment for products derived from Massachusetts forests we felt it was not productive to speculate on the role of offsite storage, particularly for the time periods we are considering below. More importantly for our analyses however, Chapter 6 assumes that the increase harvest intensity for biomass energy wood doesn't change the disposition of materials that would be harvested absent biomass extraction.

Below we describe the widely-accepted models and inventory data we used to understand the role of forest management in stand-level forest carbon dynamics. Where appropriate, we describe the limitations of the models and data and how they were used to inform the analyses in Chapter 6. Models are a representation of a complex ecological reality and are best used to investigate trends and likely outcomes, not predetermined certainty. Data are generally presented in aggregate to show broad trends, but specific examples are also given to illustrate points.

## 5.2 INVENTORY DATA AND FOREST CARBON MODELS

Data used in the analyses were based upon Forest Inventory and Analysis (FIA) data from the U.S. Forest Service. We obtained inventory data from the FIA DB version 4.0 Data Mart from 1998–2008.[1] FIA plot data (including tree lists) were imported into the Northeast (NE) Variant of the US Forest Service Forest Vegetation Simulator (FVS)[2] and are accepted as compatible with the model (Ray et al., 2009). FVS is a widely-accepted growth model within current forest carbon offset standards (e.g., Climate Action Reserve Forest Project Protocol 3.1[3] and the Chicago Climate Exchange Forest Offset Project Protocol [4]) and as a tool to understand carbon implications of forest management within the scientific community (e.g., Keeton 2006; Ray et al., 2009; Nunery and Keeton, 2010). The modeling package relies

---

[1] http://fia.fs.fed.us/tools-data/default.asp

[2] http://www.fs.fed.us/fmsc/fvs/

[3] http://www.climateactionreserve.org/wp-content/uploads/2009/03/Forest-Project-Protocol-Version-3.1.pdf

[4] http://www.chicagoclimatex.com/docs/offsets/CCX_Forestry_Sequestration_Protocol_Final.pdf

on NE-TWIGS (Hilt and Teck, 1989) as the growth and yield model to derive carbon biomass estimates in the Northeast. These growth and yield models are based on data collected by the USFS's Forest Inventory and Analysis unit from the 1950s through the 1980s. Developed by the US Forest Service and widely used for more than 30 years, the FVS is an individual tree, distance independent growth and yield model with linkable modules called extensions, which simulate various insect and pathogen impacts, fire effects, fuel loading, snag dynamics, and development of understory tree vegetation (Crookston and Dixon 2005). FVS can simulate a wide variety of forest types, stand structures, pure or mixed species stands, and allows for the modeling of density dependent factors.

The FVS model modifies individual tree growth and mortality rates based upon density-dependent factors. As would be expected to be observed in nature, the model uses maximum stand density index and stand basal area as important variables in determining density related mortality. The NE Variant uses a crown competition factor CCF as a predictor variable in some growth relationships. Potential annual basal area growth is computed using a species-specific coefficient applied to DBH (diameter at breast height) and a competition modifier value based on basal area in larger trees is computed. In the NE Variant there are two types of mortality. The first is background mortality which accounts for occasional tree deaths in stands when the stand density is below a specified level. The second is density related mortality which determines mortality rates for individual trees based on their relationship with the stand's maximum density. Regeneration in the NE Variant is user-defined (stump sprouting is built in) and we describe the regeneration inputs in more detail below.

The FVS Fire and Fuels Extension includes a carbon submodel that tracks carbon biomass volume based upon recognized allometric equations compiled by Jenkins et al. (2003). The carbon submodel allows the user to track carbon as it is allocated to different "pools." Calculated carbon pools include: total aboveground live (trees); merchantable aboveground live; standing dead; forest shrub and herbs; forest floor (litter, duff); forest dead and down; belowground live (roots); belowground dead (roots). Soil carbon was not included explicitly in this analysis. Our FVS model simulations captured the carbon dynamics associated with the forest floor and belowground live and belowground dead root systems. Mineral soils were not included in our analyses, but appear generally not to be a long-term issue. A meta-analysis published in 2001 by Johnson and Curtis found that forest harvesting, on average, had little or no effect on soil carbon and nitrogen. However, a more recent review (Nave et al., 2010) found consistent losses of forest floor carbon in temperate forest, but mineral soils showed no significant, overall change in carbon storage due to harvest, and variation among mineral soils was best explained by soil taxonomy. It is important to recognize the current scientific uncertainty around the role of timber harvesting in carbon dynamics but the evidence presented to date does not modify our conclusions derived from the modeling.

## 5.3 MODEL SCENARIOS

FIA data for both private and public lands from inventories between 1998–2008 were imported into a database for manipulation into the FVS model. The most current inventory year from each plot was used in the analysis and grown to the year 2010 using the model described below. Plots were categorized by forest cover type based on tree species list from each plot (Exhibit 5-1).

We selected a subset of the FIA plots that met a condition of having ≥ 25 Metric Tons of Carbon (MTC) per acre of aboveground living biomass ("aboveground live carbon") prior to any harvest in 2010 to represent stands that are typically harvested across the state. This was important to match the assumptions made in the Chapter 3 supply analysis and is consistent with the approach of Kelty et al. (2008). These plots represented a mean aboveground live carbon stocking of 31 MTC/acre (or approximately 124 green tons per acre). We refer to these plots as "operable" stands as they represent the majority of 70-100 year old stands with a likelihood of being harvested in the near term. A total of 88 FIA plots were used for the analyses of operable stands (Mixed Oak n=4; Northern Hardwood n=31; Mixed Hardwood n= 29; Hemlock n=3; White Pine n= 21).

The model scenarios we tested were designed to understand the carbon implications of varying intensity of harvest (i.e., removal rates) including an evaluation of "no management" or "let it grow" scenarios. In particular, we were interested in the implications of harvests that were defined as "biomass" harvests that removed the majority of tops and limbs (65%) and represented higher rates of total removal than that defined as "Business as Usual" (BAU) in supply analysis (Chapter 3). FVS allows the user to

**Exhibit 5-1: Cover Type Classification for FIA Plots**

| Cover Type | Cover Type Code | Dominant Species | Parameter |
|---|---|---|---|
| Mixed Oak | MO | *Quercus* spp. (hickories secondary) | > 50% trees > 5" dbh are *Quercus* spp. |
| White Pine | WP | Eastern White Pine | > 50% trees > 5" dbh are *Pinus strobus* |
| Northern Hardwoods | NH | Red and Sugar Maple, Beech, Yellow Birch, Black Birch | > 50% trees > 5" dbh are northern hardwood spp. |
| Hemlock | HE | Eastern Hemlock | > 50% trees > 5" dbh are *Tsuga canadensis* |
| Mixed Hardwood | MH | Northern Hardwoods/Mixed Oak | default classification (can contain pine and hemlock) |

select and customize forest management scenarios based on input criteria such as target residual basal area (BA), target percent removal, specification of diameter and species preferences, and tops and limbs retention preferences. Twenty scenarios were run using data from all FIA plots representing a range of intensity from no management to a silvicultural clearcut that removed all trees > 2" DBH (Exhibit 5-2). Scenarios are categorized as follows: (1) Unmanaged Accumulation; (2) Business as Usual Harvest (BAU); (3) Biomass Harvests; and (4) Sensitivity Analysis Harvests. The sensitivity analyses were designed to elucidate the carbon dynamics associated with retaining versus removing tops and limbs in biomass harvests and to understand the dynamics of conducting harvests with silvicultural objectives that included promoting crop tree development and moving towards uneven-aged silvicultural systems.

We chose to model carbon accumulation within a period between 2010 and 2100. Modeling on such a time frame comes with a degree of uncertainty and we acknowledge the limitations of this approach. In particular, projections do not include the impacts on carbon accumulation from stochastic natural disturbances, climate change, or the influence of exotic species. However, using these data to understand the potential long-term trajectories is appropriate and can tell us a great deal about response trends.

**Exhibit 5-2: Summary of FVS Treatment Scenarios Analyzed**

| Scenario | Name | Harvest Scenarios | Category | Tops and Limbs Removed From Site (%) | Regeneration Scenario (see Exhibit 5-3) |
|---|---|---|---|---|---|
| MS1 | Unmanaged | Unmanaged | Unmanaged | 0 | 1 |
| MS2 | BAU 32% | Common Partial Harvest (Business As Usual), Thin 25% of stand BA from Above | BAU | 0 | 2 |
| MS3 | BAU 32% Light Biomass | BAU with 65% Tops and Limbs Removed | Biomass | 65 | 2 |
| MS4 | BAU 32% Heavy Biomass | BAU with 100% of Tops and Limbs Removed | Biomass | 100 | 2 |
| MS5 | Heavy Harvest BA 40 | Heavy Harvest, Thin from Above to 40 ft2/acre BA | Sensitivity | 0 | 3 |
| MS6 | Heavy Harvest BA 40 Light Biomass | Heavy Harvest w/ Light Biomass | Biomass | 65 | 3 |
| MS7 | Commercial Clearcut (Tops and Limbs left) | Commercial Clear Cut | Sensitivity | 0 | 4 |
| MS8 | Commercial Clearcut | Commercial Clearcut with 65% Tops and Limbs Removed | Biomass | 65 | 4 |
| MS9 | Selection Cut | "Quality" Individual Tree Selection (75 ft2/acre BA retained) | Sensitivity | 0 | 2 |
| MS10 | Selection Cut Light Biomass | "Quality" Individual Tree Selection (75 ft2/acre BA retained), 65% Tops and Limbs removed | Sensitivity | 65 | 2 |
| MS11 | Silvicultural Clearcut | Silvicultural Clearcut No Legacy (>2" DBH trees removed) | Sensitivity | 0 | 4 |
| MS12 | Silvicultural Clearcut No Regen | Commercial Clearcut, No Legacy Trees Left, No Regen | Sensitivity | 0 | x |
| MS13 | DBH BA60 | Thinning through diameter classes to BA 60 ft2/acre of trees > 8" DBH | Sensitivity | 65 | 3 |
| MS14 | DBH All BA60 | Thinning through diameter classes to BA 60 ft2/acre | Sensitivity | 65 | 3 |
| MS15 | Biomass BA60 | Thin from Above to BA 60 ft2/acre | Biomass | 65 | 3 |
| MS16 | BAU 20% | Common Partial Harvest, Thin from Above (15% BA removed = 20% volume) | BAU | 0 | 2 |
| MS17 | BAU 20% Light Biomass | Common Partial Harvest, Thin from Above (15 % BA removed = 20% Volume), 65% Tops and Limbs Removed | Sensitivity | 65 | 2 |
| MS18 | BAU 35% Light Biomass | Common Partial Harvest, Thin from Above (20% BA removed = 35% volume removed), 65% Tops and Limbs removed. | Sensitivity | 65 | 2 |
| MS19 | BAU 40% Light Biomass | Common Partial Harvest, Thin from Above (30% BA removed = 40% volume removed), 65% Tops and Limbs removed. | Biomass | 65 | 2 |
| MS20 | BAU 15% | Common Partial Harvest, Thin from Above (10% BA removed = 15% volume) | Sensitivity | 0 | 2 |

Shorter-term projections (ca. 30 to 50 years) have been verified to have a higher degree of confidence since the impacts of these uncertainties are minimized by low probability of occurrence (Yaussy, 2000). We also focused on the stand-level response following a single harvest event at Time = 0 (i.e., 2010) rather than conduct a more complicated series of repeated harvest entries. We can infer a "sawtooth" response from repeated entries to a target basal area or residual condition, but single entry scenarios provided us the best information to evaluate the short-term impacts and response of stands following "biomass" harvests needed to inform Chapter 6.

The FVS NE Variant does not add regeneration elements by default (except for stump sprouting for appropriate species following harvest). Regeneration inputs were required to more appropriately reflect the behavior of forest stands following harvest. We followed the methods of Nunery and Keeton (2010) and adapted conservative regeneration inputs that were designed to be appropriate to the cover type and disturbance intensity but still within a range of natural variability (Exhibit 5-3). Conceptually, seedling inputs were periodically entered into the simulation throughout the time period to mimic baseline regeneration rates in an unmanaged stand. In harvested stands, larger numbers of seedlings were input immediately post harvest to mimic the pulse of regeneration that would be expected to follow a disturbance. Exhibit 5-3 shows the number of seedling inputs relative to the harvest scenario. Greater removal of overstory trees promotes the opportunity for larger numbers of seedlings to become established. The mix of species in heavier harvests was weighted more heavily to shade intolerant and intermediate shade tolerant species as would be expected following an actual harvest (after Leak et al. 1987 and Leak 2005). Regeneration inputs in harvested stands were then gradually reduced over time to mimic a stand initiation period followed by baseline regeneration. Site indices were inconsistently available for the FIA dataset so we used the default FVS value set to sugar maple with a site index of 56.

**Exhibit 5-3: Regeneration Inputs Used in FVS Model Scenarios**

| Regeneration Group | Harvest Scenarios | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2015 | 2025 | 2035 | 2045 | 2055 | 2065 | 2075 | 2085 | 2095 | 2105 | 2115 |
| 1 | Unmanaged Baseline Regeneration | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| 2 | Light Partial Harvest Response | 2,500 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| 3 | Heavy Partial Harvest Response | 5,000 | 2,500 | 2,500 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| 4 | Commercial Clearcut Response | 20,000 | 5,000 | 2,500 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |

*Note: Regeneration is expressed in trees (seedlings) per acre. Inputs based on methods described in Nunery and Keeton (2010) and regeneration response to harvests described in Leak et al. (1987), Hornbeck and Leak (1992), and Leak (2005) (5-3a).*

| | Shade Tolerance | | | |
|---|---|---|---|---|
| Cover Type | Intolerant | Intermediate | Tolerant | Total |
| HE | 16% | 21% | 63% | 100% |
| MH | 33% | 40% | 27% | 100% |
| MO | 23% | 43% | 34% | 100% |
| NH | 18% | 54% | 28% | 100% |
| WP | 32% | 31% | 37% | 100% |
| Mean | 24% | 43% | 33% | 100% |

*Note: Species were allocated based on proportional representation within each cover type and weighted to reflect a higher proportion of intolerant and intermediate shade tolerant species in the Heavy Partial Harvest and Commercial Clearcut scenarios.*

## 5.4 GENERAL RESULTS AND MODEL EVALUATION

### 5.4.1 GENERAL RESULTS

All values below are expressed in terms of Metric Tons of Carbon per Acre (MTC/acre). Approximately 50% of dry wood weight is considered to be made up of carbon (or 25% of green wood weight). We also present values either in terms of Total Stand Carbon (TSC) or Aboveground Live Carbon (AGL). AGL is simply the carbon biomass associated with the aboveground elements of a live tree. TSC is comprised of aboveground live and dead trees, belowground live and dead roots, lying dead wood, forest floor, and shrub and herb carbon pools. AGL dynamics reflect behavior foresters would be more accustomed to and are analogous to stand basal area and merchantable volume response. Basal area to AGL relationships are typically more linearly related than AGL and merchantable volume (Ducey and Gunn, unpublished data).

Not surprisingly, unmanaged stands result in greater onsite carbon storage than any of the management scenarios we simulated when both TSC and AGL are considered over the 90 year horizon (Exhibits 5-4a and 5-4b). Here, a range of management scenarios (including unmanaged) are shown to illustrate the response of a light diameter-limit partial harvest, a heavy harvest that removes 65% of the tops and limbs, and a commercial clearcut that removes all trees greater than 5" DBH. The mean values include both public and private landowners, and all cover types are aggregated. These patterns were also observed by Nunery and Keeton (2010) in Northern Hardwood stands and even held true when offsite storage of carbon was considered. There were a few plots where managed stands met or exceeded the unmanaged scenario by 2100. These plots were typically understocked at the time of harvest and a heavy harvest was able to "release" the advanced regeneration and promote the growth of the intolerant and intermediate shade tolerant species that were input following the harvest. These fast growing species begin to decline after 40 to 50 years and it is likely that a decline would be observed beyond our modeling period as a result of mortality in these short-lived species. If longer-living shade tolerant species were present in the pre-harvest canopy or mid-story, it is likely that these species would persist longer than the intolerants in the managed scenario.

**Exhibit 5-4a: Total Stand Carbon Accumulation over Time**
(see next page)

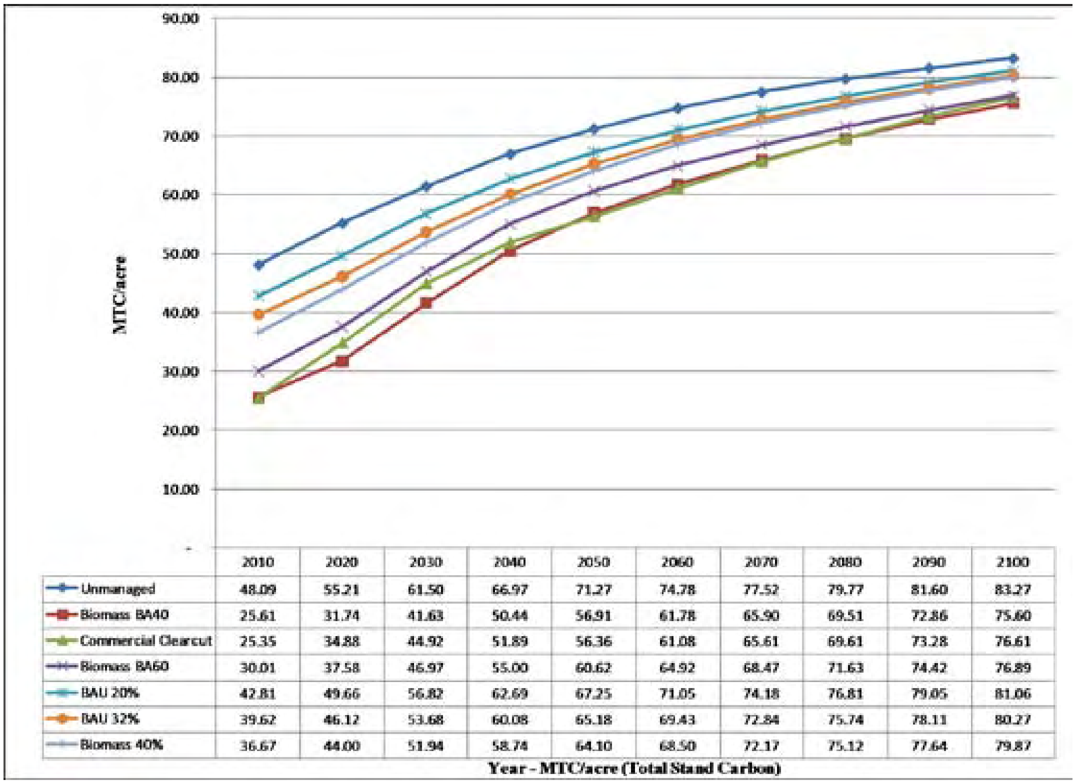
**5-4b: Aboveground Live Carbon Accumulation over Time**
(see next page)

Light partial harvests in stands that remove larger diameter trees recover slowly and roughly parallel to unmanaged stands, but gradually approach unmanaged volumes over a 90-year period. This is likely because residual mean diameter is still relatively high following the harvest and the associated growth response is slow. These light diameter-limit partial harvests (e.g., BAU 20% and BAU 32%) represent the mean harvest intensity across Massachusetts. The light harvest in the canopy increases the growth rate in the initial ten year period, but very quickly returns to approximately the same as the unmanaged growth rate. Over time these BAU stands approach unmanaged stocking but don't quite catch up after 90 years. This finding is consistent with work in the Harvard Forest by O'Donnell (2007) who found that carbon uptake in live biomass following a light partial harvest recovered quickly after an initial decline to equal the un-harvested control site's carbon uptake rates. If this relationship holds into the future, the onsite stocks would not catch up to the unmanaged site. In contrast, the scenarios we defined as "biomass" harvests (Biomass 40%, Biomass BA40, Biomass BA60) maintain high growth rates for several decades. Because of this increased growth rate, even the heavier harvested stands can reach almost 90% of the volume that could have been achieved in an unmanaged scenario. So, over a long period of time, biomass harvests have an opportunity to recover a large portion of the carbon volume removed during the harvest. However, this assumes no future harvests in the stand as well as an absence of any significant disturbance event. Both are unlikely. This return interval, or cutting cycle, in a silvicultural system will clearly play a role in the recovery of onsite carbon storage over time. If stands are consistently entered prior to achieving complete recovery, the result will be a declining "sawtooth" pattern of growth and recovery of carbon volume stored onsite. With planning and monitoring, uneven-aged silvicultural systems can be implemented that allow adequate time for recovery while maintaining a basal area that promotes quality sawlog production (Hornbeck and Leak, 1992).

Canopy and sub-canopy density plays an important role when the harvest is not heavy enough to reduce the crown completion factors. Heavy harvests create light and space for fast growing intolerant hardwood species to succeed, which can create a pulse of fast growing AGL. The heavy harvest also generates more lying dead wood from the tops and limbs. This may keep the initial post-harvest TSC value high, until this material decays and is lost from subsequent carbon pools. However, this loss is very rapidly recovered by the fast growing species. The curves in Exhibits 5-4a and 5-4b show the general pattern of a faster growth rate in the periods immediately following a harvest event, followed by a gradual slowing at the end of the modeling period. This is not surprising particularly for the unmanaged scenario which would represent plots that are reaching ages around 200 years old by the end of the modeling period. The FIA data that forms the basis of the NE Variant modeling would have had few plots that represented stands of this age, so accumulation behavior this far out in time is uncertain and requires further research (e.g., Keeton et al., In Press).

The Heavy Harvest (BA40) and Commercial Clearcut harvest scenarios behave very similarly to each other. This is largely because the Commercial Clearcut retained trees greater than 5" DBH which effectively brought the stand to 40 ft$^2$/acre of basal area. Depending upon the density of trees > 5" DBH in the plot, the Heavy Harvest could actually be a heavier harvest than the Commercial Clearcut—which may explain the greater carbon accumulation after 2020. Note that Total Stand Carbon is actually higher for a time in the Commercial Clearcut plots, possibly a product of mortality from the regeneration inputs that are lost through density competition within the smaller stems in that scenario. When we look at the impacts of a Silvicultural Clearcut that removes trees down to 2" DBH, it becomes obvious that there are immediate carbon benefits (AGL) to leaving behind advance regeneration when it is available (Exhibit 5-5). Even though 20,000 seedlings per acre are being input into the stand following harvest, it takes some time before those stems contribute significantly to the AGL, eventually the curve approaches the Commercial Clearcut, but not before 100 years.

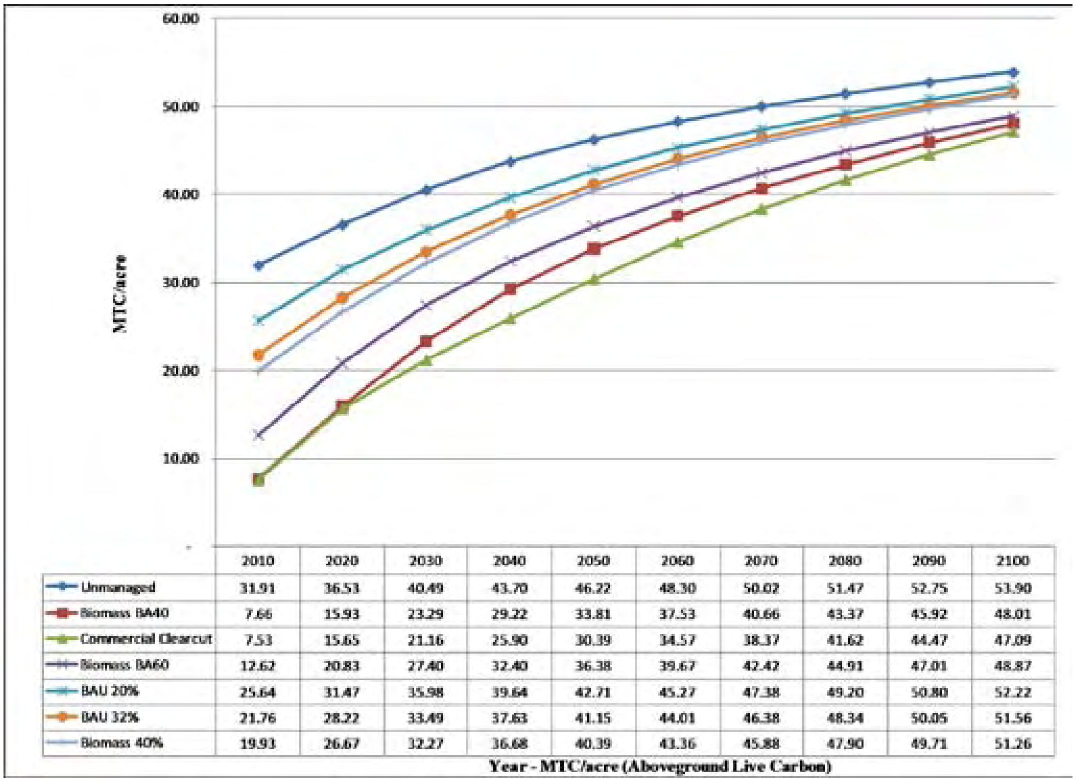
### Exhibit 5-4a: Total Stand Carbon Accumulation over Time



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Unmanaged | 48.09 | 55.21 | 61.50 | 66.97 | 71.27 | 74.78 | 77.52 | 79.77 | 81.60 | 83.27 |
| Biomass BA40 | 25.61 | 31.74 | 41.63 | 50.44 | 56.91 | 61.78 | 65.90 | 69.51 | 72.86 | 75.60 |
| Commercial Clearcut | 25.35 | 34.88 | 44.92 | 51.89 | 56.36 | 61.08 | 65.61 | 69.61 | 73.28 | 76.61 |
| Biomass BA60 | 30.01 | 37.58 | 46.97 | 55.00 | 60.62 | 64.92 | 68.47 | 71.63 | 74.42 | 76.89 |
| BAU 20% | 42.81 | 49.66 | 56.82 | 62.69 | 67.25 | 71.05 | 74.18 | 76.81 | 79.05 | 81.06 |
| BAU 32% | 39.62 | 46.12 | 53.68 | 60.08 | 65.18 | 69.43 | 72.84 | 75.74 | 78.11 | 80.27 |
| Biomass 40% | 36.67 | 44.00 | 51.94 | 58.74 | 64.10 | 68.50 | 72.17 | 75.12 | 77.64 | 79.87 |

*Note: Plots included are from FIA plots with >25 MTC/acre of Aboveground Live Carbon (pre-harvest) in 2010. Private and public owners and all cover types are aggregated (see Exhibit 5-2 for harvest scenario descriptions).*

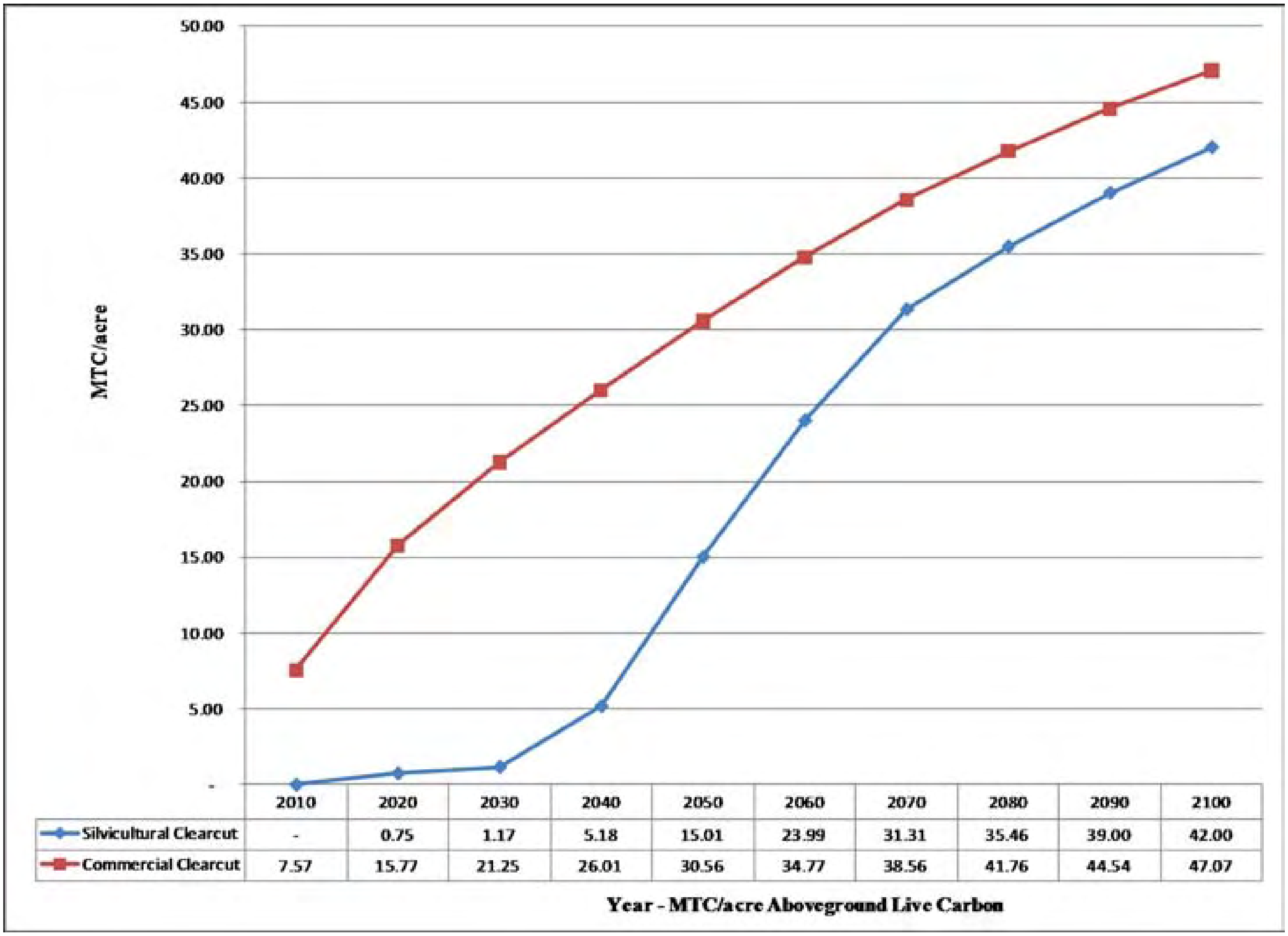
### Exhibit 5-4b: Aboveground Live Carbon Accumulation over Time



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Unmanaged | 31.91 | 36.53 | 40.49 | 43.70 | 46.22 | 48.30 | 50.02 | 51.47 | 52.75 | 53.90 |
| Biomass BA40 | 7.66 | 15.93 | 23.29 | 29.22 | 33.81 | 37.53 | 40.66 | 43.37 | 45.92 | 48.01 |
| Commercial Clearcut | 7.53 | 15.65 | 21.16 | 25.90 | 30.39 | 34.57 | 38.37 | 41.62 | 44.47 | 47.09 |
| Biomass BA60 | 12.62 | 20.83 | 27.40 | 32.40 | 36.38 | 39.67 | 42.42 | 44.91 | 47.01 | 48.87 |
| BAU 20% | 25.64 | 31.47 | 35.98 | 39.64 | 42.71 | 45.27 | 47.38 | 49.20 | 50.80 | 52.22 |
| BAU 32% | 21.76 | 28.22 | 33.49 | 37.63 | 41.15 | 44.01 | 46.38 | 48.34 | 50.05 | 51.56 |
| Biomass 40% | 19.93 | 26.67 | 32.27 | 36.68 | 40.39 | 43.36 | 45.88 | 47.90 | 49.71 | 51.26 |

*Note: Plots included are from FIA plots with >25 MTC/acre of Aboveground Live Carbon (pre-harvest) in 2010. Private and public owners and all cover types are aggregated (see Exhibit 5-2 for harvest scenario descriptions).*

**Exhibit 5-5: Aboveground Live Carbon Accumulation Following Clearcut Harvests**



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Silvicultural Clearcut | - | 0.75 | 1.17 | 5.18 | 15.01 | 23.99 | 31.31 | 35.46 | 39.00 | 42.00 |
| Commercial Clearcut | 7.57 | 15.77 | 21.25 | 26.01 | 30.56 | 34.77 | 38.56 | 41.76 | 44.54 | 47.07 |

*Note: Comparison is between a Commercial Clearcut (removing trees >5" DBH) vs. Silvicultural Clearcut (removing trees > 2" DBH).*

Aboveground Live Carbon typically follows a pattern of faster growth when mean diameters are small and densities are not limiting; then slows down as basal area maximums are reached and the lifespan maximums are approached. This is typical of what would be expected based on principles outlined in Oliver and Larson's classic Forest Stand Dynamics text (1996). Total Stand Carbon provides interesting insight primarily in the short term responses of stands as carbon pools are influenced by material left on the site. Later in the trajectory, the TSC becomes interesting again as mortality occurs and contributions of material to the dead standing and lying dead pools can vary.

### 5.4.2 COVER TYPE AND OWNERSHIP DIFFERENCES IN CARBON ACCUMULATION

Species response rates can vary depending upon silvical characteristics and this can be illustrated in some variation among cover type responses. Below are some examples of variation among cover types (Exhibits 5-6a through 5-6c). In general, the patterns are similar. The differences occur in terms of starting carbon volume and then become more pronounced near the end of the modeling period. For example, the Hemlock cover type accumulates the greatest amount of carbon over the long term as would be expected from a shade tolerant and long-lived species. However, these curves are based on only 3 plots, so a larger sample might bring it in line with other types. In addition, the future of Hemlock in Massachusetts is highly uncertain given the current status of the Hemlock Woolly Adelgid. For the other cover types, response to harvests (Exhibits 5-6b and 5-6c) generally follows the same trends with the real differences being accentuated late in the model period as with the Hemlock. Though there are minor differences among the cover types, we generally will report the results in Chapter 6 in aggregate.

Likewise, for the purposes of this analysis, we aggregated plots regardless of ownership type (Public and Private). Ownership does not result in major differences in terms of carbon trajectories and response to harvests (e.g., Exhibit 5-7). Minor differences do occur in starting carbon volume, but the plots behave similarly over time. Kelty et al. (2008) documented differences in growth between ownership types but were using two different data sets to make those comparisons (FIA for private lands and MA DCR Continuous Forest Inventory for public lands). Utilizing the Continuous Forest Inventory Plots from the MA DCR proved to be logistically challenging to integrate into FVS with the FIA plots data. Since data were available for both Public and Private lands within FIA, we decided to maintain consistency by only using FIA data.

**Exhibit 5-6a: Unmanaged TSC Accumulation by Cover Type** (see page 91)

**Exhibit 5-6b: BAU 32% Removal TSC Accumulation by Cover Type** (see page 91)

**Exhibit 5-6c: Heavy Harvest BA40 TSC Accumulation by Cover Type** (see page92)

**Exhibit 5-7: Ownership Similarities in Carbon Accumulation Over Time by Cover Type (TSC)** (see page 92)

### 5.4.3 REGENERATION CONTRIBUTION TO CARBON ACCUMULATION

Appropriately reflecting a realistic regeneration scenario is an important component of extending the time frame in which the FVS model results can be meaningful. Simply put, regeneration fills space made available by disturbances or natural mortality. In our simulations, we have followed the basic principle that heavier disturbances create more space and light, and therefore allow increasing larger numbers of seedlings to become established. Lighter harvests create less space and light in which regeneration will be successfully established. The successful seedlings will be appropriate to the amount of shade they can tolerate. Regeneration species composition is generally related to species already present within a stand and adjacent stands. But heavy harvests in the NE would typically result in 2/3 of the regenerating species being either shade intolerant or intermediate tolerance. Biologically relevant amounts and species composition were integrated into our approach.

The silvical characteristics of the regeneration are the primary factor contributing to forest carbon dynamics over time. Shade intolerants are typically faster growing species, but they are shorter lived. Thus, they can be responsible for an immediate increase in carbon biomass but will slow and decline after 50–60 years, whereas shade tolerant and intermediate shade tolerant species would persist in the stand and continue accumulating carbon for a longer period. However, Exhibit 5-5 above illustrates that the interaction between starting condition and the amount removed during a harvest are major drivers of carbon accumulation after a harvest.

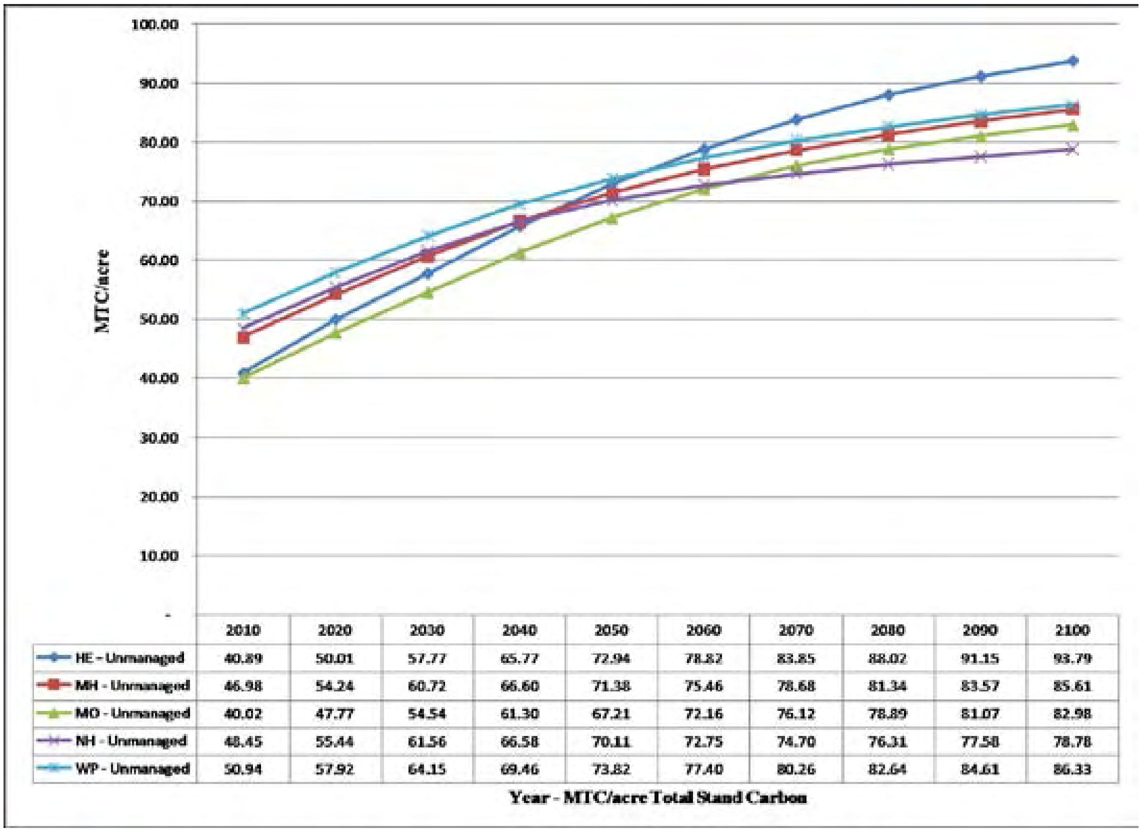
### 5.4.4 ROLE OF TOPS AND LIMBS IN CARBON BUDGET

We evaluated the carbon implications of the removal of tree tops and limbs during a harvest. We chose to simulate a removal rate of 65% tops and limbs based upon the standards recommended in Chapter 4 and the operability limitations described in Chapter 3. Removal of 65% tops and limbs generates on average between 1.23 MTC/acre and 4.22 MTC/acre depending on the intensity of the overall harvest. This carbon volume decays very rapidly if left on the forest floor, but is compensated for by new growth generally within 10 years following the harvest (Exhibit 5-8). The tops and limbs left in the forest can be observed as a pulse of carbon in the "lying dead" carbon pool, but it moves relatively quickly into the forest floor and ultimately is mostly lost to the atmosphere within a short time period (e.g., Exhibit 5-9). Thus, if tops and limbs are harvested in one scenario, and left in another, Total Stand Carbon in both scenarios will nearly converge within one decade. This recovery of carbon lost from tops and limbs could theoretically be faster if there is significant material left onsite suppressing regeneration. Overall, the model results indicate that the removal of tops and limbs is generally a minor stand level carbon issue; however, as shown in Chapter 6, they can have a significant impact on carbon recovery profiles if they represent a significant proportion of the total harvest.

**Exhibit 5-8: Tops and Limbs Contribution to Total Stand Carbon** (see page 93)

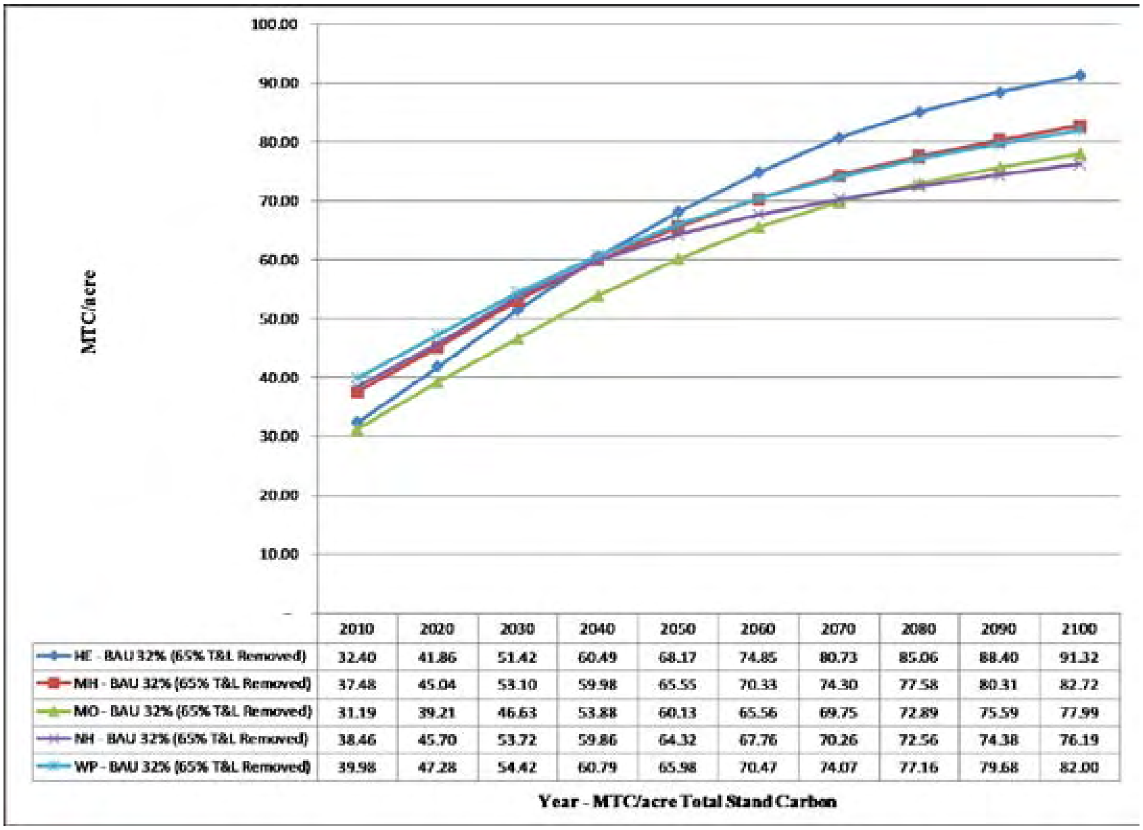
**Exhibit 5-9: Carbon Pool Comparison** (see page 93)

## Exhibit 5-6a: Unmanaged TSC Accumulation by Cover Type



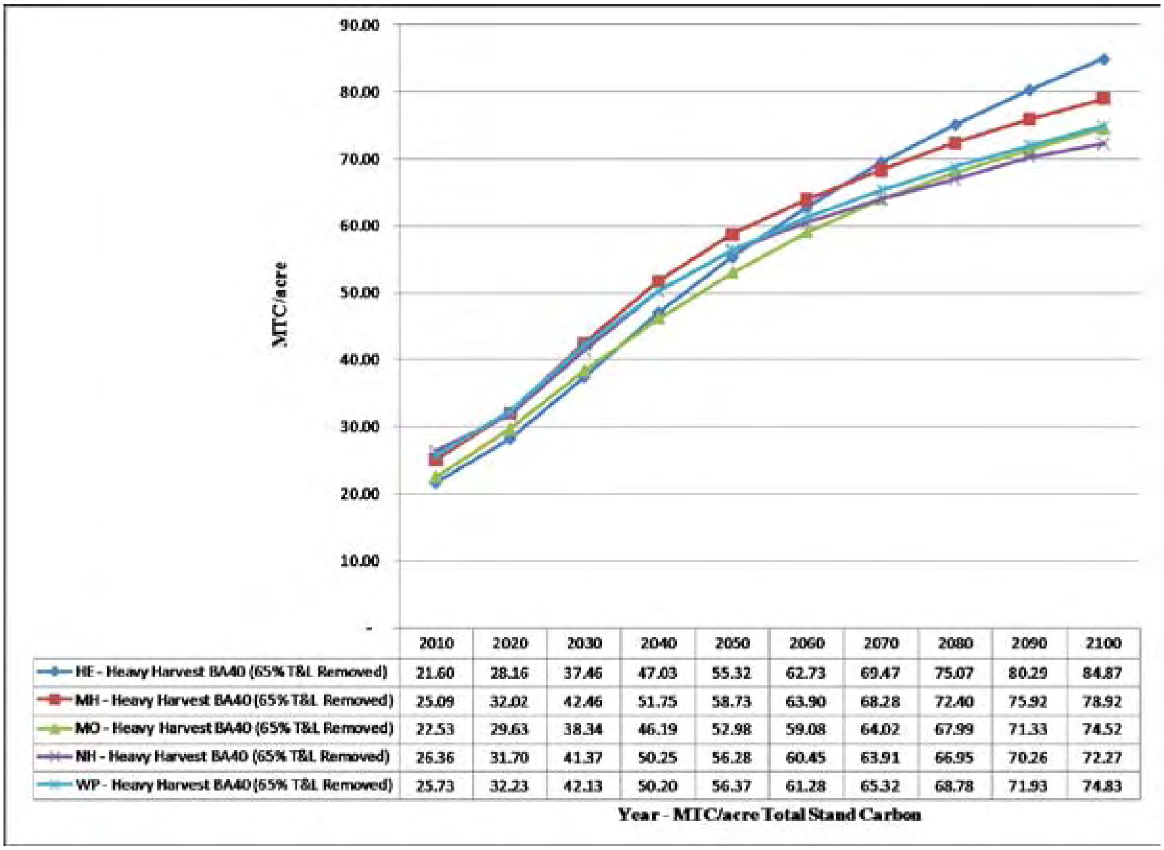
| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| HE - Unmanaged | 40.89 | 50.01 | 57.77 | 65.77 | 72.94 | 78.82 | 83.85 | 88.02 | 91.15 | 93.79 |
| MH - Unmanaged | 46.98 | 54.24 | 60.72 | 66.60 | 71.38 | 75.46 | 78.68 | 81.34 | 83.57 | 85.61 |
| MO - Unmanaged | 40.02 | 47.77 | 54.54 | 61.30 | 67.21 | 72.16 | 76.12 | 78.89 | 81.07 | 82.98 |
| NH - Unmanaged | 48.45 | 55.44 | 61.56 | 66.58 | 70.11 | 72.75 | 74.70 | 76.31 | 77.58 | 78.78 |
| WP - Unmanaged | 50.94 | 57.92 | 64.15 | 69.46 | 73.82 | 77.40 | 80.26 | 82.64 | 84.61 | 86.33 |

## Exhibit 5-6b: BAU 32% Removal TSC Accumulation by Cover Type



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| HE - BAU 32% (65% T&L Removed) | 32.40 | 41.86 | 51.42 | 60.49 | 68.17 | 74.85 | 80.73 | 85.06 | 88.40 | 91.32 |
| MH - BAU 32% (65% T&L Removed) | 37.48 | 45.04 | 53.10 | 59.98 | 65.55 | 70.33 | 74.30 | 77.58 | 80.31 | 82.72 |
| MO - BAU 32% (65% T&L Removed) | 31.19 | 39.21 | 46.63 | 53.88 | 60.13 | 65.56 | 69.75 | 72.89 | 75.59 | 77.99 |
| NH - BAU 32% (65% T&L Removed) | 38.46 | 45.70 | 53.72 | 59.86 | 64.32 | 67.76 | 70.26 | 72.56 | 74.38 | 76.19 |
| WP - BAU 32% (65% T&L Removed) | 39.98 | 47.28 | 54.42 | 60.79 | 65.98 | 70.47 | 74.07 | 77.16 | 79.68 | 82.00 |

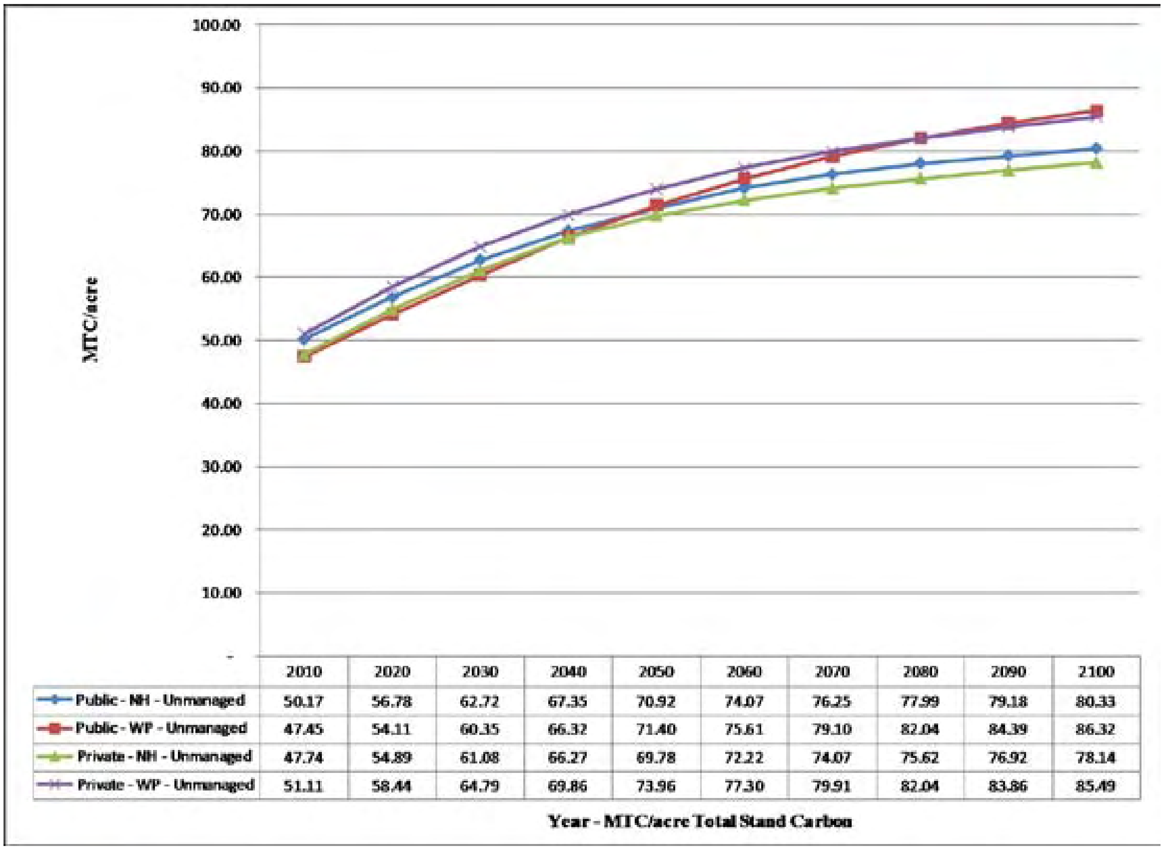
## Exhibit 5-6c: Heavy Harvest BA40 TSC Accumulation by Cover Type



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| HE - Heavy Harvest BA40 (65% T&L Removed) | 21.60 | 28.16 | 37.46 | 47.03 | 55.32 | 62.73 | 69.47 | 75.07 | 80.29 | 84.87 |
| MH - Heavy Harvest BA40 (65% T&L Removed) | 25.09 | 32.02 | 42.46 | 51.75 | 58.73 | 63.90 | 68.28 | 72.40 | 75.92 | 78.92 |
| MO - Heavy Harvest BA40 (65% T&L Removed) | 22.53 | 29.63 | 38.34 | 46.19 | 52.98 | 59.08 | 64.02 | 67.99 | 71.33 | 74.52 |
| NH - Heavy Harvest BA40 (65% T&L Removed) | 26.36 | 31.70 | 41.37 | 50.25 | 56.28 | 60.45 | 63.91 | 66.95 | 70.26 | 72.27 |
| WP - Heavy Harvest BA40 (65% T&L Removed) | 25.73 | 32.23 | 42.13 | 50.20 | 56.37 | 61.28 | 65.32 | 68.78 | 71.93 | 74.83 |

Year - MTC/acre Total Stand Carbon

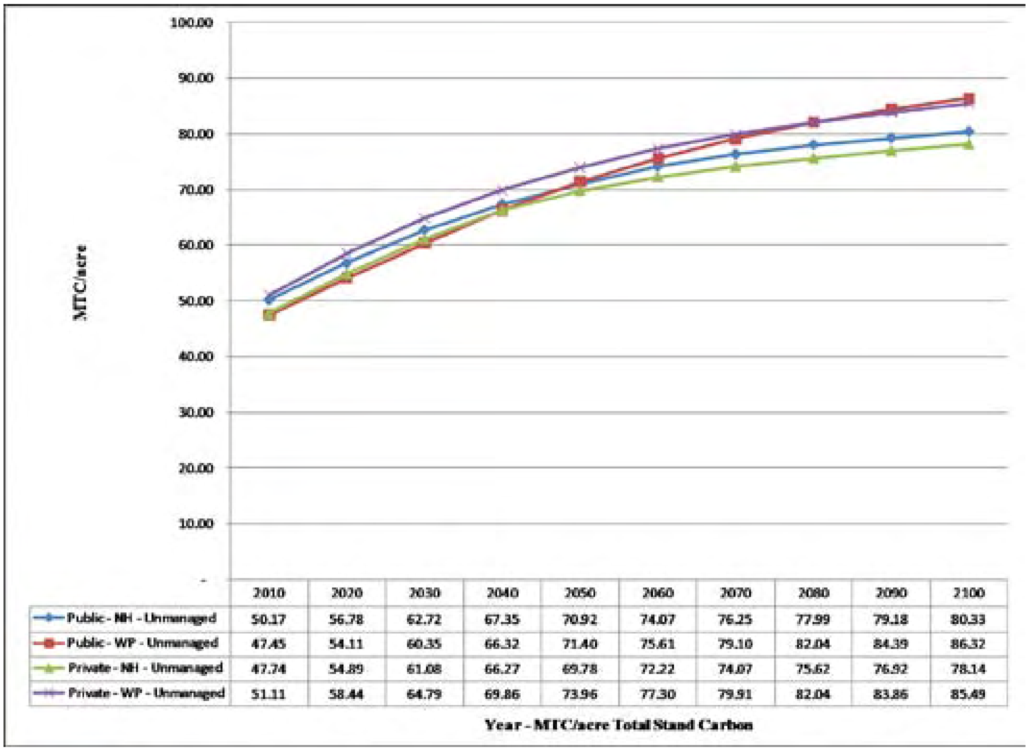
## Exhibit 5-7: Ownership Similarities in Carbon Accumulation Over Time by Cover Type (TSC)



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Public - NH - Unmanaged | 50.17 | 56.78 | 62.72 | 67.35 | 70.92 | 74.07 | 76.25 | 77.99 | 79.18 | 80.33 |
| Public - WP - Unmanaged | 47.45 | 54.11 | 60.35 | 66.32 | 71.40 | 75.61 | 79.10 | 82.04 | 84.39 | 86.32 |
| Private - NH - Unmanaged | 47.74 | 54.89 | 61.08 | 66.27 | 69.78 | 72.22 | 74.07 | 75.62 | 76.92 | 78.14 |
| Private - WP - Unmanaged | 51.11 | 58.44 | 64.79 | 69.86 | 73.96 | 77.30 | 79.91 | 82.04 | 83.86 | 85.49 |

Year - MTC/acre Total Stand Carbon

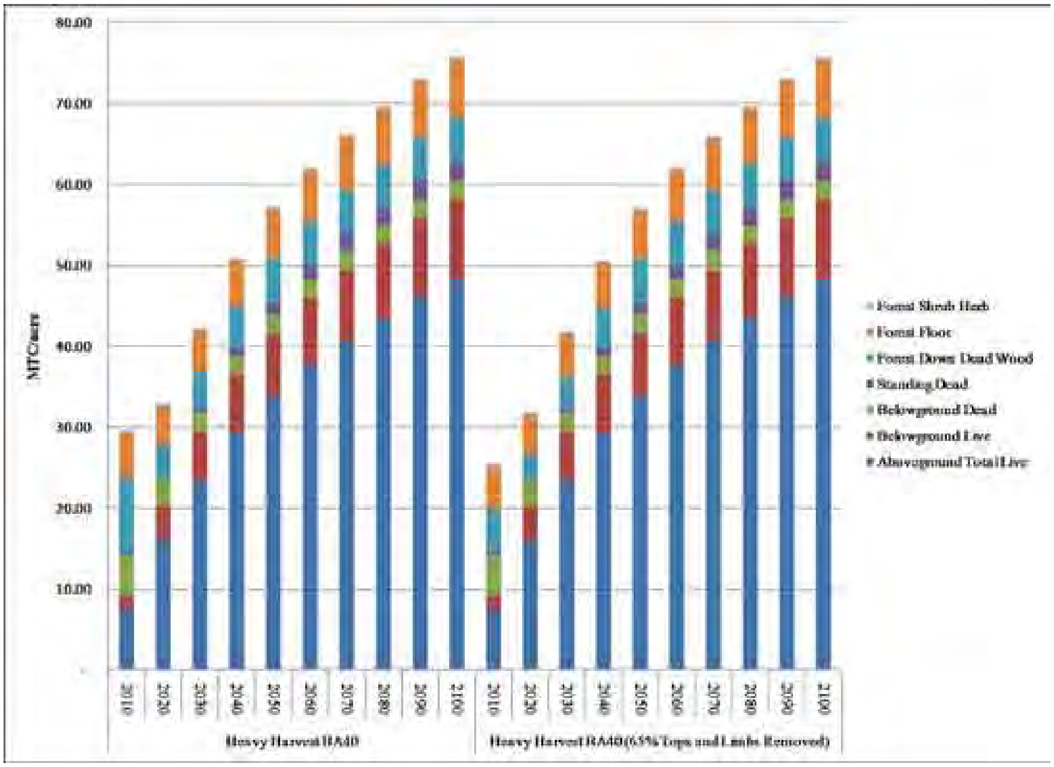
### Exhibit 5-8: Tops and Limbs Contribution to Total Stand Carbon



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Public - NH - Unmanaged | 50.17 | 56.78 | 62.72 | 67.35 | 70.92 | 74.07 | 76.25 | 77.99 | 79.18 | 80.33 |
| Public - WP - Unmanaged | 47.45 | 54.11 | 60.35 | 66.32 | 71.40 | 75.61 | 79.10 | 82.04 | 84.39 | 86.32 |
| Private - NH - Unmanaged | 47.74 | 54.89 | 61.08 | 66.27 | 69.78 | 72.22 | 74.07 | 75.62 | 76.92 | 78.14 |
| Private - WP - Unmanaged | 51.11 | 58.44 | 64.79 | 69.86 | 73.96 | 77.30 | 79.91 | 82.04 | 83.86 | 85.49 |

*Note: Comparison of harvest scenarios with all tops and limbs retained onsite following harvest versus removing 65% of tops and limbs (BAU 32%, Heavy Harvest BA40, and Commercial Clearcut). Total Stand Carbon values reflect the movement of carbon from tops and limbs into the down dead and forest floor carbon pools over time.*

### Exhibit 5-9: Carbon Pool Comparison



*Note: Carbon pools after a Heavy Harvest (BA40) when 100% of Tops and Limbs are retained vs. 65% removed.*

## 5.5 CONCLUSION

What do we know about modeling carbon accumulation patterns with and without harvesting?

- The basic elements of stand dynamics (and thus carbon dynamics) are the interaction among: space, light, species silvical characteristics (how they grow, regenerate, light tolerance, moisture tolerance), and site characteristics. The FVS model handles the first three elements quite well. We have held the fourth element constant throughout.

- Starting condition matters. No two acres of "natural" forest will be exactly alike. Stand development (particularly in the form of carbon growth and yield) is the reflection of the unique attributes of a given acre, but broad patterns are somewhat predictable based on what we know about the silvical characteristics of individual species and how they interact with each other. Starting diameter distribution (or mean diameter) is a driver of carbon accumulation rates since growth rates will depend on the current diameter of the individual trees making up the stand.

- Basal Area (square feet per acre) in combination with Trees Per Acre (density) is a driver of carbon accumulation rates since it reflects the space available to grow and regenerate.

- Species composition of a plot/stand is also a driver. Differential rates of growth drive differential rates of carbon accumulation. Allometric equations of hardwood vs. softwood are also a factor (e.g., taper, tree architecture).

- The above elements all relate to the influence of stand history on current conditions as well. This history includes the impacts of prior harvests and stand origin (e.g., old field, fire, 1938 hurricane). From a modeling and stand dynamics perspective, stand age (and tree age) also influences biomass/carbon growth rates. Some opportunities exist to "reset" an understocked or degraded stand. Conventional wisdom of foresters often says you would be better off starting over; it appears that can be true if regeneration yields desirable species—but it may just be a carbon/biomass response and the quality species mix for long-term growth may be sacrificed.

- The removal of tops and limbs generally has little impact on stand level carbon dynamics in Massachusetts forests. Tops and limbs that are not removed during a harvest decay quickly, generally within 10 years. If tops and limbs are a small proportion of the total harvest, then new growth will compensate for the removal within 10 years as well.

- Apart from severely understocked or degraded stands, carbon accumulation onsite in unmanaged stands will exceed onsite storage in managed stands in the long term (i.e., greater than 90 years).

- The current "business-as-usual" light harvest in the canopy increases the growth rate in the initial ten-year period, but very quickly returns to approximately the same as the unmanaged growth rate. Over time these BAU stands approach unmanaged carbon stocking but do not quite catch up after 90 years. When considered in the context of the amount of forest harvested annually in Massachusetts there is little impact of harvesting on the onsite forest carbon balance across the state.

- The scenarios we defined as "biomass" harvests (Biomass 40%, Biomass BA40, Biomass BA60) maintain high growth rates for several decades. Because of this increased growth rate, even the heavier harvested stands can reach almost 90% of the volume that could have been achieved in an unmanaged scenario. So, over a long period of time, biomass harvests have an opportunity to recover a large portion of the carbon volume removed during the harvest. However, this assumes no future harvests in the stand as well as an absence of any significant disturbance event. Both are unlikely.

- The FVS NE Variant is an effective tool to evaluate stand-level response of forest carbon to harvesting for relatively long time periods in Massachusetts. The model has known limitations but generally reflects what we know about trends in forest stand dynamics.

## REFERENCES

Crookston, N.L., and Dixon, G.E. 2005. The forest vegetation simulator: a review of its structure, content and applications. Comput. Electron. Agric. 49(1): 60–80.

Foley, T.G., D. deB. Richter, and C.S. Galik. 2009. Extending rotation age for carbon sequestration: A cross-protocol comparison of North American forest offsets *Forest Ecology and Management* 259:201-209.

Hilt, D.E., and R.M. Teck. 1989. NE-TWIGS: An individual-tree growth projection system for the Northeastern United States. *The Compiler* 7: 10-16.

Hornbeck, J.W. and W.B. Leak. 1992. Ecology and management of northern hardwood forests in New England. *General Technical Report* NE-159 USDA, Forest Service, Northeastern Forest Experiment Station. 41 pp.

IPCC. 2007. Climate Change 2007: The Physical Basis. Summary for Policy Makers. Available on-line: www.ipcc.ch/SPM2feb07.pdf

Jenkins, J.C., D.C. Chojnacky, L.S. Heath, and R.A. Birdsey. 2003. National-scale biomass estimators for United States tree species. *Forest Science* 49:12-35.

Johnson, D.W., and P.S. Curtis. 2001. Effects of forest management on soil C and N storage: meta analysis. *Forest Ecology and Management* 140: 227-238.

Keeton, W.S. 2006. Managing for late-successional/old-growth characteristics in northern hardwood-conifer forests. *Forest Ecology and Management* 235: 129-142

Keeton, W.S., A. A. Whitman, G.G. McGee, and C.L. Goodale. In Press. Late-successional biomass development in northern hardwood-conifer forests of the northeastern United States. *Forest Science.*

Kelty, M.J., T.W. D'Amato, and P.K. Barten. January 2008. *Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts*. Prepared for the Massachusetts Department of Energy Resources and the Massachusetts Department of Conservation and Recreation. 65 p.

Leak, W.B., 2005. Effects of small patch cutting on sugar maple regeneration in New Hampshire northern hardwoods. *Northern Journal of Applied Forestry* 22, 68–70.

Leak, W.B., Solomon, D.S., and DeBald, P.S., 1987. Silvicultural *Guide for Northern Hardwood Types in the Northeast (revised)*. In: USDA Forest Service, Northeastern Research Station, General Technical Report NE-603.

Luyssaert, S., E. Detlef Schulze, A. Börner, A. Knohl, D. Hessenmöller, B. E. Law, P. Ciais, and J. Grace. 2008. Old-growth forests as global carbon sinks. *Nature* 455:213–215.

National Council on Science for Sustainable Forestry (NCSSF). 2008. *Beyond Old Growth: Older Forests in a Changing World, A synthesis of findings from five regional workshops*. National Council for Science and the Environment. Washington DC. 44 pp.

Nave, L.E., E.D. Vance, C.W. Swanston, and P.S. Curtis. 2010. Harvest impacts on soil carbon storage in temperate forests. *Forest Ecology and Management* 259:857-866.

Nunery, J.S., and W.S. Keeton. 2010. Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. *Forest Ecology and Management* 259:1363-1375.

O'Donnell, F.C. 2007. Carbon Dynamics of a New England Temperate Forest Five Years After Selective Logging. Senior Thesis in Organismic and Evolutionary Biology. *Harvard Forest*.

Oliver, C. D., and B. C. Larson. 1996. *Forest Stand Dynamics*. John Wiley & Sons, Inc. New York, NY. 520 pp.

Perez-Garcia, J., Lippke, B., Comnick, J., Manriquez, C., 2005. An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. Wood Fib. Sci. 37, 140–148.

Ray, D.G., Saunders, M.R., Seymour, R.S., 2009. Recent changes to the northeast variant of the forest vegetation simulator and some basic strategies for improving model outputs. *Northern Journal of Applied Forestry* 26, 31–34.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey. 2006. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. Gen. Tech. Rep. NE-343. USDA For. Serv., Northeastern Res. Stn., Newtown Square, PA.

Urbanski, S., C. Barford, S. Wofsy, C. Kucharik, E. Pyle, J. Budney, K. McKain, D. Fitzjarrald, M. Czikowsky, and J. W. Munger (2007), Factors controlling CO2 exchange on timescales from hourly to decadal at Harvard Forest, J. Geophys. Res., 112, G02020, doi:10.1029/2006JG000293.

Van Deusen, P. In Press. Carbon sequestration potential of forest land: Management for products and bioenergy versus preservation, *Biomass and Bioenergy*. 2010. doi:10.1016/j.biombioe.2010.03.007

Yaussy, D.A. 2000. Comparison of an empirical forest growth and yield simulator and a forest gap simulator using actual 30-year growth from two even-aged forests in Kentucky. *Forest Ecology and Management* 126:385-398.

# CHAPTER 6

# CARBON ACCOUNTING FOR FOREST BIOMASS COMBUSTION

## 6.1 INTRODUCTION

Greenhouse gas (GHG) emissions from bioenergy systems raise complex scientific and energy policy issues that require careful specification of an appropriate carbon accounting framework. This accounting framework should consider both the short and long term costs and benefits of using biomass instead of fossil fuels for energy generation. In most cases, the carbon emissions produced when forest biomass is burned for energy are higher than the emissions from burning fossil fuels. But over the long term, this carbon can be resequestered in growing forests. A key question for policymakers is the appropriate societal weighting of the short term costs and the longer term benefits of biomass combustion. This chapter provides analysis designed to help inform these decisions.

As discussed in Chapter 1, government policies have reflected a widely-held view that energy production from renewable biomass sources is beneficial from a GHG perspective. In its simplest form, the argument has been that because growing forests sequester carbon, then as long as areas harvested for biomass are remain forested, the carbon is reabsorbed in growing trees and consequently the net impact on GHG emissions is zero.[1] In this context, biomass combustion for energy production has often been characterized as "carbon neutral."

Assumptions of biomass carbon neutrality—the view that forest biomass combustion results in no net increase in atmospheric GHG levels—have been challenged on the grounds that such a characterization ignores differences in the *timing* of carbon releases and subsequent resequestration in growing forests (Johnson, 2008). Burning biomass for energy certainly releases carbon in the form of $CO_2$ to the atmosphere—in fact, as will be discussed below, per unit of useable energy biomass typically releases more $CO_2$ than natural gas, oil or coal. In "closed loop" bioenergy systems—for example biomass from plantations grown explicitly to fuel bioenergy facilities—energy generation will be carbon neutral or close to carbon neutral if the biomass plantation represents stored carbon that would not have been there absent the biomass plantation. Net GHG impacts of biomass from sources other than natural forests may also be carbon neutral (or close) where these materials would have quickly entered the atmosphere through decay (e.g., residue from landscaping and tree work, construction waste). But for natural forests where stocks of carbon are harvested for biomass, forest regeneration and growth will not instantaneously recapture all the carbon released as a result of using the woody material for energy generation, although carbon neutrality—resequestering all the forest biomass carbon emitted—may occur at some point in the future if the harvested land is sustainably managed going forward, for example under one of the widely recognized forest certification programs (e.g., FSC, SFI or PEFC). How long this will take for typical Massachusetts forest types and representative energy facilities, and under what conditions, is a primary focus of this study.

### 6.1.1 BRIEF REVIEW OF PREVIOUS STUDIES

The issue of net GHG benefits from burning forest biomass has been a topic of discussion since the early to mid-1990s. Beginning in 1995, Marland and Schlamadinger published a series of papers that addressed the issue, pointing out the importance of both site-specific factors and time in determining the net benefits of biomass energy (Marland and Schlamadinger, 1995; Schlamadinger and Marland, 1996a, 1996b and 1996c). This work initially was based on insights from a simple spreadsheet model, which evolved over time into the Joanneum Research GORCAM model (Marland et al., undated). A variety of other models are now available for performing similar types of bioenergy GHG analyses. These include $CO_2$Fix (Schellhaas et al., 2004), CBM-CFS3 (Kurz et al., 2008), and RetScreen (Natural Resources Canada, 2009). Generally these models differ in their choice of algorithms for quantifying the various carbon pools, their use of regional forest ecosystems information, and the methods used to incorporate bioenergy scenarios. Other studies have addressed these issues for specific locations using modeling approaches developed for the conditions in the region (Morris, 2008). Work on the development of appropriate models of biomass combustion carbon impacts continues to be a focus of the Task 38 initiatives of the International Energy Agency (Cowie, 2009).

In general, the scientific literature on the GHG impacts of forest biomass appears to be in agreement that impacts will depend on the specific characteristics of the site being harvested, the energy technologies under consideration, and the time frame over which the impacts are viewed (IEA, 2009). Site-specific factors that may have an important influence include ecosystem productivity, dynamics and disturbance (e.g., dead wood production and decay rates, fire, etc.); the volume of material harvested from a site for biomass; the efficiency of converting biomass to energy; and the characteristics of the fossil fuel system replaced. Recent research has also raised several other site-specific issues. Cowie (2009) cites research at Joanneum on albedo effects, which in some locations have the ability to offset some or potentially all the GHG effects of biomass combustion.[2] The effect of climate change itself on carbon flows into and out of soil and above-ground live and dead carbon pools is another factor that has yet to be routinely incorporated into biomass energy analyses.

Because of the site-specific nature of biomass GHG effects, we have developed an approach to evaluating impacts using available data on the characteristics of regional energy facilities and a forest

---

[1] Even when lifecycle biomass production emissions are taken into account, the argument is that net impacts on GHG, while perhaps not zero, are at least very low.

[2] This has generally been considered a more serious issue for harvests in forests located at higher latitudes than Massachusetts—areas where harvests interact with longer periods of snow cover to increase reflectivity.

ecosystems model that represents conditions in Massachusetts. In the next section, we discuss the overall carbon accounting framework for our analysis.

### 6.1.2 CARBON ACCOUNTING FRAMEWORK

Energy generation, whether from fossil fuel or biomass feedstocks, releases GHGs to the atmosphere. The GHG efficiency—the amount of lifecycle GHG emissions per unit of energy produced—varies based on both the characteristics of the fuel and the energy generation technology. However, biomass generally produces greater quantities of GHG emissions than coal, oil or natural gas. If this were not the case, then substituting biomass for fossil fuels would immediately result in lower GHG emissions. The benefits of biomass energy accrue only over time as the "excess" GHG emissions from biomass are recovered from the atmosphere by growing forests. Researchers have recently argued that the carbon accounting framework for biomass must correctly represent both the short term costs and the longer term benefits of substituting biomass for fossil fuel (Hamburg, 2010).[3]

At the most general level, the carbon accounting framework we employ is constructed around comparisons of fossil fuel scenarios with biomass scenarios producing equivalent amounts of energy. The fossil fuel scenarios are based on lifecycle emissions of GHGs, using "$CO_2$ equivalents" as the metric ($CO_2e$).[4] Total GHG emissions for the fossil scenarios include releases occurring in the production and transport of natural gas, coal or oil to the combustion facility as well as the direct stack emissions from burning these fuels for energy. Similarly, GHG emissions from biomass combustion include the stack emissions from the combustion facility and emissions from harvesting, processing and transporting the woody material to the facility. Most importantly, both the fossil fuel and biomass scenarios also include analyses of changes in carbon storage in forests through a comparison of net carbon accumulation over time on the harvested acres with the carbon storage results for an equivalent stand that has not been cut for biomass but that has been harvested for timber under a business-as-usual (BAU) scenario. Our approach includes the above- and below-ground live and dead carbon pools that researchers have identified as important contributors to forest stand carbon dynamics.[5]

The conceptual modeling framework for this study is intended to address the question of how atmospheric GHG levels will change if biomass displaces an equivalent amount of fossil fuel generation in our energy portfolio. With this objective, the modeling quantifies and compares the cumulative net annual change in atmospheric $CO_2e$ for the fossil and biomass scenarios, considering both energy generation emissions and forest carbon sequestration. In the fossil fuel scenarios, there is an initial $CO_2e$ emissions spike associated with energy generation—assumed here to be equivalent to the energy that would be produced by the combustion of biomass harvested from one acre—which is then followed by a drawing down over time (resequestration) of atmospheric $CO_2e$ by an acre of forest from which no biomass is removed for energy generation. For the biomass scenario, there is a similar initial release of the carbon from burning wood harvested from an identical acre of natural forest, followed by continued future growth and sequestration of carbon in the harvested stand.

This process is summarized in the hypothetical example shown Exhibit 6-1 below. Energy emissions represent flows of carbon to the atmosphere and forest sequestration represents capture of carbon that reduces atmospheric levels. We assume the fossil fuel and biomass scenarios produce exactly the same amount of useable energy. The example is based on a fossil fuel facility that generates 10 tonnes of lifecycle C emissions and a BAU (timber cutting but no biomass removals) where total stand carbon (TSC) in all pools is rising by 0.15 tonnes per year. In the biomass scenario, lifecycle bioenergy emissions are 15 tonnes of C and TSC on the forest, which was harvested for both timber and biomass, is increasing by 0.25 tonnes of C per year, a reflection of higher rates of forest growth that can result from increases in sunlight and growing space in the more heavily harvested stand.

The bottom row of Exhibit 6-1 shows the incremental emissions from biomass energy generation (5 tonnes C) and the incremental (beyond a BAU forest management scenario) change in forest carbon sequestration (0.1 t/C/y or 1 tonne of carbon per decade). The cumulative net change (referred to hereafter as the carbon "flux") in atmospheric C is equivalent for the two feedstocks at the point in time where cumulative TSC increases, above and beyond the accumulation for the fossil fuel scenario, just offset the incremental C emissions from energy generation. In the example this occurs at year 2060 when the forest has sequestered an additional 5 tonnes of C, equivalent to the initial "excess" biomass emissions. Before that time, cumulative carbon flux is higher for the biomass scenario, while after 2060 the biomass scenario results in lower cumulative atmospheric C flux. In this comparison, not until after 2060 would the biomass energy option become better than the fossil fuel with respect to impact on GHGs in the atmosphere. Furthermore, in the example full carbon neutrality would not be achieved, assuming no change in growth rates, until five decades after 2110, at which point the entire 15 tonnes of biomass energy emissions will have been recovered in new forest growth.

---

[3] More broadly, climate and energy policies should consider the full range of alternative sources of energy. Energy conservation and sources such as wind, solar or nuclear have no or very low carbon emissions and may also provide additional, potentially competing, options for reducing GHGs.

[4] These adjustments incorporate the IPCC's normalization factors for methane and nitrous oxides.

[5] Typically wood products would also be included as an important carbon pools but because we assume these products are produced in the same quantities in both the BAU forest management and biomass scenarios, there will be no net change and thus there is no reason to track these explicitly. We also have not modeled soil carbon explicitly as recent papers suggest that this variable is not particularly sensitive to wood harvests (Nave et al., 2010).

**Exhibit 6-1: Carbon Accounting Framework (tonnes-carbon)**

| Scenario | Energy Generation Emissions | Forest Stand Cumulative Total Carbon Accumulation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2010** | **2020** | **2030** | **2040** | **2050** | **2060** | **2070** | **2080** | **2090** | **2100** | **2110** |
| **Biomass** | -15 | 2.5 | 5.0 | 7.5 | 10.0 | 12.5 | 15.0 | 17.5 | 20.0 | 22.5 | 25.0 |
| **Fossil** | -10 | 1.5 | 3.0 | 4.5 | 6.0 | 7.5 | 9.0 | 10.5 | 12.0 | 13.5 | 15.0 |
| **Net Change** | -5 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 |

Adoption of this conceptual framework allows a useful and potentially important reframing of the biomass carbon neutrality question. From a GHG perspective, environmental policymakers in Massachusetts might prefer biomass to fossil fuels even if biomass combustion is not fully carbon neutral—that is even if biomass burning increases carbon levels in the atmosphere for some period of time. For example, it is possible that over some policy-relevant time frame burning biomass for energy could result in cumulatively lower atmospheric $CO_2e$ levels than generating the same amount of energy from coal, oil or natural gas—although these levels may still represent an increase in GHGs relative to today's levels. Rather than focusing all the attention on the carbon neutrality of biomass, our approach illustrates that there is a temporal component to the impacts of biomass GHG emissions to the atmosphere. The questions then become: (1) do policymakers seek to promote an energy source that could benefit the atmosphere over the long term, but that imposes increased GHG levels relative to fossil fuels in the shorter term (perhaps several decades); and (2) do the long term atmospheric benefits outweigh the short term costs?

A useful way to understand the relative carbon dynamics is to isolate the key drivers of net carbon flux. From this perspective, the incrementally greater amount of $CO_2e$ associated with biomass energy is the relevant starting point. Following on the terminology developed by Fargione et al. (2008), we refer to these incremental emissions as the biomass "carbon debt."

In addition, we introduce the concept of "carbon dividends," which represent the longer term benefits of burning biomass. In the example in Exhibit 6-1, these dividends can be thought of as the reductions in future atmospheric carbon represented in the years after the carbon debt has been recovered (i.e., after 2060). For example, by 2100 all 5 tonnes of excess C from biomass burning have been recovered plus another 4 tonnes (the dividend) that reflects additional reductions in emissions beyond what would have resulted if only fossil fuel had been used to generate energy.

Graphically, the concepts of carbon debt and carbon dividend are illustrated in Exhibit 6-2. Exhibit 6-2a shows hypothetical carbon sequestration profiles for a stand harvested in a "business as usual" timber scenario and the same stand with a harvest that augments the BAU harvest with removal of 20 tonnes of additional carbon. Exhibit 6-2b shows the net carbon recovery profile for the biomass versus BAU harvest. This represents the incremental growth of the stand following the biomass harvest (relative to the BAU harvest) that is needed to recover the biomass carbon debt and begin accruing carbon dividends (calculated as the difference in growth between the biomass and BAU harvests). In the example, the carbon debt (9 tonnes) is shown as the difference between the total C harvested for biomass (20 tonnes) and the C released by fossil fuel burning (11 tonnes) that produces an equivalent amount of energy.

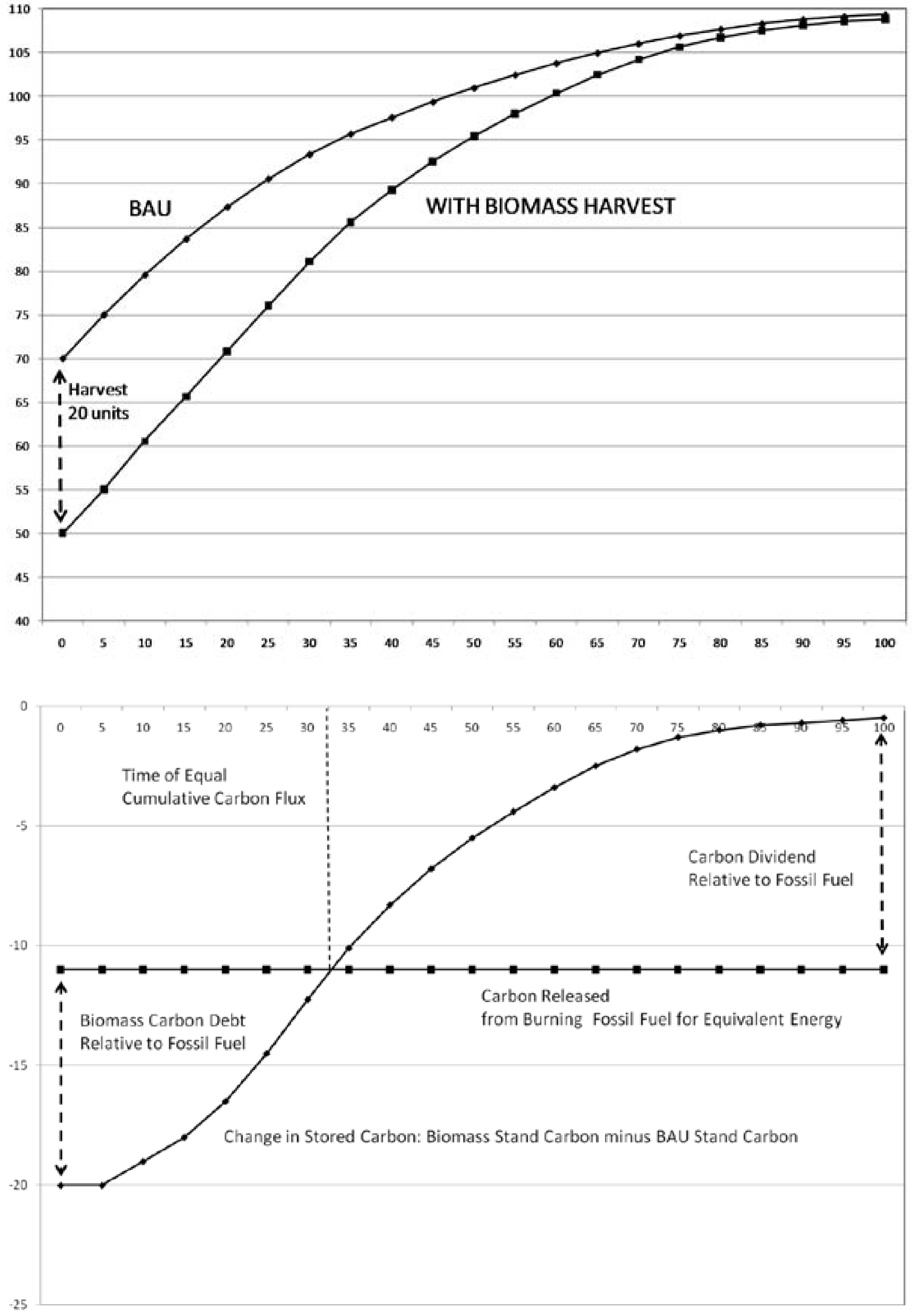
**Exhibit 6-2a and 6-2b: Total Stand Carbon and Carbon Recovery Times (tonnes carbon)** (see next page)

The carbon dividend is defined in the graph as the fraction of the equivalent fossil fuel emissions (11 tonnes) that are offset by forest growth at a particular point in time. In the example, after the 9 tonne biomass carbon debt is recovered by forest growth (year 32), atmospheric GHG levels fall below what they would have been had an equivalent amount of energy been generated from fossil fuels. This is the point at which the benefits of burning biomass begin to accrue, rising over time as the forest sequesters greater amounts of carbon relative to the BAU. Throughout this report we quantify these dividends as the percentage of the equivalent fossil fuel emissions that have been offset by forest growth. By approximately year 52, the regrowth of the stand has offset an additional 6 tonnes of emissions beyond what was needed to repay the carbon debt—representing an offset (or dividend) equal to 55% of the carbon that would have been emitted by burning fossil instead of biomass feedstocks.[6] In this context, a 100% carbon dividend (almost achieved in year 100 in the example) represents the time at which all 20 tonnes of emissions associated with burning biomass have been resequestered as new forest growth. In a benefit-cost analytical framework, decisionmakers would decide whether the tradeoff of higher initial atmospheric carbon levels—occurring in the period before the carbon debt is fully recovered—is an acceptable cost given the longer term benefits represented by the carbon dividends.

---

[6] The carbon dividend, expressed as the percentage of the equivalent fossil fuel emissions offset by the growing forest, is calculated as the 6 tonnes of reduction (beyond the debt payoff point) divided by the 11 tonnes of fossil fuel equivalent that would have been needed to generate the energy produced by burning wood that released 20 tonnes of carbon.

**Exhibit 6-2a and 6-2b: Total Stand Carbon and Carbon Recovery Times (tonnes carbon)**



To see why carbon debt is an important driver of impacts, consider the hypothetical case where a biomass fuel's lifecycle $CO_2e$ emissions from electricity production are one gram less per megawatt-hour (MWh) than that of coal (i.e., the carbon debt is negative). All else equal, one would prefer biomass from a GHG perspective since the emissions are initially lower per unit of energy, and this is the case even if one ignores that fact that cumulative net carbon flux to the atmosphere will fall further in the future as carbon is resequestered in regenerating forests. In the example, biomass would not be immediately carbon neutral, but would still have lower emissions than coal and would begin to accumulate carbon dividends immediately.

From an atmospheric GHG perspective, the policy question only becomes problematic when $CO_2e$ emissions from biomass are above that of the fossil fuel alternative (i.e., where the carbon debts for biomass are positive). Because wood biomass emissions are typically higher than coal, oil and natural gas at large-scale electric, thermal or CHP facilities, this is in fact the decision policymakers face.

Framing the problem this way shifts the focus away from total emissions, allowing the net carbon flux problem to be viewed in purely incremental terms. *In our forest carbon accounting approach, the question then becomes how rapidly must the forest carbon sequestration rate increase after a biomass harvest in order to pay back the biomass carbon debt and how large are the carbon dividends that accumulate after the debt is recovered?* The debt must be paid off before atmospheric GHG levels fall below what they would have been under a fossil fuel scenario. After that point, biomass energy is yielding net GHG benefits relative to the fossil fuel scenario.

In this framework, the net flux of GHGs over time depends critically on the extent to which the biomass harvest changes the rate of biomass accumulation on the post-harvest stand. If the rate of total stand carbon accumulation, summed across all the relevant carbon pools increases very slowly, the biomass carbon debt may not be paid back for many years or even decades, delaying the time when carbon dividends begin to accumulate. Alternatively, for some stands, and especially for slow-growing older stands, harvesting would be expected to increase the carbon accumulation rate (at least after the site recovers from the initial effects of the harvest) and lead to relatively more rapid increases in carbon dividends. Determining the time path for paying off the carbon debts and accumulating carbon dividends is a principle focus of our modeling approach.

In this context, it is also important to note that the point at which the cumulative carbon flux from biomass just equals the cumulative flux from fossil fuels (the point at which the biomass carbon debt is paid off) is not necessarily the point at which a policymaker is indifferent between the biomass and fossil fuel scenarios. For example, the policymaker might only be indifferent at the time when the discounted damages resulting from the excess biomass emissions just equals zero—this is the point in time at which early damages due to increased GHG levels from biomass are just offset by lower biomass damages in later years when net cumulative GHG flux from biomass is below that of the fossil fuel alternative. In this case, longer time periods are needed to reach the point defined as "fully-offset damages." The higher the discount rate—indicative of a greater preference for lower GHG levels in the near-term, the longer the time to reach the point of fully-offset damages.

### 6.1.3 OTHER CONSIDERATIONS: LANDSCAPE OR STAND-LEVEL MODELING

A key question in developing the conceptual framework for biomass GHG analysis is whether to analyze the problem at the level of the individual stand or across the entire landscape affected by biomass harvests. A recent formulation of the biomass carbon neutrality argument focuses on the forested landscape across the entire wood supply zone for a biomass plant—as opposed to individual harvested stands—and suggests that as long as landscape-scale forest growth is in excess of harvests, then biomass is embedded in the natural carbon cycle of the forests and is causing no net increase in GHG emissions (Miner, 2010). In our view, however, this landscape approach to carbon neutrality is incomplete because it does not fully frame the issue with respect to the carbon sequestration attributes of the forested landscape in a "business as usual" scenario. In general, the carbon accounting model should be premised on some knowledge of how lands will be managed in the future absent biomass harvests, and this becomes a critical reference point for analyzing whether burning biomass for energy results in increased or decreased cumulative GHG emissions over time.

Consequently, appropriate characterization of the BAU baseline is essential to the development of an accurate carbon accounting model of forest biomass combustion. In the case of the landscape argument for carbon neutrality, the conclusion that biomass burning has no net impact on GHG emissions does not account for the fact that in the absence of biomass harvests, the forests would likely have continued to sequester carbon anyway.[7] Therefore, a well-framed landscape analysis needs to consider the net carbon emissions of biomass burning relative to the BAU scenario of continued carbon accumulation by forests across the landscape. Framing the problem this way does not necessarily negate the landscape carbon neutrality argument—it simply recognizes that the landscape level carbon accounting problem is a more complicated one. However, when a complete representation of the baseline is taken into account, the landscape-scale and the

---

[7] This assumes that additional biomass stumpage revenues will not dramatically alter the acreage devoted to commercial forestry activities. We believe this is a reasonable assumption given the current low prices for biomass stumpage. At $1 to $2 per green ton, few, if any, landowners would see enough change in revenue from biomass sales to alter their decisions about whether to keep forest land or sell it to someone who is looking to change the land use (e.g., a developer). As a result, we do not address the carbon issues associated with conversion of natural forests to energy plantations. We also do not address "leakage" issues that might arise if productive agricultural land is converted to energy plantations and this leads to clearing forests somewhere else to create new cropland.

stand-level frameworks may yield the same result. The following simplified numerical example provides an illustration of why this is the case.

The example assumes an integrated energy/forest system made up of three carbon pools—the forest, atmosphere, and fossil fuel pools—each initially containing 1000 tonnes of carbon. In addition, we assume burning biomass releases 50 percent more emissions than burning fossil fuels for an equivalent level of energy production—close to the estimate of carbon debts when comparing biomass and coal-fired electricity generation. Finally, we specify that an average forest's total stand carbon across the above- and below-ground carbon pools increases by 5% per year, or 50 tonnes in our example.

In year one of a coal-fired electric scenario, we assume energy production at a level that transfers 10 units of carbon from the fossil fuel pool to the atmosphere. In the same year, the forest removes 50 tonnes of carbon from the atmosphere. The net values for each pool after one year are:

- **Fossil Fuel Carbon Pool:** 990 tonnes (1000 tonnes–10 tonnes released from energy production)
- **Forest Carbon Pool:** 1050 tonnes (1000 tonnes + 50 tonnes forest sequestration)
- **Atmospheric Carbon Pool:** 960 tonnes (1000 tonnes+ 10 tonnes emissions–50 tonnes forest sequestration).

Alternatively, we consider a change in energy production that replaces fossil fuel with biomass, in this case releasing 15 tonnes of carbon versus 10 tonnes in the equivalent energy fossil scenario. We also assume that cutting the forest does not reduce total carbon sequestration (i.e., that the harvested areas of the forest still add carbon at the 5 percent rate).[8] At the end of the first year, the carbon pools are as follows:

- **Fossil Fuel Carbon Pool:** 1000 tonnes (no change)
- **Forest Carbon Pool:** 1035 tonnes (1000 tonnes–15 tonnes biomass + 50 tonnes forest sequestration)
- **Atmospheric Carbon Pool:** 965 tonnes (1000 tonnes + 15 tonnes emissions–50 tonnes forest sequestration).

In the example, it is true that forest growth across the landscape exceeds the amount of biomass harvested (50 tonnes of new sequestration versus 15 tonnes of biomass removals)—the condition under which advocates of landscape-level carbon neutrality would argue that biomass burning is embedded in a natural cycle in which forest sequestration (50 t-C/y) exceeds removals for biomass (15 t-C/y). But it is also true that the initial effect of switching to biomass is to increase atmospheric carbon levels, in this case by 5 tonnes. The result makes clear that when the BAU baseline is correctly specified, the net change in GHG from biomass is equivalent to the biomass carbon debt, and therefore that carbon neutrality is not achieved immediately.

Introducing the assumption that additional stands are harvested in subsequent years to provide fuel for a biomass plant—while adding greater complexity to the analysis—does not alter the basic conclusions as long as stands are harvested randomly (e.g., stands with rapid carbon recovery rates are no more or less likely to be harvested than stands with slower carbon recovery). For each additional year of harvests, a carbon debt is incurred and these are additive over time. Similarly, the period required to pay off the debt is extended one year into the future for each additional year of harvests. Finally, the longer-term dividends are also additive and will accumulate over time as greater quantities of fossil fuel emissions are offset by forest growth.

The one area where landscape scale analysis might alter conclusions about carbon debts and dividends is a situation where the stands with more rapid carbon recovery profiles can be scheduled for harvest sooner than the slower recovery stands. This has the potential to accelerate the time to debt payoff and the onset of the carbon dividends. To implement such an approach, one would need to be able to identify the characteristics of the rapid carbon recovery stands and be able to influence the scheduling of harvests across the landscape. Detailed analysis to clearly identify rapid recovery stands is beyond the scope of the analysis in this report. Nonetheless, we would like to note that, while harvest scheduling may be possible for large industrial forest ownerships, it would be difficult to accomplish across a landscape like Massachusetts that is fragmented into many small ownerships. For this report, we have confined our focus to stand level analyses, which should provide useful indicators of the timing and magnitude of carbon debts and dividends in Massachusetts.

## 6.2 TECHNOLOGY SCENARIOS AND MODELING ASSUMPTIONS

### 6.2.1 OVERVIEW OF TECHNOLOGIES AND APPROACH

To illustrate the relative carbon life-cycle impacts associated with various energy scenarios, we compare the emission profiles for a representative set of biomass energy generation facilities relative to their appropriate fossil fuel baselines. Our analysis considers the following technologies:

- **Utility-Scale Electric:** A utility-scale biomass electric plant (50 MW) compared to a large electric power plant burning coal or natural gas.
- **Thermal Chips:** A thermal generation facility relying on green biomass chips relative to a comparable facility burning fuel oil (#2 or #6) or natural gas.

---

[8] This is likely a conservative scenario for the first year after harvest when the stand is recovering from the impacts of the cut. Assuming a lower than 5% rate of carbon growth on these acres would lower the overall average across the landscape to below 5%; the assumptions made above therefore may overstate the amount of carbon in the forest pool and understate the carbon in the atmosphere.

- **Thermal Pellets:** A thermal generation facility relying on wood pellets relative to a comparable facility burning fuel oil or natural gas.
- **CHP:** A combined heat and power (CHP) facility compared to a similar facility burning oil or natural gas.

We selected these scenarios to illustrate the range of likely wood-based bioenergy futures that we judge to be feasible in the short- to mid-term in Massachusetts. This choice of technologies reflects differences in scale, efficiency and fuel choice. The emission profiles of more advanced technologies—such as cellulosic ethanol production and biomass pyrolysis—are not modeled based on lack of commercial demonstrations, scale requirements that make development in Massachusetts unlikely, or because of a lack of available GHG emissions data.

As detailed in our conceptual framework, each scenario is made up of two primary components: a stand-level forest carbon model and an energy facility GHG emissions model. In the fossil fuel scenarios, we assume the stand is harvested for timber but not for biomass. We then track the total amount of C in the stand's various carbon pools—including above- and below-ground live and dead wood—over a 90-year time frame. For the biomass scenarios, consistent with the supply analysis discussed in Chapter 3, we assume a heavier harvest that removes additional material in the form of logging residues and low-quality trees. For each scenario, we then model the change in total stand carbon over the same 90-year time frame in order to provide comparisons of net changes in total stand-level carbon relative to the baseline "no biomass" scenario. The energy facility emissions model is designed to take into account both the direct stack emissions of energy generation as well as the indirect emissions that come from producing, processing and transporting fuels to the facility. These are expressed as (1) biomass carbon debts, which denote the incremental percentage of carbon emissions due to harvesting and combusting wood relative to the lifecycle GHG emissions of the alternative fossil fuel, and (2) biomass carbon dividends which are the longer term benefits from reducing GHGs below fossil baseline levels. For each scenario, the combined forest and energy carbon models provide an appropriate accounting for the emissions from energy production and the carbon sequestration behavior of a forest stand that has been harvested (1) only for timber or (2) for both timber and biomass.

The details of the forest harvest scenarios are described below, followed by a discussion of the GHG modeling process for energy facilities.

### 6.2.2 FOREST HARVEST SCENARIOS

We take the individual stand as the basis for our carbon accounting process. For the fossil fuel baseline scenarios, we assume a "business as usual" forest management approach where the stand is harvested for timber but not for biomass. The model provides a dynamic baseline for comparisons with the biomass alternative. The scenarios are summarized in Exhibit 6-3 below and include two alternative BAU specifications, one a relatively heavy cut that removes approximately 32% of the above-ground live biomass, and a lighter BAU that removes 20%. The heavier BAU is intended to represent the case where the landowners who decide to harvest biomass are the ones who cut more heavily in the BAU. The lighter harvest BAU represents a scenario where the distribution of landowners harvesting biomass is spread more evenly across the full range of landowners who currently harvest timber, as specified in the Massachusetts Forest Cutting Plan data discussed in Chapter 3. We assume in the BAU that all logging residues are left in the forest.

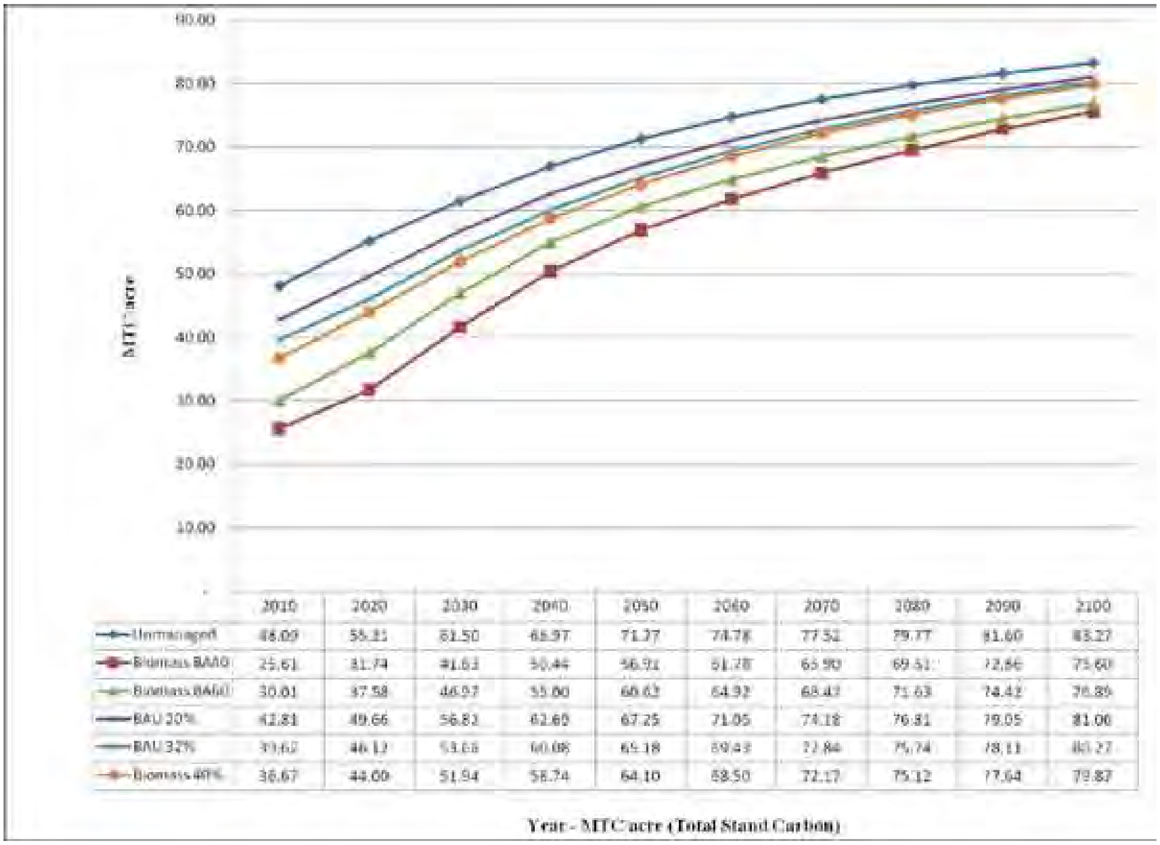
Using the FVS model, described in Chapter 5, we quantify changes in total stand carbon by decade through an evaluation of carbon in the above- and below-ground live and dead carbon pools for the following six biomass harvest scenarios. Carbon recovery profiles represent averages for a set of 88 plots in the Massachusetts FIA database with an initial volume of more than 25 tonnes of carbon per acre in the above-ground live pool.

**Exhibit 6-3: BAU and Biomass Harvest Scenarios**

| Harvest Category | Description | Carbon Removed (tonnes) | Above-Ground Live Carbon Harvested (%) | Logging Residues Left On-Site (%) |
|---|---|---|---|---|
| BAU 20% | Lighter BAU removal | 6.3 | 20 | 100 |
| BAU 32% | Heavier BAU removal | 10.2 | 32 | 100 |
| Biomass BA60 | Moderate biomass removal: BAU & Biomass removal down to 60 ft2 of stand basal area | 19.3 | 60 | 35 |
| Biomass 40% | Lighter biomass removal: BAU plus biomass removal equals 40% stand carbon | 12.0 | 38 | 35 |
| Biomass BA40 | Heavier biomass removal: BAU & Biomass removal down to 40 ft2 of stand basal area | 24.3 | 76 | 35 |

The results of the FVS analysis provide profiles of total stand carbon and above-ground live carbon over time for the BAU and biomass harvest scenarios. These are graphed on the next page in Exhibits 6-4 and 6-5.

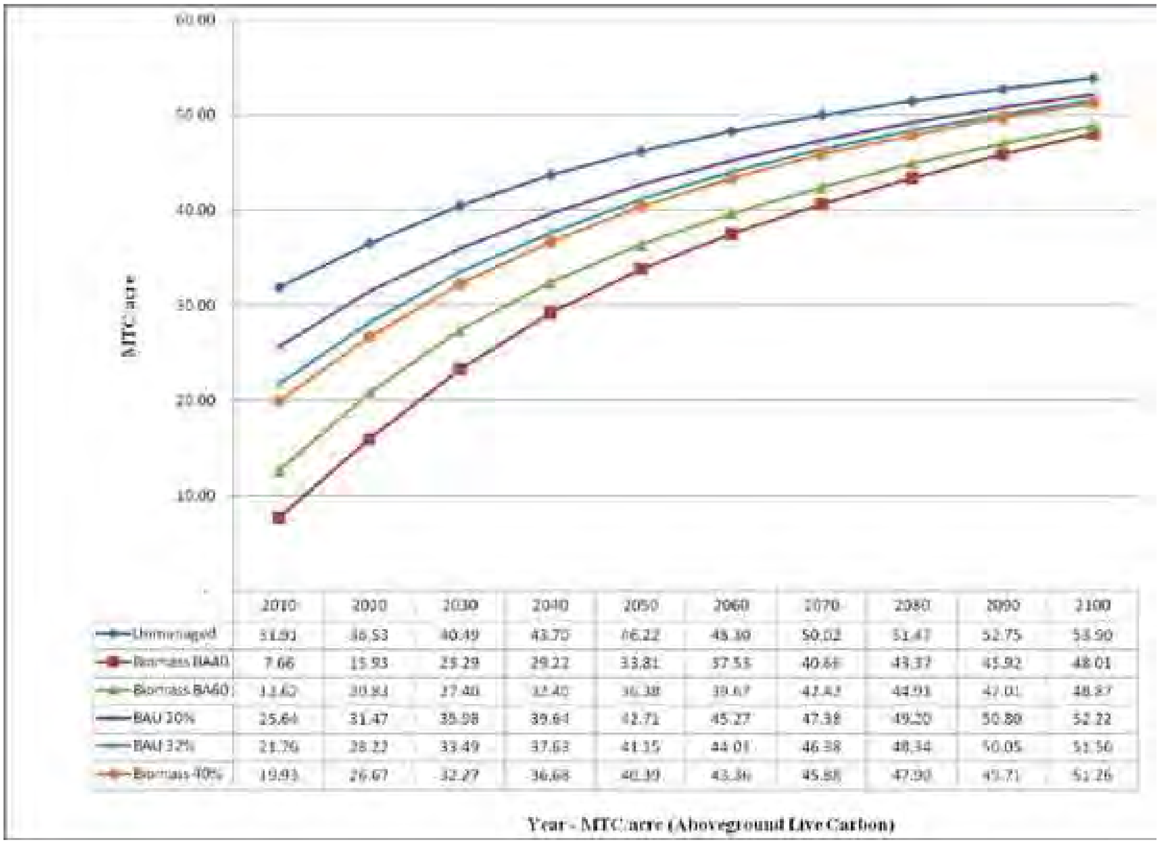
## Exhibit 6-4: Total Stand Carbon



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Unmanaged | 48.09 | 55.31 | 61.50 | 66.97 | 71.27 | 74.78 | 77.52 | 79.77 | 81.60 | 83.27 |
| Biomass BA40 | 25.61 | 31.74 | 41.63 | 50.44 | 56.91 | 61.78 | 65.90 | 69.51 | 72.66 | 75.60 |
| Biomass BA60 | 30.01 | 37.58 | 46.97 | 55.00 | 60.62 | 64.92 | 68.42 | 71.63 | 74.42 | 76.89 |
| BAU 20% | 42.81 | 49.66 | 56.81 | 62.60 | 67.25 | 71.05 | 74.18 | 76.81 | 79.05 | 81.00 |
| BAU 32% | 39.62 | 46.12 | 53.66 | 60.08 | 65.18 | 69.43 | 72.84 | 75.74 | 78.11 | 80.27 |
| Biomass 40% | 36.67 | 44.00 | 51.94 | 58.74 | 64.10 | 68.50 | 72.17 | 75.12 | 77.64 | 79.87 |

Year - MTC/acre (Total Stand Carbon)

## Exhibit 6-5:Above-Ground Live Stand Carbon



| | 2010 | 2020 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 | 2090 | 2100 |
|---|---|---|---|---|---|---|---|---|---|---|
| Unmanaged | 31.91 | 36.53 | 40.49 | 43.75 | 46.22 | 48.30 | 50.02 | 51.47 | 52.75 | 53.90 |
| Biomass BA40 | 7.66 | 15.93 | 23.29 | 29.22 | 33.81 | 37.53 | 40.66 | 43.37 | 45.92 | 48.01 |
| Biomass BA60 | 12.62 | 20.83 | 27.40 | 32.40 | 36.38 | 39.67 | 42.43 | 44.93 | 47.01 | 48.87 |
| BAU 20% | 25.64 | 31.47 | 35.98 | 39.64 | 42.71 | 45.27 | 47.38 | 49.20 | 50.80 | 52.22 |
| BAU 32% | 21.76 | 28.22 | 33.49 | 37.63 | 41.15 | 44.01 | 46.38 | 48.34 | 50.05 | 51.56 |
| Biomass 40% | 19.93 | 26.67 | 32.27 | 36.68 | 40.39 | 43.36 | 45.88 | 47.90 | 49.71 | 51.26 |

Year - MTC/acre (Aboveground Live Carbon)

Due to model constraints, the FVS analyses rely on "thin-from-above" harvest strategies to simulate both BAU and biomass harvests, although we conducted some limited analysis of the sensitivity of the results to alternative assumptions. For all the biomass harvests, we assume 65% of the logging residues are removed from the forest, with the remainder left on the ground.

The results were analyzed to determine how the stands harvested for biomass responded relative to their response in the BAU scenario. This analysis is designed to show relative rates of recovery of forest carbon stocks following biomass harvests.

## 6.2.3 BIOMASS AND FOSSIL FUEL GHG EMISSIONS

To estimate biomass carbon debts relative to fossil fuel technologies, we assembled estimates of GHG emissions per unit of energy produced by each technology. These estimates included both the direct combustion emissions as well as the indirect emissions related to feedstock production, processing and transportation. To the extent that data were available, we work in $CO_2$ equivalents ($CO_2e$), a metric that considers other greenhouse gases (e.g., methane from coal mines) and expresses them in terms of the amount of $CO_2$ that would have an equivalent global warming effect. The emissions estimates for both the biomass and fossil fuel technologies are shown below in Exhibit 6-6, where they have been converted to kilograms of carbon per energy unit.

**Exhibit 6-6: Carbon Emission Factors by Technology* Kilograms per Unit of Energy****

| Scenarios | Biomass | Coal | Oil (#6) | Oil (#2) | Natural Gas |
|---|---|---|---|---|---|
| **Utility-Scale Electric** | **Kilograms/MWh** | | | | |
| Fuel Prod & Transport | 7 | 9 | | | 34 |
| Fuel Combustion | 399 | 270 | | | 102 |
| Total | 406 | 279 | | | 136 |
| **Thermal** | **Kilograms/MMBtu** | | | | |
| Fuel Prod & Transport | 1 | | 6 | 6 | 6 |
| Fuel Combustion | 35 | | 27 | 25 | 17 |
| Total | 36 | | 33 | 31 | 23 |
| **CHP** | **Kilograms/MMBtu** | | | | |
| Fuel Prod & Transport | 1 | | 7 | 6 | 6 |
| Fuel Combustion | 35 | | 29 | 27 | 18 |
| Total | 36 | | 35 | 33 | 24 |

** As discussed below, emissions factors for pellets are characterized relative to the thermal technology using green chips which is shown in this table.*

*** Sources and calculations for these data are described in the text.*

**Emissions from Biomass Harvest, Processing and Transportation:** For the biomass technologies, we include estimates of the $CO_2e$ releases associated with harvesting, processing and transporting the biomass fuel to a bioenergy facility. For green chips (delivered to a large-scale electric, thermal or pellet facility), the estimates are based on releases of $CO_2$ associated with diesel fuel consumption in each of these processes. We estimated harvest and chipping costs using the U.S. Forest Service's Fuel Reduction Cost Simulator (also used to estimate harvesting costs for the wood supply analysis and described in Chapter 3). We assumed chips were transported 100–120 miles (round-trip) to the combustion facility, using trucks carrying 25–30 green tonnes with an average fuel efficiency of 5 mpg. Our results were verified for consistency with other relevant studies including: CORRIM (2004); Department of Forest Resources, University of Minnesota (2008); Finkral and Evans (2008); and Katers and Kaurich (2006).

Indirect $CO_2e$ emissions make a very small contribution to the overall life-cycle emissions from biomass energy production, generally on the order of 2%. A simple way to understand this is as follows. Diesel consumption in harvesting and processing forest biomass is typically less than one gallon (we have calculated an average of 0.75 gallons per green ton based on the sources described above). Diesel consumption in transport is also assumed to be less than one gallon (we have calculated 0.85 gallons per green ton). The combustion of a gallon of diesel releases 22 pounds of $CO_2$, while the combustion of a ton of green wood (45% moisture) releases one ton of $CO_2$ [9]; thus, $CO_2$ emissions per gallon of diesel are equivalent to about 1% of stack emissions. The amount of carbon dioxide released per MWh or per MMBtu will of course depend on the green tonnes of wood required, but the ratio between indirect $CO_2e$ emissions and combustion emissions will remain the same.

**Lifecycle Emissions from Utility-Scale Electric:** For these facilities, all emissions are initially calculated as $CO_2e$ /MWh of electrical output, and then expressed as C/MWh. The biomass estimate is based on analysis of electricity generation and wood consumption from a set of power plants in this region with efficiencies in the 20% to 25% range. These data have been compiled from a combination of information from company websites and financial reports. On average, these plants release about 1.46 tonnes of $CO_2$ (399 kg of C) per MWh. When combined with the indirect emissions discussed above, lifecycle $CO_2e$ for biomass plants total approximately 1.49 tonnes per MWh (or 406 kg of C).

The comparable data for natural gas and coal have been developed by NREL (Spath and Mann, 2000 and Spath et al., 1999) and include the full lifecycle $CO_2e$ emissions. On a per MWh basis,

---

[9] A bone-dry ton of wood is assumed to be 50% carbon. A green ton of wood with 45% moisture weighs 1.82 tons. Thus, the ratio of green wood (45% moisture) to its carbon content is 3.64 (or 1.82 / 0.5). This is essentially the same as the ratio of a ton of carbon dioxide to its carbon content (3.67, equal to the ratio of the molecular weight of CO2 to C, or 44/12). So, the combustion of one green ton of wood releases one ton of CO2.

lifecycle $CO_2e$ emissions for a large (505 MW) combined-cycle natural gas power plant are approximately 0.5 tonnes (136 kg of C) per MWh, of which 75 percent results from the combustion facility itself and 25 percent is from gas production and transportation. The comparable lifecycle estimate for a large coal generating station is approximately 1.0 tonne (279 kg of C) per MWh, with 97 percent of the emissions attributable to the generating station emissions and the remainder to mining and transportation of the coal. The natural gas plant was assumed to be very efficient at 48% due to the combined-cycle technology, while the coal plant was closer to average efficiency at 32%. These plants were selected to bracket the range of emissions of fossil fuel plants relative to their biomass electric counterparts.

We note that co-firing of biomass with coal represents another technology variant for electric utilities. The emissions characteristics of co-firing biomass with coal are expected to similar to those from a stand-alone utility scale biomass electricity plant since the biomass combustion efficiency will be similar in both types of operations. As long as this is the case, the results for utility-scale biomass electricity are indicative of the emissions characteristics of biomass emissions at electricity plants using co-firing.

**Lifecycle Emissions from Thermal Facilities:** All emissions for these facilities are expressed as C/MMBtu of thermal output. Biomass is based on a typical thermal plant with 50 MMBtu's per hour of capacity and 75% efficiency, which has heat input of 120,000 MMBtu/yr (see Chapter 2 for a more detailed description of this pathway and technology). Assuming the gross heating value of oven-dry wood to be 8,500 Btu's/lb, the total lifecycle estimate for carbon emissions is 36 kg/MMBtu.

Emissions data for heating oil and natural gas thermal plants were developed assuming that the typical capacity of the plants was also 50 MMBTH (these technologies and pathways are described in Chapter 2). The oil facilities were assumed to run at 80% efficiency, while the natural gas plants were assumed to be more efficient at 85%. We consider oil facilities that use distillate fuel oil (#2 or #4) and residual fuel oil (#6). The majority of the commercial and industrial facilities in Massachusetts use distillate oil (about 70%), but it is possible that wood biomass may compete more directly with plants burning residual fuel oil. For natural gas, indirect emissions were calculated using the same percentages available in the NREL analysis of electric power plants. Indirect emissions from oil are based on estimates from the National Energy Technology Laboratory (Gerdes, 2009). Lifecycle carbon emissions were calculated to be 33 kg/MMBtu for #6 fuel oil, 31 kg/MMBtu for #2 fuel oil, and 23 kg/MMBtu for natural gas. Because of the differences in relative combustion efficiencies, the gap between biomass and fossil fuel technologies for thermal facilities is smaller than the gap for utility-scaled electric facilities.

**Lifecycle Emissions from Pellet Applications:** Emissions for thermal pellet applications require the addition of emissions from plant operations and for transport and distribution of pellets from the plant to the final consumer. The limited analysis that we have seen for these operations (for example, Katers and Kaurich, 2006) suggest that the increased efficiencies in boiler combustion achieved with pellets approximately offsets most of the increased emissions from plant operations and additional transport of pellets from the plant to their final destination.

**Lifecycle Emissions from CHP Facilities:** Emissions for CHP facilities are also expressed on the basis of MMBtu of heat output, in which electrical energy is converted to a Btu equivalent. The analysis of these operations depends critically on the mix of thermal and electrical output in the plant design. In general, thermal-led facilities tend to relative emissions profiles that are similar to their thermal counterparts, while electric-led facilities more closely resemble the emissions profiles of electric power plants. While some variations can result from the scale of facilities, the specifics of the design, and the type of heat recovery systems employed, the utility-scale electric and dedicated thermal technologies provide approximate bounds for the wide range of possibilities for CHP facilities.

**Carbon Debt Summary:** Exhibit 6-7 below summarizes the carbon debts for biomass relative to each technology and fuel. These are expressed as the percentage of total biomass-related emissions accounted for by the incremental GHG releases from biomass relative to a specific fossil fuel and technology combination. For example, using the data from Exhibit 6-6, we calculate the 31% for coal electric as ((406–279)/406)*100.

**Exhibit 6-7: Carbon Debt Summary Table*
(Excess Biomass Emissions as % of Total Biomass Emissions)**

| Scenarios | Coal | Oil (#6) | Oil (#2) | Natural Gas |
|---|---|---|---|---|
| Electric | 31% | | | 66% |
| Thermal | | 8% | 15% | 37% |
| CHP | | 2% | 9% | 33% |

* *See text for pellet applications.*

It is clear from this table that carbon debt depends on both the choice of fuel (and hence its heating value) and the choice of technology. Carbon debt for biomass compared to natural gas in electric power is much higher than the carbon debt in the thermal scenario. These differences are attributable to the relative efficiencies of the technologies in each scenario—natural gas electric power has a large advantage in this case due to the assumed use of combined-cycle technology.

Carbon debts for CHP raise another important issue when comparing biomass fuel with other technological alternatives. While comparisons of biomass CHP and CHP using oil or natural gas may be straightforward, there are no data on how much fossil-fuel based CHP capacity is now operating in Massachusetts and could potentially be a candidate for replacement. Nevertheless, this comparison may still be useful in assessing the relative carbon merits of constructing a new biomass CHP plant or a new fossil fuel-fired CHP plant. On the other hand, it is interesting to note that if biomass CHP facilities were developed, it is likely that they would replace a mix of independent thermal and electric applications. Since a large amount of heat is wasted in producing stand-alone electricity, these comparisons may show biomass CHP with no carbon debt at the outset. For example, if thermal-led biomass CHP at a commercial location replaces a current mix of heat from oil and power from coal, then total carbon emissions generated at the new site are likely to decline relative to the fossil scenario as long as a significant percentage of the waste heat is utilized. In contrast, if natural gas is consumed in the current energy mix, the situation may be reversed.

## 6.3 FOREST BIOMASS CARBON ACCOUNTING RESULTS

### 6.3.1 INTRODUCTION

As discussed in the conceptual framework section, our carbon accounting analysis for biomass focuses on biomass carbon debt, biomass carbon dividends and the number of years until debts are paid off and dividends begin accumulating. These are a function of the bioenergy technology as well as the biophysical characteristics of the forest and management practices used. The transition from debt to dividend occurs at the point when the atmospheric carbon level resulting from the lifecycle biomass emissions falls to the point where it just equals the level resulting from lifecycle fossil fuel emissions.[10]

To examine the carbon debts, dividends and the timing of the transition from one to the other, we analyzed a wide array of integrated energy technology/forest management scenarios. These consider the impacts of potential differences in (1) energy technology and efficiency and (2) the biophysical characteristics of the forest and assumptions about the intensity and type of silvicultural approach used for harvests in both the BAU and biomass scenarios.

Our analysis approaches the problem by establishing integrated technology and forest scenarios that we find to be representative of average or typical conditions and management practices. Energy technologies are characterized in terms of typical lifecycle carbon emissions. Representative forest carbon recovery paths are estimated using FVS model simulations averaged across 88 actual forest stands that are included in the U.S. Forest Service's system of FIA sampling plots in Massachusetts. Overall these analyses provide guidance on the range of *average* forest carbon recovery times for each technology. It is important to note, however, that care should be exercised when translating these average results into policy. Our concern is primarily the result of three factors. First, energy technologies are continually evolving and the characteristics of any specific project proposal could differ from the typical existing configurations that we have analyzed. Second, our lack of knowledge of how stands will be harvested in response to increased demand for forest biomass may introduce substantial uncertainty in the projections of forest carbon recovery rates. Third, modeling the carbon dynamics of forest stands is complex, and although our analysis provides indications of broad general trends, these are subject to considerable uncertainty about stand-level changes in carbon pools.

In the remainder of this chapter, the presentation of results in organized around three principal topics:

- How do choices about biomass technology and assumptions about the fossil fuel it will replace affect carbon recovery times?
- How do forest management choices with respect to harvest intensity and silvicultural practice interact with the biophysical properties of forests to determine carbon recovery profiles?
- What are the carbon dividend levels associated with the various biomass energy scenarios?

To answer these questions, we first present data from our modeling of the various energy/forest scenarios. We then summarize our overall conclusions and discuss some considerations regarding how our results are most appropriately interpreted and used in energy and environmental policymaking processes.

### 6.3.2 ENERGY TECHNOLOGY AND CARBON DEBT RECOVERY

A key insight from our research is the wide variability in the magnitude of carbon debts across different biomass technologies. This results from the way specific lifecycle GHG characteristics of a bioenergy technology combine with the GHG characteristics of the fossil fuel energy plant it replaces to determine carbon debts. As shown in Exhibit 6-7, carbon debts for situations where biomass thermal replaces oil-fired thermal capacity can be as low as 8%, whereas the debt when biomass replaces combined-cycle natural gas in large-scale electricity generation can range as high as 66%.

Exhibit 6-8 illustrates how debt payoff varies with technology, with detailed supporting numbers included in the table in Exhibit 6-9. The scenario represented in this exhibit is one that assumes a relatively heavy BAU harvest of timber—32% removal of above-ground live carbon using a diameter limit partial harvest—and a biomass harvest that extends the diameter limit approach to removal of all trees down to a residual basal area of 60 ft$^2$ per acre. Exhibit 6-8(a) illustrates the FVS model results for total stand carbon in stands harvested only for timber (BAU) and for the same stands where the BAU harvest is augmented by the additional removals of biomass including the harvest of 65% of all tops and limbs. Exhibit 6-8(b) captures the relative differences in growth between the two stands, indicating an initial harvest of 38 green tons of biomass.[11] For these scenarios,

---

[10] Offsetting of earlier damages from higher biomass GHG levels would require additional years of lower GHG levels (or dividends) in the biomass scenario. Full carbon neutrality would not be achieved until the point at which the entire release of carbon from burning biomass has been resequestered in the forest carbon pools.

[11] This relative difference in growth is derived by subtracting the BAU recovery curve from the biomass harvest recovery curve in Exhibit 6-8(a) In this case, the relationship in Exhibit 6-8(b) can be interpreted as the incremental growth in the stand harvested for biomass relative to growth of the BAU stand. Only through this incremental growth will carbon debts be recovered.

the graph shows that post-harvest biomass stands sequester carbon more rapidly than BAU stands harvested only for timber. In this scenario, the biomass harvest removed an additional 9.1 tonnes of above-ground live carbon from the stand (and resulted in the loss of another 0.5 tonnes of below ground carbon). After one decade of growth, the total carbon in the biomass stand has increased by approximately 1.1 tonnes compared to the BAU stand and continues to increase to a cumulative total 6.2 tonnes of carbon after 90 years. At this point in time, the biomass stand has recovered approximately 65% of the carbon removed from the stand and used for biomass energy generation (6.2 tonnes versus 9.6 tonnes harvested).

**Exhibit 6-8(a): Forest TSC Sequestration Rates under Scenario 1** (tonnes carbon)

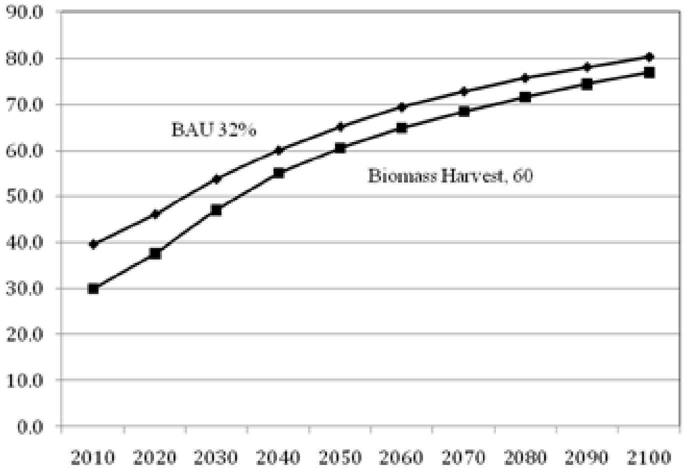
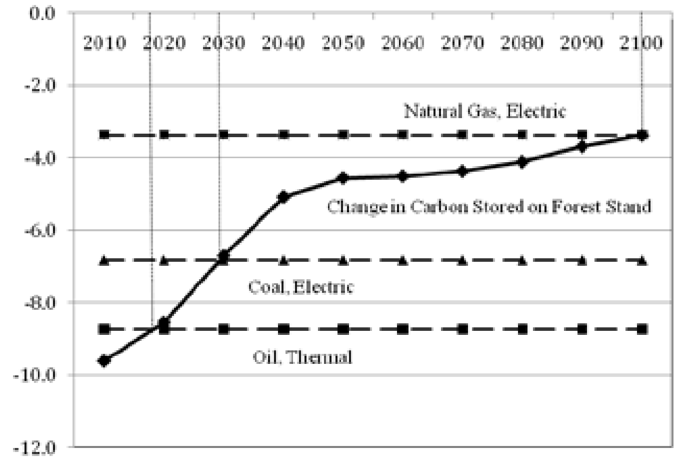


Exhibit 6-8(b) also indicates the time required on average for the stands to recover the carbon debt for various technologies. Oil-fired thermal facilities are represented by the horizontal line indicating that for the equivalent level of energy production they emitted about 12% less carbon than a thermal biomass plant when full lifecycle carbon emissions are taken into account.[12] The intersection of the thermal-oil emissions line and the forest carbon recovery curve identifies the year in which the carbon debt is fully recovered in this scenario—about 10 years for replacement of oil-fired thermal capacity with biomass. At that time, the net atmospheric levels of GHGs are equivalent for the biomass and fossil fuel technologies. Prior to that point, biomass resulted in higher GHG levels, but in later years biomass GHG levels are lower than those for fossil fuels because the forest continues to remove relatively greater amounts of the carbon than the stand in the BAU scenario. These are the benefits we characterize as carbon dividends.

**Exhibit 6-8(b): Carbon Recovery Rates under Scenario 1** (tonnes carbon)



The carbon debt recovery periods are also plotted in Exhibit 6-8(b) for biomass replacement of coal and natural gas electricity generation. The results make clear that technologies with higher carbon debts have longer payoff times, indicative of carbon dividends that do not appear until further in the future. Technology scenarios with shorter payoff times have lower GHG impacts than scenarios with higher carbon debts. In general, the analysis indicates that thermal carbon debts can be substantially lower than debts from large-scale electricity generation.

Our analyses also considered the carbon debt characteristics of wood pellet technology and CHP systems. In general, we find that carbon debts associated with burning pellets in thermal applications do not differ significantly from debts resulting from use of green wood chips. The differences relate primarily to location of GHG emissions associated with water evaporation from green wood rather than the overall magnitude of the lifecycle GHG emissions. For CHP, carbon debts generally fall somewhere between those of thermal and large-scale electric, depending upon whether the CHP plant is designed to optimize thermal or electric output; however, in our cases, initial carbon debts are shown to be lower than thermal because all waste heat is fully utilized and some reductions in the gross efficiency of oil and gas are recognized due to higher electrical efficiencies.

The technology scenario rankings described above generally hold true as long as the forest management and silvicultural practices are the same for the various energy generation technologies (however, as demonstrated below in Section 6.3.3.4, this may not be the case if harvesting methods preclude the removal and use of tops and limbs). Within this general hierarchy, however, the absolute and relative timing of carbon recovery for the different technologies will vary depending on the specific harvesting assumptions and results from the forest modeling process (discussed in detail in Section 6.3.3 below).

In interpreting the technology/carbon debt results, it is important to recognize that the carbon debts discussed above are based on average levels of GHG emissions per unit of energy for typical

---

[12] This represents an average of residual fuel oil (#6) and distillate fuel oil (#2).

energy generation systems readily available today.[13] Biomass energy technology, however, is evolving and there are technologies that have yet to be commercialized in the U.S. that are more efficient and thus produce less GHG emissions per unit of useable energy—for example the biomass CHP gasification technologies discussed in Chapter 2. Bioenergy proposals based on new technologies with lower carbon debts are feasible and have the potential to reduce GHG impacts and associated carbon debts.

### 6.3.3 FOREST MANAGEMENT AND CARBON RECOVERY

Within the broad context of biomass carbon debts and dividends for specific technologies, the timing of carbon recovery is a direct function of two factors related to forests and forest management—(1) the biophysical characteristics of Massachusetts forests and (2) assumptions about the intensity and type of silvicultural approach used for harvests in both the BAU and biomass harvest scenarios.

As described in Chapter 5, we rely on FIA data for basic biophysical information about Massachusetts forests, and we evaluate carbon dynamics using the U.S. Forest Service FVS model. The FIA data are intended to provide a set of forest stands that is representative of the range of forest cover types, tree size distributions, species growth characteristics, and per-acre wood inventories across Massachusetts. For presentation and analysis purposes we generally characterize our results as carbon recovery rates averaged across the 88 stands in our FIA database that are at a stage in their development that makes them available for biomass harvests (i.e., stands with greater than 25 tonnes of carbon in the above-ground live carbon pool). This approach provides a reasonable basis for capturing the impact on carbon debt recovery of differences in the biophysical characteristics of the forests.

Assumptions about the nature of forest management in both the BAU and biomass harvest scenarios also have important impacts on the timing of the transition from carbon debt to carbon dividends. In order to analyze biomass harvest scenarios, we need to specify the BAU harvest level, the incremental amount of material removed in the biomass cut, the percentage of tops and limbs left on-site, and the silvicultural approaches used to harvest the material. For all scenarios, the biomass carbon calculations assume that in the absence of biomass demand, landowners will continue to manage their forests for timber and other wood products. To establish the BAU baseline, we define both the silvicultural practice used in harvesting the wood and the total quantity removed in the baseline harvest. Generally speaking, our knowledge of logging practices in the state suggests a relatively high probability that landowners would apply diameter limit, partial harvest approaches, removing the largest and best quality trees in the stand. Chapter 3 indicates that based on Forest Cutting Plan data, average harvests historically have removed between 4.5 and 6 tonnes of carbon per acre (approximately 20 to 25 green tons). Using FVS, we modeled this baseline through a removal of 20% of above-ground live stand carbon using a "thin from above" silvicultural prescription.

We also analyzed an alternative baseline in which we assume a significantly heavier BAU harvest, one that removes approximately 32% of the above-ground live carbon. We include this BAU to account for uncertainty regarding which landowners will be more likely to harvest biomass. This scenario would be consistent with the assumption that landowners who have harvests that are heavier than statewide averages would be more likely to harvest biomass.

We then created three biomass harvest options, designed to model light, medium and heavy biomass cuts, all of which include the removal of 65% of all tops and limbs. These were combined with the two BAUs to generate six scenarios representing the impact of different management and harvest assumptions on the timing of the transition from carbon debt to carbon dividends. The results for the six scenarios are summarized in the table included as Exhibit 6-9 (next page). For each scenario, the table shows the quantity of carbon removed in the biomass harvest (i.e., the carbon removal incremental to the harvest in the timber only BAU) and statistics on the recovery by decade of this carbon through growth of the stand. For each scenario, the first row provides the difference in tonnes of total stand carbon between the BAU stand and the biomass stand in years 10 through 90. The second row indicates the tonnes of carbon recovered by the biomass stand relative to the BAU. The third row presents the cumulative percentage of the original biomass carbon recovered by decade.[14]

#### 6.3.3.1 Impacts of Alternative BAUs

The results graphed in Exhibit 6-10 demonstrate that carbon recovery times are somewhat, but not highly, sensitive to assumptions about the volume of timber removed in the BAU harvest. The graph shows carbon recovery curves for Scenarios 1 and 5, the light and heavy BAU harvests, followed by a medium-intensity biomass cut, in this case removal via a diameter limit cut of biomass down to a residual stand basal area of 60 ft$^2$. The results indicate that the heavier BAU results in a somewhat, but not dramatically, more rapid recovery of carbon in the stand following the biomass harvest. Carbon debts resulting from biomass replacement of coal-fired electricity capacity would take about 20 years in the heavy BAU case, and about 25 years in the light BAU scenario. After these points in time, carbon dividends begin to accrue because atmospheric GHG levels are below those that would have resulted had an equivalent amount of energy been generated using fossil fuel.

---

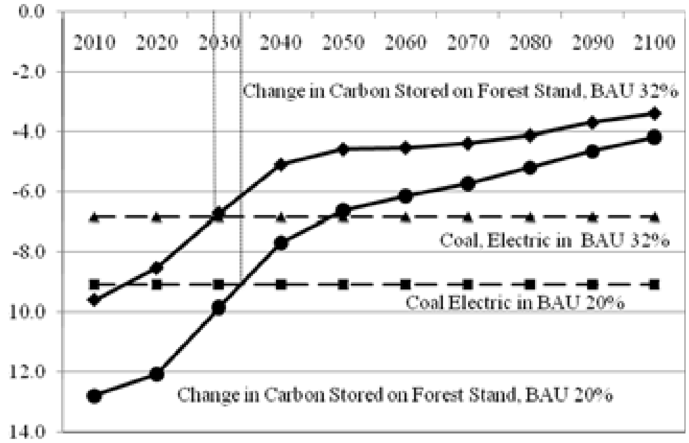
[13] In the case of large-scale electricity generated by natural gas, the scenario here assumes a very efficient combined-cycle technology, and this provides a high-end estimate of carbon debts compared to biomass replacement at less efficient natural gas facilities.

[14] For example, in Scenario 1, in year 1 the harvest resulted in an initial loss of 9.6 tonnes of total stand carbon (of which 9.1 tonnes is above-ground live carbon). By year 10, the difference in total stand carbon has narrowed to 8.5 tonnes, the relative differences in stand carbon accumulation between the two stands. In this case the biomass stand accumulated an additional 1.1 tonnes of carbon more than the BAU stand (9.6 tonnes minus 8.5 tonnes). This represents recovery of 11.1% of the original carbon removed in the biomass harvest (1.1/9.6).

**Exhibit 6-9: Graph of Carbon Recovery Times for Scenarios 1 and 5** (tonnes carbon)

| Scenario | | | BAU vs. Biomass Total Stand Carbon Difference by Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | **Description** | **Harvest** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** |
| **1** | BAU32%-BioBA60 | 9.1 | 8.5 | 6.7 | 5.1 | 4.6 | 4.5 | 4.4 | 4.1 | 3.7 | 3.4 |
| | CumRecovered | | 1.1 | 2.9 | 4.5 | 5.0 | 5.1 | 5.2 | 5.5 | 5.9 | 6.2 |
| | %Recovery | | **11.1** | **30.2** | **47.1** | **52.5** | **53.1** | **54.5** | **57.2** | **61.6** | **64.8** |
| **2** | BAU32%-Bio40% | 1.8 | 2.1 | 1.7 | 1.3 | 1.1 | 0.9 | 0.7 | 0.6 | 0.5 | 0.4 |
| | CumRecovered | | 0.8 | 1.2 | 1.6 | 1.9 | 2.0 | 2.3 | 2.3 | 2.5 | 2.6 |
| | %Recovery | | **28.1** | **41.0** | **54.6** | **63.4** | **68.5** | **77.3** | **79.0** | **84.1** | **86.4** |
| **3** | BAU32%-BioHHBA40 | 14.1 | 14.4 | 12.1 | 9.6 | 8.3 | 7.7 | 6.9 | 6.2 | 5.3 | 4.7 |
| | CumRecovered | | -0.4 | 2.0 | 4.4 | 5.7 | 6.4 | 7.1 | 7.8 | 8.8 | 9.3 |
| | %Recovery | | **-2.6** | **14.0** | **31.2** | **41.0** | **45.4** | **50.5** | **55.5** | **62.5** | **66.7** |
| **4** | BAU20%-Bio40% | 5.7 | 5.7 | 4.9 | 4.0 | 3.2 | 2.6 | 2.0 | 1.7 | 1.4 | 1.2 |
| | CumRecovered | | 0.0 | 0.8 | 1.8 | 2.5 | 3.2 | 3.7 | 4.0 | 4.3 | 4.5 |
| | %Recovery | | **0.7** | **13.4** | **28.5** | **41.5** | **51.3** | **60.1** | **65.3** | **69.9** | **73.5** |
| **5** | BAU20%-BioBA60 | 13.0 | 12.1 | 9.9 | 7.7 | 6.6 | 6.1 | 5.7 | 5.2 | 4.6 | 4.2 |
| | CumRecovered | | 0.7 | 3.0 | 5.1 | 6.2 | 6.7 | 7.1 | 7.6 | 8.2 | 8.6 |
| | %Recovery | | **5.6** | **23.0** | **39.9** | **48.2** | **52.1** | **55.4** | **59.5** | **63.8** | **67.4** |
| **6** | BAU20%-BioHHBA40 | 18.0 | 17.9 | 15.2 | 12.3 | 10.3 | 9.3 | 8.3 | 7.3 | 6.2 | 5.5 |
| | CumRecovered | | -0.7 | 2.0 | 5.0 | 6.9 | 7.9 | 8.9 | 9.9 | 11.0 | 11.7 |
| | %Recovery | | **-4.2** | **11.7** | **28.8** | **39.9** | **46.1** | **51.9** | **57.6** | **64.0** | **68.3** |

**Exhibit 6-10: Graph of Carbon Recovery Times for Scenarios 1 and 5** (tonnes carbon)



## 6.3.3.2 IMPACTS OF ALTERNATIVE BIOMASS HARVEST INTENSITIES

Next we examined the impact of varying the intensity of the biomass harvest on carbon debt recovery. Exhibit 6-9 shows the impact of the light, medium and heavy biomass harvests when combined with the heavy harvest BAU and the comparable results when a lighter BAU harvest is assumed.

The results suggest that for very light biomass harvests, the time required to pay off the carbon debt and begin accumulating dividends is relatively rapid. This is evident in Scenario 2—a heavy BAU coupled with a light biomass harvest—where only 3 tonnes of biomass carbon is removed. In this example, both oil-thermal and coal-electric debts are recovered in the first decade and natural gas electric debts are paid back in approximately 50 years. As discussed in Section 6.3.3.4 below, the rapid recovery occurs because the small removal is comprised of a much greater proportion of logging residues that would have been left on the ground to decay in a BAU harvest. This relatively large magnitude of the decay losses in the BAU results in a rapid recovery of lost carbon in the biomass harvest. Such light harvest, however, would not necessarily produce the supplies forecast in Chapter 3 and may not be the economic choice of landowners.

As harvest intensity increases, however, recovery times become longer. Scenarios 1, 4 and 5, where biomass harvests range from 5.7 to 13.0 tonnes of carbon, all have carbon recovery profiles that are longer than Scenario 2, although all three show steady progress in the recovery of carbon debts. In the three scenarios, oil-thermal debts are recovered roughly between years 10 and 20 and coal-electric debts are recovered between years 20 and 30. For Scenarios 3 and 6, where the biomass removal is close to what would be considered a clearcut, the stand harvested for biomass actually loses carbon relative to the BAU stand in the first decade, creating a delay in carbon recovery that persists for many decades. This may be the result of complex interactions between regeneration and woody debris decay in the years immediately following harvest, although in the case of these more extreme harvests, we may be pushing the model to an extreme case where its results are simply less robust. Given the low likelihood that most biomass harvests will be in the form of clearcuts (see Chapter 3), we do not view the uncertainties in the Scenario 3 and 6 results as having great relevance to the overall patterns of carbon recovery.

### 6.3.3.3 Impacts of Alternative Silvicultural Prescriptions

The impact of different silvicultural prescriptions has been more difficult to evaluate using the FVS model. The present set of scenarios uses a thin-from-above strategy linked to residual stand carbon targets for all harvests. These types of harvests tend to open the canopy and promote more rapid regeneration and growth of residual trees. While this silvicultural approach may provide a reasonable representation of how a landowner who harvests stands heavily in a BAU is likely to conduct a biomass harvest, it is less likely that someone who cuts their land less heavily would continue to remove canopy trees for biomass (unless they had an unusual number of canopy cull trees remaining after the timber quality trees are removed). More likely in this case is that the landowners would harvest the BAU timber trees and then selectively remove poor quality and suppressed trees across all diameter classes down to about 8 inches. We hypothesized that this type of harvest would result in a slower recovery compared to thinning from above. Unfortunately, the complexity of this type of harvest was difficult to mimic with FVS.

Although project resources were not adequate to manually simulate this type of harvest for all FIA stands, we did conduct a sensitivity analysis for two stands with average volumes. For each of these stands we simulated a BAU harvest removing 20% of the stand carbon, followed by removal of residual trees across all diameter classes above 8 inches down to basal areas similar to the target in Scenario 4. For these two stands, the results, shown in Exhibit 6-11, do indicate a slowing of carbon recovery profiles relative to Scenario 4, although two stands are not enough to draw any conclusions about average impacts of this silvicultural prescription. What can be said is that stands harvested in this manner will probably recover carbon more slowly than would be suggested by Scenario 4; how much more slowly on average we did not determine; it is clear however that on a stand-by-stand basis the magnitude of the slowdown can vary considerably.

### 6.3.3.4 Impacts of Harvesting Methods and the Role of Tops and Limbs

The harvest and use of tops and limbs for biomass can have an important influence on carbon recovery times and profiles: tops and limbs decay quickly if left in the forest and so their use comes with little carbon "cost" which tends to shorten carbon recovery times. Conversely, if tops and limbs from a biomass harvest of cull trees were left in the woods to decay, this "unharvested" carbon would delay recovery times, effectively penalizing wood biomass relative to fossil fuels. Tops and limbs are available from two "sources" in our biomass harvest scenarios: (1) the material left behind following an industrial roundwood harvest in a BAU scenario and (2) tops and limbs from standing trees harvested specifically for bioenergy in the biomass harvest scenarios.

As discussed in the wood supply analysis in Chapter 3, the harvest of tops and limbs would likely be economical only when harvested with whole-tree systems. Biomass harvested in this manner can be used for any type of bioenergy technology. However, biomass can also be harvested with traditional methods or cut-to-length methods when these systems are preferred due to operating restrictions and/or landowner preferences. These roundwood operations tend to be more costly, but yield higher-quality bole chips that are preferred by thermal, CHP and pellet facilities. Importantly, leaving tops and limbs behind as forest residues would increase carbon recovery times for bioenergy technologies that utilize the bole chips that are produced. The discussion that follows helps to demonstrate how the use of tops and limbs affects our carbon recovery results.

The carbon recovery times in the six scenarios presented in Exhibit 6-9 are all based on the assumptions that 100% of tops and limbs are left in the forest in the BAU scenarios and 65% of all tops and limbs (from both the BAU and the incremental biomass harvest) are harvested in the biomass scenarios. These carbon recovery times (for the three BAU32 scenarios) are compared with the carbon recovery times when all tops and limbs are left in the forest in Exhibit 6-12.

**Exhibit 6-11: Carbon Recovery Times**
**Alternative Harvest Analyses** (tonnes carbon)

| Scenario | | | BAU vs. Biomass Total Stand Carbon Difference by Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Number** | **Description** | **Harvest** | **10** | **20** | **30** | **40** | **50** | **60** | **70** | **80** | **90** |
| **1** | BAU20:Bio40DBH | 7.5 | 8.1 | 6.6 | 3.6 | 2.3 | 1.7 | 0.5 | -0.2 | -0.7 | -0.9 |
| | CumRecovered | | -0.6 | 0.9 | 3.9 | 5.2 | 5.8 | 7.0 | 7.8 | 8.2 | 8.5 |
| | %Recovery | | -9.6 | 15.1 | 63.5 | 84.6 | 94.8 | 113.9 | 126.4 | 133.6 | 137.8 |
| **1** | BAU20:Bio40 | 5.9 | 6.0 | 4.4 | 2.4 | 2.1 | 3.3 | 1.6 | 1.8 | -0.5 | 0.2 |
| | CumRecovered | | 0.0 | 1.5 | 3.5 | 3.8 | 2.7 | 4.4 | 4.2 | 6.5 | 5.8 |
| | %Recovery | | -0.3 | 25.6 | 59.2 | 64.4 | 44.7 | 73.7 | 70.2 | 108.9 | 97.1 |
| **2** | BAU20:Bio40 | 4.2 | 4.3 | 4.4 | 4.3 | 3.2 | 1.3 | 1.6 | 0.4 | 0.6 | 0.0 |
| | CumRecovered | | -0.1 | -0.3 | -0.1 | 0.9 | 2.9 | 2.6 | 3.8 | 3.5 | 4.2 |
| | %Recovery | | -2.7 | -6.4 | -3.1 | 22.6 | 68.6 | 62.5 | 90.4 | 84.4 | 100.9 |
| **2** | BAU20:Bio40 | 6.4 | 6.0 | 5.1 | 4.1 | 3.5 | 1.9 | 2.0 | 0.0 | 0.5 | 0.4 |
| | CumRecovered | | 0.4 | 1.3 | 2.2 | 2.8 | 4.4 | 4.4 | 6.3 | 5.9 | 5.9 |
| | %Recovery | | 6.1 | 20.4 | 34.8 | 44.6 | 69.5 | 69.1 | 99.4 | 92.3 | 93.5 |

When tops and limbs are left on-site, all three scenarios show net carbon losses between the initial period and the 10-year mark; in addition, carbon losses in year 10 are substantial relative to the recovery levels in the scenarios in which tops and limbs are taken and used for bioenergy. Scenario 2 (the lightest biomass harvest) shows the greatest impact from not utilizing tops and limbs, with carbon recovery times delayed by about three decades (about 50% of the original biomass harvest was comprised of tops and limbs). Thus, if BAU32 was followed by a light biomass harvest of only roundwood for use by a thermal facility, carbon debt recovery would require 20 to 30 years (when compared to oil-based thermal), rather than occurring in less than 10 years when tops and limbs are taken in whole-tree harvests.

In contrast, in the heavier biomass harvests, recovery times are extended only about ten years. In Scenario 1, the carbon debt incurred by replacing oil thermal by biomass thermal would be recovered in 20 years instead of the 10 years indicated when tops and limbs are utilized. In Scenario 3, carbon debt recovery times for replacement of oil thermal are extended from 20 years to 30 years.

Finally, it is interesting to consider the "harvest" and use of just tops and limbs. While this may not be directly applicable to forest management in Massachusetts (due to poor markets for pulpwood and limited opportunities for log merchandizing), it may be representative of situations involving non-forest biomass sources, such as tree trimming/landscaping or land clearing. The results in this case (also shown in Exhibit 6-12) indicate rapid recovery, with nearly 70% of the carbon losses "recovered" in one decade. Thus, all bioenergy technologies—even biomass electric power compared to natural gas electric—look favorable when biomass "wastewood" is compared to fossil fuel alternatives.

**Exhibit 6-12: The Impact of Tops and Limbs on Carbon Recovery Times in BAU32**

| | Number of Years from Initial Harvest | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 |
| **Scenario 1** | | | | | |
| Original (with T&L) | 11% | 30% | 47% | 53% | 53% |
| No T&L | -9% | 11% | 31% | 38% | 38% |
| **Scenario 2** | | | | | |
| Original (with T&L) | 28% | 41% | 54% | 63% | 68% |
| No T&L | -12% | -4% | 16% | 31% | 39% |
| **Scenario 3** | | | | | |
| Original (with T&L) | -3% | 14% | 31% | 41% | 45% |
| No T&L | -22% | -6% | 14% | 25% | 31% |
| Tops and Limbs Only | 68% | 87% | 93% | 96% | 97% |

### 6.3.3.5 IMPACTS OF DIFFERENCES IN STAND HARVEST FREQUENCIES

A final factor that merits consideration in interpreting the modeling results is the effect of harvest frequencies on the timing of the transition of carbon debt to carbon dividend. Frequent re-entry to the stand to remove biomass has the general effect of extending carbon recovery times. For example, if a stand is re-entered before the time at which carbon levels have recovered to the point where atmospheric concentrations are equivalent to those from fossil fuel burning, a new carbon debt is added to what remains of the initial one and the period required for that stand to reach the equivalent flux point is extended. Conversely, if a second harvest is not conducted until after the stand has begun contributing to actual reductions in GHG levels relative to a fossil fuel scenario, net benefits in the form of carbon dividends will have been positive; additional benefits will depend on the amount of carbon debt incurred in the second harvest and the growth rate of the forest following the additional removal.

As a result of this effect, it is clear that carbon recovery times are sensitive to the frequency at which a landowner chooses to harvest. Data on frequency of harvests indicates landowners who manage for timber typically cut their stands relatively frequently, which suggests our estimated carbon recovery times may be shorter than would actually occur in practice; as a result actual times to the to pay off carbon debts and begin accumulating carbon dividends may be longer.

### 6.3.3.6 CARBON DIVIDENDS

Beyond the point in time when the carbon debt is paid off, and as long as the total carbon recovery rates of stands harvested for biomass are at least as high as the recovery rates in the BAU stands, the carbon dividends from biomass energy continue to accumulate. This means that in the years after the point of carbon debt repayment, there will be less carbon in the atmosphere than had a comparable amount of energy been generated with fossil fuel. As long as the stand harvested for biomass is accumulating carbon faster than the BAU stand, this benefit—lower GHG concentrations relative to the fossil fuel scenario—continues to increase. Even if the two stands ultimately reach a point where carbon accumulates at the same rates, there continues to be a dividend in the form of an ongoing reduction in GHG levels from what they would otherwise have been. As a result, the magnitude of carbon dividends varies depending on the year in which they are evaluated. Exhibit 6-13 indicates the year in which the carbon debt is paid off and provides estimates of the percentage carbon dividend in 2050 and 2100, 40 and 90 years respectively after the modeled biomass harvest.[15]

As discussed in more detail in Section 6.1.2, the carbon dividends in the table indicate the extent to which burning biomass has

---

[15] FVS simulations become increasingly uncertain as they are extended over long time periods. We believe 90-year simulations represent a reasonable length of time for providing insights into long-term carbon recovery effects.

reduced GHG levels beyond what they would have been had the same energy been generated from fossil fuels. For example, if a biomass thermal plant with an initial carbon debt of 15% emitted 150 tonnes of lifecycle carbon, and the harvested forest recovered an incremental 115 tonnes of carbon over 60 years compared to a BAU scenario, the carbon dividend is 73%. This indicates that the biomass carbon debt has been completely recaptured in forest carbon stocks and in addition GHGs have been reduced by 73%[16] from what they would have been if fossil fuels had been used to generate the equivalent amount of energy. In this context, a carbon dividend of 100% indicates that biomass combustion has achieved full carbon neutrality—all the energy emissions from biomass burning have been fully offset in the form of newly sequestered carbon.

As was the case for carbon debt payoff, the dividend levels clearly indicate benefits are strongly a function of the fossil technology that is being replaced. Where whole-tree harvesting is used, replacement of oil-fired (#6) thermal by biomass thermal results in carbon dividends in excess of 38% by 2050 even in the slowest carbon recovery scenario. These reductions in GHG levels relative to a fossil fuel baseline rise to greater than 60% by 2100. With the exception of biomass replacement of natural gas electric capacity, carbon dividends after 90 years always result in fossil fuel offsets that exceed 40%. These dividends, however, are potentially reduced if stands are re-entered and additional material is harvested prior to the 90-year reference point discussed above. Carbon dividends are consistently low (and in one case negative) for biomass replacement of natural gas electricity generation.

Another way of comparing the relative contributions of carbon debts and carbon dividends is to estimate the difference in cumulative net atmospheric carbon emissions between using biomass and fossil fuel for energy at some future point in time. Due to the importance of demonstrating progress in reducing greenhouse gas emissions by 2050 as part of the Massachusetts Global Warming Solutions Act, we have provided such a comparison for our six harvest scenarios in Exhibit 6-14.

Conceptually, the analysis is perhaps best understood as follows. In the first year, a bioenergy plant consumes a specified volume of wood and establishes a carbon debt relative to the amount of carbon that would have been released in generating the same amount of energy from a fossil fuel alternative. The pattern is then repeated each year and continues until the year 2050. We then calculate the total difference in atmospheric carbon in 2050 from each harvest year and sum the results. For example, the difference in carbon from the first year is simply equal to our estimate of the carbon dividend in year 2050, 40 years after our initial harvest. The difference in carbon from the second year is the carbon dividend that we observe after 39 years, the difference in carbon from the third year is the carbon dividend that we observe after 38 years, etc. The process continues until the last year (2050) at which time the difference in carbon is equal to the difference in year one, or in other words, it is equal to the initial carbon debt.[17] This allows us to compute the total carbon "savings" from burning biomass for a 40-year period, and then compare this value with the total amount of carbon that would have been released by using fossil fuel. When expressed in this manner, the concept is identical to our carbon dividend; however, rather than calculating a dividend at a single point in time, we now have measured the cumulative dividend in 2050, which indicates the total net change in atmospheric carbon at that time due to 40 years of biomass use.

The cumulative dividend net of forest carbon resequestration results from these calculations are shown in Exhibit 6-14: a value of 0% indicates that the carbon dividends during the 2010–2050 period have exactly offset the carbon debt; a positive value indicates that the cumulative carbon dividends have more than offset the carbon debts and have reduced atmospheric carbon compared to what would have been the case had fossil fuels been used (for example, 22% for oil (#6), thermal in harvest scenario 1 indicates that atmospheric carbon is 22% lower in 2050 due to the replacement of oil with biomass); a negative value indicates that total carbon dividends have not yet offset the cumulative debt levels (for example, -13% for natural gas, thermal in harvest scenario 1 indicates that there is still 13% more carbon in the atmosphere in 2050 as a result of having replaced a natural gas thermal plant with biomass and operating it for 40 consecutive years.

Several key observations can be made from these results: (1) the percentage carbon dividend for the entire 2010–2050 period is significantly less than the single year percentage dividend in 2050 that was based only on emissions in 2010 (shown in Exhibit 6-13, next page)—the dividend resulting from only the initial year of emissions will always be the maximum because our empirical analysis has shown that forest carbon resequestration is generally an increasing function (at least after the first few decades); (2) cumulative carbon dividends are positive for oil (#6), thermal for all harvest scenarios; using biomass to displace residual fuel oil in thermal applications would result lower atmospheric carbon levels by an average of about 20% in 2050; (3) cumulative carbon dividends are mostly negative in 2050 for the three other fossil fuel technologies indicating that 40 years is not sufficient for biomass to reduce atmospheric carbon levels using these technology/fuel combinations.

Finally, it should be noted that extending this analysis beyond 2050 will continue to show higher cumulative dividends over

---

[16] Carbon dividend = (total carbon recovered – carbon debt)/(total carbon emissions –carbon debt) or (115 –(0.15*150))/(150-(150*0.15)) = 73%

[17] Mathematically, there are several ways to compute these values: 1) sum the carbon differences in 2050 for each harvest year, as described above; 2) sum the total carbon released from biomass (net of forest carbon recapture) from 2010–2050 and compare this with the total carbon released from 40 years of burning fossil fuel; or, equivalently, 3) sum the total excess carbon generated from burning biomass (the excesses prior to the point of equal carbon flux) and compare these with the sum of carbon reductions relative to fossil fuel during the phase when dividends are positive.

**Exhibit 6-13: Carbon Debt and Dividends**

| Harvest Scenario | Fossil Fuel Technology | Carbon Debt Payoff (yr) | Carbon Dividend | |
|---|---|---|---|---|
| | | | 2050 | 2100 |
| 1 | Oil (#6), Thermal | 7 | 47% | 58% |
| | Coal, Electric | 21 | 32% | 46% |
| | Gas, Thermal | 24 | 26% | 41% |
| | Gas, Electric | >90 | -38% | -9% |
| 2 | Oil (#6), Thermal | 3 | 64% | 75% |
| | Coal, Electric | 12 | 54% | 68% |
| | Gas, Thermal | 17 | 50% | 65% |
| | Gas, Electric | 45 | 7% | 35% |
| 3 | Oil (#6), Thermal | 14 | 38% | 62% |
| | Coal, Electric | 30 | 21% | 52% |
| | Gas, Thermal | 36 | 13% | 47% |
| | Gas, Electric | 89 | -61% | 3% |
| 4 | Oil (#6), Thermal | 10 | 53% | 76% |
| | Coal, Electric | 27 | 40% | 70% |
| | Gas, Thermal | 31 | 34% | 67% |
| | Gas, Electric | 59 | -22% | 39% |
| 5 | Oil (#6), Thermal | 15 | 46% | 64% |
| | Coal, Electric | 25 | 31% | 54% |
| | Gas, Thermal | 28 | 24% | 49% |
| | Gas, Electric | 86 | -41% | 6% |
| 6 | Oil (#6), Thermal | 15 | 39% | 66% |
| | Coal, Electric | 32 | 22% | 56% |
| | Gas, Thermal | 37 | 14% | 52% |
| | Gas, Electric | 85 | -59% | 11% |

time. When cumulative dividends through 2100 are considered (Exhibit 6-15), they are higher than the results shown for 2050, although these longer term results will overstate benefits if biomass comes from forests that are harvested more than once or experience significant mortality-causing natural disturbance during the 2010–2100 period.

**Exhibit 6-14: Cumulative Carbon Dividends: 2010 to 2050**

| Harvest Scenario | Fossil Fuel Technology | | | |
|---|---|---|---|---|
| | Oil (#6), Thermal | Coal, Electric | Gas, Thermal | Gas, Electric |
| 1 | 22% | -3% | -13% | -110% |
| 2 | 34% | 11% | 3% | -80% |
| 3 | 8% | -22% | -34% | -148% |
| 4 | 15% | -13% | -24% | -129% |
| 5 | 16% | -11% | -22% | -126% |
| 6 | 7% | -25% | -36% | -153% |

**Exhibit 6-15: Cumulative Carbon Dividends: 2010 to 2100**

| Harvest Scenario | Fossil Fuel Technology | | | |
|---|---|---|---|---|
| | Oil (#6), Thermal | Coal, Electric | Gas, Thermal | Gas, Electric |
| 1 | 40% | 19% | 12% | -63% |
| 2 | 56% | 42% | 36% | -18% |
| 3 | 31% | 8% | 0% | -86% |
| 4 | 43% | 24% | 17% | -54% |
| 5 | 37% | 16% | 9% | -69% |
| 6 | 31% | 8% | -1% | -86% |

The interpretation of the carbon dividend results should recognize that neither carbon dividends nor carbon debts provide direct indications of the associated environmental benefits or damages. This would require a detailed analysis of the actual climate impacts of increased GHG levels in the period before carbon debts are paid off and lower GHG levels after that point in time. Potential non-linearity in the climate damage functions make such formal benefit-cost analysis challenging and beyond the scope of this study; consequently we leave this analysis to other researchers. Nonetheless, information on initial carbon debts, dividends accrued up to a point 90 years in the future, and estimates of the number of years needed to pay off carbon debts and begin accruing benefits should help inform the development of biomass energy policies.

### 6.3.4 DISCUSSION OF RESULTS

The analyses presented above make clear that technology choices for replacing fossil fuels, often independent of any forest management considerations, play an important role in determining the carbon cycle implications of burning biomass for energy. The choice of biomass technology, and the identification of the fossil capacity it replaces, will establish the initial carbon debt that must be recovered by forest growth above and beyond BAU growth. These carbon debts vary considerably across technologies. For typical existing configurations, replacement of oil-fired thermal systems with biomass systems leads to relatively low carbon debts. Carbon debts for large-scale electrical generation are higher. Because of its much lower GHG emissions per unit of useable energy, replacing natural gas for either thermal or electric applications results in significantly higher carbon debts than incurred in replacing other fossil fuels.[18] The carbon recovery profile for combustion of wood pellets is roughly similar to burning green wood chips in terms of total lifecycle GHG emissions. CHP facilities, particularly those that optimized for thermal rather than electricity applications, also show very low initial carbon debts.

While the relative ranking of technologies by their carbon recovery times provides useful insights on relative carbon emissions per unit of useable energy, the specific time required in each case to pay off carbon debts and begin realizing the benefits of biomass energy, represented in this study by the carbon dividends, depends on what happens in the forests harvested for biomass fuel. The results of our analyses provide some broad insights into biomass carbon dynamics but are also subject a number of uncertainties that are difficult to resolve.

A key finding of our work is that the magnitude and timing of carbon dividends can be quite sensitive to the forest management practices adopted by landowners. Carbon recovery times can differ by decades depending upon assumptions about (1) the intensity of harvests; (2) the silvicultural prescriptions and cutting practices employed; (3) the fraction of the logging residues removed from the forest for biomass; and (4) the frequency

---

[18] Cowie (2009) draws similar conclusions in a recent presentation of work on IEA Bioenergy Task 38.

at which landowners re-enter stands to conduct future harvests. If the landowners responding to demands for increased biomass are the same ones who harvest their lands heavily today, then it is probably reasonable to assume that carbon debts are recovered relatively rapidly, along the lines suggested by our Scenario 1. In this case, the transition from debt to dividends that results from replacing oil-fired thermal with biomass is between 10 and 20 years and the biomass coal-electric transition occurs after 20 to 30 years. But if the response is more evenly distributed across all landowners and the biomass harvests are more heavily focused on removal of suppressed and understory cull trees, we expect that recoveries would likely be slower. How much slower, and the impact on subsequent carbon dividends, cannot be predicted without a better understanding than we currently have about future landowner forest management practices. While detailed landowner surveys might improve our understanding of this issue, this uncertainty cannot be completely resolved until we can observe actual landowner behavior in response to increased biomass demand.

Finally, it is important to emphasize that after the point in time where GHG levels are equivalent for biomass and fossil fuels, biomass energy provides positive reductions in future GHG levels. Over time, under some scenarios these carbon dividends can become substantial, reducing GHGs by up to 85% in some scenarios relative to continued fossil fuel use. But the key question remains one of the appropriate weighting of near-term higher GHG levels with long-term lower ones. Policymakers will need to sort out these issues of societal time preferences and weight near term higher GHG emissions against longer term lower ones.

## 6.4 FINAL CONSIDERATIONS

The Massachusetts Department of Energy Resources has indicated that it hopes this study will provide valuable information to help guide its decisions on biomass energy policy. The study discusses a complex subject that is technically challenging and inevitably we have not been able to resolve all critical uncertainties. Policymakers should carefully weigh the significant uncertainties that remain, as well as other factors not addressed by our study, in deciding whether to encourage or discourage biomass development. In light of that, we conclude with some general observations on how the results of our carbon accounting analyses should be interpreted by policymakers and the public at large.

- As suggested in the discussion of carbon recovery, we have used average and/or typical values for GHG emissions from biomass and fossil fuel energy facilities. With continually evolving technology, biomass developers may be able to demonstrate lower GHG emissions per unit of useable energy. This can be expected to reduce carbon debts and change the overall time required to pay off these debts through forest growth. Consequently, our carbon debt and dividend conclusions should be viewed as representative of typical or average conditions today, a state of affairs that will likely change in the future given the evolution of technologies.

- Our carbon analysis considers only biomass from natural forests. Tree care and landscaping sources, biomass from land clearing, and C&D materials have very different GHG profiles. Carbon from these sources may potentially enter the atmosphere more quickly and consequently carbon debts associated with burning these types of biomass could be paid off more rapidly, yielding more immediate dividends. Our results for biomass from natural forests likely understate the benefits of biomass energy development relative to facilities that would rely primarily on these other wood feedstocks.

- Our analyses of recovery of carbon recovery by forests have focused primarily on average or typical forest conditions in Massachusetts. The responses of individual stands vary around these average responses, with some stands recovering carbon more rapidly and others less rapidly than the average. Due to the complexity of responses at the individual stand level, this study has not been able to isolate the characteristics of rapidly recovering stands using FVS. Should better data become available on this topic, it might be possible to design and implement forest biomass harvest policies that accelerate the average carbon recovery times reported here.

- Some landowners may face alternative BAU baselines that we have not considered, and this raises issues about generalizing our results too widely—particularly beyond Massachusetts and New England. We have used the historical harvest trends in Massachusetts as the basis for our BAUs and we believe this is the most likely future for landowners in the Commonwealth. However, we cannot rule out other BAU scenarios that could change the carbon recovery results in important ways. For example, if no biomass plants are sited in Massachusetts, will landowners actually face an alternative BAU where they can sell this material to out-of-state energy facilities? If so, GHG impacts are likely the same as if the material were used in state. Or is there an alternative BAU for an out-of-state facility that sells renewable energy to Massachusetts—for example bioenergy facilities in Maine that may be competing for biomass supplies that would otherwise go to paper production and enter the GHG system relatively more quickly? The existence of alternative baselines would result in different carbon debts and recovery profiles than those that we have identified for Massachusetts.

- Views about how long it will take before we have truly low or no carbon energy sources play a critical role in biomass policy decisions. If policymakers believe it will take a substantial amount of time to develop and broadly apply low or no carbon sources of energy, they may be more inclined to promote the development of biomass. Conversely, if they think that no or low carbon alternatives will be available relatively soon, say in a matter of one or two decades, they may be less inclined to promote development of biomass, especially for applications where carbon debts are relatively higher and where longer payoff times reduce future carbon dividends.

- Concerns about the relative importance of short- versus long-term consequences of higher carbon emissions may also play a role in how one interprets the results of this study. Those who believe that short-run increases in GHG levels need to be avoided at all costs will be less likely to favor biomass development than those focused on the potentially quite significant, but longer term benefits of reduced GHG levels that could ultimately result from biomass development.

In light of all these factors, we stress that our work should be viewed as providing general indicators of the time frames for recovery of biomass carbon and the key factors that influence these estimates. Uncertainties remain and we have tried to be transparent about them. For the variety of reasons discussed above, the carbon recovery and dividend profile for a specific facility is likely to deviate from the average facilities analyzed in this report. As such, we suggest that new energy and environmental policies that rely on insights from this study should clearly take into account the impacts of the various uncertainties embedded in the report's analytic framework, assumptions and methods.

## REFERENCES

Bauen, A., G. Berndes, M. Junginger , M. Londo, and F. Vuille. 2009. Bioenergy – A Sustainable and Reliable Energy Source: A review of status and prospects. IEA Bionenergy, ExCo: 2009:06.

CORRIM (Consortium for Research on Renewable Industrial Materials). 2004. Forest Resources: Pacific Northwest and Southeast, Phase I Final Report, Module A.

Cowie, A. 2009. Global challenges for sustainability of biofuels: life cycle assessment of GHG emissions. IEA Bioenergy Task 38. url: www.iea.org/work/2009/bangkok/2_2_Cowie.pdf.

Department of Forest Resources, University of Minnesota. 2008. Assessment of Carbon Flows Associated with Forest Management and Biomass Procurement for the Laskin Biomass Facility. Staff Paper Series No. 198.

Fargione, J., J. Hill, D. Tilman, S. Polasky and P. Hawthorne. 2008. Land Clearing and the Biofuel Carbon Debt. Science Vol. 319 1235-1238.

Finkral, A.J. and Evans, A.M. 2008. The effects of thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. *Forest Ecology and Management* 255 (2008) 2743–2750.

Gerdes, K.J. 2009. NETL's Capability to Compare Transportation Fuels: GHG Emissions and Energy Security Impacts. National Energy Technology Laboratory. http://www.netl.doe.gov/energy-analyses/pubs/Petroleum%20Fuels%20GHG%20Modeling_Feb%2025a.pdf

Hamburg, S. 2010. Biomass feedstocks and the climate implications of bioenergy. Presentation at EIA 2010 Energy Conference: Short-Term Stresses Long-Term Change. url: www.eia.doe.gov/conference/2010/session2/hamburg.pdf

Johnson, E. (2008). Goodbye to carbon neutral: Getting biomass footprints right. Environmental Impact Assessment Review

Katers, J.F. and Kaurich, J. 2006. Heating Fuel Life-Cycle Assessment. University of Wisconsin—Green Bay.

Kurz, W.A., C.C. Dymond, T.M. White, G. Stinson, C.H. Shaw, G.J. Rampley, C. Smyth, B.N. Simpson, E.T. Neilson, J.A. Trofymow, J. Metsaranta, M.J. Apps. 2008. CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. Ecological Modeling 220 (2009) 480-504.

Marland, G. and B. Schlamadinger. 1995. Biomass Fuels and Forest-Management Strategies: How Do We Calculate the Greenhouse-Gas Emissions Benefits? Energy 20: 1131-1140.

Marland, G., B. Schlamadinger, and L. Canella. Undated. The Model GORCAM. www.joanneum.at/gorcam.htm.

Miner, R. 2010. Biomass Carbon Neutrality. National Council for Air and Stream Improvement (NCASI). url: nafoalliance.org/wp-content/uploads/NCASI-Biomass-carbon-neutrality.pdf.

Morris, G. 2008. Bioenergy and Greenhouse Gases. Green Power Institute, The Renewable Energy Program of the Pacific Institute. Berkeley.

Natural Resources Canada. 2009. RETScreen International. url:www.retscreen.net/.

Schelhaas, M.J., P.W. van Esch, T.A. Groen, B.H.J. de Jong, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, T. Palosuo, L. Pedroni, A. Vallejo, T. Vilén. 2004. CO2FIX V 3.1 - description of a model for quantifying carbon sequestration in forest ecosystems and wood products. ALTERRA Report 1068. Wageningen, The Netherlands.

Schlamadinger, B. and G. Marland. 1996a. Carbon Implications of Forest Management Strategies, pp. 217-232 in M.J. Apps and D.T. Price (eds.) Forest Ecosystems, Forest Management and the Global Carbon Cycle, Proceedings of a NATO Advanced Research Workshop, NATO ASI Series I, Volume 40, Springer-Verlag, Berlin.

Schlamadinger, B., and G. Marland. 1996b. The Role of Forest and Bioenergy Strategies in the Global Carbon Cycle, *Biomass and Bioenergy* 10: 275-300.

Schlamadinger, B. and G. Marland. 1996c. Full Fuel-Cycle Carbon Balances of Bioenergy and Forestry Options, Energy Conservation and Management 37: 813-818.

Spath, P.L. and M.K. Mann. 2000. Life Cycle Assessment of Natural Gas Combined-Cycle Power Generation System. NREL (National Renewable Energy Laboratory). NREL/TP-570-27715.

Spath, P.L., M.K. Mann, D.R. Kerr. 1999. Life Cycle Assessment of Coal-fired Power Production. NREL (National Renewable Energy Laboratory). NREL/TP-570-25119.

# APPENDIX 1-A

# FEDERAL, STATE AND REGIONAL BIOMASS ENERGY POLICIES

The following summary of federal and select state policies and incentives related to the development of biomass energy facilities addresses the following areas:

- A summary of relevant federal policies affecting the development of biomass energy;
- A review of relevant regional policies and regulatory initiatives impacting the development of biomass energy;
- A summary of current policies in the State of Massachusetts that relate to renewable energy and biomass facilities as well as state policies related to sustainable forestry issues; and
- A review of notable biomass policies and incentives in other states, with a particular focus on renewable energy, forest sustainability, carbon regulation, and climate change issues.

The information presented here is drawn from several sources including work prepared for the Biomass Energy Resources Center by Shems Dunkiel Raubvogel & Saunders PLLC, research conducted by Charles Niebling of New England Wood Pellet, analysis conducted by the Biomass Thermal Energy Council, analysis conducted by Jesse Caputo of the Environmental and Energy Study Institute, and analysis provided by the Pinchot Institute for Conservation.

This discussion includes a historical review of prior federal policies under the Public Utility Regulatory Policy Act of 1978 (PURPA), which spurred development of many existing biomass energy facilities in the U.S.

## I. Federal Policies & Incentives Relevant to Biomass

Federal incentives for renewable energy (including biomass) have taken many forms over the past four decades. The focus of most of these programs has been on encouraging renewable electricity generation and, more recently, production of renewable transportation fuels, such as ethanol with little attention to or investment in the thermal energy sector. Consequently, biomass as an energy source is being primarily directed into the large scale production of liquid biofuels and/or large scale electric generation. In addition, existing renewable energy policy provides little or no connection to efficiency requirements, sustainable forestry provisions or carbon sequestration goals.

As discussed below, federal policy initially focused on encouraging renewable electricity generation by requiring utilities to purchase electricity from renewable energy generators at a fixed cost through the Public Utility Regulatory Policy Act (PURPA).

More recently, federal policy has shifted towards encouraging renewable energy through tax incentives and direct grants—with the primary focus on renewable transportation fuels and renewable electricity generation.

### *A. Historical Review of Major Federal Policies Incentivizing Biomass Development*

Development of biomass energy facilities in the U.S. in the last four decades has been largely driven by federal energy policies and incentives designed to encourage renewable energy development and diversification of energy sources. Historically speaking, the most important of these federal policies was the Public Utility Regulatory Policy Act (PURPA). PURPA was passed in 1978, primarily in response to the sharp spike in oil prices during the 1970s, and embodied a national effort to reduce reliance on foreign oil and diversify domestic energy generation.

To achieve these goals, PURPA contained several provisions specifically designed to spur development of renewable energy generation in the U.S. Chief among these provisions was the requirement that utilities purchase the power output from certain small renewable energy generators—known as "qualified facilities" (QF)—at the utility's "avoided cost." The certainty of these guaranteed, highly favorable rates led to a dramatic increase in renewable energy generation, including an estimated three-fold increase in biomass facilities in the 1980s and early 1990s.

But the spike in biomass facilities developed under PURPA was relatively short lived and market conditions and regulatory changes have limited the value and application of the "avoided cost" provisions of PURPA. Deregulation efforts in the 1990s also led to increased competition among energy generators in many parts of the U.S., opening the grid to a greater number of small or independent power producers. Due to the perceived increase in competition in power markets, Congress revised PURPA in 2005 and, combined with subsequent regulator action, PURPA no longer serves as a significant incentive for the development of biomass facilities in the US.

### *B. Current Federal Policies Related to Biomass Energy Development*

Current federal policies and incentives for renewable energy facilities take many different forms. This review focuses on incentives relevant to biomass power or combined heat and power vs. the production of liquid biofuels, which is beyond the scope of this project. These incentives have moved away from the "guaranteed cost" approach implemented under PURPA, and now rely primarily on either (1) federal tax incentives, or (2) direct federal grants or loans from federal agencies. Specific examples of these two types of incentives are summarized below.

### Federal Tax Incentives

Overall, existing federal tax incentives for renewable energy focus on electric power generation and the production of liquid biofuels. Consequently, biomass feedstocks are being directed preferentially towards these types of energy applications. In addition, existing federal tax incentives provide little or no connection to efficiency requirements, sustainable forestry provisions or carbon sequestration goals.

1. Production Tax Credit (IRS Code Section 45)

The Renewable Energy Production Tax Credit (PTC) provides a tax credit for owners or operators of qualifying renewable electric generation facilities for the first ten years of operation. Qualifying resources include both "closed-loop biomass" and "open loop biomass" facilities that sell power to the public. Co-fired units (those burning both fossil fuel and biomass) are not eligible. The 2009 American Recovery and Reinvestment Act recently extended the PTC for projects placed into service from the end of 2010 through the end of 2013. The benefit of this production tax credit can only be realized by an entity with sufficient taxable income to take advantage of the credit; the PTC will not provide an incentive to entities that do not pay federal taxes unless they partner with other entities with federal tax exposure. This program is not subject to annual appropriations, but does need to be extended every year.

2. Business Energy Investment Tax Credit (IRS Code Section 48)

The Business Energy Investment Tax Credit (ITC) provides a credit based on the value of the investment in certain types of electrical generation and combined heat and power (CHP) biomass facilities and was also recently expanded to apply to general closed and open loop biomass facilities. The CHP ITC is a 10 percent tax credit for the first 15MW of a system up to 50MW. The CHP ITC extends through December 31, 2016. The 2009 ARRA also expanded the availability of the ITC to other closed loop and open loop biomass facilities (besides CHPs) that are otherwise eligible for the PTC. Under this new provision, the owner of a biomass facility that qualifies for the PTC may elect to claim an ITC in lieu of the PTC.

3. Grant in Lieu of Investment Tax Credit

The 2009 ARRA also created a new program that allows taxpayers eligible for the ITC to elect to receive a grant from the U.S. Treasury. This is technically a direct federal grant, not a tax credit, but is covered here for sake of continuity with the related ITC and PTC provisions. This cash grant may be taken in lieu of the federal business energy investment tax credit (ITC). Eligible CHP property includes systems up to 50 MW in capacity that exceed 60 percent energy efficiency. The efficiency requirement does not apply to CHP systems that use biomass for at least 90 percent of the system's energy source.

4. Clean Renewable Energy Bonds (CREBs) (IRS Code Section 54)

The Clean Renewable Energy Bonds (CREBs) program was created by the Energy Policy Act of 2005. The program provides "tax-credit" bonds to renewable energy projects developed by governments or electric coops. The bonds are awarded to eligible entities on a competitive basis by the IRS. Both closed-loop and open-loop biomass facilities are eligible for the program. Unlike typical bonds, which pay interest to the bondholder, the tax-credit bonds provide bondholders a credit against their federal income tax, effectively providing the issuer of the bonds a 0% loan with the federal treasury covering the interest payments. The 2009 ARRA allocated an additional $1.6 billion for this program.[1]

5. Five-Year Modified Accelerated Cost Recovery System (MACRS) (IRS Code Section 168)

Certain biomass facilities are also eligible for the Modified Accelerated Cost-Recovery System (MACRS). Under the MACRS program, businesses may recover investments in certain properties through accelerated depreciation deductions. At the present time, combined heat and power facilities powered by biomass are in the five-year accelerated depreciation class for this program.

6. New Market Tax Credits

Although not specific to biomass projects, The New Markets Tax Credit (NMTC) Program could potentially provide an additional tax incentive for biomass facilities, depending on the location of the facility, and potentially, on the clients the facility serves. The purpose of the NMTC program is to encourage development that would benefit low income people and populations. It provides a tax credit against Federal income taxes for taxpayers making qualified equity investments in designated Community Development Entities (CDEs). The potential application of this tax credit program to any particular project is very site specific. A map of NMTC-qualifying areas in western Massachusetts can be found at http://www.ceimaine.org/content/view/215/233/. $13.4 billion in NMTC have been finalized or committed by May 2009 out of $19.5 billion awarded through 2008. An additional $1.5 billion was awarded in May 2009.

### Federal Grants and Loans

The second major category of incentives is direct grants and loans from federal agencies including primarily the Department of Agriculture (USDA) and the Department of Energy (DOE). Some of the relevant programs from each agency are discussed below. The major portion of these funds are available through the Department of Energy, with the Exception of USDA's Biomass Crop Assistance Program (as discussed below). While there are several important programs at USDA that address smaller scale biomass energy options, these initiatives generally have low appropriations levels and, in many cases, have never been funded. By contrast the DOE programs generally focus on large scale production of liquid biofuels and/or electric generation and are funded at much higher levels than the array of USDA programs. Again, this creates incentives for certain biomass energy applications—biofuel production and electricity generation—at the federal level.

*A. USDA Grant & Loan Programs*

---

[1] http://www.taxalmanac.org/index.php/Sec._54._Credit_to_holders_of_clean_renewable_energy_bonds.

The majority of relevant USDA biomass programs are based on provisions of the 2008 Farm Bill. The relevant portions of the bill are focused on encouraging development of renewable biomass facilities. The Farm Bill specifically includes biomass in the definition of renewable energy, and defines "renewable biomass" broadly as "any organic matter that is available on a renewable or recurring basis from non-Federal land" and certain materials from public lands, if harvested during preventative treatments to reduce hazardous fuels, address infestation, or restore "ecosystem health." The following specific programs may provide incentives for biomass facilities and projects.

### *1. The Rural Energy for America Program (Sec. 9007 of 2008 Farm Bill)*

The Rural Energy for America Program (REAP) provides financial assistance to rural communities in order for them to become more energy independent through increased production of renewable energy and energy efficiency. Grants and loan guarantees are available for energy efficiency and renewable energy investments (including biomass) for agricultural producers and rural small businesses. Grants may be up to 25% of project cost (up to a maximum of $500,000 for renewable energy projects), loan guarantees are capped at $25 million/loan and grants and loan guarantees together may be up to 75%. A portion of grants are reserved for small projects.

### *2. The Rural Energy Self-Sufficiency Initiative (Sec. 9009 of 2008 Farm Bill)*

Authorizes a new program to provide financial assistance to increase energy self-sufficiency of rural communities. Provides grants to conduct energy assessments, formulate plans to reduce energy use from conventional sources, and install integrated renewable energy systems. Integrated renewable energy systems are defined as community-wide systems that reduce conventional energy use and incorporate renewable energy use. Federal-cost share for any grant is limited to 50% of project cost. The 2008 bill authorizes appropriations of $5 million annually for FY 2009-12.

### *3. Biomass Crop Assistance Program (BCAP) (Sec. 9011)*

Created in the 2008 Farm Bill, BCAP is an innovative program intended to support establishment and production of eligible crops for conversion to bioenergy, and to assist agricultural and forest landowners with collection, harvest, storage, and transportation (CHST) of these eligible materials to approved biomass conversion facilities (BCF).

The program pays for up to 75% of establishment costs of new energy crops. In addition, farmers participating in a selected BCAP project area surrounding a qualifying BCF can collect 5 years of payments (15 years for woody biomass) for the establishment of new energy crops. An additional matching payment of up to $45/ton (on a $1 to $1 basis) to assist with collection, harvest, storage and transportation (CHST) of an eligible material to a BCF will also be available for a period of 2 years.

However, the launch of this new program has proved problematic. Rather than focusing funding on the front-end of the program, establishment of new energy crops, the Farm Service Agency (FSA) announced funds for the back-end of the program (via a Notice of Funding Availability (NOFA) for the Collection, Harvest, Storage and Transportation (CHST). It also interpreted CHST as an "entitlement" and allowed payment for a broad range of agricultural and forested materials delivered to an approved BCF.

The result amounted to a substantial, new subsidy for the existing wood market with significant market impact. Large numbers of existing biomass conversion facilities (led by lumber, pellet and paper mills currently burning wood for their own energy use without a federal subsidy) submitted applications to USDA to be approved as qualifying facilities. Consequently, funds obligated (though not yet spent) for BCAP through the end of March 2010 soared to over $500 million, more than seven times BCAP's estimated budget of $70 million in the 2008 Farm Bill. The USDA now estimates BCAP costs at $2.1 billion on CHST from 2010 through 2013.

The proposed rule for BCAP was announced February 8 with a final rule anticipated late summer 2010.

### *4. Forest Biomass for Energy (Sec. 9012)*

Authorizes new competitive research and development program to encourage use of forest biomass for energy. To be administered by USDA's Forest Service; priority project areas include:

- developing technology and techniques to use low-value forest biomass for energy production
- developing processes to integrate energy production from forest biomass into biorefineries
- developing new transportation fuels from forest biomass
- improving growth and yield of trees intended for renewable energy

Authorizes appropriation of $15 million annually for FY 2009-12.

### *5. Community Wood Energy Program (Sec. 9013)*

The Community Wood Energy Program is administered by the USDA and provides grants of up to $50,000 to state and local governments to develop community wood energy plans. Once a plan has been approved, qualified applicants may request up to 50% matching grants toward the capital costs of installing biomass energy systems. The Farm Bill authorizes $5 million per year from FY 2009 through FY 2012 for this program, but to date, no funds have actually been appropriated.

### *6. Business and Industry Guaranteed Loan Program*

The Business and Industry Guaranteed Loan Program administered by USDA Rural Development. The purpose of the B&I Guaranteed Loan Program is to improve, develop, or finance business, industry, and employment and improve the economic and environmental climate in rural communities. A borrower may be a cooperative, corporation, partnership, or other legal entity organized and operated on a profit or nonprofit basis; an Indian tribe on a Federal or State reservation or other federally recognized tribal group; a public body; or an individual. A borrower may be eligible if they are engaged in a business that will reduce reliance on nonrenewable energy resources by encouraging the development and construction of renewable energy systems.

### 7. Rural Business Enterprise Grants (RBEGs)

The RBEG program provides grants for rural projects that finance and facilitate development of small and emerging rural businesses (defined as those that will employ 50 or fewer new employees and have less than $1 million in projected gross revenues). The program is not specific to biomass projects, but biomass projects could benefit from the grants.

## B. Department of Energy Grant & Loan Programs

### 1. Renewable Energy Production Incentive

The Renewable Energy Production Incentive (REPI) provides financial incentive payments for electricity generated and sold by new qualifying renewable energy generation facilities. Qualifying facilities- including biomass facilities—are eligible for annual incentive payments for the first 10-year period of their operation, subject to the availability of annual appropriations in each Federal fiscal year of operation. This program serves as an alternative to the PTC for entities that are not eligible to take advantage of that tax program (i.e. entities that do not have federal tax liabilities).

### 2. DOE Loan Guarantee Program

Title XVII of the Energy Policy Act of 2005 authorizes DOE to provide loan guarantees for energy projects that reduce air pollutant and greenhouse gas emissions. DOE recently released its second round of solicitations for $10 billion in loan guarantees for energy efficiency, renewable energy, and advanced transmission and distribution projects under EPACT 2005 with a primary focus on transportation and electric generation. The final regulation provides that the DOE may issue guarantees for up to 100 percent of the amount of a loan. The 2009 ARRA extended the authority of the DOE to issue loan guarantees and appropriated $6 billion for this program. Under this legislation, the DOE may enter into guarantees until September 30, 2011.

### 3. Energy Efficiency and Conservation Block Grants

The Energy Efficiency and Conservation Block Grant (EECBG) Program provides federal grants to local government, Indian tribes, states, and U.S. territories to improve energy efficiency and reduce energy use and fossil fuel emissions in their communities. Activities eligible for funding include energy distribution technologies that significantly increase energy efficiency, including distributed generation, CHP, and district heating and cooling systems. A total of $3.2 billion was appropriated for the EECBG Program for fiscal year 2009. This funding will generally flow directly to states or local municipalities and is typically awarded on a competitive basis.

### 4. Sec. 471, Energy Independence and Security Act of 2007

Sec. 471 of the 2007 Energy Bill authorizes a program for Energy Efficiency and Sustainability Grants for implementing or improving district energy systems, combined heat and power applications, production of energy from renewable resources, developing sources of thermal energy and other applications. These funds would leverage investments by eligible public sector entities including institutions of high education, local governments, municipal utilities and public school districts. The Act authorizes $250 million for grants and $500 million for loans under this program for FY2009-2013 with maximum grants limited to $500,000. The program has never been funded.

### 5. Other ARRA Programs and Funding Opportunities Specific to Combined Heat and Power Facilities.

In addition to these major programs, the 2009 ARRA authorized a number of small grant and loan programs through DOE, some of which apply to potential biomass facilities including CHP and thermal district energy facilities. Of these, two grant opportunities were particularly relevant to biomass energy applications.

DOE-FOA-0000044, issued through the National Energy Technology Laboratory, provided $156 million for deployment of CHP systems, district energy systems, waste energy recovery systems, and efficient industrial equipment. Approximately 350 responses were submitted representing $9.2 billion in proposed projects with a $3.4 billion federal share, a demand far in excess of the available funding. DE-FOA-0000122, provided $21 million for community renewable energy development, with awards going to 5 projects nationwide.

The Department of Energy also has other solicitations specifically for combined heat and power systems. For example, the Industrial Technologies Program (ITP), part of DOE's Office of Energy Efficiency and Renewable Energy, recently released a funding opportunity for or up to $40 million in research, development and demonstration of combined heat and power (CHP) systems, based on annual appropriations, not ARRA funds.

## II. Review and summary of Massachusetts state policies relevant to biomass energy and sustainable forestry.

Massachusetts has implemented policies to increase the use of biomass to meet energy needs in the electricity sector, the transportation sector, and the building heating sector, although state policies are focused primarily on implementing biomass to replace fossil fuels in the electricity and transportation sectors. Combined with the state's regulatory scheme designed to implement the Regional Greenhouse Gas Initiative (RGGI) (which sets an emissions cap on fossil fuel fired electrical generation systems of 25 megawatts or greater), this has created significant incentives in the state driving biomass towards larger scale electric generation capacity vs. smaller scale or thermal applications. A recent exception to this trend is the Massachusetts Green Communities Act of 2008 which established new Renewable and Alternative Energy Portfolio Standards (RPS and APS) which allow eligible CHP units to receive credits for useful thermal energy. This program promotes the installation and effective operation of new CHP units for appropriate residential, commercial, industrial, and institutional applications. It does not, however, eliminate or counterbalance the overall focus on encouraging development of the biomass electric power sector.

Following is a summary of the range of statutory and regulatory provisions that directly address biomass in Massachusetts, with an emphasis on biomass policy within the electricity sector.

## A. Biomass in Renewable Energy Policy

### 1. *Electricity*

Massachusetts has two regulatory schemes that directly impact the incentives for developing biomass-fueled electricity in the state. The first is the Massachusetts Renewable Portfolio Standard (RPS), which is administered by the Department of Energy Resources (DOER), and the second is the implementation of the state's membership in the Regional Greenhouse Gas Initiative (RGGI), which is administered by the Department of Environmental Protection (DEP). We discuss RGGI and the Massachusetts regulatory scheme implementing RGGI in Part III, in the context of regional biomass policy initiatives. In this section of the paper, we discuss the implications for biomass energy under the RPS program regulations as currently written, recognizing that DOER has suspended RPS review of all proposed biomass-fueled electricity generators pending completion of the Manomet study.

The Massachusetts RPS program currently mandates that all retail electricity suppliers must include minimum percentages of RPS Class I Renewable Generation, RPS Class II Renewable Generation, and RPS Class II Waste Energy in the retail electricity they sell to consumers. For 2010, the Class I requirement is 5 percent, the Class II Renewable requirement is 3.6 percent, and the Class II Waste requirement is 3.5 percent. The definition of "eligible biomass fuel" under the RPS program is:

> *Fuel sources including brush, stumps, lumber ends and trimmings, wood pallets, bark, wood chips, shavings, slash and other clean wood that are not mixed with other unsorted solid wastes; by-products or waste from animals or agricultural crops; food or vegetative material; energy crops; algae; organic refuse-derived fuel; anaerobic digester gas and other biogases that are derived from such resources; and neat Eligible Liquid Biofuel that is derived from such fuel sources.*

It is notable that this definition contains no "sustainability" requirement. The RGGI definition, by contrast, does contain such a requirement, though the criteria for sustainability in that definition are not fleshed out at this time. This definition also includes liquid biofuels, which are expressly excluded from the definition of "eligible biomass" for purposes of the Massachusetts RGGI program.

Biomass facilities may qualify as RPS Class I or Class II generation units as long as they are classified as "low-emission, advanced biomass Power Conversion Technologies using an Eligible Biomass Fuel." Both the Class I and Class II RPS regulations also allow generators that co-fire to qualify as RPS Renewable Generation as long as certain requirements are met. This provision in the RPS program is analogous to the biomass exemption from carbon dioxide emissions accounting in the RGGI program.

In 2008, the Massachusetts Green Communities Act established new Renewable and Alternative Energy Portfolio Standards (RPS and APS) allowing Combined Heat and Power facilities to be included as an eligible technology provided the thermal output of a CHP unity is used in Massachusetts. APS eligible CHP units receive credits for the useful thermal energy of a CHP unit delivered to Massachusetts end-uses, subject to the formula included in the regulations. The DOER rules issued for this program will, for the first time in the Commonwealth, promote the installation and effective operation of new CHP units for appropriate residential, commercial, industrial, and institutional applications.

There are two other regulatory programs, aside from the DOER process for RPS approval, which could address the sustainability and the carbon neutrality of biomass-fueled electricity generation. The first is the Energy Facilities Siting Board review process for generation facilities, and the second is the Massachusetts Environmental Policy Act (MEPA).

All electricity generation facilities proposed in Massachusetts must be approved by the Energy Facilities Siting Board within the Department of Public Utilities. The Board reviews the environmental impacts of generation facilities to ensure that the plans for the facility are consistent with current health and environmental protection policies and the commonwealth's energy policies; and that the plans minimize environmental impacts and related mitigation costs. The Board is also responsible for adopting performance standards for emissions from generating facilities. The Board also has the authority to preempt other state agency or local regulatory bodies that pose hurdles to electricity facility siting. In making such decisions, the board has already has a track record of taking issues of carbon neutrality and sustainable fuel supplies into account.

The other regulatory vehicle for screening the sustainability and carbon neutrality of biomass electric generation facilities is environmental impact review through MEPA. However, as MEPA review is only mandatory for any new electric facility with a capacity of 100 MW or more, it may not have a great deal of promise for effective implementation of regulatory goals for biomass because facilities are unlikely to meet this size threshold. Further, the process is "informal," and "MEPA and [its implementing regulations] do not give the Secretary the authority to make any formal determination regarding . . . consistency or compliance" with "any applicable Federal, municipal, or regional statutes and regulations."

### 2. *Transportation and Heating*

The focus of Massachusetts policy on biomass in the transportation and heating sectors seems to be on liquid biofuels. In 2006, the commonwealth instituted a policy requiring the use of a minimum percentage of biofuels in state vehicles and instituting a pilot study on the use of biofuels in heating systems in state buildings. Additionally, the commonwealth created the "Advanced Biofuels Task Force" in late 2007 to explore how Massachusetts could accelerate use of advanced biofuels.[2] The Task Force issued a report, which explores the environmental life cycle of biofuels, and contains recommendations heavily focused on the transportation sector, in the spring of 2008. (Advanced Biofuels Task Force, 2007)

Following the report's publication, the commonwealth passed the Clean Energy Biofuels Act, which exempts cellulosic biofuels from the state gasoline tax, requires transportation diesel and home heating oil to contain 2-5% of cellulosic biofuels from 2010-2013, and requires the commonwealth to develop a low-carbon fuel standard that will reduce transportation GHG emissions by 10%. DOER has been implementing the Biofuels Act through regulations related to the tax exemptions for cellulosic biofuels. The proposed regulation includes a definition of "Lifecycle Greenhouse Gas Emissions" and eligibility criteria for the tax exemption that include requirements for the reductions in lifecycle GHG emissions achieved by eligible biofuels compared to fossil fuels.

## B. Biomass and Forestry

Massachusetts has a statutory framework as well as administrative regulations addressing forest harvesting. By statute, the Commonwealth recognizes that:

> *the public welfare requires the rehabilitation, maintenance, and protection of forest lands for the purpose of conserving water, preventing floods and soil erosion, improving the conditions for wildlife and recreation, protecting and improving air and water quality, and providing a continuing and increasing supply of forest products for public consumption, farm use, and for the woodusing industries of the commonwealth.*

Accordingly, it is the policy of the Commonwealth that:

> *all lands devoted to forest growth shall be kept in such condition as shall not jeopardize the public interests, and that the policy of the commonwealth shall further be one of cooperation with the landowners and other agencies interested in forestry practices for the proper and profitable management of all forest lands in the interest of the owner, the public and the users of forest products.*

The Massachusetts Department of Conservation and Recreation (DCR) is the regulatory agency charged with administering timber harvesting on public and private forest lands. DCR has jurisdiction over all commercial forest cutting that produces more than 25,000 board-feet or 50 cords on any parcel of land. Under the regulations, any landowner planning a cut within DCR's jurisdiction must complete a "forest cutting plan." Proposed cuts that include a clearcut exceeding 25 acres are subject to additional regulatory process mandated by the Massachusetts Environmental Policy Act.

In addition to administering the Forest Cutting Practices regulations DCR has joined with DOER to form the Sustainable Forest Bioenergy Initiative (SFBI). The goal of the SFBI is to "provide research and development on forest management and market infrastructure needs, and enable the state to provide the resources necessary to develop the biomass supply market." The Initiative has produced a number of technical reports regarding woody biomass energy, woody biomass supply in the state, forest harvesting systems for biomass production, economic impact analyses, and silvicultural and ecological considerations for forest harvesting.

Documents produced under the SFBI state that the "carbon dioxide produced by burning wood is roughly equal to the amount absorbed during the growth of the tree." Other documents estimate between 500,000 and 890,000 dry tons of biomass from public and private forests located in the state can be sustainably harvested per year, and that the demand for woody biomass from forestry is approximately 526,000 dry tons per year. The SFBI has carried out extensive state-specific work on biomass energy and forest sustainability issues relevant to this study.

## C. Other Massachusetts Incentives Related to Renewable or Alternative Energy Development and Biomass

The following paragraphs comprise a set of tax incentives and other programs available in Massachusetts that may have an impact on biomass development in the Commonwealth.

1. Renewable Energy Trust Fund—Two separate public benefits funds to promote renewable energy and energy efficiency for all customer classes. The renewable energy fund, known as the Massachusetts Renewable Energy Trust (MRET), is supported by a surcharge on customers of all investor-owned electric utilities and competitive municipal utilities in Massachusetts. The Massachusetts Technology Collaborative (MTC), a quasi-public research and development entity, administers the MRET with oversight and planning assistance from the Massachusetts Department of Energy Resources (DOER) and an advisory board. The MRET may provide grants, contracts, loans, equity investments, energy production credits, bill credits and rebates to customers. The fund is authorized to support a broad range of renewable energy technologies including low-emission advanced biomass power conversion technologies using fuels such as wood, by-products or waste from agricultural crops, food or animals, energy crops,

---

[2] Advanced Biofuels Task Force. (2007). Retrieved 2010 from http://www.mass.gov/?pageID=eoeeaterminal&L=4&L0=Home&L1=Energy%2c+Utilities+%26+Clean+Technologies&L2=Alternative+Fuels&L3=Clean+Energy+Biofuels+in+Massachusetts&sid=Eoeea&b=terminalcontent&f=eea_biofuels_biofuels_report&csid=Eoeea

biogas, liquid biofuels; and combined heat and power (CHP) systems less than 60 kilowatts (kW).

2. Large Onsite Renewables Initiative (Massachusetts Renewable Energy Trust Fund)—Program funds support grid-tied renewable-energy projects (excluding PV) greater than 10 kilowatts (kW) in capacity that are located at commercial, industrial, institutional and public facilities that will consume more than 25% of the renewable energy generated by the project on-site. The applicant and project site must be a customer of a Massachusetts investor-owned electric distribution utility or a municipal utility that pays into the Renewable Energy Trust. Grant awards may be used to facilitate the installation of renewable-energy projects on existing buildings (retrofits) or in conjunction with new construction/major renovation projects, including green buildings.

3. Business Expansion Initiative—The Massachusetts Technology Collaborative (MTC), as administrator of the state's Renewable Energy Trust Fund, offers loans to support renewable energy companies entering or expanding within the manufacturing stage of commercial development. Companies that currently, or plan to, manufacture renewable energy technology products in Massachusetts are generally eligible. Products may be new or existing, or a combination of the two.

4. Clean Energy Pre-Development Financing Initiative (Massachusetts Technology Collaborative)—Offers grants and loans to support the development of grid-connected renewable energy systems in New England. Eligible technologies or resources include wind energy; naturally flowing water and hydroelectric power; landfill gas; anaerobic digestion; and low-emission, advanced power-conversion technologies using "eligible biomass fuel." Biomass and wind energy projects must have a minimum capacity of three megawatts (MW), and hydroelectric, landfill gas and digester gas projects must have a minimum capacity of 250 kilowatts (kW). Projects must be designed to lead to the development of new renewable grid-connected generating capacity for the wholesale electricity market. Therefore, more than 50% of the renewable energy produced must be provided to the wholesale market.

5. Massachusetts Technology Collaborative (MTC) - Sustainable Energy Economic Development (SEED) Initiative—Provides financial assistance to support renewable-energy companies in the early stage of development. Applicants are companies that generally have a unique technology but have not yet demonstrated commercial viability to an extent sufficient to attract venture capital. Awards of up to $500,000 are available as a convertible loan on a competitive basis. Since 2004, the Massachusetts Renewable Energy Trust has invested over $4.9 million in Massachusetts-based renewable energy companies through the SEED Initiative.

6. Net Metering—The state's investor-owned utilities must offer net metering. Municipal utilities may do so voluntarily. (The aggregate capacity of net metering is limited to 1% of each utility's peak load.

7. The Biomass Energy Policy and Market Development Program (U.S. Department of Energy's State Energy Program)—The Biomass Energy Policy and Market Development Program promoted biomass with a comprehensive biomass energy policy initiative to improve the policy and market conditions and foster biomass economic development. The project informed the Renewable Portfolio Standard eligibility criteria for biomass projects and forestry management, assessed the regional woody biomass resource, and evaluated the potential for rural economic development. It increased the use of biofuels and biodiesel for building heating through outreach, formal collaboration with other state agencies to formalize comprehensive biomass energy policy and implementation plan, engaging with public and private sectors to inform policy discussions and understand and address issues, promote project activities within state agencies and private market to adopt bioenergy fuels, legal review and input, outreach policy and project development to industry, municipalities, concerned citizens, and renewable energy developers.

8. Alternative Energy and Energy Conservation Patent Exemption (Corporate)—Corporate excise tax deduction for (1) any income received from the sale or lease of a U.S. patent deemed beneficial for energy conservation or alternative energy development by the Massachusetts Department of Energy Resources, and (2) any income received from the sale or lease of personal property or materials manufactured in Massachusetts and subject to the approved patent.

9. Alternative Energy and Energy Conservation Patent Exemption (Personal)—Personal income tax deduction for any income received from a patent deemed beneficial for energy conservation or alternative energy development. The Massachusetts Commissioner of Energy Resources determines if a patent is eligible.

10. Biodiesel Blend Mandate (Massachusetts Session Law 206)—All diesel motor vehicle fuel and all other liquid fuel used to operate motor vehicle diesel engines must contain at least 2% renewable diesel fuel by July 1, 2010; 3% renewable diesel fuel by July 1, 2011; 4% renewable diesel fuel by July 1, 2012; and 5% renewable diesel fuel by July 1, 2013. For these purposes, eligible renewable diesel fuel includes diesel fuel that is derived predominantly from renewable biomass and yields at least a 50% reduction in lifecycle greenhouse gas (GHG) emissions relative to the average lifecycle GHG emissions for petroleum-based diesel fuel sold in 2005. The Massachusetts Department of Energy Resources must also study the feasibility, benefits, and costs of applying the percentage mandates on a statewide average basis rather than for every gallon of diesel motor fuel sold.

11. Biofuels Incentives Study (Massachusetts Session Law 206)—A special commission is established to study the feasibility and effectiveness of various forms of incentives to promote the development and use of advanced biofuels in Massachusetts, including, but not limited to, production credits, the production and harvesting of woody biomass, feedstock incentives and direct consumer credits for the use of advanced biofuels in various applications. The commission reported the results of its investigation and recommendations in March 2009.

12. Massachusetts - Green Power Purchasing Commitment—In April 2007, Massachusetts Governor Deval Patrick signed Executive Order 484, "Leading by Example: Clean Energy and Efficient Buildings." This order establishes energy targets and mandates for state government buildings and directed state government agencies to procure 15% of annual electricity consumption from renewable sources by 2012 and 30% by 2020. This mandate may be achieved through procurement of renewable energy supply, purchase of renewable energy certificates (RECs), and/or through the production of on-site renewable power. Only renewable sources that qualify for the Massachusetts renewable portfolio standard (RPS) are eligible.

13. Boston - Green Power Purchasing—In April 2007, Boston Mayor Thomas Menino issued an executive order that established a green power purchasing goal of 11% for the city government, and a goal of 15% by 2012. The executive order also requires all existing municipal properties to be evaluated for the feasibility of installing solar, wind, bio-energy, combined heat and power (CHP), and green roofs and set goals for greenhouse gas emissions reductions, recycling, green building, vehicle fuel efficiency, biofuels use, and the development of the Boston Energy Alliance, a non-profit corporation dedicated to implementing large-scale energy efficiency, renewable energy, and demand response projects citywide.

## III. Review and summary of regional policy and regulatory initiatives impacting development of biomass energy.

### A. Regional Greenhouse Gas Initiative

Massachusetts is a member of the Regional Greenhouse Gas Initiative (RGGI), a group of ten New England and Mid-Atlantic states that has agreed to cap greenhouse gas (GHG) emissions from the generation of electric power and to lower this cap over time. Under the RGGI agreement, each participating state has been assigned a certain number of carbon dioxide allowances, serving as that state's emissions cap. The individual states are responsible for assigning carbon allowances to the covered emissions sources within the state, and to adopt rules to implement the emissions accounting, trading, and monitoring necessary to achieve the initial cap and subsequent reductions of GHG emissions. Eight of the ten participating states, including Massachusetts, exempt biomass-fueled electricity generation from carbon dioxide emissions accounting such that any carbon dioxide emitted from biomass-fueled processes is not counted against that state's carbon cap. The RGGI emissions cap applies to fossil fuel-fired electricity generators with a capacity of 25 megawatts or greater.

As a consequence of this program, Renewable Energy Credits are issued in Massachusetts (and the other RGGI states) for biomass-fueled electric power generation, providing a significant incentive and market driver for large scale biomass-fueled electric power generation over other uses such as thermal, Combined Heat and Power, or smaller scale applications.

In addition to the complete exemption from the RGGI system for generators whose fuel composition is 95 percent or greater biomass, the RGGI Model Rule and all participating states except for Maine and Vermont provide partial exemptions for facilities that co-fire with smaller percentages of biomass. This partial exemption provides that any carbon dioxide emissions attributable to "eligible biomass" may be deducted from a facility's total carbon dioxide emissions when calculating whether the facility's emissions are within its carbon-allowance budget.

The Model Rule defines "eligible biomass" as follows:

> *Eligible biomass includes sustainably harvested woody and herbaceous fuel sources that are available on a renewable or recurring basis (excluding old-growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, unadulterated wood and wood residues, animal wastes, other clean organic wastes not mixed with other solid wastes, biogas, and other neat liquid biofuels derived from such fuel sources. Sustainably harvested will be determined by the [participating state's designated regulatory agency].*

In Massachusetts, the regulation defines "eligible biomass" identically except that it deletes the language "and other neat liquid biofuels." Additionally, the Massachusetts definition states, "Liquid biofuels do not qualify as eligible biomass." It is unclear why the Massachusetts regulators decided to eliminate liquid biofuels from the definition, especially since liquid biofuels are included in the "eligible biomass fuel" definition in Massachusetts' RPS program. As illustrated in Table 1, below, several other states similarly exclude liquid biofuels from their RGGI definitions of "eligible biomass." In Massachusetts, the Department of Environmental Protection is charged with defining the sustainable harvesting criteria for sustainable harvesting of biomass under RGGI.

**Exhibit A-1: Summary of biomass provisions in the RGGI implementing regulations of the ten participating RGGI states.**

| State | Allows deduction for biomass-attributable emissions | Includes liquids as eligible biomass | Uses December 2008 Model Rule for biomass calculation | Uses January 2007 Model Rule for biomass calculation |
|---|---|---|---|---|
| Massachusetts | X | | | X |
| Connecticut | X | | X | |
| Delaware | X | X | X | |
| Maine | | | | |
| Maryland | X | Not found | X | |
| New Hampshire | X | X | X | |
| New Jersey | X | X | X | |
| New York | X | | X | |
| Rhode Island | X | | X | |
| Vermont | | | | |

### B. Midwestern Greenhouse Gas Reduction Accord and Western Climate Initiative

While RGGI is the only fully developed and implemented regional cap and trade program for GHG emissions reductions in the United States, several Midwestern states and the Canadian province of Manitoba have joined together to achieve GHG emissions reductions through their own regional cap and trade system. The Midwestern agreement is called the Midwestern Greenhouse Gas Reduction Accord (Accord), and in June 2009, the Accord's Advisory Group issued a set of recommendations for emissions reductions targets and for designing a regional cap-and-trade system. The Advisory Group recommended that a broader set of sectors be included in the emissions reduction program than RGGI covers, such that the program would cover not only electricity generation, but also industrial sources, fuels serving residential, industrial, and commercial buildings, and transportation fuels. However, the recommendations include an exemption for carbon dioxide emissions "from the combustion of biomass or biofuels, or the proportion of carbon dioxide emission from the combustion of biomass or biofuels in a blended fuel," which essentially mirrors the RGGI exemption.

After the Advisory Group recommendations were published, the Accord issued a draft Model Rule in October 2009 The rule contains a definition of "eligible biomass" that is exactly identical to the RGGI Model Rule definition, including the liquid biofuels measure. Additionally, the Accord's Model Rule includes the same provision allowing a GHG source to deduct all biomass-attributable GHG emissions from its total GHG emissions when determining compliance with the source's GHG allowance budget. The Accord's Model Rule does not, however, contain any provision detailing how the biomass-attributable GHG emissions are to be calculated.

Similar to RGGI and the Midwestern Accord, several western states and Canadian provinces have joined in the Western Climate Initiative to enact similar GHG emissions reductions through a cap-and-trade system. The WCI, like the Accord, recommends that the program cover not just electricity, but also transportation, industrial and commercial fossil fuel combustion, industrial process emissions, and residential fuel use. Further, the WCI has issued draft program recommendations, which include a recommendation that "biomass determined by each WCI Partner jurisdiction to be carbon neutral" should not be included in the cap-and-trade program, except for reporting purposes. Further, the recommendations state that "[c]arbon dioxide emissions from the combustion of pure biofuels, or the proportion of carbon dioxide emissions from the combustion of biofuel in a blended fuel" would not be included in the program. The WCI recommendations also indicate that each participating jurisdiction "will assess whether and how to include upstream emissions from biofuel and fossil fuel production." These recommendations, unlike the RGGI Model Rule or the Accord's recommendations and Model Rule, exhibit more caution regarding the carbon neutrality of biomass fuel use.

## IV. Review and summary of outstanding state policies impacting development of biomass energy, with a focus on renewable energy, forest sustainability and climate issues.

This section provides a summary of relevant policies in several states with notable approaches to biomass development, with a particular focus on renewable energy incentives, forest sustainability and climate change issues. Specifically, this section: characterizes the state-level approach to biomass usage in general; reviews the typical basket of state policies that address biomass; highlights some outstanding state policies with regard to biomass; and concludes with a listing of relevant state policies. It is based on a review of eleven states' policies regarding biomass: Arizona, California, Connecticut, Maryland, Minnesota, Missouri, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin.

The thrust of state policies promoting biomass and/or biofuels is focused on electric generation and less so on transportation and thermal. All surveyed states have numerous policies, programs and/or incentives to promote electric generation from renewable sources of energy, including biomass. A few states have policies to support the use of biomass/biofuels for transportation (California, Minnesota, Oregon, Pennsylvania, Washington, and Wisconsin) and/or for thermal production (Arizona, Connecticut, Missouri, Oregon, Pennsylvania, Vermont, Washington, and Wisconsin).

Typically, states include biomass as one of a number of sources of renewable energy in a variety of policies and programs aimed at increasing electric generation from renewable energy. A common method to advance biomass electric generation policies is via renewable portfolio standards, which typically mandate that utilities provide a certain percentage of renewably generated electricity by a certain date. Other common state policies supportive of biomass electric generation are net metering programs; public benefits funds which, among other activities, distribute grants and/or loans for biomass research and/or development; other grant and/or loan programs for biomass research and/or development; power purchasing programs at the state and/or local level; and a variety of tax incentives. The range of tax incentives includes: production tax incentives such as energy production tax credits, or deductions or exemptions for installing certain types of biomass manufacturing systems; sales tax incentives for purchasing qualifying equipment for harvesting, transportation, and manufacturing or processing of biomass; personal tax incentives such as income tax credits and deductions for installation of certain types of renewable energy systems; and property tax incentives such as exemptions, exclusions and credits for property (including equipment) used for the siting of qualifying manufacturing facilities or the transport of biomass.

States with large sources of biomass supply, such as Minnesota, Missouri, Oregon, Washington and Wisconsin, also tend to have biomass-specific policies or programs in addition to general programs such as renewable portfolio standards. These states are also likely to have biomass working groups or a biomass program (Connecticut, Minnesota, Oregon, Pennsylvania, and Vermont). Some have produced biomass reports, including woody biomass supply assessments. (Arizona, California, Minnesota, Oregon, Vermont, Washington, and Wisconsin). These reports typically focus more on biomass promotion and less on sustainability, and some discuss the linkage between biomass utilization and climate change. Finally, some states have produced woody biomass harvesting guidelines that focus on best management practices for harvesting woody biomass in an ecologically sensitive and sustainable manner (Minnesota, Missouri, Pennsylvania, and Wisconsin). All such harvesting guidelines are voluntary, guidance only.

The following state programs stand out regarding the sustainable utilization of biomass for renewable energy generation:

**The Vermont Energy Act of 2009** aims to expand the market for renewable-energy technologies in Vermont in a number of innovative programs that address the issue from different directions. Its key elements include: clarification that the Clean Energy Development Fund's grants and loans also apply to thermal energy projects (discussed further below); a standard offer for renewable energy (discussed further below); incentives that allow utilities to recover permitting costs for renewable energy; pilot downtown-community renewable-energy projects in two towns, Montpelier and Randolph (Village Green Program); improvements to residential- and commercial-building standards; provision for the creation of clean energy assessment districts so that towns, cities, and incorporated villages can use municipal bonds to finance residential renewable-energy or energy-efficiency projects; and limitations on the power of municipalities and deeds to prohibit residential installation of renewable-energy and energy-efficiency devices, such as solar panels, residential wind turbines, and clothes lines.

The Vermont Clean Energy Development Fund, Vermont's principle renewable energy incentive program, has provided millions of dollars to wind, solar, biomass, and other renewable energy projects in the form of grants and loans over the past several years. The Vermont Energy Act of 2009 clarified the scope of the CEDF to include thermal energy and geothermal resources, including combined heat-and-power systems, which sets Vermont's program apart from most state programs. Grant funding is available to four categories of projects: pre-project financial assistance, small-scale systems (microturbines, fuel cells, and CHP), large-scale systems, and special demonstration projects. Proposed projects must have an electric generation component and be grid-connected; off-grid projects and thermal projects (except CHP systems) are not eligible. There is a special funding opportunity in 2009 for municipalities, public schools, and colleges to explore renewable energy projects and feasibility up to $5,000. Low-interest fixed-rate loans are available to individuals, companies, nonprofits and municipalities for purchasing land and buildings for qualifying projects, purchasing and installing machinery and equipment, and providing working capital. Eligible clean electric-energy technologies include solar, wind, biomass, fuel cells and combined heat and power.

The **Vermont Standard Offer for Qualifying SPEED Resources** was enacted as part of the 2009 Vermont Energy Act. It requires all Vermont retail electricity providers to purchase electricity generated by eligible renewable energy facilities through the Sustainably Priced Energy Enterprise Development (SPEED) Program. This "feed-in tariff" is intended to provide a reasonable return on investment to renewable energy facility developers, thereby spurring deployment of renewable energy. The program establishes a set price that utilities must pay to purchase renewable energy from certain qualifying sources, by means of long-term contracts. The standard offer price will be available to facilities with a plant capacity of 2.2 MW or less, for a total of 50 MW of renewable power state-wide. The applications for 50 MW of SPEED standard-offer contracts are fully subscribed and a lottery was implemented to select final solar and biomass projects. Wood biomass is included as a potential qualifying renewable energy source, but may only receive the standard offer if the plant's system efficiency is 50% or greater. If the program's goals (included in the appendix) are not met, then the RPS will become mandatory and require the state's electric utilities to meet any increase in statewide retail electricity sales between 2005 and 2012 by using renewables with associated attributes, by purchasing RECs, or by making an alternative compliance payment to the Vermont Clean Energy Development Fund.

**Oregon** is a biomass leader. It has developed a comprehensive wood biomass supply assessment at state and regional levels. The state's active **Forest Biomass Working Group** has produced a comprehensive analysis of forest biomass opportunities map that includes existing wood-based energy facilities and the power transmission grid. The **Oregon Strategy for Greenhouse Gas Reduction** aims to reduce wildfire risk by creating a market for woody biomass from forests. It incorporates use of biomass into discussions linking climate change, wildfire protection plans, and economic development for rural communities. It notes that an additional 100 MW produced from woody biomass plants would result in the thinning of 2.4 million acres over 30 years, and the average annual sequestration from reduced crown fires and improved forest health would be 3.2 million metric tons of CO2. This CO2 reduction is in addition to, and does not include, displacing fossil fuels with biomass fuels. It promotes biofuels use and production, and expands research on how climate change could affect expanded production of renewable power including bioenergy. **Oregon House Bill 2200** authorized the State Forester to establish programs to market, register, transfer or sell forestry carbon offsets on behalf of state forestland beneficiaries, the Forest Resource Trust, and other non-federal forest landowners. The bill recognizes a wide range of forest management activities—those designed to protect our environment as well as those designed to provide our wood products—as having the potential to give rise to forestry carbon offsets. Oregon's **Biomass Logging Bill** (SB 1072) promotes the use of biomass from logging projects on federal land as both a restoration tool and electricity generation mechanism. It also directs the Oregon Department of Forestry to participate in federal forest project planning and land management. It spells out that the "Policy of the State" of Oregon is to support efforts to build and place in service biomass fueled electrical power generation plants that utilize biomass collected from forests or derived from other sources such as agriculture or municipal waste. It requires the Oregon Board of Forestry to direct the State Forester to enter into stewardship contract agreements with federal agencies to carry out forest management activities on federal lands. Finally, the **Oregon Renewable Energy Action Plan** (REAP) outlines a plan of action for renewables. Specifically for biomass, it provides that twenty-five megawatts of new biomass-fueled electric generation will be built or under construction, in addition to 5 megawatts of biogas facilities; it allows biomass facilities to qualify for net metering and allows the Oregon Public Utility Commission to adopt rules to increase the 25-kilowatt limit on a net metering facility for customers of Portland General Electric and Pacific Power; it encourage the development and utilization of small energy efficient biomass heating and electrical systems for heating and providing power to institutions, state offices, schools, etc., especially in rural Oregon; and it promotes greater public awareness of the primary and secondary benefits of biomass energy production.

**California's State Biofuels Development Plan / Biofuels Production Mandate and Alternative Fuel Use Study** is notable for its ambition. California plans to use biomass resources from agriculture, forestry, and urban wastes to provide transportation fuels and electricity to satisfy California's fuel and energy needs. The state will produce its own biofuels at a minimum of 20% by 2010, 40% by 2020, and 75% by 2050. Regarding the use of biomass for electricity, the state shall meet a 20 percent target within the established state goals for renewable generation for 2010 and 2020. The Bioenergy Action Plan includes: research and development of commercially viable biofuels production and advanced biomass conversion technologies; evaluation of the greenhouse gas reductions benefits of bio-fuels and biomass production and use; evaluation of the potential for biofuels to provide a clean, renewable source for hydrogen fuel; and state agencies' purchase of flexible fuel vehicles as 50% of total new vehicles by 2010.

# APPENDIX 2-A

# 18 SELECTED TECHNOLOGY PATHWAYS

**Pathway #1: Power Plant—Electricity (green wood)**

This technology pathway is fueled by green wood with bark. On average, woodchips have roughly 40 percent moisture content. This means that while one ton of dry woodchips would produce 16.5 million Btus[1] (MMBtu) of heat, one ton of green woodchips would produce only 9.9 MMBtu. The green wood with bark will have some implications on the emissions of this system as bark has high ash content. This technology pathway will use direct combustion using a fluidized bed. This combustion technique suspends the woodchips in midair using jets of upward-blowing air. This increases the contact between carbon and oxygen and hence increases efficiency. A medium (like sand, or lime) is used to make the process uniform and controllable. The resulting hot gases travel up from the furnace to the boiler to heat water and convert it into a high-pressure steam.

The high-pressure steam then travels to a condensing steam turbine, the secondary process in this pathway. When steam enters the turbine, it is hotter per unit weight than when it exits the turbine. Upon leaving, the exhaust steam is condensed below atmospheric pressure which increases the pressure drop between input and exhaust steam. This produces greater power per unit weight of the input steam. The spinning turbine creates electrical energy.

Lastly, when the hot gases travel out of the furnace, they are likely carrying some ash, fines, and other particulates. In order to reduce the particulate emissions from this pathway, an electrostatic precipitator (ESP) removes particles from the air using an electrostatic charge. Gases are not impeded as they move through the ESP, but particulates like dust and smoke remain instead of leaving with the gas. The clean flue gases are discharged to the atmosphere through a high stack.

**Pathway #2: Power Plant—Electricity (co-fired, 20% green wood, 80% coal)**

In this pathway, green wood with bark is most commonly co-fired with coal. In co-firing, biomass can burn simultaneously with coal, comprising 20 percent of the load that is combusted in a regular coal boiler system. No efficiency is lost in the process. The intent is to reduce the use of fossil fuel and substitute renewable biomass, which is low-carbon if sustainably managed, and sulfur oxide emissions are lowered because biomass has nearly no sulfur content. When the two fuels are burned and release hot gases, they heat water in the boiler which in turn heats the high-pressure steam needed for the condensing steam turbines (as described in Pathway #1). The turbines create electrical energy. In some current applications, co-firing has been found to increase PM emissions. In this pathway, an ESP will be an important component in collecting particulates from the flue gases.

**Pathway #3: Power Plant—Electricity (coal)**

This technology pathway utilizes bituminous coal, which is the most abundant type of coal in the United States. It is second highest in energy output (after anthracite). The coal is used in a direct combustion furnace. The hot gases created in the furnace travel upward to the boiler to heat water and convert that into a **steam**. The steam then moves into a condensing steam turbine, as used in Pathway #1. The spinning turbine creates electrical energy.

An ESP is used in this pathway to capture particulates.

**Pathway #4: Power Plant—Electricity (natural gas)**

This pathway utilizes natural gas. Natural gas is composed mostly of methane, has drastically more energy per unit than either oil or propane, and emits lower amounts of nitrogen oxides and carbon dioxide than oil or coal. In this pathway, it is combusted directly to create steam using simple cycle technology representative of most existing gas-fired systems. The steam moves to a gas turbine, also known as a combustion turbine. Three steps are involved in this process. First, incoming air gets compressed to a very high pressure. Then, the combustor burns the fuel, producing a high-pressure, high-velocity gas. As the gas moves through the combustion chamber, it spins the turbine that creates electricity.

No emissions control equipment is associated with this technology pathway.

**Pathway #5: Thermal Energy (cordwood)**

Green wood with bark is used in this pathway in the form of cordwood. Firewood is commonly measured in units of cords which are a measure of volume, not weight. A standard cord of stacked wood is equal to the amount of wood in a four foot by four foot by eight foot stack (this is equivalent to 128 cubic feet). The energy content of cordwood can vary widely based on species and moisture content. It is very important to note that cords are also used as a volume measure of roundwood and this roundwood cord measure is different (a cord of roundwood is only 85 cubic feet, compared to 128 cubic feet of cordwood). This difference between the two measures is due to less air space between pieces of cordwood that are cut, split, and neatly stacked.

The cordwood is loading by hand and combusted directly in a traditional boiler, such as may be found in a home's basement or possibly even an outdoor boiler. This boiler heats water which is used for domestic water and heating purposes (thermal energy) in a residential setting.

**Pathway #6: Thermal Energy (cordwood)**

This pathway also utilizes cordwood but is combusted in an EPA-certified boiler in a residential setting. These boilers combine high efficiency combustion with hydronic thermal storage. The hot

---

[1] Btu: British thermal unit, a standard unit of energy equal to the heat required to raise the temperature of one pound of water one degree Fahrenheit

water storage aids in increasing the system's efficiency because the boiler does not have to operate during times of low-load as long as enough thermal storage is available to meet the demand.

### Pathway #7a: Wood Pellets (green wood)

This technology pathway produces pellets and is fueled by green wood with bark. The wood is processed so that it can go through the drying and densification process, in which the air is expelled from the wood at very high pressures and then formed into pellets. Natural plant lignin in the pellet material is melted during the extrusion process and holds the pellets together without glues or additives. Pellets have significantly lower moisture content than the woodchips from which they were created (six percent versus an average of 40 percent, respectively) which means they produce greater Btus per unit. This pathway, combined with 7b, represent the full energy implications of using pellets from forst, through production and combustion of pellets.

### Pathway #7b: Thermal Energy (pellets)

After the densification of green wood with bark to create pellets, the process in this pathway is to use direct combustion to burn the pellets to create thermal energy. This combustion occurs in the furnace in which the pellets come in direct contact with the fire. The purpose of biomass burner technologies is to get all of the carbon in pellets to react with oxygen in the air to make carbon dioxide. As this is an exothermic reaction, it will generate a lot of heat. The challenge here is to convert all the carbon and get maximum heat. When the flue gas travels out of the furnace, water captures the heat and is then piped throughout the building or number of buildings for heating and domestic hot water. The water used for heating the air is then piped back to the furnace to be re-heated and looped out again.

The emission control device utilized in this pathway is a cyclone-baghouse combination. With the correct design and choice of fabric, particulate control efficiencies of over 99 percent can be achieved even for very small particles (one micrometer or less) by fabric filters or baghouses. The lowest emission rate for large wood-fired boilers controlled by fabric filters reported is 0.01 lb/MMBtu. For large thermal-only applications (boilers over four to five MMBtu), a baghouse is usually sufficient to handle particulate matter (PM) control (along with a multi-cyclone which is generally included with the boiler by the manufacturer). Considered with Pathway 7a, this represents an application using pellets at the commercial scale, from forest to combustion.

### Pathway #8: Thermal Energy (green wood)

This technology pathway is fueled by green woodchips with bark and undergoes direct combustion in a fluidized bed (as described in Pathway #1). The interim product is hot water (and not high pressure steam). The water in the boiler will capture the heat from the combustion chamber and will then be piped through the building for heat and hot water, or thermal energy. The cold water will be piped back to boiler.

A fabric filter or baghouse will collect the particulates to lower the emission rates.

### Pathway #9: Thermal Energy (heating oil)

This pathway involves the direct combustion of residual heating oil, which includes number 5 and 6 heating oils. These are often referred to as "heavy oils" because they are what remain after gasoline and distillate oils have been extracted in the distillation process. This oil is laden with high amounts of pollutants, sulfur dioxide being one of the greatest. Residual oil has a high viscosity so before it can be used in a boiler, it must be heated so that it flows more smoothly. Once this has been achieved, the oil gets combusted directly in a furnace where it heats water for thermal applications.

No emissions control equipment is associated with this technology pathway.

### Pathway #10: Thermal Energy (natural gas)

This pathway involves the direct combustion of natural gas. The gas is combusted in a furnace where it heats water for thermal applications.

No emissions control equipment is associated with this technology pathway.

### Pathway #11: CHP—Electricity (green wood)

In this pathway, the green wood with bark goes through direct combustion in a fluidized bed (as described in Pathway #1). In this pathway, the high-pressure steam moves through to the second part of the process that is in a backpressure steam turbine. The steam enters the turbine where it expands. During expansion, some of its thermal energy is converted into mechanical energy that runs an electrical generator. The low pressure steam that exits the turbine returns to the plant to satisfy thermal applications. As backpressure turbines satisfy both process and heating requirements, they are ideal for combined heat and power (CHP) applications that are far more efficient than electrical energy production alone.

An ESP will serve as the pollution control equipment to remove particulates from the air.

### Pathway #12: Gasifier—Electricity (green wood)

In this pathway, the green wood with bark is used to create a producer gas using the process of gasification. Gasification is a thermo-chemical process that converts solid fuel materials into combustible gases that can then be used for heat and power. When biomass is heated with a fraction of what is needed for efficient combustion, it gasifies into the interim product, a mixture of carbon monoxide and hydrogen—synthesis gas or syngas or producer gas. Combustion occurs as a result of mixing oxygen with hydrocarbon fuel. Because gaseous fuels mix with oxygen more easily than liquid fuels, which in turn mix more easily than solid fuels, syngas inherently burns cleaner and more efficiently than the solid biomass from which it was made. One advantage of gasification technology is that it is a decentralized energy conversion system that operates economically even when used in small-scale applications. Although the technology is currently not commercially available in the United States, it has proven to be economical in many locations.

The producer gas is then used in an internal combustion engine to power a generator. The generator spins to create electrical energy while waste heat from both the gasifier and the internal combustion engine can be captured and used as thermal energy, thereby creating a CHP system.

### Pathway #13: CHP—Electricity (heating oil)

Residual heating oil is combusted directly, in this pathway, to create steam. This pathway differs from the former because the steam moves through to a backpressure steam turbine. As backpressure turbines create both electrical and thermal energy, they are ideal for CHP applications that are far more efficient than electrical energy production alone.

No emissions control equipment is associated with this technology pathway.

### Pathway #14: CHP—Electricity (natural gas)

In this technology pathway, natural gas is combusted directly to create steam. The steam travels to a backpressure steam turbine as described in Pathway #11. The electricity produced by the spinning generator and the over-pressurized steam that satisfies thermal applications at the plant fulfills the CHP component.

No emissions control equipment is associated with this technology pathway.

### Pathway #15: Cellulosic Ethanol (green wood)

In order to create ethanol, green wood with bark goes through a primary process of hydrolysis and fermentation (ERRE, 2009). This is a multiple step process. First, sulfuric acid is mixed with the woodchips at which point a hydrolysis reaction occurs. Here, the complex chains of sugars that make up the hemicellulose in the wood get broken and release simple sugars. Later in the process, what cellulose remains gets hydrolyzed into glucose. This glucose then goes through the fermentation process, in which microorganisms convert it to ethanol.

As a by-product of ethanol production, lignin can get combusted directly to produce the electricity required for the production process, or, since more electricity is generally created than is needed, selling the electricity may help the process economics.

An ESP can be applied to the furnace in which the lignin is burned to reduce PM emissions.

### Pathway #16: Bio-oil & Bio-Char (green wood)

In this Pathway, green wood with bark undergoes a primary process of pyrolysis at a bio-refinery. Pyrolysis is the rapid chemical decomposition of wood in the absence of oxygen, and occurs spontaneously when the temperature is high enough. This process breaks the wood down into a gas, liquid (bio-oil), and a solid (Biochar). By rapidly decomposing the biomass at high temperatures, it will result in a greater amount of bio-oil whereas slow pyrolysis will produce Bio-Char. Bio-oil can be substituted for conventional liquid fuels, and while it contains roughly 54 percent the heating value of #6 fuel oil (Innovative Natural Resource Solutions, 2004), its benefit is that it is sourced from a renewable resource rather than a non-renewable fossil fuel.

As bio-oil can be substituted for conventional fuels, it can be burned in a furnace to heat water for thermal energy applications.

This pathway utilizes an ESP as its emissions control equipment.

### Pathway #17: Bio-products (green wood)

This pathway also utilizes green wood with bark to create a syngas through the process of gasification. Syngas is composed of hydrogen and carbon monoxide. The Fischer–Tropsch process (or Fischer–Tropsch Synthesis) is a set of chemical reactions that convert a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. The process, a key component of gas-to-liquids technology, produces a petroleum substitute, typically from biomass for use as synthetic lubrication and as synthetic liquid fuel, such as ethanol. Electricity is also created by combusting lignin, the by-product of ethanol production.

An ESP is used to remove the particulates from the air exiting the plant.

### Pathway #18: Gasification—Cellulosic Ethanol (green wood)

In technology pathway #6, green wood with bark undergoes a primary process of fast pyrolysis at a bio-refinery. The bio-oil produced from fast pyrolysis can be used to produce a variety of bio-products, such as plastics, glues, organic fertilizers, and fuel additives.

This pathway utilizes an ESP as its emissions control equipment.

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | | | | | | | | | | TECHNOLOGY PATHWAYS SUMMARY | | | | | | | | |
| 3 | No. | Technology Pathway | Main Product | Co-products | Typical Capacity | Unit | Hours of operation per year | Output Heat Mmbtu/yr | Gross Effic. | Net Effic | Heat Input MMBtu/yr | Btu/lb | Tons (dry) per year | Fuel Requirements lbs (dry) /MMBtu output heat | CO2 Emissions lbs/MMBtu input heat | CO2 Emissions lbs/MMBtu output heat | C Emissions lbs/MMBtu input heat | C Emissions lbs/MMBtu output heat | Maximum Affordable Cost of Biomass with 40% MC ($/ton) |
| 4 | | | | | | | | (F)*(H)*3.412 | | | (I)/(J) | | (L)/(M) | (N)/(I) | | (P)*(L)/(I) | (P)/3.6667 | (Q)/3.6667 | |
| 5 | 1 | Power | Electricity | | 50 | MW | 7,200 | 1,228,320 | 25% | 25% | 4,913,280 | 8,500 | 289,016 | 470.59 | 215.69 | 862.75 | 58.82 | 235.29 | $31 |
| 6 | | (green wood) | | | | | | | | | | | | | | | | | |
| 7 | 2 | Power | Electricity | | 500 | MW | 7,200 | 12,283,200 | 32% | 32% | 7,677,000 | 8,500 | 451,588 | 73.53 | 215.69 | 134.80 | 58.82 | 36.76 | $31 |
| 8 | | (coal & | | | | | | | | | 30,708,000 | 10,506 | 1,461,451 | 237.96 | 205.30 | 513.25 | 55.99 | 139.98 | |
| 9 | | green wood- | | | | | | | | | 38,385,000 | 10,105 | 1,913,039 | 311.49 | 207.38 | 648.05 | 56.56 | 176.74 | |
| 10 | | 20% co-firing) | | | | | | | | | | | | | | | | | |
| 11 | 3 | Power | Electricity | | 500 | MW | 7,200 | 12,283,200 | 32% | 32% | 38,385,000 | 10,506 | 1,826,813 | 297.45 | 205.30 | 641.56 | 55.99 | 174.97 | |
| 12 | | (coal) | | | | | | | | | | | | | | | | | |
| 13 | 4 | Power | Electricity | | 500 | MW | 7,200 | 12,283,200 | 33% | 33% | 37,221,818 | 1,028 | 36,207,994 | 2.95 | 117.00 | 354.55 | 31.91 | 96.69 | |
| 14 | | (Natural Gas) | | | | | | | | | | cubic ft | dtherms | dtherms | | | | | |
| 15 | 5 | Thermal | Thermal | | 0.1 | MMBTH | 1,800 | 180 | 60% | 60% | 300 | 8,500 | 18 | 196.08 | 215.69 | 359.48 | 58.82 | 98.04 | $104 |
| 16 | | Energy | energy | | | | | | | | | | | | | | | | |
| 17 | | (cordwood) | | | | | | | | | | | | | | | | | |
| 18 | 6 | Thermal | Thermal | | 0.1 | MMBTH | 1,800 | 180 | 68% | 68% | 265 | 8,500 | 16 | 173.01 | 215.69 | 317.19 | 58.82 | 86.50 | $104 |
| 19 | | Energy | energy | | | | | | | | | | | | | | | | |
| 20 | | (cordwood) | | | | | | | | | | | | | | | | | |
| 21 | 7a | Wood | Wood pellets | | 10,000 | TPY | | 159,800 | 85% | 85% | 188,000 | 8,500 | 11,059 | 138.41 | 215.69 | 253.75 | 58.82 | 69.20 | $0 |
| 22 | | pellets | | | | | | | | | | | | | | | | | |
| 23 | 7b | Thermal | Thermal | | 5 | MMBTH | 1,800 | 9,000 | 80% | 80% | 11,250 | 8,500 | 662 | 147.06 | 215.69 | 269.61 | 58.82 | 73.53 | $167 |
| 24 | | energy | energy | | | | | | | | | | | | | | | | (40% MC) |
| 25 | | (pellets) | | | | | | | | | | | | | | | | | |
| 26 | 8 | Thermal | Thermal | | 50 | MMBTH | 1,800 | 90,000 | 75% | 75% | 120,000 | 8,500 | 7,059 | 156.86 | 215.69 | 287.58 | 58.82 | 78.43 | $104 |
| 27 | | (green wood) | energy | | | | | | | | | | | | | | | | |
| 28 | 9 | Thermal | Thermal | | 50 | MMBTH | 1,800 | 90,000 | 80% | 80% | 112,500 | 152,000 | 740,132 | 8.22 | 173.90 | 217.38 | 47.43 | 59.28 | |
| 29 | | (oil) | energy | | | | | | | | | /gallon | gallons | gallons | | | | | |
| 30 | 10 | Thermal | Thermal | | 50 | MMBTH | 1,800 | 90,000 | 85% | 85% | 105,882 | 1,028 | 102,998 | 1.14 | 117.00 | 137.65 | 31.91 | 37.54 | |
| 31 | | (natural gas) | energy | | | | | | | | | cubic ft | dtherms | dtherms | | | | | |
| 32 | 11 | CHP | Electricity | | 5 | MW | 7,200 | 368,496 | 75% | 25% | 491,328 | 8,500 | 28,902 | 156.86 | 215.69 | 287.58 | 58.82 | 78.43 | $104 |
| 33 | | (green wood) | | Thermal | 245,664 | MMBtu | | | | | | | | | | | | | |
| 34 | | | | Electrical | 122,832 | | | | | | | | | | | | | | |
| 35 | 12 | Gasifier | Electricity | | 5 | MW | 7,200 | 317,669 | 75% | 29% | 423,559 | 8,500 | 24,915 | 156.86 | 215.69 | 287.58 | 58.82 | 78.43 | $104 |
| 36 | | (green wood) | | Thermal | 194,837 | MMBtu | | | | | | | | | | | | | |
| 37 | | | | Electrical | 122,832 | MMBtu | | | | | | | | | | | | | |
| 38 | 13 | CHP (oil) | Electricity | | 5 | MW | 7,200 | 341,200 | 75% | 27% | 454,933 | 152,000 | 2,992,982 | 8.77 | 173.91 | 231.88 | 47.43 | 63.24 | |
| 39 | | | | Thermal | 218,368 | MMBtu | | | | | | per gallon | gallons | gallons | | | | | |
| 40 | | | | Electrical | 122,832 | MMBtu | | | | | | | | | | | | | |
| 41 | 14 | CHP (gas) | Electricity | | 5 | MW | 7,200 | 297,775 | 80% | 33% | 372,218 | 1,028 | 362,080 | 1.22 | 117.00 | 146.25 | 31.91 | 39.89 | |
| 42 | | | | Thermal | 174,943 | MMBtu | | | | | | cubic ft | dtherms | dtherms | | | | | |
| 43 | | | | Electrical | 122,832 | MMBtu | | | | | | | | | | | | | |
| 44 | 15 | Cellulosic | Cellulosic | Thermal | 100 | MMGPY | | 10,256,098 | 50% | 41% | 20,512,195 | 8,500 | 1,206,600 | 235.29 | 127.26 | 254.51 | 34.71 | 69.41 | $70 |
| 45 | | Ethanol | ethanol | Energy | 1,846,098 | MMBtu | | | | | | | | | | | | | |
| 46 | 16 | Bio-oil | Bio-oil | Thermal | 15 | MMGPY | | 1,542,667 | 65% | 45% | 2,373,333 | 8,500 | 139,608 | 181.00 | 118.63 | 182.50 | 32.35 | 49.77 | $90 |
| 47 | | & Bio-char | | Energy | 474,667 | MMBtu | | | | | | | | | | | | | |
| 48 | 17 | Bio- | | Thermal | 15 | MMGPY | | 1,542,667 | 65% | 45% | 2,373,333 | 8,500 | 139,608 | 181.00 | 118.63 | 182.50 | 32.35 | 49.77 | $90 |
| 49 | | products | | Energy | 474,667 | MMBtu | | | | | | | | | | | | | |
| 50 | 18 | Cellulosic | | Thermal | 100 | MMGPY | | 10,256,098 | 50% | 41% | 20,512,195 | 8,500 | 1,206,600 | 235.29 | 127.26 | 254.51 | 34.71 | 69.41 | $70 |
| 51 | | Ethanol | | Energy | 1,846,098 | MMBtu | | | | | | | | | | | | | |
| 52 | | (gasification) | | | | | | | | | | | | | | | | | |

# APPENDIX 2-B: TECHNOLOGY PATHWAYS SUMMARY

## Technology Pathways Summary Table

Orange = Formulas

Yellow = Typical Values assumed by BERC

Green = Calculated Values

Blue = Values taken from References

References (identified by cell)

Published Data by Biomass Power Plant: J5, K5

NREL: J7, K7, J11, K11, J13, K13

Published data by vendors: J15, K15, J18, K18, J21, K21, J23, K23, J26, K26, J28, K28,J30, K30, J32, K32, J35, K35, J38, K38, J41, K41, J46, K46, J48, K48, J50, K50

EERE, DOE: J44, K44

Calculated based on conversion of all carbon to carbon dioxide: P5, P7, P15, P18, P21, P23, P26, P32, P35, P44, P46, P48, P50

EIA: P8, P11, P13, P28, P30, P38, P41

## Conversion Factors and Assumptions

1) 1 MWH = 3.412 MMBtu
2) High Heating Value of cellulosic ethanol = 84,100 (DOE)
3) High Heating Value of Bio-oil = 71,200 (DOE)
4) High Heating Value of Wood pellets (dry basis) = 17 MMBtu/ton (BERC)
5) High Heating Value of Wood chips (dry basis) = 17 MMBtu/ton (BERC)
6) High Heating Value of Coal = 10,506 Btu/lb (DOE)
7) High Heating Value of Natural Gas = 1,028 Btu/cubic ft.(DOE)
8) High Heating Value of #6 oil = 152,000 Btu/gallon(DOE)
9) 1 lb. Carbon = 3.6667 lbs CO2
10) From Cell K12: co-firing with 20% biomass

NREL: Life Cycle Assessment of Coal Fired Power Production by Pamela L Spath & others at http://www.nrel.gov/docs/fy99osti/25119.pdf

EERE, DOE: Theoretical Ethanol Yield Calculator http://www1.eere.energy.gov/biomass/ethanol_yield_calculator.html

EIA: U S Energy Information Administration Independent Statistics and Analysis Voluntary Reporting of Green House Gases program (Fuel & energy Source Codes & emission coefficients) www.eia.doe.gov/oiaf/1605/coefficients.html

# APPENDIX 2-C

# AFFORDABLE PRICE OF BIOMASS—CALCULATION ASSUMPTIONS

| | | |
|---|---|---|
| Power | | |
| Sale price of electricity | 12.5 | cents/kWh |
| Cost of biomass | 33% | |
| Cost of biomass | 0.04125 | $/kWh |
| | 3.02242E-06 | $/Btu |
| | 3.02 | $/MMBtu |
| HHV of woodchips(dry) | 8500 | Btu/lb |
| HHV of woodchips(dry) | 17 | MMBtu/ton |
| HHV of woodchips(40 % MC) | 10.2 | MMBtu/ton |
| Affordable price of woodchips (40% MC) | 31 | $/ton |
| | | |
| Thermal energy | | |
| Oil price | 3 | $/gallon |
| heating value of oil | 138,000 | Btu/gallon |
| effciency | 80% | |
| useful energy | 110,400 | Btu/gallon |
| cost of energy | 27.17 | $/MMBtu |
| Affordable price of woodchips as % of cost of oil | 50% | |
| Affordable price of woodchips | 13.59 | $/MMBtu |
| effciency of woodchip boiler | 75% | |
| available heat per ton | 7.65 | MMBtu/ton |
| affordable price of woodchips (40% MC) | 104 | $/ton |
| | | |
| wood pellets (6% MC) | | |
| HHV of wood pellets (6% MC) | 15.98 | MMBtu/ton |
| efficiency | 80% | |
| Available heat per ton | 12.784 | MMBtu/ton |
| Affordable price of wood pellets (6% MC) as % of cost of oil | 75% | |
| Affordable price of wood pellets (6% MC) | 20 | $/MMBtu |
| Affordable price of wood pellets (6% MC) | 261 | $/ton |
| | | |
| Woodchips to wood pellets | | |
| efficiency | 85% | |
| wood pellets price | 261 | $/ton |
| woodchips MC | 40% | |
| Wood pellets MC | 6% | |
| woodchips required per ton of wood pellets | 1.575 | ton/ton |
| Affordable price of woodchips as % of cost of wood pellets | 60% | |
| Affordable price of woodchips | 85 | $/ton |

## APPENDIX 3-A

# REVIEW OF PREVIOUS STUDIES OF MASSACHUSETTS BIOMASS AVAILABILITY

In the past few years, the Massachusetts Sustainable Forest Bioenergy Initiative has funded two studies that address forest biomass availability in Massachusetts: Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts (Kelty, D'Amato, and Barten, 2008) and Biomass Availability Analysis—Five Counties of Western Massachusetts (Innovative Natural Resource Solutions (INRS), 2007). Here we review the components of these studies that focus on forest biomass, considering both their methodologies and results.

The general approach to forest biomass fuel used in these two studies is quite similar: both studies estimate net forest growth over an operable land base and equate this volume to biomass availability; thus, they assess how much wood could be harvested on an ongoing basis so that inventories do not decline below current levels. However, there are several important differences in the methods and details of implementing this approach and comparing their results with each other is not straightforward.

As will be seen in the following discussion, the data provided by Kelty et al. (2008) are presented in a manner that is most directly comparable to our own analysis. Kelty et al. (2008) provides two estimates of forest biomass availability on private lands to cover the wide range of potential responses by private landowners. The average of these two estimates is 750,000 green tons per year. When compared with our analysis, this average is consistent with our estimate of biomass supply at high biomass stumpage prices (the High-Price Biomass scenario). Kelty et al. (2008) is focused on forest growth and does not consider harvesting costs, energy prices, or general operational issues. This suggests that the biomass availability estimates provided by Kelty et al. would be reasonable estimates of supply only if bioenergy plants pay substantially higher prices for wood than in current markets.

Our adjustment of the INRS (2007) estimate to a statewide total suggests that biomass availability in Massachusetts would be about 1.4 million green tons per year. However, given the assumptions in this study, it is not clear how to adjust these estimates for sawtimber volumes and the split between private and public lands. Based on our review of this analysis, it would seem that the appropriate range for only biomass fuel on private lands would be about half of this volume, which suggests about 700,000 green tons, similar to the average of Kelty et al. (2008).

### REVIEW OF "SILVICULTURAL AND ECOLOGICAL CONSIDERATIONS OF FOREST BIOMASS HARVESTING IN MASSACHUSETTS"

The portion of this report that is focused on statewide biomass availability states that the question is: "what is the total annual sustainable harvest from Massachusetts forests (that is, the total annual harvest that would not exceed the total annual [net] forest growth)?" The report states that the intention was to assess the biomass levels that "exist in Massachusetts forests" on land that is "likely to be involved in timber harvesting." The report also provides a detailed analysis of biomass availability at the stand level, however, this analysis appears to be independent of the statewide analysis and have no influence on those results.

The methodology consists of three basic steps: 1) calculate average per-acre growth rates for timber stands in Massachusetts, with private and public lands evaluated separately; 2) identify the acreage available for harvesting; 3) adjust this total volume growth to separate sawtimber from other standing wood. These steps are described in more detail below and some key data are shown in Exhibit 3A-1.

Growth rates were developed on the basis of 50-year projections using the Forest Vegetation Simulator for the Northeast. The mean value of this time period was used as a measure of the growth rate in the future.

Two scenarios were established for private land areas because of the difficulty in predicting harvest activity among private landowners: one included all lands in size classes greater than or equal to 10 acres, while the other included only land greater than or equal to 100 acres. These two groups of private forest land areas were then reduced by 7% due to operational constraints such as terrain and wetland areas. Private lands were further reduced by 30% to adjust for landowners that were assumed would not be willing to harvest their lands for timber production.

Public forest land areas were reduced for operational constraints only. The reduction was 7%, the same as for private lands.

Total annual volumes of sustainable wood harvest were then calculated by multiplying growth per-acre growth rates times the number of acres available in each case. These data were then adjusted downward by 36% to account for timber that would likely be removed for sawtimber and not available to bioenergy facilities.

Results are presented iºn Exhibit 3A-1. "Sustainable" biomass availability was estimated to be about 500,000 green tons per year from public lands. For private lands, annual volumes ranged from 400,000-to-1.1 million green tons. Thus, the combined statewide total for biomass availability was estimated to range from 900,000-to-1.6 million green tons per year.

**Exhibit 3A-1: Calculations for Biomass Availability Based on Kelty et al. (2008)**

| | Public | Private | |
|---|---|---|---|
| | | ≥ 100 acres | ≥ 10 acres |
| Growth (dry tons/acre) | 0.94 | 0.89 | 0.89 |
| Growth (green tons/acre) | 1.71 | 1.62 | 1.62 |
| Net Land Area (acres) | 465 | 379 | 1,073 |
| Total Volume Growth (gt/yr) | 795 | 614 | 1,736 |
| Biomass Fuel Only (gt/yr) | 509 | 393 | 1,111 |

*Note: Data for dry tons and land areas taken directly from Exhibit 3-10 in Kelty et al. (2008). Data for green tons have been calculated assuming 45% moisture content.*

## REVIEW OF "BIOMASS AVAILABILITY ANALYSIS—FIVE COUNTIES OF WESTERN MASSACHUSETTS"

The INRS (2007) report is comprehensive in its coverage of a wide range of sources of woody biomass. It is focused on the five western "core" counties of Massachusetts (Middlesex and Norfolk counties also are included as buffer counties, but are not reported separately from the buffer region). As above, we focus only on the portion of this study that addresses forest biomass.

This study considers forest biomass *growth* and forest *residues* separately. Forest biomass growth is estimated using net growth and removals from FIA data along with an adjustment factor for the growth of tops and branches. Net growth less removals results in estimated annual growth of 1.9 million green tons for western Massachusetts This volume is then reduced by half: "because of landowner constraints, access issues, economic availability, nutrient concerns and the need to harvest less than growth to address landscape-level forest sustainability concerns, INRS suggest that half of this wood be considered actually 'available' to the marketplace" This leaves a total of 960,000 green tons per year of biomass availability. An additional 110,000 green tons of forest residue are estimated to be available in this region (based on TPO data), resulting in an annual total of 1.1 million green tons.

These estimates do not consider the share of wood that might be used for sawtimber. The INRS report indicates that their estimate likely overstates the availability of forest biomass for this reason and others: "In practical terms, it is highly unlikely that this volume of wood could be harvested in an economic or environmentally responsible manner to supply biomass fuel. Further, some of this wood is sawlogs or other high-value material, and as such would be sent to other markets."

We have attempted to put these estimates on a basis that is comparable to the Kelty et al. (2008) analysis by adjusting them to the state level (growth and forest residues are not considered separately because of the small residue share). There are several alternatives for increasing these data from the western region to the state total, but it is not obvious which method would be most appropriate. Relative measures of timberland area, timber inventory, and growth-drain ratios result in expansion factors ranging from 20% to 40%. Thus, the total for biomass availability would be increased to 1.3-to-1.5 million green tons per year.

These estimates are close to the high end of the range (1.6 million green tons) provided by the Kelty et al. (2008). However, it is unclear how to adjust these estimates for potential sawtimber volumes. Kelty et al. (2008) project total net growth and then subtract the sawtimber component, whereas the INRS report projects "net growth less removals" so the growth estimates already partially reflect an adjustment for sawtimber. In addition, for purposes of comparison, it would be useful to separate the INRS volumes by private and public ownerships; however, the analysis reduces net growth on all forest lands by 50% and there appear to be no explicit assumptions regarding the mix of wood available from the two ownerships.

# APPENDIX 3-B

# LOGGING RESIDUE DATA AND ESTIMATION

Although estimation of this supply would seem to be straightforward, problems with logging residue data make it difficult to estimate both the total volume of residues that are generated as well as the share that is recoverable. Some of these problems are general conceptual issues, while others are specific to the Northeast and/or Massachusetts. An important issue relates simply to the definition of logging residues. Logging residues are not defined by the parts of a tree, but by what is left behind in the forest after a site has been logged. In addition to the obvious candidates for unused material after felling, such as crowns and branches, trees that have been killed or damaged during a logging operation are considered to be part of logging residues.[1] Thus, this becomes a difficult empirical issue because harvesting is dynamic and logging residues will change and evolve with technology, timber demand, and relative costs and prices. Once utilized, the material no longer conforms to the definition of logging residues and this can be a source of confusion.

Another important problem with logging residue data is that the parameters used to derive these estimates are from mill and timber utilization studies that are dated. The primary source of logging residue data in most studies is the Timber Products Output (TPO) reports from the U.S. Forest Service. These reports contain data on both softwood and hardwood residues and are disaggregated to the county level.[2] In the Northeast, these studies were last conducted in 1985, and thus do not reflect current utilization standards, prices, costs, and technologies. In addition, the calculation of logging residues requires a combination of surveys, each with its own problems and sampling errors. These problems are likely to be more serious in small states (where interstate trade is important) because wood flows and sourcing patterns can change substantially over time.

As it turns out, the logging residue data reported by TPO for Massachusetts could not be used because the on-line program generates the data incorrectly.[3] In order to generate logging residues that are consistent with the TPO methodology, we have applied the timber utilization matrices underlying the TPO estimates to their estimates of roundwood harvests.

According to the production data from the TPO reports, industrial roundwood production in Massachusetts is comprised of essentially two "products," sawlogs and pulpwood. ("Other industrial products" is a third category and accounts for 1% of the industrial roundwood total).[4] The volume of logging residues generated per unit of roundwood production is shown in Exhibit 3A-1. Logging residues from softwood harvests are less than for hardwoods because of differences in tree geometry and differences in end-use markets and products. Logging residues for pulpwood are less than for sawlogs because of the ability to utilize a higher proportion of the main stem.

The TPO data for Massachusetts in 2006 indicate that sawlogs accounted for 87% of the industrial roundwood production, and that softwood accounted for 60% of the sawlog production. Applying the coefficients in Exhibit 3B-1 to these data suggest that logging residues totaled 4.27 million cubic feet in 2006, or 50% of roundwood production. This implies that approximately 128,000 green tons of logging residues were generated in 2006 (using a conversion of 30 green tons per thousand cubic feet).

**Exhibit 3B-1: Logging Residue Generation in Massachusetts By Product and Species Group**
(cubic feet of logging residues per cubic foot of roundwood)

| | Softwood | Hardwood |
|---|---|---|
| Sawlogs | 0.43 | 0.67 |
| Pulpwood | 0.36 | 0.56 |

*Source: Personal communication with USFS.*

Importantly, these data appropriately measure only unutilized residues—wood left behind after a logging operation—and thus would be the correct measure of the total volume of residues that could be available for biomass. However, as noted earlier, a closer look at these data suggests that a significant share of this material can be attributed to breakage or residual stand damage, and thus could not be transported to a landing during a harvesting operation. For this reason, it is often assumed that 50% of "logging residues" are recoverable. Using this assumption, 64,000 green tons of logging residues would have been available for biomass supply in 2006.

Concerns about the TPO data and with implementing those estimates in a manner that is consistent with our projection and harvesting methodology have led us to a second approach: estimation of logging residue generation by calculating the volume of tops and limbs associated with harvesting trees of varying diameter

---

[1] According to Forest Resources of the United States, 2002 (Smith et al.), logging residues are defined as: "The unused portions of growing stock and non-growing stock trees cut or killed by logging and left in the woods." This includes material that is sound enough to chip (and excludes rotten wood), downed dead trees, and downed cull trees. Material that has been badly damaged during logging but is still standing should be included in logging residues; however, the definitions are confusing in this regard.

[2] The reports are available on-line (www.fia.fs.fed.us/tools-data/other/) and can be accessed on the National Renewable Energy Laboratory website.

[3] The on-line TPO program reports that 8.451 million cubic feet of industrial roundwood products were produced in Massachusetts in 2006. The same number is reported as the total for "Logging Residues" and also for "Mill Residues."

[4] There is also a large volume of fuelwood production; in fact, the volume is substantially higher than industrial roundwood production. However, the TPO methodology assumes that residential fuelwood harvests do not contribute to logging residues.

classes. From a biomass perspective, this approach provides a more useful estimate of "logging residues" since this material has a much better chance of being delivered to a landing at a reasonable cost using whole-tree harvesting methods.[5]

Exhibit 3B-2 shows the average volume of tops and limbs as a share of the merchantable tree volume in the standing inventory of live trees in Massachusetts. These data suggest that for all species combined, reasonable estimates of "logging residues" generated would be about 22%, on average, for sawtimber harvests and 35% for pulpwood. Thus, using the same data on industrial roundwood production as above (from TPO for 2006), logging residues would have been about 2.0 million cubic feet, or 60,000 green tons. Given that this material could be moved to a landing more easily because it consists strictly of tops and limbs, the recovery rate of this material for biomass fuel use could be considerably higher than 50%.

**Exhibit 3B-2: Volume of Tops and Limbs as a Share of Merchantable Tree Volume**
Based on Massachusetts Inventory Data, 2008

| DBH, inches | Share |
|---|---|
| 5.0–6.9 | 38% |
| 7.0–8.9 | 31% |
| 9.0–10.9 | 27% |
| 11.0–12.9 | 24% |
| 13.0–14.9 | 22% |
| 15.0–16.9 | 21% |
| 17.0–18.9 | 19% |
| 19.0–20.9 | 18% |
| 21.0–22.9 | 18% |
| 23.0–24.9 | 17% |

*Source: Based on USFS, FIA data. DBH is tree diameter measured at breast height (4.5 feet above ground level).*

---

[5] One shortcoming of this approach is that it is not possible to estimate how much of this topwood and limbwood may already be being utilized due to differing utilization standards for products, or for harvests of firewood.

# APPENDIX 3-C

# FIREWOOD DATA

Fuelwood is by far the largest market for timber cut in Massachusetts, but fuelwood data are poor because the market is unregulated with large numbers of consumers and producers, and there is a large personal use sector where consumers cut their own wood. The FCPs show some data on fuelwood harvests, but these numbers are small and only pertain to volumes that are associated with larger-scale commercial-based harvesting. The large majority of fuelwood cut in Massachusetts is not registered in these plans.

The Timber Product Output reports provide one estimate of fuelwood production in Massachusetts; however, these data are derived from U.S. Census data rather than collected directly from U.S. Forest Service surveys (the source of other TPO data). TPO data indicate that fuelwood production in Massachusetts in 2006 was 41.3 million cubic feet (517,000 cords or 1.3 million green tons), which would suggest that it would have accounted for about 83% of the timber harvest in Massachusetts (see Exhibit 3C-1.) According to this report, virtually all of the fuelwood comes from non-growing stock sources, which includes cull trees (rough and rotten), dead trees, tops and stumps of growing stock trees, and non-forestland sources of trees such as yard trees.

**Exhibit 3C-1: Fuelwood Production in Massachusetts, 2006**
Million Cubic Feet

| | Industrial | Fuelwood | Total | Fuelwood (cords) |
|---|---|---|---|---|
| Growing Stock | 7.0 | 1.2 | 8.2 | 15 |
| Non-Growing Stock | 1.5 | 40.1 | 41.6 | 502 |
| Total | 8.5 | 41.3 | 49.8 | 517 |

*Source: TPO Reports (USDA, FS).*

Unlike the data on industrial roundwood products, the data on fuelwood have not been collected by the USFS since some time prior to 1980. Since then, the data have been collected by Energy Information Administration as part of their Residential Energy Consumption Survey. These data are surveyed at the Census division level and allocated to individual states on the basis of the total number of housing units. In the case of Massachusetts, this methodology clearly overstates fuelwood consumption since Massachusetts accounts for about half of the housing units in New England. For example, in 2007, New England consumption was estimated to be about 927,000 cords, and 439,000 cords were allocated to Massachusetts. Prior to the time when this methodology was adopted, Massachusetts share of New England fuelwood consumption was only 35% in 1975 (and jumped to 49% when housing units were used as the basis of the allocation).

An important question in assessing biomass supplies in Massachusetts is how the residential fuelwood sector might interface with an expanded harvest of forest biomass fuel. Fuelwood is typically harvested in relatively small volumes and on small areas, often by landowners cutting for their own use. We have assumed that forest biomass harvests are unlikely to be integrated with harvests of residential fuelwood due to: 1) the number of acres cut in a typical fuelwood harvest; 2) the volume of logging residue left behind on each acre; and 3) the type of equipment used in these logging operations.

# APPENDIX 3-D

# A CLOSER LOOK AT BIOMASS POTENTIAL IN SOUTHERN NEW HAMPSHIRE

The analysis of inventories, industry location, and landowner attitudes in this report suggests that the border counties in New Hampshire, Vermont, and New York hold the most potential for increasing supplies of forest biomass. The New Hampshire border zone is the largest of these areas and the one with perhaps the best data. Here we look more closely at recent historical harvests (New Hampshire Report of Cut, 2008) and prices trends (New Hampshire Timberland Owner's Association, Timber Crier) in New Hampshire to see if there are any patterns that suggest than an expansion of timber production looks likely.

## Timber Harvest Trends

In New Hampshire, the sawlog harvest declined from 2000 to 2006, with most of the decrease occurring by 2003. This is somewhat surprising given the strength of the housing market during this period. Part of this decline was offset by an increase in pulpwood and fuelwood harvest. Whole-tree chip production was fairly stable over these seven years, averaging about 800,000 green tons per year, equivalent to about 25% of New Hampshire's roundwood harvest.[6]

The harvest in the three counties of southern New Hampshire has been fairly stable as a share of the total cut in the state, fluctuating in the range of 20%–23% during 2000–2006. Similar to overall state trends, sawlog production declined (from 400,000 green tons in 2000 to 300,000 green tons in 2006), while pulpwood rose and whole-tree chip production remained steady at about 230,000 green tons.

Several aspects of these trends have implications for our analysis: 1) in spite of rising timber inventories in New Hampshire, recent harvest levels have been declining; 2) the southern counties share of the harvest has been stable; 3) in the southern counties, whole-tree harvests have been stable as a share of the overall harvest.

Overall trends do not show New Hampshire as a state that is expanding its forest products industries and its harvest levels. In general, this is not a positive trend for a bioenergy industry that is thought to have it biggest advantage when its raw material comes from integrated harvests that depend on other commercial products. Also, the southern share of state harvests has been stable: if the share were rising, one might have some evidence that the region has some competitive advantage, possibly in the area of wood supply.7

## The Relationship of Timber Harvest to Inventory Levels

A key metric that is often used to measure tightness in the timber market is the ratio of timber harvest to timber inventory (FIA data). We have compiled these estimates for the three New Hampshire regions to see if they provide any additional information about harvest potential (see Exhibit 3D-1). The cut-to-inventory ratio statewide is 1.1% (as noted in the table, the harvest data do not include residential fuelwood and logging residues which would likely move this ratio closer to 1.5%). These ratios decline as one moves from north to south: the ratio is 1.3% for the northern counties, 1.1% for the central counties, and 0.9% for the southern counties. As might be expected, timber inventories are growing more slowly in the central and northern areas. In fact, harvesting in the north has outpaced growth and timber inventories on private lands have declined an average of 500,000 green tons per year according to FIA estimates. These higher rates of harvesting in the north are also reflected in stocking levels which we estimate to be only 50 green tons per acre on private lands in the north, compared to 66 tons/acre in the central region, and 75 tons/acre in the south.

These data seem to suggest that if there are opportunities for expansion in New Hampshire, they may lie in the south. However, one cannot draw this conclusion on the basis of cut/inventory ratios or stocking levels alone unless the land in the inventory is similar and managed the same way. For example, it is common to see high cut/inventory ratios for industrial land ownerships (there are forest industry lands in northern New Hampshire) and lower cut/inventory ratios on non-industrial private lands where timber production may not be the most important objective of landowners.

**Exhibit 3D-1: Harvest Ratios in New Hampshire**
000 Green Tons and Percent

| | Harvest | Cut/Inv |
|---|---|---|
| New Hampshire | 3,238 | 1.1% |
| North | 1,731 | 1.3% |
| Central | 809 | 1.1% |
| South | 698 | 0.9% |

*Notes: Harvest data is the average for 2000–2006 and includes sawlogs, pulpwood, fuelwood, and whole-tree chips. "Cut/Inv" is the ratio of harvest to growing stock on private and public timberland. Harvest data exclude residential fuelwood and logging residues and thus understate timber removals.*

In spite of low cut/inventory ratios and expanding timber inventories in the southern counties of New Hampshire, the harvesting data have shown the south's position as a timber producer has been relatively stable. The southern counties are not growing in an absolute sense, nor have harvest levels increased relative to the central or northern areas. Importantly, we have also seen that whole-tree harvesting is already prevalent in southern New Hampshire. Thus, opportunities for expansion as part of integrated

---

[6] Similar to Massachusetts, harvesting of fuelwood does not need to be reported if the volume is considered to be small and for personal use. For New Hampshire, this maximum volume is set at 20 cords.

[7] When sawlog production declines, the production and availability of mill residues will also decline (assuming sawlogs are milled in the "home" market). This is another factor that has negative consequences for biomass fuel supply.

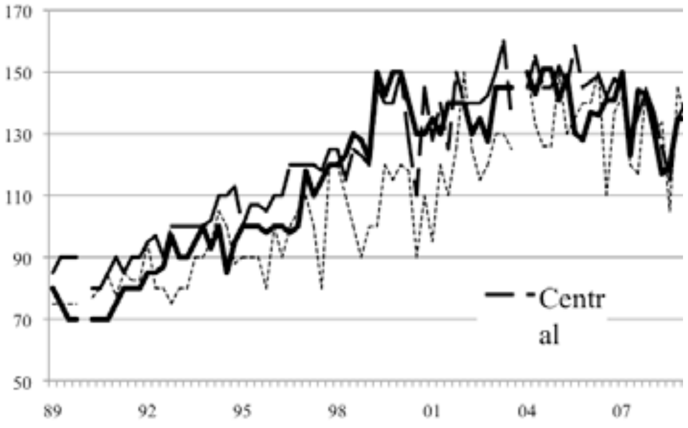
operations might be more limited than in other border zones where whole-tree harvesting is much less common.

### Prices and Pockets of Opportunity

The final measure we consider—perhaps the single best indicator—is relative pricing. In a market in equilibrium, prices will track together. If prices deviate from the overall trend, particularly if they are drop lower at times, this may be due to weaker demand and might be an indicator that more timber can be harvested with the region remaining competitive. In Exhibit 3D-2, we have compared white pine sawtimber stumpage prices for the three regions of New Hampshire. We selected white pine because it accounts for about 50% of the sawtimber harvest and is widely distributed through the state (spruce/fir is the next largest species group with 13%, but it is almost entirely produced in the northern zone). We selected sawtimber because: 1) biomass is generally expected to be a follower of higher-valued commercial harvest; and, 2) biomass stumpage prices can easily diverge within regions because they are such a small share of total delivered costs.

Prices for white pine sawtimber stumpage in southern New Hampshire fall right in line with those in the central region suggesting that the buyers of wood can access both areas on an equal footing; hence the south would not appear ripe for greater expansion relative to other New Hampshire regions. The north is a bit more erratic, dropping below the southern price at times and for an extended period in 1997–2000. The data do not suggest any obvious gaps in the south that would be an incentive to build new capacity; in fact, the data suggest that such opportunities may have existed in the north during the 1990s. Although forests in the north have been cut more intensively than elsewhere in the state, prices have not moved higher suggesting that overall pressures on the resource remain similar in the three regions when ownership, attitudes, management objectives and other variables are taken into account.

**Exhibit 3D-2: White Pine Sawtimber Stumpage Prices in New Hampshire**
Dollars per 1,000 board feet International log rule



*Source: New Hampshire Timberland Owner's Association, Timber Crier, various issues: mid-range stumpage prices.*

## REFERENCES

Innovative Natural Resource Solutions LLC. 2007. Biomass Availability Analysis—Five Counties of Western Massachusetts.

Kelty M.J., D'Amato A.W., and Barten P.K. 2008. Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts. Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA.

New Hampshire Report of Cut. 2008. Summary data generated by Matt Tansey, New Hampshire Division of Forest & Lands.

New Hampshire Timberland Owner's Association. Timber Crier. Various issues.

New Hampshire Timberland Owner's Association. 2010. Website: www.nhtoa.org.

Northeast State Foresters Association. 2007a. The Economic Importance and Wood Flows from the Forests of Maine, New Hampshire, Vermont and New York, 2007.

Northeast State Foresters Association. 2007b. The Economic Importance and Wood Flows from Vermont's Forests, 2007.

University of Massachusetts Amherst. 2008. Southern New England Stumpage Price Report. MassWoods, maintained by Paul Catanzaro. www.masswoods.net/sne_stumpage/

U.S. Department of Agriculture, Forest Service. Forest Inventory and Analysis National Program. Forest Inventory Data Online: www.fia.fs.fed.us/tools-data.

U.S. Department of Agriculture, Forest Service. Timber Product Output Mapmaker Version 1.0. On-line software for the Timber Product Output Database Retrieval System (TPO). www.fia.fs.fed.us/tools-data/other/

Vermont Department of Taxes. 2010. Annual Report. Division of Property Valuation and Review.

Vermont Forest Resource Harvest Summary. Various years. Vermont Department of Forests, Parks & Recreation.

# APPENDIX 4–A

# ECOLOGY OF DEAD WOOD IN THE NORTHEAST

ALEXANDER M. EVANS AND MATTHEW J. KELTY

## TABLE OF CONTENTS

## 1. INTRODUCTION

Although dead wood and decaying trees have historically had little commercial value, they do have substantial ecological value. This paper reviews the scientific literature to provide the background necessary to craft recommendations about the amount and type of dead wood that should be retained in the forest types of the northeastern U.S. Establishing the ecological requirements for dead wood and other previously low-value material is important because of the increased interest in this material for energy and fuel. More intensive extraction of biomass from the forest may impinge on the forest's ability to support wildlife, provide clean water, sequester carbon, and regenerate a diverse suite of plants.

This background paper covers the topics of dead wood, soil compaction, nutrient conservation, and wildlife habitat in temperate forests generally as well as in specific forest types of the Northeast. Complex issues related to carbon storage in forests and the climate impacts of using forest material for energy and fuel are very important and deserve an in-depth investigation beyond the scope of this paper. Similarly, this paper will not discuss the state of biomass harvesting in the U.S. (Evans 2008, Evans and Finkral 2009) or existing biomass harvesting guidelines (Evans and Perschel 2009) which have been addressed in other recent publications.

The goal of this background paper is to provide a concise summary that can inform discussions about biomass harvesting standards in the Northeast. However, it is important to note that this document makes no suggestions about how a biomass harvest should be conducted or what should be left in the forest after a harvest. Rather we have attempted to lay out the basic science on which recommendations can be built.

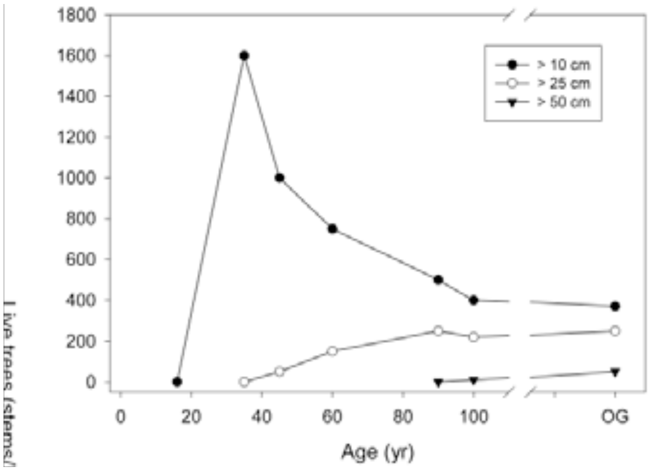
## 2. ECOLOGY OF DEAD WOOD IN THE NORTHEAST

### 2A. DEAD WOOD AND STAND DEVELOPMENT

Dead wood is important not only in terms of total volume or mass in a stand, but also in terms of piece size—usually measured as diameter at breast height (DBH) for snags (and for live trees) or diameter of the large end for down woody material (DWM). Large-diameter snags or down logs are important habitat for numerous animal species, persist for long periods, store nutrients, and provide substrate for seed germination.

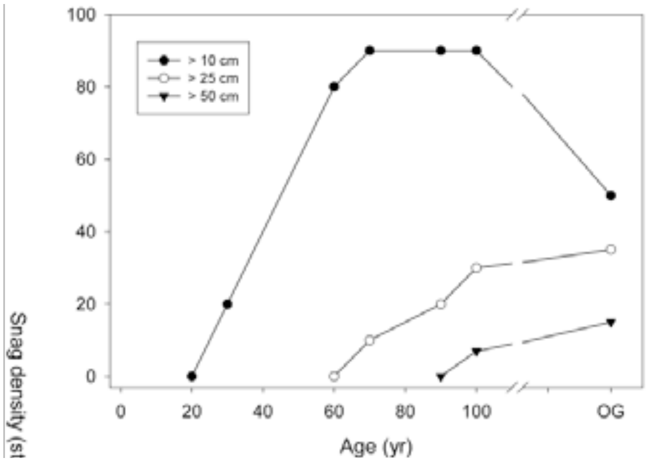
The process of dead wood accumulation in a forest stand consists of the shift from live tree to snag to DWM unless a disturbance has felled live trees, shifting them directly to DWM. The graphs below (Figures 1, 2, and 3) show the general pattern of the production of dead wood in total amount and size. The data in these graphs are taken from research in northern hardwood forests (Gore and Patterson 1986, Goodburn and Lorimer 1998, Hale et al. 1999, McGee et al. 1999, Nyland et al. 2000). The 4 in (10 cm) diameter size is within the range of the minimum size used in most coarse woody material (CWM) inventories. Fine woody material (FWM) refers to smaller-sized dead material. The graphs depict the patterns for a stand that had been harvested as a conventional clearcut, leaving a large amount of small woody material (nearly all <10 in (25 cm) diameter), but no trees >4 in (>10 cm) DBH and no snags. The pattern is shown from just after the clearcut (age 0)–age 100 years, and in the old-growth condition.

**Figure 1. General Pattern of Tree Density Over Time**



The young stand produces large numbers of trees (~600 stems/ac or ~1500 stems/ha) at age 30, and the intense competition among these trees causes mortality of smaller stems, which creates an increasing number of small snags (Figure 2). Trees begin to grow into 10 in (25 cm) DBH size by age 40, and trees of this size begin to dominate the stand by age 80. Snags of the 10 in (25 cm) DBH size begin to appear at age 60 as mortality of larger trees occur. Large live trees (>20 in or >50 cm) begin to appear at age 90—100, with snags of that size as well.

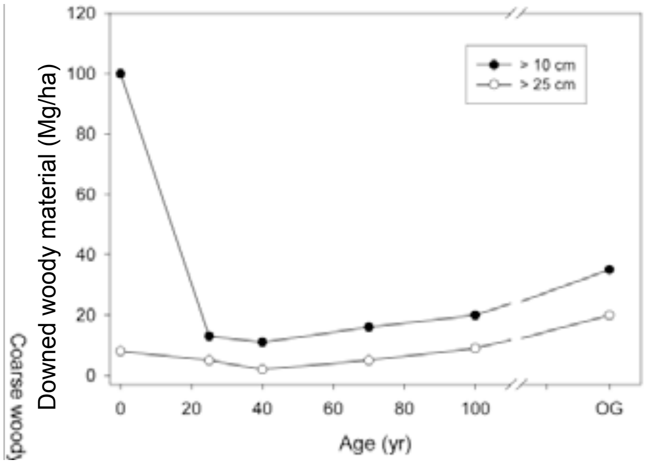
**Figure 2. General Pattern of Snag Density Over Time**



The large amount of DWM present just after the clearcut (which consists mostly of pieces <10 in (<25 cm) diameter) decomposes rapidly in the first 25 years and continues to decline in mass to age 40. From age 40—100 years, DWM increases as small snags fall, and then larger snags begin to contribute to DWM that include pieces >10 in (>25 cm) diameter. Very few large (> 20 in or >50 cm) pieces of DWM are produced. Large DWM often results from wind or other disturbances that fell large trees in the old-growth stage. Thus, large DWM tends to accumulate periodically from these disturbance pulses; whereas small DWM accumulates in a more predictable pattern in earlier stages of stand development.

This process produces the U-shaped pattern that is often described with a dearth of DWM in the intermediate ages (Figure 3). This pattern shows the importance of retaining large live trees and large snags at the time of harvest; they will contribute large DWM to the forest floor throughout the development of the stand.

**Figure 3. General Pattern of DWM Density Over Time**



## 2B. WILDLIFE AND BIODIVERSITY

Dead wood is a central element of wildlife habitat in forests (Freedman et al. 1996). Many forest floor vertebrates have benefited or depended on DWM (Butts and McComb 2000). In the southeastern U.S., more than 55 mammal species, over 20 bird species, and many reptiles and amphibian species were relying on dead wood (Lanham and Guynn 1996, Loeb 1996, Whiles and Grubaugh 1996) with similar numbers for the forests of the Pacific Northwest (Carey and Johnson 1995, McComb 2003). In New England, De Graaf and colleagues (1992) catalogued at least 40 species that rely on DWM.

Some examples of relationships between animals and DWM in the Northeast include a study showing that low densities of highly decayed logs (less than one highly decayed log/ha ) had a negative impact on red-back voles (*Clethrionomys gapperi*) in a northern hardwood forest in New Brunswick, Canada (Bowman et al. 2000). DWM retention increased spotted salamander (*Ambystoma maculatum*) populations in a Maine study (Patrick et al. 2006). While DWM is important habitat for red-backed voles in Maine, it did not effect populations at volumes as low as 543 $ft^3$/ac (38 $m^3$/ha; McCay and Komoroski 2004). The quantity of DWM had no effect on white-footed mice (*Peromyscus leucopus*) abundance in an Appalachian study, but at the micro-site scale, mice were more often located near DWM (Marcus et al. 2002). Similarly, shrew (*Tupaia* sp.) showed minimal or no response to drastic decreases in the abundance of large logs in managed loblolly pine (*Pinus taeda*) forests of the southeastern coastal plain (McCay and Komoroski 2004) .

In aquatic environments, DWM provided crucial refuge from predation (Angermeier and Karr 1984, Everett and Ruiz 1993). Logs that fell in the water formed a critical component of aquatic habitat by ponding water, aerating streams, and storing sediments (Gurnell et al. 1995, Sass 2009). In fact, removal of large woody material from streams and rivers had an overwhelming and detrimental effect on salmonids (Mellina and Hinch 2009).

DWM is a key element in maintaining habitat for saproxylic insects (Grove 2002). For example, some specialist litter-dwelling fauna that depend on DWM appear to have been extirpated from some managed forests (Kappes et al. 2009). A study from Ontario suggests that overall insect abundance was not correlated with the volume of DWM, though abundance of the fungivorous insect guild was positively related to the volume of DWM (Vanderwel et al. 2006b). Extensive removal of DWM could reduce species richness of ground-active beetles at a local scale (Gunnarsson et al. 2004). More generally, a minimum of 286 $ft^3$/ac (20 $m^3$/ha) of DWM has been suggested to protect litter-dwelling fauna in Europe (Kappes et al. 2009).

Dead logs served as a seedbed for tree and plant species (McGee 2001, Weaver et al. 2009). Slash could be beneficial to seedling regeneration after harvest (Grisez, McInnis, and Roberts 1994). Fungi, mosses, and liverworts depended on dead wood for nutrients and moisture, and in turn, many trees were reliant on mutualistic relationships with ectomycorrhizal fungi (Hagan and Grove 1999, Åström et al. 2005). In general, small trees and branches hosted more species of fungus per volume unit than larger trees and logs; however larger dead logs may be necessary to ensure the survival of specialized fungus species such as heart-rot agents (Kruys and Jonsson 1999, Bate et al. 2004).

## 2C. SOIL PRODUCTIVITY

DWM plays an important physical role in forests and riparian systems. DWM added to the erosion protection by reducing overland flow (McIver and Starr 2001, Jia-bing et al. 2005). DWM also had substantial water-holding capacity (Fraver et al. 2002). DWM in riparian systems provided sites for vegetation colonization, forest island growth and coalescence, and forest floodplain development (Fetherston et al. 1995).

In many ecosystems, CWM decomposed much more slowly than foliage and FWM, making it a long-term source of nutrients (Harmon et al. 1986, Johnson and Curtis 2001, Greenberg 2002, Mahendrappa et al. 2006). DWM decomposed through physical breakdown and biological decomposition (Harmon et al. 1986). The diameter of each piece of DWM, temperature of the site, amount of precipitation, and tree species all influenced the rate of DWM decomposition (Zell et al. 2009). In general, conifers decayed more slowly than deciduous species (Zell et al. 2009). Other factors that encouraged decomposition included warmer temperatures, rainfall between 43 and 51 in/year (1100 and 1300 mm/year), and small-sized pieces (Zell et al. 2009). While there is great variation across ecosystems and individual pieces of DWM, log fragmentation generally appears to occur over 25–85 years in the U.S. (Harmon et al. 1986, Ganjegunte et al. 2004, Campbell and Laroque 2007).

In some ecosystems, DWM represents a large pool of nutrients and is an important contributor to soil organic material (Graham and Cromack Jr. 1982, Harvey et al. 1987). However, review of DWM in Northern coniferous forests suggested that DWM may play a small role in nutrient cycling in those forests (Laiho and Prescott 2004). The same review showed that DWM contributes less than 10 percent of the nutrients (Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg) returned in aboveground litter annually, and approximately five percent of the N and P released from decomposing litter or soil annually (Laiho and Prescott 2004). Although DWM is often low in N itself, N fixation in DWM was an important source of this limiting nutrient in both terrestrial and aquatic ecosystems (Harmon et al. 1986). There was a wide range of non-symbiotic N fixation, but temperate forests received average input of about 1.8–2.7 lb/ac/yr (2–3 kg/ha/year) of N (Roskoski 1980, Yowhan Son 2001).

A review of scientific data suggests that when both sensitive sites (including low-nutrient) and clearcutting with whole-tree removal are avoided, then nutrient capital can be protected (see also Hacker 2005). However, there is no scientific consensus on this point because of the range of treatments and experimental sites (Grigal 2000). It is important to emphasize that the impact on soil nutrients is site dependent. Low-nutrient sites are much more likely to be damaged by intensive biomass removal than sites with great nutrient capital or more rapid nutrient inputs. A report on impacts of biomass harvesting from Massachusetts suggested that with partial removals (i.e., a combination of crown thinning and low thinning that removes all small trees for biomass and generates from 9–25 dry t/ac or 20–56 Mg/ha) stocks of Ca, the nutrient of greatest concern, could be replenished in 71 years (Kelty et al. 2008). The Massachusetts study was based on previous research with similar results from Connecticut (Tritton et al. 1987, Hornbeck et al. 1990). Leaching, particularly of Ca due to acidic precipitation, can reduce the nutrients available to forests even without harvests (Pierce et al. 1993). However, the Ca-P mineral apatite may provide more sustainable supplies of Ca to forests growing in young soils formed in granitoid parent materials (Yanai et al. 2005).

15 years of data from Hubbard Brook Ecosystem Study indicate that a whole-tree clear cut did not result in the depletion of exchangeable Ca pools (Campbell et al. 2007). The Environmental Impact Statement from the White Mountain National Forest (2005 p. 3–19) demonstrated the variation in Ca removed by treatment and forest type, though even whole-tree clear cut was estimated to remove only four percent of the total Ca pool. A study of an aspen/mixed-hardwood forest showed that even with a clearcut system, Ca stocks would be replenished in 54 years (Boyle et al. 1973). Minnesota's biomass guidelines present data that showed soil nutrient capital was replenished in less than 50 years even under a whole-tree harvesting scenario (Grigal 2004, MFRC 2007). Whole-tree clearcutting (or whole-tree thinning, e.g., Nord-Larsen 2002) did not greatly reduced amounts of soil carbon or N in some studies (Hornbeck et al. 1986, Hendrickson 1988, Huntington and Ryan 1990, Lynch and Corbett 1991, Olsson et al. 1996, Johnson and Todd 1998). Lack of significant reduction in carbon and N may be due to soil mixing by harvesting equipment (Huntington and Ryan 1990). However, intensive cutting, such as clearcutting with whole-tree removal, can result in significant nutrient losses (Hendrickson 1988, Federer et al. 1989, Hornbeck et

al. 1990, Martin et al. 2000, Watmough and Dillon 2003)—in one case, 13 percent of Ca site capital (Tritton et al. 1987).

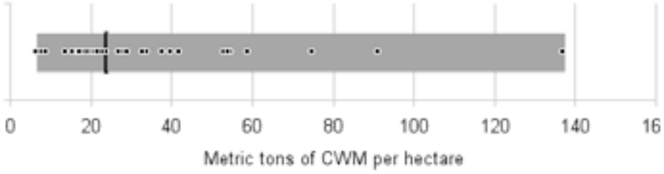
Low-impact logging techniques that reduce soil disturbance can help protect nutrient capital (Hallett and Hornbeck 2000). Harvesting during the winter after leaf fall can reduce nutrient loss from 10–20 percent (Boyle et al. 1973, Hallett and Hornbeck 2000). Alternatively, if logging occurs during spring or summer, leaving tree tops on site would aid in nutrient conservation. Nordic countries have demonstrated that leaving cut trees on the ground in the harvest area until their needles have dropped (one growing season) can also reduce nutrient loss (Nord-Larsen 2002, Richardson et al. 2002).

## 2D. QUANTITIES OF DEAD WOOD

Site productivity and the rate of decomposition helped determine the amount of dead wood in a given stand (Campbell and Laroque 2007, Brin et al. 2008). As mentioned above, DWM decomposition varies greatly but generally occurs over 25–85 years in the U.S. (Harmon et al. 1986, Ganjegunte et al. 2004, Campbell and Laroque 2007). All mortality agents including wind, ice, fire, drought, disease, insects, competition, and senescence create dead wood (Jia-bing et al. 2005). Of course, these mortality agents often act synergistically.

A review of 21 reports of quantitative measures of DWM in Eastern forest types shows great variability across forest types and stand development stages (Roskoski 1980, Gore and Patterson 1986, Mattson et al. 1987, McCarthy and Bailey 1994, Duvall and Grigal 1999, Idol et al. 2001, Currie and Nadelhoffer 2002). The reports ranged from 3–61 t/ac (7 to 137 Mg/ha) with a median of 11 t/ac (24 Mg/ha) and a mean of 15 t/ac (33 Mg/ha; see Figure 4). Measurements of old forests (>80 years old), had a median of 11 t/ac (24 Mg/ha) and a mean of 13 t/ac (29 Mg/ha) in DWM.

**Figure 4. Distribution of DWM Measured in Eastern Forests**



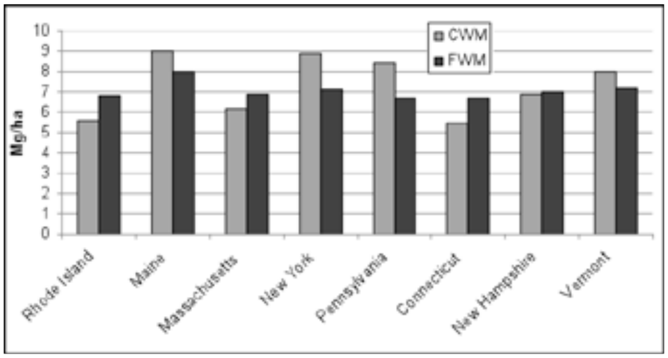
The gray bar shows the range of DWM measurement, the black line shows the median value, and each dot represents one measurement of DWM.

In contrast, a study of U.S. Forest Service inventory plots found a mean of 3.7 t/ac (8.3 Mg/ha) and a median of 2.9 t/ac (6.5 Mg/ha) of DWM across 229 plots in the Northeast (Chojnacky et al. 2004 see Figure 2). This low level of DWM across the landscape may be due to widespread clearcutting in the 1880-1930 period.

**Figure 5. U.S. Forest Service Inventory Estimates of Deadwood** Data from Chojnacky et al. 2004

## 3. Research by Forest Type

The following section uses the best available scientific literature to examine the dead wood dynamics of specific forest types in the Northeast. This region encompasses three ecological provinces including Northeastern mixed forest, Adirondack-New England mixed forest-coniferous forest, and Eastern broadleaf forest (McNab et al. 2007). Major forest types in the region are white/red/jack pine (*Pinus* sp.), spruce-fir (*Picea* sp. - *Abies* sp.), oak-hickory (*Quercus* sp. - *Carya* sp.) or transitional hardwood forests, and northern hardwood forests (Eyre 1980).



The average year round temperature in the Northeast is 46°F (8°C). Winter temperatures average 24°F (-4.3°C) while summer temperatures average 67°F (19.6°C; National Climate Data Center 2008). The prevailing wind direction, from west-to-east, creates a continental climate except for coastal areas moderated by the Atlantic Ocean (Barrett 1980). On average, the region receives 41 in (104 cm) of precipitation which is evenly distributed throughout the year (National Climate Data Center 2008). Elevations range from sea level to mountain tops above 5,300 ft (1,600 m), but much of the region is set on upland plateaus between 500 ft and 1500 ft (150 and 460 m; Barrett 1980). Glaciation created young soils which vary considerably across small spatial scales (Barrett 1980).

Much of the southern portion of Northeastern forests was cleared for agriculture in the early 19th century, leaving less than one percent of the forest cover in an old-growth condition (Cogbill et al. 2002). Currently much of the region is comprised of second- or third-growth forest that has yet to reach late seral stages (Irland 1999). There are about 80 million ac (32 million ha) of timberlands (areas where commercial timber could be produced) and about 4 million ac (1.6 million ha) of reserved forest where harvests are not permitted (Alvarez 2007). Approximately 1,272 million ft3 (36 million $m^3$) of wood are harvested annually out of 3,157 million ft3 (89 million $m^3$) of net tree growth (Alvarez 2007).

## 3A. SPRUCE-FIR FORESTS

Spruce-fir forests dominate the inland areas of Maine as well as the mountain tops northernmost portions of New York, New Hampshire, and Vermont. These forests have cold temperatures and relatively coarse, acidic soils (Barrett 1980). Dead wood is important in spruce-fir ecosystems. For example, in Maine (the state with the greatest area of spruce-fir forests in the Northeast), DWM, snags, and cavity trees are important habitat for 20 percent of bird, 50 percent of mammal, 44 percent of amphibian, and 58 percent of reptile species found there (Flatebo et al. 1999). Animals that rely on DWM in spruce-fir forests include pine marten (Martes americana atrata) (Kyle and Strobeck 2003) and may include some saproxylic vertebrates (Majka and Pollock 2006).

In 2001, researchers found the volume of down dead wood in Maine's spruce-fir forest to be 530 $ft^3$/ac (37 $m^3$/ha) or 3.4 t/ac (7.5 Mg/ha) (Heath and Chojnacky 2001, Table 36). While the average was 3.4 t/ac (7.5 Mg/ha) non-industrial private lands only had 3 t/ac, public lands had 3.3 t/ac, while industrial lands had 3.7 t/ac (Heath and Chojnacky 2001, Table 37). The quadratic-mean, large-end diameter of down wood in Maine's spruce fir-forests measured 6.7 in (17 cm; Heath and Chojnacky 2001). The number of dead trees in nine red spruce-balsam fir forests ranged from 85–232/ ac (210–574/ ha) or from 11–43 percent of the basal area (Tritton and Siccama 1990). The nine paper birch-red spruce-balsam fir stands survey ranged from 33–86 dead trees/ac (81–212/ha) or 11–35 percent of basal area (Tritton and Siccama 1990), and overall, 14 percent of the trees in Maine were standing dead (Griffith and Alerich 1996). Dead wood provided an important substrate for spruce and hemlock seedling development (Weaver et al. 2009). While a commercial clearcut reduced the area of dead wood available for seedling growth, 5- and 20-year-selection cutting cycles were not statistically different from the uncut reference stand with 362–501 $ft^2$/ac (83–115 $m^2$/ha) of dead wood (Weaver et al. 2009).

As described above, spruce-fir forests tend to have two peaks in DWM over time: one early in stand development and a second peak after the stem exclusion phase (Figure 3). For example, one study showed a change from 63 t/ac (28 Mg/ha) in a stand <20 years, 22 t/ac (10 Mg/ha) in the 41–60-year age class, to 117 t/ac (52 Mg/ha) in the 61–80-year age class, and returning to less than 56 (25 Mg/ha) in the 101–120-year age class (Taylor et al. 2007). Fraver and colleagues (2002) showed that pre-harvest an Acadian forest had 10 t/ac (23 Mg/ha) of DWM. The harvest in this study increased the mass of DWM, but more of the pieces were small diameter (Fraver et al. 2002). While the harvest method (whole tree, tree length, or cut to length) and harvest system affect the amount of DWM left after harvest, many studies do not specify how material was removed.

Snag densities in balsam fir forests of Newfoundland followed a similar pattern over time. Stands contained nearly 16 snags/ac (40/ha) the first year post harvest; then the density declined below the 4 snags/ac (10/ha) required by the regional forest management guidelines at 20 years post harvest; and finally the number of snags returned to initial levels in the 80–100 years post-harvest stands (Smith et al. 2009). Smith and colleagues (2009) recommended retention and recruitment of white birch snags to ensure sufficient snag and DWM density. The Canadian province of Newfoundland and Labrador requires retention of 4 snags/acre while Maine recommends retention of 3 snags greater than 14 inches DBH and one greater than 24 inches DBH (Flatebo et al. 1999, Smith et al. 2009). Other guidelines recommend between 5 and 6 snags/acre greater than 8 inches and an additional 4–6 potential cavity trees (Woodley 2005).

A study of two old-growth balsam and black spruce sites demonstrated a wide range of average DWM piece sizes even in unmanaged lands. In the two study sites, the average diameter of the DWM structures were 54.8 cm and 16.1 cm; average height of snags was 4.73 m and 2.52 m; and length of logs were 5.91 m and 4.81 m (Campbell and Laroque 2007). The differences between the two sites are due, in part, to differences in rates of decomposition, i.e., higher rates of decomposition reduce the average size of DWM pieces.

One study of pre-commercial thinning in spruce-fir forests showed that the mass of DWM was reduced from 29–15 t/ac (64–34 Mg/ha; Briggs et al. 2000). In one study of a spruce-fir whole tree clearcut in Maine, 35 percent of organic matter was in trees and 12 percent was in woody litter and forest floor (Smith Jr et al. 1986). In that study, 23 t/ac (52 Mg/ha) of DWM were left after the harvest, but the whole-tree removal took about 91 percent of N, P, K, and Ca from the site, which was between 2 and 4 times the nutrient removal from a bole-only harvest (Smith Jr et al. 1986). Depletion of Ca is of some concern in Maine, though not as great a concern as in the Central and Southeastern U.S. (Huntington 2005). Spruce-fir forests generally incorporate Ca into merchantable wood at 1.6 kg Ca/ac/yr (1.6 kg ha-1yr-1; Huntington 2005).

Some sites such as Weymouth Point, Maine, have documented Ca-depletion problems (Smith Jr et al. 1986, Hornbeck et al. 1990, Briggs et al. 2000). The rate of weathering replenishment of Ca in Maine is uncertain, and the Ca-rich mineral apatite may be an important source of Ca (Huntington 2005, Yanai et al. 2005). Climate change and the associated warming and species composition shift may exacerbate Ca depletion in spruce-fir forests (Huntington 2005).

## 3B. NORTHERN HARDWOOD FORESTS

Northern hardwood forests are dominated by maple (*Acer* sp.), beech (*Fagus grandifolia*), and birch (*Betula* sp.) and cover lower elevations and southern portions of Maine, New York, New Hampshire, Vermont, and the northern portion of Pennsylvania. Northern hardwood forests also include conifers, e.g., hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*), in the mixture (Westveld 1956).

In general, the amount of DWM in northern hardwood forests follows the 'U' pattern mentioned above. Young stands have large quantities of DWM; mature stand have less; and older or uncut stands have more. For example, a study in New Hampshire measured 38 t/ac (86 Mg/ha) of DWM in a young stand, 14 t/ac (32 Mg/ha) in mature stands, 20 t/ac (54 Mg/ha) in old stand, and 19 t/ac (42 Mg/ha) in an uncut stand (Gore and Patterson 1986). Gore and Patterson (1986) also note that stands under a selection system had lower quantities of DWM, i.e., 16 t/ac (35 Mg/ha). A review of other studies identified similar temporal patterns and quantities of DWM (see Figure 6 from data described in Roskoski 1977, Tritton 1980, Gore and Patterson 1986, McCarthy and Bailey 1994, McGee et al. 1999, Bradford et al. 2009).

Estimates of the volume of down dead wood in Maine's northern hardwood forests are 598 ft$^3$/ac (42 m$^3$/ha) or 9 t/ac (20.5 Mg/ha Heath and Chojnacky 2001). Keeton (2006) estimates a volume of 600 ft$^3$/ac (42 m$^3$/ha) of DWM in a multi-aged northern hardwood forest.

The number of dead trees in five hemlock-yellow birch forests range from 16–45/ac (40–112/ha) or from 3–14 percent of the basal area (Tritton and Siccama 1990). The 14 sugar maple-beech-yellow birch stands survey ranged from 14–99 dead trees/ac (35–245/ha) or 5–34 percent of basal area (Tritton and Siccama 1990). Other estimates of snag densities in northern hardwood forests include 5/ac (11/ha) (Kenefic and Nyland 2007), 15/ac (38/ha) (Goodburn and Lorimer 1998), and 17/ac (43/ha) (McGee et al. 1999). Tubbs and colleagues (1987) recommend leaving a between of one and ten live decaying trees/acre of least 18 inches DBH.

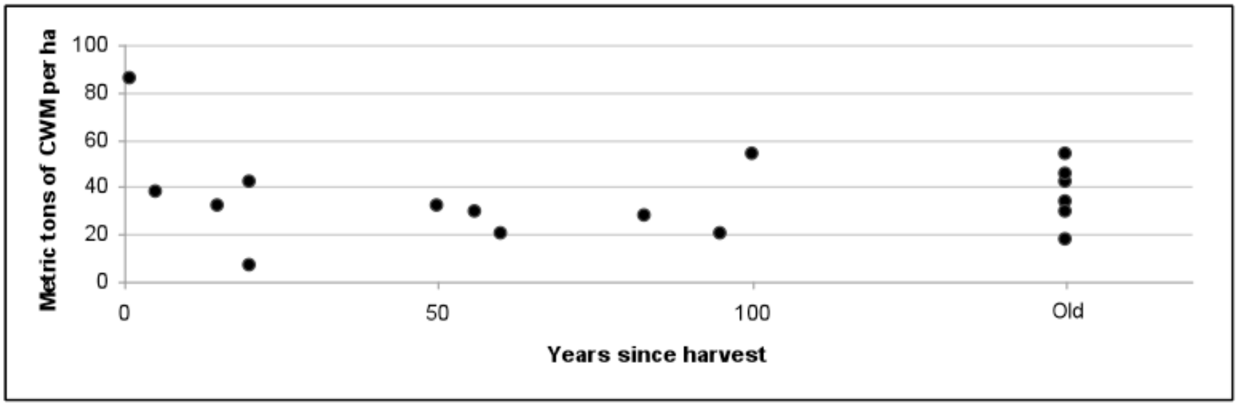
The number of cavity trees is another important habitat element in northern hardwood forests that is reduced by harvest. For example, studies in northern hardwood forests have shown a reduction from 25 cavity trees/ac (62/ha) before harvest and to 11 (27/ha) afterward (Kenefic and Nyland 2007). Another study measured 7 cavity trees/ac (18/ha) in old-growth, 4/ac (11/ha) in even-aged stand, and 5/ac (13/ha) in a stand selection system (Goodburn and Lorimer 1998).

## 3C. TRANSITION HARDWOOD FORESTS

Oak-hickory forests occupy the southernmost portions of the region. The oak-hickory forests are also considered a transitional forest type between the northern hardwood forests type and the Appalachian hardwoods that dominate further south (Westveld 1956).

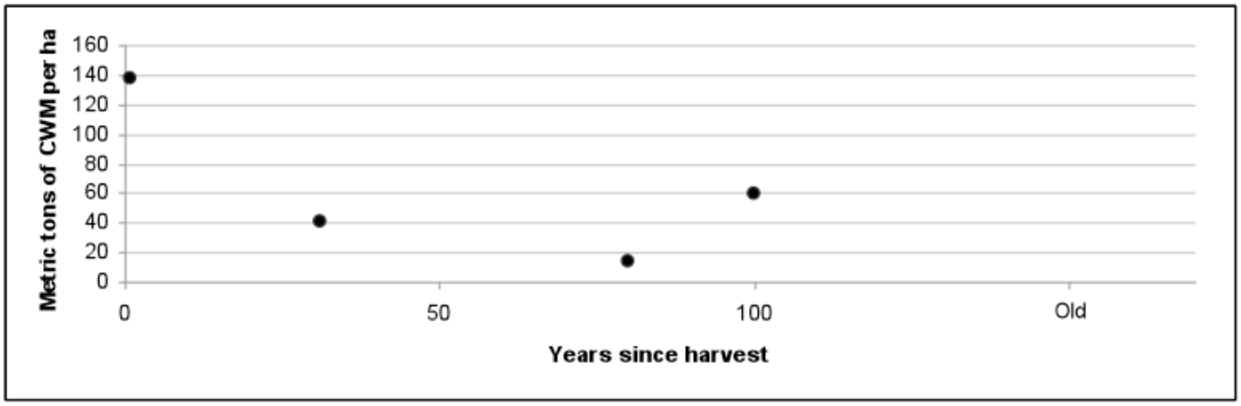
As with the other forest types discussed, DWM density tends to follow a 'U' shape in oak-hickory forests. For example, Idol and colleagues (2001) found 61 t/ac (137 Mg/ha) in a one-year post-harvest stand, 18 t/ac (40 Mg/ha) in a 31-year-old stand, and 26 t/ac (59 Mg/ha) in a 100-year-old stand. Tritton and colleagues (1987) measured 5.8 t/ac (13 Mg/ha) in an 80-year-old stand in Connecticut.

**Figure 6. Quantities of DWM in Northern hardwood forests Forests**



*Data described in Gore and Patterson 1986, McCarthy and Bailey 1994, McGee et al. 1999, Bradford et al. 2009, and Roskoski 1977*

**Figure 7. DWM in Oak-Hickory Forests**



*Data described in (Tritton et al. 1987, Idol et al. 2001)*

Estimates of the volume of down dead wood in Maine's oak-hickory forests are 244 ft$^3$/ac (17 m$^3$/ha) or 0.7 (1.5 Mg/ha; Heath and Chojnacky 2001). Wilson and McComb (2005) estimated the volume of downed logs in a western Massachusetts forest at 143 ft$^3$/ac (10 m$^3$/ha).

Out of seven oak stands in Connecticut, the number of dead trees ranged from 19–44/ac (46–109/ha) or 5–15 percent of basal area (Tritton and Siccama 1990). The decadal fall rates of snags in a Massachusetts study varied from 52–82 percent (Wilson and McComb 2005). Snags, particularly large-diameter snags, provide important nesting and foraging sites for birds (Brawn et al. 1982). In general, wildlife habitat requirements for dead wood are poorly documented, but it is clear that some wildlife species rely on dead wood in oak-hickory forests (Kluyver 1961, DeGraaf et al. 1992).

A study in Appalachian oak-hickory forests showed that the decomposing residues left after a sawlog harvest increased concentration of Ca, K, and Mg in foliage and soils after 15 years in comparison to a whole-tree harvest (Johnson and Todd 1998). However, the study found no impacts on soil carbon, vegetation biomass, species composition, vegetation N or P concentration, soil-bulk density, or soil N because of the whole-tree harvest (Johnson and Todd 1998).

## 3D. WHITE PINE AND RED PINE FORESTS

Pine forests are found in the coastal areas of Maine and New Hampshire and much of central Massachusetts. Pine forests tend to occupy sites with coarse-textured, well-drained soils (Barrett 1980).

Estimates of the volume of down dead wood in Maine's pine forests are 255 ft$^3$/ac (18 m$^3$/ha) or 1.6 t/ac (3.5 Mg/ha; Heath and Chojnacky 2001). A review of research on DWM in the red pine forests of the Great Lakes area showed that there were 50 t/ac (113 Mg/ha) of DWM in an unmanaged forest at stand initiation and 4.5 t/ac (10 Mg/ha) in a 90-year-old stand (Duvall and Grigal 1999). In comparison, the managed stand Duvall and Grigal (1999) studied had less DWM at both initiation 8.9 t/ac (20 Mg/ha) and at 90 years 2.9 t/ac (6.6 Mg/ha). The same review showed the unmanaged stand had 30 snags/ac (74/ha) while the managed forest had 6.9/ac (17/ha; Duvall and Grigal 1999). Red and white pine that fall to the ground at time of death will become substantially decayed (decay class IV of V) within 60 years (Vanderwel et al. 2006a).

While not a recognized forest type, stands with a mix of oak, other hardwoods, white pine, and hemlock are common. Many of the red oak and white pine stands on sandy outwash sites are susceptible to nutrient losses because of a combination of low-nutrient capital and past nutrient depletion (Hallett and Hornbeck 2000).

## 4. REFERENCES

Alvarez, M. 2007. The State of America's Forests. Society of American Foresters, Bethesda, MD.

Angermeier, P. l., and J. r. Karr. 1984. Relationships between Woody Debris and Fish Habitat in a Small Warmwater Stream. *Transactions of the American Fisheries Society* 113(6):716-726.

Åström, M., M. Dynesius, K. Hylander, and C. Nilsson. 2005. Effects of Slash Harvest on Bryophytes and Vascular Plants in Southern Boreal Forest Clear-Cuts. *Journal of Applied Ecology* 42(6):1194-1202.

Barrett, J. W. 1980. The Northeastern Region. Pages 25-65 in J. W. Barrett, editor. *Regional Silviculture of the United States*. John Wiley and Sons, New York, NY.

Bate, L. J., T. R. Torgersen, M. J. Wisdom, and E. O. Garton. 2004. Performance of Sampling Methods to Estimate Log Characteristics for Wildlife. *Forest Ecology and Management* 199(1):83-102.

Bowman, J. C., D. Sleep, G. J. Forbes, and M. Edwards. 2000. The Association of Small Mammals with Coarse Woody Debris at Log and Stand Scales. *Forest Ecology and Management* 129(1-3):119-124.

Boyle, J. R., J. J. Phillips, and A. R. Ek. 1973. "Whole Tree" Harvesting: Nutrient Budget Evaluation. Journal of Forestry 71(12):760-762.

Bradford, J., P. Weishampel, M.-L. Smith, R. Kolka, R. A. Birdsey, S. V. Ollinger, and M. G. Ryan. 2009. Detrital Carbon Pools in Temperate Forests: Magnitude and Potential for Landscape-Scale Assessment. *Canadian Journal of Forest Research* 39(4): 802–813.

Brawn, J. D., W. H. Elder, and K. E. Evans. 1982. Winter Foraging by Cavity Nesting Birds in an Oak-Hickory Forest. *Wildlife Society Bulletin* 10(3):271-275.

Briggs, R. D., J. W. Hornbeck, C. T. Smith, R. C. Lemin, and M. L. McCormack. 2000. Long-Term Effects of Forest Management on Nutrient Cycling in Spruce-Fir Forests. *Forest Ecology and Management* 138(1-3):285-299.

Brin, A., C. Meredieu, D. Piou, H. Brustel, and H. Jactel. 2008. Changes in Quantitative Patterns of Dead Wood in Maritime Pine Plantations over Time. *Forest Ecology and Management* 256(5):913-921.

Butts, S. R., and W. C. McComb. 2000. Associations of Forest-Floor Vertebrates with Coarse Woody Debris in Managed Forests of Western Oregon. *The Journal of Wildlife Management* 64(1):95-104.

Campbell, J. L., C. T. Driscoll, C. Eagar, G. E. Likens, T. G. Siccama, C. E. Johnson, T. J. Fahey, S. P. Hamburg, R. T. Holmes, A. S. Bailey, and D. C. Buso. 2007. Long-Term Trends from Ecosystem Research at the Hubbard Brook Experimental Forest. GTR-NRS-17, U.S. Forest Service, Northern Research Station, Newtown Square, PA.

Campbell, L. J., and C. P. Laroque. 2007. Decay Progression and Classification in Two Old-Growth Forests in Atlantic Canada. Forest Ecology and Management 238(1-3):293-301.

Carey, A. B., and M. L. Johnson. 1995. Small Mammals in Managed, Naturally Young, and Old-Growth Forests. *Ecological Applications* 5(2):336-352.

Chojnacky, D. C., R. A. Mickler, L. S. Heath, and C. W. Woodall. 2004. Estimates of Down Woody Materials in Eastern Us Forests. *Environmental Management* 33:S44-S55.

Cogbill, C. V., J. Burk, and G. Motzkin. 2002. The Forests of Presettlement New England, USA: Spatial and Compositional Patterns Based on Town Proprietor Surveys. *Journal of Biogeography* 29(10-11):1279-1304.

Currie, W. S., and K. J. Nadelhoffer. 2002. The Imprint of Land-Use History: Patterns of Carbon and Nitrogen in Downed Woody Debris at the Harvard Forest. *Ecosystems* 5(5):446-460.

DeGraaf, R. M., M. Yamasaki, W. B. Leak, and J. W. Lanier. 1992. New England Wildlife: Management Forested Habitats. General Technical Report NE-144, USDA Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Duvall, M. D., and D. F. Grigal. 1999. Effects of Timber Harvesting on Coarse Woody Debris in Red Pine Forests across the Great Lakes States, USA. 12(29):1926-1934.

Evans, A. M. 2008. Synthesis of Knowledge from Woody Biomass Removal Case Studies. The Forest Guild, Santa Fe, NM.

Evans, A. M., and A. J. Finkral. 2009. From Renewable Energy to Fire Risk Reduction: A Synthesis of Biomass Harvesting and Utilization Case Studies in Us Forests. *Global Change Biology Bioenergy* 1(3):211-219.

Evans, A. M., and R. T. Perschel. 2009. An Assessment of Biomass Harvesting Guidelines. The Forest Guild, Santa Fe, NM.

Everett, R. A., and G. M. Ruiz. 1993. Coarse Woody Debris as a Refuge from Predation in Aquatic Communities. *Oecologia* 93(4):475-486.

Eyre, F. H. 1980. *Forest Cover Types of the United States and Canada*. Society of American Foresters, Bethesda, MD.

Federer, C. A., J. W. Hornbeck, L. M. Tritton, C. W. Martin, R. S. Pierce, and C. T. Smith. 1989. Long-Term Depletion of Calcium and Other Nutrients in Eastern Us Forests. *Environmental Management* 13(5):593-601.

Fetherston, K. L., R. J. Naiman, and R. E. Bilby. 1995. Large Woody Debris, Physical Process, and Riparian Forest Development in Montane River Networks of the Pacific Northwest. *Geomorphology* 13(1-4):133-144.

Flatebo, G., C. R. Foss, and S. K. Pelletier. 1999. Biodiversity in the Forests of Maine: Guidelines for Land Management. University of Maine, Cooperative Extension, Orono, ME.

Fraver, S., R. G. Wagner, and M. Day. 2002. Dynamics of Coarse Woody Debris Following Gap Harvesting in the Acadian Forest of Central Maine, U.S.A. *Canadian Journal of Forest Research* 32(12):2094-2105.

Freedman, B., V. Zelazny, D. Beaudette, T. Fleming, G. Johnson, S. Flemming, J. S. Gerrow, G. Forbes, and S. Woodley. 1996. Biodiversity Implications of Changes in the Quantity of Dead Organic Matter in Managed Forests. *Environmental Reviews* 4(3):238–265.

Ganjegunte, G. K., L. M. Condron, P. W. Clinton, M. R. Davis, and N. Mahieu. 2004. Decomposition and Nutrient Release from Radiata Pine (*Pinus Radiata*) Coarse Woody Debris. *Forest Ecology and Management* 187(2-3):197-211.

Goodburn, J. M., and C. G. Lorimer. 1998. Cavity Trees and Coarse Woody Debris in Old Growth and Managed Northern Hardwood Forests in Wisconsin and Michigan. *Canadian Journal of Forest Reseach* 28:427–438.

Gore, J. A., and W. A. Patterson, III,. 1986. Mass of Downed Wood in Northern Hardwood Forests in New Hampshire: Potential Effects of Forest Management. *Canadian Journal of Forest Research* 16(2):335-339.

Graham, R. L., and K. Cromack Jr. 1982. Mass, Nutrient Content, and Decay Rate of Dead Boles in Rain Forests of Olympic National Park. *Canadian Journal of Forest Research* 12(3):511–521.

Greenberg, C. H. 2002. Response of White-Footed Mice (Peromyscus Leucopus) to Coarse Woody Debris and Microsite Use in Southern Appalachian Treefall Gaps. *Forest Ecology and Management* 164(1-3):57-66.

Griffith, D. M., and C. L. Alerich. 1996. Forest Statistics for Maine, 1995. RB-NE-135, U.S. Forest Service, Northeastern Research Station, Newtown Square, PA.

Grigal, D. F. 2000. Effects of Extensive Forest Management on Soil Productivity. *Forest Ecology and Management* 138(1-3):167-185.

Grigal, D. F. 2004. An Update of Forest Soils. A Technical Paper for a Generic Environmental Impact Statement on Timber Harvesting and Forest Management in Minnesota. Laurentian Energy Agency, Virginia, MN.

Grisez, T. J. 1960. Slash Helps Protect Seedlings from Deer Browsing. *Journal of Forestry* 58(5):385-387.

Grove, S. J. 2002. Saproxylic Insect Ecology and the Sustainable Management of Forests. *Annual Review of Ecology and Systematics* 33(1):1-23.

Gunnarsson, B., K. Nittérus, and P. Wirdenäs. 2004. Effects of Logging Residue Removal on Ground-Active Beetles in Temperate Forests. *Forest Ecology and Management* 201(2-3):229-239.

Gurnell, A. M., K. J. Gregory, and G. E. Petts. 1995. The Role of Coarse Woody Debris in Forest Aquatic Habitats: Implications for Management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 5(2):143-166.

Hacker, J. J. 2005. Effects of Logging Residue Removal on Forest Sites: A Literature Review. Resource Analytics and West Central Wisconsin Regional Planning Commission, Eau Claire, WI.

Hagan, J. M., and S. L. Grove. 1999. Coarse Woody Debris: Humans and Nature Competing for Trees. *Journal of Forestry* 97(1):6-11.

Hale, C. M., J. Pastor, and K. A. Rusterholz. 1999. Comparison of Structural and Compositional Characteristics in Old-Growth and Mature, Managed Hardwood Forests of Minnesota, U.S.A. *Canadian Journal of Forest Research* 29:1479-1489.

Hallett, R. A., and J. W. Hornbeck. 2000. Managing Oak and Pine Stands on Outwash Sands: Protecting Plant Nutrients. *Northern Journal of Applied Forestry* 17(2):57-61.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack Jr., and K. W. Cummins. 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems Advances in Ecological Research. Pages 133-302 in A. MacFadyen and E. D. Ford, editors. *Advances in Ecological Research*. Academic Press, London, UK.

Harvey, A. E., M. F. Jurgensen, M. J. Larsen, and R. T. Graham. 1987. Decaying Organic Materials and Soil Quality in the Inland Northwest: A Management Opportunity. GTR-INT-225, U.S. Forest Service, Intermountain Research Station., Ogden, UT.

Heath, L. S., and D. C. Chojnacky. 2001. Down Dead Wood Statistics for Maine Timberlands, 1995. RB-NE-150, Forest Service, Northeastern Research Station, Newtown Square, PA.

Hendrickson, O. Q. 1988. Biomass and Nutrients in Regenerating Woody Vegetation Following Whole-Tree and Conventional Harvest in a Northern Mixed Forest. *Canadian Journal of Forest Research* 18(11):1427–1436.

Hornbeck, J. W., C. W. Martin, R. S. Pierce, F. H. Bormann, G. E. Likens, and J. S. Eaton. 1986. Clearcutting Northern hardwood forests: Effects on Hydrologic and Nutrient Ion Budgets. *Forest Science* 32:667-686.

Hornbeck, J. W., C. T. Smith, Q. W. Martin, L. M. Tritton, and R. S. Pierce. 1990. Effects of Intensive Harvesting on Nutrient Capitals of Three Forest Types in New England. *Forest Ecology and Management* 30(1-4):55-64.

Huntington, T. G. 2005. Assessment of Calcium Status in Maine Forests: Review and Future Projection. *Canadian Journal of Forest Research* 35(5):1109-1121.

Huntington, T. G., and D. F. Ryan. 1990. Whole-Tree-Harvesting Effects on Soil Nitrogen and Carbon. *Forest Ecology and Management* 31(4):193-204.

Idol, T. W., R. A. Figler, P. E. Pope, and F. Ponder. 2001. Characterization of Coarse Woody Debris across a 100 Year Chronosequence of Upland Oak-Hickory Forests. *Forest Ecology and Management* 149(1-3):153-161.

Irland, L. C. 1999. *The Northeast's Changing Forests*. Harvard Forest, Petersham, MA.

Jia-bing, W., G. De-xin, H. Shi-jie, Z. Mi, and J. Chang-jie. 2005. Ecological Functions of Coarse Woody Debris in Forest Ecosystem. *Journal of Forestry Research* 16(3):247-252.

Johnson, D. W., and P. S. Curtis. 2001. Effects of Forest Management on Soil C and N Storage: Meta Analysis. *Forest Ecology and Management* 140(2-3):227-238.

Johnson, D. W., and D. E. Todd, Jr. 1998. Harvesting Effects on Long-Term Changes in Nutrient Pools of Mixed Oak Forest. *Soil Science Society of America Journal* 62(6):1725-1735.

Kappes, H., M. Jabin, J. Kulfan, P. Zach, and W. Topp. 2009. Spatial Patterns of Litter-Dwelling Taxa in Relation to the Amounts of Coarse Woody Debris in European Temperate Deciduous Forests. *Forest Ecology and Management* 257(4):1255-1260.

Keeton, W. S. 2006. Managing for Late-Successional/Old-Growth Characteristics in Northern Hardwood-Conifer Forests. *Forest Ecology and Management* 235(1-3):129-142.

Kelty, M. J., A. W. D'Amato, and P. K. Barten. 2008. Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts. Department of Natural Resources Conservation, University of Massachusetts, Amherst, MA.

Kenefic, L. S., and R. D. Nyland. 2007. Cavity Trees, Snags, and Selection Cutting: A Northern Hardwood Case Study. *Northern Journal of Applied Forestry* 24(3):192-196.

Kluyver, H. N. 1961. Food Consumption in Relation to Habitat in Breeding Chickadees. *The Auk* 78(4):532-550.

Kruys, N., and B. G. Jonsson. 1999. Fine Woody Debris Is Important for Species Richness on Logs in Managed Boreal Spruce Forests of Northern Sweden. *Canadian Journal of Forest Research* 29(8):1295–1299.

Kyle, C. J., and C. Strobeck. 2003. Genetic Homogeneity of Canadian Mainland Marten Populations Underscores the Distinctiveness of Newfoundland Pine Martens (Martes Americana Atrata). *Canadian Journal of Zoology* 81(1):57-66.

Laiho, R., and C. E. Prescott. 2004. Decay and Nutrient Dynamics of Coarse Woody Debris in Northern Coniferous Forests: A Synthesis. *Canadian Journal of Forest Research* 34(4):763-777.

Lanham, J. D., and D. C. Guynn, Jr. 1996. Influences of Coarse Woody Debris on Birds in Southern Forests. Pages 101-107 in J. W. McMinn and D. A. Crossley, editors. B*iodiversity and coarse woody debris in southern forests: effects on biodiversity*. U.S. Forest Service. GTR-SE-94.

Loeb, S. C. 1996. The Role of Coarse Woody Debris in the Ecology of Southeastern Mammals. Pages 108-118 in J. W. McMinn and D. A. Crossley, editors. *Biodiversity and coarse woody debris in southern forests: effects on biodiversity*. U.S. Forest Service. GTR-SE-94.

Lynch, J. A., and E. S. Corbett. 1991. Long-Term Implications of Forest Harvesting on Nutrient Cycling in Central Hardwood Forests. Pages 500-518 in L. H. McCormick and K. W. Gottschalk, editors. *8th Central Hardwood Forest Conference*. GTR-NE-148. U.S. Forest Service, Northeastern Forest Experiment Station, University Park, PA.

Mahendrappa, M. K., C. M. Pitt, D. G. O. Kingston, and T. Morehouse. 2006. Environmental Impacts of Harvesting White Spruce on Prince Edward Island. *Biomass and Bioenergy* 30(4):363-369.

Majka, C. G., and D. A. Pollock. 2006. Understanding Saproxylic Beetles: New Records of Tetratomidae, Melandryidae, Synchroidae, and Scraptiidae from the Maritime Provinces of Canada (Coleoptera: Tenebrionoidea). *Zootaxa*(1248):45-68.

Marcus, W. A., R. A. Marston, C. R. Colvard, and R. D. Gray. 2002. Mapping the Spatial and Temporal Distributions of Woody Debris in Streams of the Greater Yellowstone Ecosystem, USA. *Geomorphology* 44(3-4):323-335.

Martin, C., J. Hornbeck, G. Likens, and D. Buso. 2000. Impacts of Intensive Harvesting on Hydrology and Nutrient Dynamics of Northern Hardwood Forests. *Canadian Journal of Fisheries and Aquatic Sciences* 57(S2):19-29.

Mattson, K. G., W. T. Swank, and J. B. Waide. 1987. Decomposition of Woody Debris in a Regenerating, Clear-Cut Forest in the Southern Appalachians. *Canadian Journal of Forest Research* 17(7):712–721.

McCarthy, B. C., and R. R. Bailey. 1994. Distribution and Abundance of Coarse Woody Debris in a Managed Forest Landscape of the Central Appalachians. *Canadian Journal of Forest Research* 24(7):1317–1329.

McCay, T. S., and M. J. Komoroski. 2004. Demographic Responses of Shrews to Removal of Coarse Woody Debris in a Managed Pine Forest. *Forest Ecology and Management* 189(1-3):387-395.

McComb, W. 2003. Ecology of Coarse Woody Debris and Its Role as Habitat for Mammals. Pages 374-404 in Cynthia J. Zabel, Robert F. Anthony, and R. G. Anthony, editors. *Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America*. Cambridge University Press, Cambridge, UK.

McGee, G. G. 2001. Stand-Level Effects on the Role of Decaying Logs as Vascular Plant Habitat in Adirondack Northern Hardwood Forests. *The Journal of the Torrey Botanical Society* 128(4):370-380.

McGee, G. G., D. J. Leopold, and R. D. Nyland. 1999. Structural Characteristics of Old-Growth, Maturing, and Partially Cut Northern Hardwood Forests. *Ecological Applications* 9(4):1316-1329

McInnis, B. G., and M. R. Roberts. 1994. The Effects of Full-Tree and Tree-Length Harvests on Natural Regeneration. *Northern Journal of Applied Forestry* 11(4):131-137.

McIver, J. D., and L. Starr. 2001. A Literature Review on the Environmental Effects of Postfire Logging. *Western Journal of Applied Forestry* 16(4):159-168.

McNab, W. H., D. T. Cleland, J. A. Freeouf, J. Keys, J.E., G. J. Nowacki, and C. A. Carpenter. 2007. Description of Ecological Subregions: Sections of the Conterminous United States. GTR-WO-76B, U.S. Forest Service, Washington, DC.

Mellina, E., and S. G. Hinch. 2009. Influences of Riparian Logging and in-Stream Large Wood Removal on Pool Habitat and Salmonid Density and Biomass: A Meta-Analysis. *Canadian Journal of Forest Research* 39(7):1280–1301.

MFRC. 2007. Biomass Harvest Guidelines. Minnesota Forest Resources Council, St. Paul, MN.

National Climate Data Center. 2008. *US Climate at a Glance*. http://www.ncdc.noaa.gov/oa/climate/research/cag3/cag3.html, last accessed 10/1/09.

Nord-Larsen, T. 2002. Stand and Site Productivity Response Following Whole-Tree Harvesting in Early Thinnings of Norway Spruce (Picea Abies (L.) Karst.). *Biomass and Bioenergy* 23(1):1-12.

Nyland, R. D., D. G. Ray, R. D. Yanai, R. D. Briggs, L. Zhang, R. J. Cymbala, and M. J. Twery. 2000. Early Cohort Development Following Even-Aged Reproduction Method Cuttings in New York Northern hardwood forests. *Canadian Journal of Forest Research* 30(1):67-75.

Olsson, B. A., H. Staaf, H. Lundkvist, J. Bengtsson, and R. Kaj. 1996. Carbon and Nitrogen in Coniferous Forest Soils after Clear-Felling and Harvests of Different Intensity. *Forest Ecology and Management* 82(1-3):19-32.

Patrick, D. A., J. Hunter, Malcolm L., and A. J. K. Calhoun. 2006. Effects of Experimental Forestry Treatments on a Maine Amphibian Community. *Forest Ecology and Management* 234(1-3):323-332.

Pierce, R. S., J. W. Hornbeck, W. C. Martin, L. M. Tritton, T. C. Smith, A. C. Federer, and H. W. Yawney. 1993. Whole-Tree Clearcutting in New England: Manager's Guide to Impacts on Soils, Streams, and Regeneration. GTR-NE-172, U.S. Forest Service, Northeastern Forest Experiment Station, Radnor, PA.

Richardson, J., R. Björheden, P. Hakkila, A. T. Lowe, and C. T. Smith, editors. 2002. *Bioenergy from Sustainable Forestry: Guiding Principles and Practice*. Kluwer Academic Publishers, Hingham, MA.

Roskoski, J. 1980. Nitrogen Fixation in Hardwood Forests of the Northeastern United States. *Plant and Soil* 54(1):33-44.

Roskoski, J. P. 1977. *Nitrogen Fixation in Northern hardwood forests Forests*. Yale University, New Haven, CT.

Sass, G. G. 2009. Coarse Woody Debris in Lakes and Streams. Pages 60-69 in G. E. Likens, editor. *Encyclopedia of Inland Waters*. Academic Press, Oxford.

Smith, C. Y., M. T. Moroni, and I. G. Warkentin. 2009. Snag Dynamics in Post-Harvest Landscapes of Western Newfoundland Balsam Fir-Dominated Boreal Forests. *Forest Ecology and Management* 258(5):832-839.

Smith Jr, C. T., M. L. McCormack Jr, J. W. Hornbeck, and C. W. Martin. 1986. Nutrient and Biomass Removals from a Red Spruce - Balsam Fir Whole-Tree Harvest. *Canadian Journal of Forest Research* 16(2):381-388.

Taylor, A. R., J. R. Wang, and H. Y. H. Chen. 2007. Carbon Storage in a Chronosequence of Red Spruce (Picea Rubens) Forests in Central Nova Scotia, Canada. *Canadian Journal of Forest Research* 37(11):2260–2269.

Tritton, L. M. 1980. *Dead Wood in the Northern Hardwood Forest Ecosystem*. Yale University, New Haven, CT.

Tritton, L. M., C. W. Martin, J. W. Hornbeck, and R. S. Pierce. 1987. Biomass and Nutrient Removals from Commercial Thinning and Whole-Tree Clearcutting of Central Hardwoods. *Environmental Management* 11(5):659-666.

Tritton, L. M., and T. G. Siccama. 1990. What Proportion of Standing Trees in Forests of the Northeast Are Dead? *Bulletin of the Torrey Botanical Club* 117(2):163-166.

Tubbs, C. H., R. M. DeGraaf, M. Yamasaki, and W. M. Healy. 1987. Guide to Wildlife Tree Management in New England Northern hardwood forests. GTR-NE-118, U.S. Forest Service, Northeastern Forest Experiment Station, Broomall, PA.

Vanderwel, M. C., J. R. Malcolm, and S. M. Smith. 2006a. An Integrated Model for Snag and Downed Woody Debris Decay Class Transitions. *Forest Ecology and Management* 234(1-3):48-59.

Vanderwel, M. C., J. R. Malcolm, S. M. Smith, and N. Islam. 2006b. Insect Community Composition and Trophic Guild Structure in Decaying Logs from Eastern Canadian Pine-Dominated Forests. *Forest Ecology and Management* 225(1-3):190-199.

Watmough, S. A., and P. J. Dillon. 2003. Base Cation and Nitrogen Budgets for Seven Forested Catchments in Central Ontario, 1983-1999. *Forest Ecology and Management* 177(1-3):155-177.

Weaver, J. K., L. S. Kenefic, R. S. Seymour, and J. C. Brissette. 2009. Decaying Wood and Tree Regeneration in the Acadian Forest of Maine, USA. *Forest Ecology and Management* 257(7):1623-1628.

Westveld, M. 1956. Natural Forest Vegetation Zones of New England. *Journal of Forestry* 54(5):332-338.

Whiles, M. R., and J. W. Grubaugh. 1996. Importance of Coarse Woody Debris to Southern Forest Herpetofauna. Pages 94-100 in J. W. McMinn and D. A. Crossley, editors. *Biodiversity and coarse woody debris in southern forests: effects on biodiversity.* U.S. Forest Service. GTR-SE-94.

White Mountain National Forest. 2005. Final Environmental Impact Statement. U.S. Forest Service, Laconia, NH.

Wilson, B. F., and B. C. McComb. 2005. Dynamics of Dead Wood over 20 Years in a New England Oak Forest. Canadian *Journal of Forest Research* 35:682–692.

Woodley, S. 2005. Snag and Cavity Tree Retention. Pages 61-64 in M. G. Betts and G. J. Forbes, editors. *Forest Management Guidelines to Protect Native Biodiversity in the Greater Fundy Ecosystem*. New Brunswick Co-operative Fish and Wildlife Research Unit, University of New Brunswick, Fredericton, NB.

Yanai, R. D., J. D. Blum, S. P. Hamburg, M. A. Arthur, C. A. Nezat, and T. G. Siccama. 2005. New Insights into Calcium Depletion in Northeastern Forests. *Journal of Forestry* 103(1):14-20.

Yowhan Son. 2001. Non-Symbiotic Nitrogen Fixation in Forest Ecosystems. *Ecological Research* 16(2):183-196.

Zell, J., G. Kändler, and M. Hanewinkel. 2009. Predicting Constant Decay Rates of Coarse Woody Debris—a Meta-Analysis Approach with a Mixed Model. *Ecological Modelling* 220(7):904-912.

# APPENDIX 4–B

# REVISED ASSESSMENT OF BIOMASS HARVESTING AND RETENTION GUIDELINES

Alexander M. Evans, Robert T. Perschel, and Brian Kittler

## TABLE OF CONTENTS

## 1. Introduction

Interest in removing low-grade wood from forests has increased because of rising fossil fuel costs, concerns about carbon emissions from fossil fuels, and the risk of uncharacteristic wildfires.[1, 19] Most existing forest practice rules and recommendations did not anticipate this increased extraction of woody biomass and offer no specific guidance on how much removal is healthy for ecosystems. Intensification of biomass utilization, particularly for energy and fuel needs, presents a range of potential environmental risks.[31, 29] This report provides a review of guidelines put forth by states and other entities to avoid these environmental risks and promote the ecological sustainability of forest biomass utilization, and can inform a similar process to develop guidelines in Massachusetts.

### 1a. Woody Biomass

While definitions of biomass are usually similar, there can be surprising differences. For instance, the definition of biomass in New Brunswick, Canada's guidelines excludes pulpwood fiber from whole-tree chipping.[42] Technically, the term woody biomass includes all the trees and woody plants in forests, woodlands, or rangelands. This biomass includes limbs, tops, needles, leaves, and other woody parts.[44] In practice, woody biomass usually refers to material that has historically had a low value and cannot be sold as timber or pulp. Biomass harvesting might even remove dead trees, down logs, brush, and stumps.[37] Markets determine which trees are considered sawtimber material and which are relegated to the low-value biomass category. Changing markets and regional variations determine the material considered biomass, but in general it is a very low quality product. In some cases, woody biomass is defined by how the material is used. For example, in Pennsylvania any material burned for energy is defined as biomass.[46]

In this report, the term **biomass** refers to *vegetation removed from the forest, usually logging slash, small-diameter trees, tops, limbs, or trees that cannot be sold as higher-quality products such as sawtimber.* This report does not discuss biomass from agricultural lands and short-rotation woody biomass plantations.


Photo: Zander Evans

Biomass can be removed in a number of ways. Some harvests remove only woody biomass, some combine the harvest of sawtimber or other products with biomass removal, and some remove biomass after other products have been removed. This report focuses on what remains in the forest after harvest and not on the type of harvest. The goal is to ensure the forest can support wildlife, provide clean water, sequester carbon, protect forest soil productivity, and continue to produce income after a biomass harvest or repeated harvests. In some regions, current wood utilization is such that no woody material is available for new markets such as energy. For these high-utilization areas, following biomass guidelines may result in more biomass being left in the forest.

### 1B. COARSE WOODY MATERIAL

Woody material is sometimes divided into coarse woody material (CWM), fine woody material (FWM), and large woody material. CWM has been defined as being more than 6 inches in diameter at the large end and FWM as less than 6 inches in diameter at the large end.37 The U.S. Forest Service defines CWM as down dead wood with a small-end diameter of at least 3 inches and a length of at least 3 feet and FWM as having a diameter of less than 3 inches.62 FWM tends to have a higher concentration of nutrients than CWM. Large downed woody material, such as logs greater than 12 inches in diameter, is particularly important for wildlife. In this report, we use the term **downed woody material (DWM)** to encompass all three of these size classes, but in some circumstances we discuss a particular size of material where the piece size is particularly important.

### 1C. WHY "BIOMASS" GUIDELINES?

> *Good biomass harvesting practices can enhance and improve forest land; poor practices can damage and devalue it.46*

In the United States, forestry on private and state forests is regulated primarily at the state level. At least 276 state agencies across the country have some oversight of forestry activities, including agencies focused on forestry and other state agencies, such as wildlife or environmental protection.[17] Federal law requires states to address non-point source pollution of waterways. All 50 states have Best Management Practice (BMP) programs that are intended to protect water quality and other values. The programs usually include sections on timber harvesting, site preparation, reforestation, stream crossings, riparian management zones, prescribed burning and fire lines, road construction and maintenance, pesticides and fertilizers, and wetlands. Programs in states vary from laws that prescribe mandatory practices to states that use voluntary BMPs and education and outreach programs. These programs can be categorized in four ways: non-regulatory with enforcement, regulated, and combination of regulatory and not regulatory. In the northeast, Massachusetts and Connecticut are considered regulated, Vermont and New Hampshire are non-regulated with enforcement and Rhode Island, New York, and Maine use a combination of approaches. These programs are routinely monitored and literature suggests that when these BMPs are properly implemented they do protect water quality.[51] With so much existing regulation, why are additional biomass harvesting guidelines necessary? Reasons for biomass harvesting guidelines are likely to mirror the reasons forestry is regulated in general, which include[16]:

- general public anxiety over environmental protection,
- the obligation to correct misapplied forestry practices,
- the need for greater accountability,
- growth of local ordinances,
- landscape-level concerns, and
- following the lead of others.

Photo: Zander Evans

More specifically, biomass harvesting guidelines are designed to fill the gaps where existing BMPs and forest practice regulations may not be sufficient to protect forest resources under new biomass harvesting regimes. In other words, BMPs were developed to address forest management issues at a particular point in time; as new issues emerge, new guidelines may be necessary. Existing guidelines did not anticipate the increased rate or new methods of biomass removal and offer no specific guidance on the amount of extraction that is acceptable for meeting a range of forest management objectives. For example, Pennsylvania's old BMPs encouraged operators "to use as much of the harvested wood as possible to minimize debris," while the new guidelines recommend leaving "15 to 30 percent of harvestable biomass as coarse woody debris."[46] Michigan's guidelines point out that while the state "has a rich history of utilizing woody biomass for bioenergy and biobased products such as lumber, pulp and paper, composites, heat and electrical generation," as "market opportunities expand for woody biomass, it is crucial that harvesting and removal of woody biomass be done using sustainable forest management principles and practices that are ecologically, economically, and socially appropriate."[36] Concerns about long-term site productivity, biodiversity, and wildlife populations drove the Minnesota state legislature to call for biomass harvesting guidelines, and the resulting guidelines are intended to be implemented in close conjunction with the existing Minnesota forestry guidelines, which cover a range of additional management considerations.[37] More generally, biomass guidelines focus on DWM levels, wildlife and biodiversity, water quality and riparian zones, soil productivity, silviculture, and, in some cases, other issues. For example, Maine's guidelines focus "on the amount of biomass that should be left on-site after harvest and the effect on soil productivity, water quality, and biodiversity."[7]

### 1D. AN EXAMINATION OF CURRENT GUIDELINES

This report reviews the biomass harvesting or retention guidelines from New York and New England, other states with specific biomass guidance, parts of Canada, Northern European counties, and other organizations, including the U.S. federal government and certification groups. We have grouped New York and the New England states together to offer a snapshot of the current situation in states geographically near Massachusetts. Maryland, Minnesota, Missouri, Michigan, Pennsylvania, Wisconsin, and California are also covered, because of their forest practices guidance on biomass harvest and retention. In some states guidelines are still under review at the time of this writing and subject to change. Readers are encouraged to use the links in Appendix II to check the latest drafts of the guidelines.

The examples in this report detail the status of rules and recommendations for removing biomass from our forests. Entities interested in addressing concerns about biomass removal have taken at least three different approaches. One is to verify that existing forest practice regulations cover the issues raised by biomass harvests, obviating the need for new guidelines. In instances where existing rules or recommendations are found to be insufficient, some entities—including Minnesota, Missouri, Pennsylvania, Wisconsin, and Maine—have taken a second type of approach and chosen to craft separate biomass guidelines that augment existing forest practice guidance. In the third case, entities such as the Forest Stewardship Council (FSC) have chosen to address concerns particular to biomass harvests by revising existing rules or recommendations.

The existing guidelines cover topics such as dead wood, wildlife and biodiversity, water quality and riparian zones, soil productivity, silviculture, and disturbance. Appendix I lists the commonly used subtopics for each and identifies which are covered in a given set of guidelines. In some cases, a subtopic is noted as covered because it appears in another set of forestry practice rules or recommendations instead of that state's biomass guidelines. The list of subtopics was developed from section headings in all the various existing guidelines and is similar to other criteria for sustainable production and harvest of forest biomass for energy.[31] It should be noted that each set of guidelines takes a slightly different approach, addressing topics with a greater or lesser degree of specificity. The precepts of sustainable forest management call for identifiable criteria and indicators, such as those identified through the Montreal Process, for the purpose of benchmarking and measuring forest practices. The critique that follows does not always address why topics are covered with more or less specificity, but presumes that more specificity will increase the likelihood that guidelines will encourage sustainable management.

## 2. BIOMASS RETENTION GUIDELINES FOR TIMBER HARVESTING IN NEW YORK AND NEW ENGLAND

### 2A. MAINE

In Maine, "guidelines specific to woody biomass retention are missing from existing best management practices and regulations."[40] Therefore, the state undertook a collaborative effort between the Maine Forest Service, the University of Maine, and the Trust to Conserve Northeast Forestlands to develop woody biomass retention guidelines. Participating committee members included Manomet Center for Conservation Sciences, the Forest Guild, the Maine Forest Products Council, and other forestry professional and environmental organizations. After a multi-year process and several drafts, *Consideration and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine* was released in 2010.[7] The project's goal was to address the growing interest in woody biomass and concerns about long-term sustainability of biomass harvesting by developing guidelines for the retention of woody biomass. The Maine guidelines define woody biomass as "logging residues, previously un-merchantable stems, and other such woody material harvested directly from the forest typically for the purposes of energy production."[40] These new guidelines augment the current Water Quality BMPs, which are effectively applied in most harvests (77 percent of stream crossings and 89 percent of approaches to the crossings[39]).

The biomass harvesting recommendations report includes an extensive background section and literature review, including three key documents:

- *Best Management Practices for Forestry,*[38]
- *Site Classification Field Guide,*[9]
- *Biodiversity in the Forests of Maine: Guidelines for Land Management.*[18]

It also includes appendices that summarize regional recommendations pertaining to wildlife trees and biomass harvesting. The background section covers soil productivity, water quality, and forest management, as well as forest biodiversity; at the end of each section are voluntary guidelines. In earlier drafts, the voluntary guidelines offered after each section were more specific and stringent, but the final version lacks specific targets. Earlier drafts referred to the entire effort as "Guidelines," but the reframing of the title indicates the struggle the committee members had in agreeing on specific targets and the vagueness of the final product. For example, the voluntary guidelines for soils indicate forest litter should be left on-site "to the extent possible" and that operators should "minimize removal" of FWM on low-fertility sites.

This lack of specificity is found in other sections as well. The commentary on setting targets for the Forest Biodiversity section helps shed light on the decision-making dynamics that led to the dilution of the final product. The background information for the Forest Biodiversity section draws heavily on *Biodiversity in the Forests of Maine*. This report, a comprehensive manual outlining recommended guidelines for maintaining biodiversity in the forests of Maine, was the culmination of a multi-year process in the 1990s that included a wide range of stakeholders, including industry representatives, forest professionals, and environmental organizations. Originally published by Flatebo and colleagues[22], it was updated by Elliot.[18] Although the final version of the current biomass retention report utilizes the recommendations from the biodiversity report as background information and indicates that woody biomass harvesting practices "will have to comply with established recommendations for biodiversity as defined for non-biomass harvests,"[7] the specific targets listed in the biodiversity report are never incorporated as guidelines. The report indicates that since there was "not widespread acceptance of those guidelines within Maine's forest industry, specific targets for maintenance of site-level biodiversity are not included" in the relevant section.[7]

The result for the Forest Biodiversity section is that the Voluntary Guidelines call for leaving "as much fine woody material as possible" without the specific guidelines for DWM retention found in some other state guidelines. The guidelines also call for leaving "some wildlife trees" without incorporating targets for numbers of trees per acre suggested in *Biodiversity in the Forests of Maine*. The report indicates that this vagueness in the guidelines reflects the challenges of setting specific targets at site levels[18] and that although science can direct selection of biological indicators, it is still weak in selecting specific target levels.[24]

### 2B. NEW HAMPSHIRE

While New Hampshire currently has no specific biomass harvesting guidelines, existing recommendations and rules address the major biomass harvesting topics. New Hampshire's Slash Law (RSA 227-J:10) focuses on "debris left after a timber harvest" and states that "these branches, leaves, stems, unmerchantable logs, and stumps may take several years to decompose. Slash represents a fire hazard and, often, a messy appearance." The Slash Law sets a limit on the height of slash that can be left on-site, but does not set any minimum to retain on site.


Photo: Christopher Riely

New Hampshire's Basal Area Law (RSA 227-J:9) states that no more than 50 percent of the basal area can be cut near streams, water bodies, and public roads. Intensive biomass removal may decrease this law's ability to prevent erosion, provide wildlife habitat, protect stream temperature and aquatic life, and preserve the aesthetics of the landscape, because removal of DWM is not regulated by a basal area restriction. In New Hampshire, BMPs are voluntary, but the guide *Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire* includes sections on soil productivity, DWM, and retention of forest structures for wildlife habitat.[13] *Good Forestry* does not provide specific guidance on retention of tops and limbs, though it does recommend leaving "some cull material" in the woods after a biomass harvest. The section on soil productivity provides recommendations that would limit biomass removal on sites with nutrient-poor soils:

- Identify low fertility soils from maps and descriptions.
- Use bole-only harvesting (taking out the main portion of tree only, leaving branches and limbs in the woods) on low-fertility soils, or where fertility is unknown, as a precaution against nutrient loss.
- If whole-tree harvesting hardwoods, try to plan harvests during leaf-off periods to retain leaves and nutrients on site.
- Limit disruption of soil organic layers except when needed to accomplish silvicultural objectives (such as regeneration of species that need a bare mineral soil seedbed).[13]

Similarly, the Habitat section recommends retention of cavity trees and snags:

- In areas under uneven-aged management, retain a minimum of 6 secure cavity and/or snag trees per acre, with one exceeding 18 inches DBH and 3 exceeding 12 inches DBH. In areas lacking such cavity trees, retain trees of these diameters with defects likely to lead to cavity formation.
- In areas under even aged management, leave an uncut patch for every 10 acres harvested, with patches totaling 5 percent of the area. Patch size may vary from a minimum of 0.25 acre. Use cavity trees exceeding 18 inches DBH or active den trees as nuclei for uncut patches. Remember, the larger the tree, the more species that can use it. Riparian and other buffers can help to satisfy this goal.
- Retain live trees with existing cavities.[13]

The *Good Forestry in the Granite State* guide also has recommendations for retention of DWM:

- Avoid damaging existing downed woody debris, especially large (18+ inches) hollow or rotten logs and rotten stumps during harvesting operations (including tree falling, skidding, and road and skid trail layout).
- Leave cull material from harvested trees, especially sound hollow logs, in the woods. Some cull material should be left behind during whole-tree or biomass harvesting operations that may otherwise utilize this material. Large pieces of cull material bucked out on the landing should be returned to the woods.
- Avoid disrupting downed logs in and adjacent to streams, ponds, and wetlands.

- Avoid disrupting upturned tree roots from May to July to protect nesting birds.
- Maintain or create softwood inclusions in hardwood stands to provide a supply of longer-lasting down woody material.[13]

A revision of Good Forestry in the Granite State is currently underway and the recommendations for DWM in the draft are similar to the existing language.

### 2C. VERMONT

Although Vermont's guide to *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont* is in its ninth printing, there is very little in the guide that would affect biomass harvesting or retention.[60] The guide's intent is to prevent discharges of mud, petroleum, and wood debris from getting into waterways. These BMPs are not mandatory unless a landowner is participating in Vermont's Use Value Act. The state's two wood-powered power plants in Burlington and Ryegate are required by the Public Service Board to ensure that their wood supply comes from sales with a harvest plan cleared by the Vermont Department of Forests, Parks and Recreation. The main focus of the review of harvest plans is to protect deer wintering areas. Related rules include the Heavy Cutting rules (Act 15), which require clearcuts (a reduction of basal area below the C-level) larger than 40 acres to have a permit (Title 10 V.S.A. Chapter 83, Section 2622). Another regulation that has some relevance to biomass harvesting is the requirement that whole-tree chip harvesters obtain a license (Title 10 V.S.A. Chapter 83, Section 2648).

An act of the Vermont Legislature created a Biomass Energy Development Working Group in 2009. That group is meeting regularly in a two-year initiative to address the major charges of (1) enhancing and developing Vermont's biomass industry while (2) maintaining forest health. As part of its process, subgroups are addressing issues such as economic incentives, supply models, available technology, and workforce availability. A Forest Health subgroup will consider guidelines for retention of woody biomass, forest health indicators, and emerging research on carbon and biomass harvesting issues.

### 2D. NEW YORK

New York's forest practice regulations are based the Environmental Conservation Law (§ 9-0105), though the regulations appear to only cover prescribed fires. *The Best Management Practices for Water Quality* has no recommendation about retention of DWM, snags, or other elements specific to biomass harvesting.[45] These BMPs cover planning, landings, stream crossings, roads and trails, vernal pools, erosion control techniques, and post-harvest considerations. This document is under revision and will include expanded sections on riparian and wetland zone management but nothing on the ecological or silvicultural aspect of biomass harvesting. New York currently has no immediate plans to develop biomass harvesting guidelines. They are monitoring developments in other states and a biomass study now taking place at the Adirondack Research Consortium.

However, when New York initiated its renewable portfolio standard, it established an eligibility procedure for electrical power generators utilizing forest biomass. The resulting requirements are modeled after Vermont's and include procurement plans for each facility to include forest management plans for source forests and harvest plans filed for all harvests. Adherence to these standards is monitored periodically by state foresters. New York varied slightly from Vermont's approach by providing exemptions to properties that are accredited by FSC, Sustainable Forestry Initiative, or Tree Farm.

### 2E. RHODE ISLAND

Rhode Island's BMP guidance is encapsulated in the document *Rhode Island Conservation Management Practices Guide*.[12] The Guide includes water-quality protections such as filter strips between harvested areas and streams or ponds. Rhode Island does require the registration of "woods operators" with the Division of Forest Environment and notification of intent to harvest timber (RI State Statues, Title 2, Chapter 2-15, Sections 1 and 2). Rhode Island has no current intentions to develop biomass harvesting guidelines, although it is aware of the issue and may address it in the future.

### 2F. CONNECTICUT

Connecticut's BMP field guide was revised in 2007 and focuses specifically on water-quality issues.[15] This guide, like New York's and Rhode Island's, has little effect on biomass removals or DWM retention.[12, 15, 45] Connecticut is now seeking funding to address biomass harvesting guidelines. Current BMPs recommend keeping slash out of water bodies and vernal pools. Connecticut's BMPs do suggest that "brush and slash may be placed in skid trails and on slopes to slow water flow and retain sediment."[15] One layer of protection is the state's certification program for foresters and loggers. Connecticut is watching the development of the biomass market carefully and would like to have some guidelines in place. It is now looking for funding for developing guidelines, possibly through a joint project between the state forestry department and the Connecticut Forest and Parks Association.

## 3. REVIEW OF STATE BIOMASS HARVESTING AND RETENTION GUIDELINES

### 3A. MICHIGAN WOODY BIOMASS HARVESTING GUIDANCE

Since 2008, the Michigan Department of Natural Resources has worked with a stakeholder group drawn from academia, environmental groups, forest industry, and state and federal agencies to develop biomass harvesting guidelines.[36] These guidelines were designed to be used in conjunction with Michigan's *Sustainable Soil and Water Quality Practices on Forest Land* manual.[35] They emphasize that "not every recommendation listed in this guidance can or should apply to every situation." While the Michigan guidelines provide a list of scientific references, there are no specific citations to support the retention or removal of forest biomass.

Topics such as riparian zones and pesticide use are covered by *Sustainable Soil and Water Quality Practices* and not in the biomass harvesting guidelines. Though brief, Michigan's biomass guidelines, in combination with *Sustainable Soil and Water Quality Practices*, cover most of the major biomass harvesting topics (see Appendix I). However, there is little guidance on retention of snags. Michigan's guidelines also lack specificity in some areas. For example, they suggest retention of anywhere from one-sixth to one-third of material less than 4 inches in diameter from harvested trees.

## 3B. MINNESOTA: BIOMASS HARVESTING GUIDELINES FOR FORESTLANDS

The Minnesota state legislature directed the Minnesota Forest Resources Council (MFRC) and the Minnesota Department of Natural Resources (DNR) to develop guidelines for sustainably managed woody biomass.[37] The goal of the guidelines was to help natural resource managers, loggers, equipment operators, contractors, and landowners make decisions about biomass harvesting. With the support of the DNR's Ecological Services, Fisheries and Wildlife, and Forestry divisions, the MFRC directed the guideline development process. The 12-member interdisciplinary technical committee developed separate guidelines for brushland as well as for forestland. The technical committee reflected a range of expertise deemed pertinent to the development of these guidelines, including soil science, wildlife biology, hydrology, forest management, and silviculture. Meeting summaries were provided online, and the committee's work was peer-reviewed and open to public comment. Minnesota's biomass harvesting guidelines were crafted to be part of the MFRC's 2005 forest management guidebook, *Sustaining Minnesota Forest Resources*, and the existing guidelines were integrated into the new biomass recommendations.


Photo: Eli Sagor

Minnesota's biomass harvesting guidelines are rooted in precepts of ecological forestry. For example, the guidelines recommend emulating natural disturbances with silviculture and maintaining biological legacies after harvest. The guidelines make the case that, in Minnesota, biomass harvesting increases the disparity between managed stands and their natural analogs because it reduces the biological legacies left after harvest, such as slash and fallen logs. The guidelines cover almost all of the topics and subtopics related to biomass harvesting we considered in our analysis (see Appendix I). The only topics not obviously included or referenced were aesthetics, forest diseases, and land conversion.

A recent field test—an experimental biomass harvest—suggests that the harvesting practices utilized for biomass harvest in Minnesota can remove woody biomass without significant negative impacts on snags and DWM. The test harvest had a small effect on the number of snags and on the amount of DWM. Reductions in DWM were small (2 tons per acre or less) and one site showed an increase in DWM.[5] In addition, of the seven test sites where snags were measured, only three had a lower number of snags after harvest.[5]

## 3C. MISSOURI: BEST MANAGEMENT PRACTICES FOR HARVESTING WOODY BIOMASS


Photo: Zander Evans

The catalyst for the development of biomass harvesting guidelines in Missouri was state legislation introduced in February 2007 concerning cellulosic ethanol.[34] In response to the lack of BMPs for biomass harvests, the Top of the Ozarks Resource Conservation and Development (RC&D), in partnership with Big Springs RC&D, Bootheel RC&D, the Eastern Ozarks Forestry Council, and the Missouri Department of Conservation, applied for and received a grant from the Northeastern Area State and Private Forestry branch of the U.S. Forest Service to develop BMPs for biomass harvesting. The BMPs development process continued to emphasize participation through a stakeholder meeting for a cross-section of interested parties to discuss issues and possible criteria to be addressed in the BMPs for harvesting woody biomass. A technical committee brought expertise on soil science, wildlife biology, hydrology, forest management, and silviculture to the process. Meeting announcements and notes were provided online to allow for transparency in the development of BMPs.

The Missouri guidelines cover the major biomass harvesting topics (see Appendix I). Subtopics not covered in the Missouri guidelines include regeneration, removal of litter and forest floor, and fuel reduction. A section on pesticides was included in an early version of the biomass guidelines, but was later dropped because of its lack of relevance to biomass.

## 3D. PENNSYLVANIA: GUIDANCE ON HARVESTING WOODY BIOMASS FOR ENERGY

Pennsylvania's guidelines are a direct result of increased interest in woody biomass for energy. The passage of Pennsylvania's Alternative Energy Portfolio Standards Act (Act 213 of 2004) helped drive that interest by requiring "all load-serving energy companies in the state to provide 18 percent of their electricity using alternative sources by the year 2020." In response to the interest in using Pennsylvania's forests to help meet alternative energy goals, the Department of Conservation and Natural Resources (DCNR) created biomass harvesting guidelines, intending to balance the need for alternative energy sources with the need to protect forest resources for all citizens and future generations. Pennsylvania's guidelines include short-term rotational biofuel crops that might not traditionally fall under forest management guidelines.

Harvests on state forests are required to follow Pennsylvania's guidelines. The guidelines also supply recommendations for private lands; these are drawn from *Best Management Practices for Pennsylvania's Forests*, which was published by the Forest Issues Working Group in 1997. However, the new biomass guidelines did not draw on wider stakeholder participation, in part because of the time pressure to produce guidelines before forest-based energy projects were initiated. Pennsylvania's guidelines are also unusual in that they include comments on biomass policy and a supply assessment. For example, the guidelines suggest that facilities requiring 2,000 tons per year are better suited to Pennsylvania than larger facilities. The guidelines also make a case for woody biomass as a carbon-neutral fuel source.

Since Pennsylvania's state forestlands are certified as meeting the standards of FSC, their biomass harvesting guidelines directly reference FSC standards. Pennsylvania's DCNR uses the FSC's Appalachia Regional Standard, but the state biomass harvesting guidelines provide greater specificity on woody biomass removals. For example, the FSC standard requires that "measures to protect streams from degradation of water quality and/or their associated aquatic habitat are used in all operations." The Pennsylvania biomass guidelines extend this idea by adding "biomass harvesting of any materials along stream and river banks or along bodies of water is unacceptable." The Pennsylvania biomass guidelines cover the range of potential biomass harvesting subtopics. Non-point source pollution and pesticides are not dealt with in the biomass harvesting guidelines, but these are covered in general forestry guidelines for Pennsylvania.

## 3E. MARYLAND: DEVELOPMENT OF FOREST BIOMASS HARVESTING GUIDELINES

Maryland is currently in the process of developing biomass harvesting guidelines. The Pinchot Institute for Conservation is facilitating a committee of individuals representing state forestry, environmental and energy agencies, cooperative extension, private landowners, non-profit conservation organizations, and local governments. Specialists in ecology, forest hydrology, forestry, economics, and other disciplines are included on the advisory committee. The guidelines will address the charge of the *Maryland Climate Action Plan*, which states, "All biomass will be sustainably harvested without depriving soils of important organic components for reducing erosion, but will maintain soil nutrient structure, and will not deplete wildlife habitat or jeopardize future feedstocks in quantity or quality." As such, Maryland's biomass guidelines will address the protection of forest soils, water quality and aquatic resources, wildlife habitat and biodiversity, and silviculture and vegetation management. Other topics may also be included in the final version of the guidelines document. This guideline document is also linked to a technical support document that addresses the potential impacts associated with forest biomass harvesting in Maryland and a review of relevant statutes and regulatory and non-regulatory programs that operate within the state.

## 3F. WISCONSIN'S FORESTLAND WOODY BIOMASS HARVESTING GUIDELINES

Wisconsin's biomass guidelines were motivated by new price incentives to produce wood-based renewable energy and concerns about the environmental impacts of increased woody biomass removal.[26] The Wisconsin Council on Forestry created an advisory committee with members from tribal, state, non-profit, and private forestry organizations. The guidelines were also reviewed by subject experts.

The guidelines cover much of the same ground as the other state guidelines (Table 1). They take advantage of the existing guidance provided by Wisconsin's *Silviculture and Forest Aesthetics Handbook and Forestry Best Management Practices for Water Quality*. Issues such as regeneration, water quality, and aesthetics are dealt with in the existing manuals rather than the new biomass guidelines. A major focus of the Wisconsin guidelines is the identification of soil types, such as shallow, sandy, or wetland, that are most at risk of nutrient depletion.

Photo: Zander Evans

## 3G. CALIFORNIA FOREST PRACTICE RULES

California has some of the most comprehensive forest management regulations in the world. While there are currently no rules designed to specifically address intensive removal of forest biomass, the existing regulations address all of the main topics and most of the subtopics of woody biomass removal (Appendix I). For example, the *California Forest Practice Rules* point out that snags, den trees, and nest trees are a habitat requirement for more than 160 species and play a vital role in maintaining forest health. The importance of snags translates into regulations that require retention of all snags except where specific safety, fire hazard, insect, or disease conditions require they be felled.[11]

California's regulations demonstrate the tradeoffs between the ecological benefits and the potential fire hazards of retaining dead wood on-site in fire-adapted ecosystems.[10] For example, the *California Forest Practice Rules* emphasize the ecological importance of DWM for soil fertility, moisture conservation, and the support of microorganisms, but regulations dictate slash removal rather than retention. However, in riparian areas the Forest Practice Rules require operations to "protect, maintain, and restore trees (especially conifers), snags, or downed large woody debris" that provide stream habitat.[11]

A technical team of the Interagency Forestry Working Group is currently reviewing whether forest practice regulations in the state assure the ecological sustainability of forest biomass production and harvest. This technical team will also examine the carbon sequestration and storage impacts of both forest management and catastrophic fires.

## 4. BIOMASS GUIDELINES AND POLICY IN CANADA

As with state biomass guidelines in the U.S., woody biomass policy and guidelines in Canada are designed and implemented at the provincial level, not by the central government. Another similarity between the U.S. and Canada is the shift from a greater proportion of private holdings in the East to greater government (i.e., Crown) land ownership in the West. While provincial biomass guidelines would apply to public land and not private land, private landowners in eastern Canada are asking provincial governments for guidance on how best to manage their private land for bioenergy.

An overview of biomass policy and guidelines from east to west in Canada reveals variation similar to that in the United States.[48] Nova Scotia has formed a multi-stakeholder biomass committee of government, industry, and environmental groups that is discussing guidelines. There is currently a two-year moratorium on harvesting logging residue there to allow for input from this committee and then the creation of a government policy. In New Brunswick, the Department of Natural Resources has prepared draft guidelines on forest biomass harvesting. New Brunswick's guidelines take advantage of a decision support tool for sustainable biomass allocation that evolved from a model used to predict impacts of atmospheric deposition. The guidelines exclude harvests on high-risk (low-nutrient) areas, and harvest and silviculture planning remain separate processes guided by the Crown land management framework. The policy calls for biomass harvesting sustainability to be assessed over an 80-year time period, which is "equivalent to the life span of an average forest stand."[42] The New Brunswick guidelines define biomass such that the guidelines do not apply to pulpwood fiber from whole-tree chipping.

Like New Brunswick, Quebec is in the process of developing biomass guidelines based on soil properties. Ontario's policy establishes objectives such as "to improve the utilization of forest resources by encouraging the use of forest biofibre for the production of energy and other value-added bioproducts." However, the management and sustainable use of forest biomass is still guided by existing legislation (e.g., the Crown Forest Sustainability Act and its associated regulated manuals and procedures). In British Columbia, biomass removals during current forest practices (e.g., full-tree with processing at roadside) are already covered under the Forest and Range Practices Act (FRPA). Regulations under the FRPA require the retention of at least 1.6 logs per acre (at least 16 feet in length and 12 inches in diameter on the coast and 6.5 feet in length and 3 inches in diameter in the interior; FRPA §68). In addition, a strategic plan for increased biomass removals is being developed, and scientists have begun to collate data that will be used to formulate guidelines for increased slash harvesting.

A 2008 conference entitled "The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies," hosted by Canada's Sustainable Forest Management Network, helped set the stage for future policy development by providing an overview of existing research on biodiversity,[33] site productivity considerations for biomass harvests,[55] and existing knowledge gaps.[56]

## 5. BIOMASS GUIDELINES AND POLICY IN NORTHERN EUROPE

Woody biomass provides a large contribution to the heat of Northern Europe and is also utilized for co-firing with coal and for straight biopower facilities in some countries such as the Netherlands and in the UK. Though management guidelines are similar across Northern Europe, their integration under the broader forest management policy is more varied. For example, the UK and Finland have determined that biomass harvesting guidelines work best as independent reference documents to help guide practitioners, whereas Austria and Sweden have integrated biomass harvesting protocols directly into their broader forest management protocols and regulations. The following section will review the approach that countries in Northern Europe have taken to biomass harvesting standards.

## 5A. SWEDEN

The use of forest-based bioenergy in Sweden increased in the 1980s as a result of growing concern over a reliance on imported oil and nuclear power. In 1991, the Swedish government introduced a carbon tax on fossil fuels used for heat and transportation. Since this time, the use of forest-based biomass for energy generation has more than doubled and forest-based bioenergy now accounts for more than 27 percent of total Swedish energy consumption (Swedish Energy Agency, 2008). Harvest regimes have responded to this growing demand for biomass by becoming increasingly mechanized, with preference for whole-tree harvesting (WTH) systems for both thinnings and final clearcut harvests.[4, 8, 50, 32] From 50 to 80 percent of slash is typically removed, depending on site conditions and economic constraints.[32] By some estimates, the share of bioenergy in Sweden could feasibly double before environmental and economic considerations fully constrain this supply.[43]

Sweden is 67 percent forested, and the vast majority of these forests are held by private owners with high willingness to manage their forest and harvest timber. The responsibility for ensuring that energy wood harvests are done in a sustainable manner is largely left to individual landowners, and the greatest area of concern that landowners have about the sustainability of biomass harvesting centers on nutrient cycling and site productivity.[52] WTH clearcutting systems can increase soil nutrient losses by up to 7 percent, lead a reduction in site productivity of up to a 10 percent, and have been linked to an increased rate of loss of biodiversity in managed forests in Sweden.[54, 8, 49] In an attempt to mitigate these risks, the Swedish Forest Agency developed a set of recommendations and good-practice guidelines for WTH in 1986; these were updated in the 1990s and codified in the Swedish Forest Act of 2002. This legislation seeks to control WTH practices in order to limit impacts to forest soils, water resources, and long-term site nutrient balances.

The general approach of Sweden's guidelines and regulations is to classify different sites according to the risks associated with biomass removal at these sites. Different recommendations are then applied based on these classifications. In Sweden these specifications are to ensure that

- all forest residues are dried and needles are left on-site before biomass removal,
- sites in northern Sweden with abundant lichens should be avoided, and
- sites with acidified soils, peat lands, or sites with a high risk of nitrogen depletion should be compensated with ash and nitrogen application.

Like other Nordic countries, Sweden prohibits in-stand drying of forest residues in late spring and early summer to manage risks associated with bark beetle infestations. The guidelines and regulations also specify appropriate forest residue removal rates for different regions of Sweden, based on the risk of soil nutrient loss associated with historic and current patterns of acid deposition in these different regions. WTH clearcut operations are prohibited where they may negatively impact endangered species. The guidelines also stipulate that at least 20 percent of all slash must be left on-site. In addition to these site-specific guidelines, Swedish guidelines and regulations include criteria and indicators for sustainable forest management, forest certification, legislation, soil fertility, soil organic matter, wood production, biodiversity and wildlife, insects and fungi, hydrology and water quality, archaeological resources, cultural resources, recreational resources, nature conservation, silviculture, retention of tree species that are less commonly left in the stand, and stump harvesting.[53]

To hedge against the risk of soil nutrient depletion, the Swedish Forest Agency introduced additional wood ash recycling requirements in 2008; these supplement existing guidance on fertilization. The updated guidelines and regulations require that ash be applied to sites if the amount of harvest residues removed over the course of a rotation exceeds a half ton per hectare (0.2 tons per acre). For areas where biomass removals do not exceed this limit, ash recycling is deemed unnecessary; however, the regulation stipulates that ash be recycled in areas of high acid deposition, such as the southwest portion of the country. In Sweden, typical biomass removals are 0.5–1 ton per hectare, so recycling is de facto required on most sites. The prescription is to apply 2–3 tons per hectare every ten years and not to exceed two applications (i.e., 6 tons of ash per hectare). Ash is also supposed to meet certain chemical composition standards and be hardened when applied to facilitate infiltration of nutrients into soils.[32] Sweden's guidelines also suggest that it is acceptable to apply ash in stands that have not yet been harvested, as a means to mitigate potential loss of site productivity if whole-tree removals are planned. Sweden is a strong proponent of forest certification, and the Swedish FSC standards specify that the recommendations of the Swedish forest agency are to be followed where biomass is used for energy.

## 5B. FINLAND

Finland is 74 percent forested with boreal and sub-boreal mixed softwood forests largely dominated by pine, spruce, and birch species. Upwards of 80 percent of the domestic roundwood supply comes from the three-quarters of the land base that is in private ownership.[27] This land base supports a robust bioenergy sector. A full 20 percent of Finland's total energy consumption comes in the form of bioenergy, with 11 percent of the nation's electricity production coming from wood.[25, 27, 50] Approximately 47 percent of the annual Finnish roundwood supply is consumed in the production of energy.[25] Finland also imports an estimated 21 percent of the total wood it consumes for energy.[30] Finnish forest policy has made a goal of increasing the annual use of wood for energy by 5 million cubic meters, or nearly 5 million green tons.[52]

As in Sweden, harvests in Finland are highly mechanized, and WTH clearcuts are common practice. It is estimated that typical harvests of this nature remove between 60 and 80 percent of the total site biomass.[54, 28, 47, 50, 61] Finnish biomass harvesting guidelines suggest that 30 percent of residue should remain and be distributed evenly over the site following clearcuts. In addition to final harvests, biomass is also produced though early and mid-rotation thinning of small-diameter trees. This activity is not widespread across Northern Europe, due to operational and economic constraints, with the exceptions being Denmark, some Baltic states, and Finland.[2, 50] Finland subsidizes both early rotation thinnings and the subsequent production of energy in order to support the production of commercial timber products.[53]

The Finnish approach to ensuring forest sustainability is to classify different sites according to the risks associated with biomass removals from these sites and to then apply different management recommendations based on these classifications. Site classifications include: mesic uplands and sites with fertile soils, sub-xeric and xeric sites, barren upland sites with lichens, peatland forest sites, stands with rocky soils, stands with low levels of available nutrients, water conservation areas, managed stands with more than 75 percent spruce, and stands where biomass removals have previously been performed through WTH clearcutting systems.[53]

Finnish guidelines contain operational protocols for site preparation, stump harvests, storing energy wood at roadside, and management of rotten wood.[3] Additional issues addressed include wood production, biodiversity, wildlife habitat, insects and fungi, recreational resources, silviculture, stump harvesting, and biomass production costs (Stupak et al., 2008). Specific recommendations include that large dead trees either standing or on the ground should not to be collected or damaged. Exceptions can be made for certain salvage harvests in the wake of a significant disturbance event, and protocols for this are explicit. Riparian areas must be left unharvested, and the requisite width of riparian management zones depends on site characteristics (e.g., slope of harvesting sites and other watershed characteristics).

In Finland, it is also common and recommended practice to remove stumps and roots in certain circumstances. This is done mainly in spruce stands as a part of preparing the site for the next planting and as a risk-management practice used to avoid root rot.[27, 52] Stump wood cannot be removed from riparian areas or steep slopes unless "preventative measures" are taken. Stumps are also not to be removed from wetlands, sites with rocky soils, dry soils, or thin soils, or if stumps are less than 6 inches in diameter. Stump removal protocols also recommend leaving a certain target number of stumps per acre for different soil types.[21] Finland prohibits in-stand drying of forest residues in late spring and early summer to manage risks associated with bark beetle infestations.

While Finland does not require ash recycling through regulations, it is estimated that more than 10 percent of wood ash produced is typically returned to forests, usually in peat soils where it acts as a fertilizer. Finnish guidelines recommend that wood ash be spread on peat land after thinnings to act as a fertilizer, or if logging residues or stumps are extracted from nutrient-poor sites.[53] Ash is commonly spread with forwarders at a rate of about 3–5 tons per acre every ten years, i.e, slightly more than is recommended in Sweden.[47, 53]

## 5C. DENMARK

Denmark has less forestland than Finland or Sweden but woody biomass is still an important energy source. The Danish Biomass Agreement of 1993 called for increasing the rate of biomass produced for energy (primarily heating) by 1.4 million tons annually, with woody biomass to contribute 0.2–0.4 million tons annually.[52]

In Denmark, whole-tree chipping of small diameter trees from mid-rotation thinning is common; guidelines for public forestry lands recommend that these materials dry for at least two months before they are chipped, to avoid nutrient losses.[47] It is not common practice to harvest slash associated with final clearcut harvests because of the logistical constraints in removing this biomass and/or because of concerns about soil nutrient depletion and impacts to plant and animal communities.[50] Issues addressed in Danish guidance documents include soil fertility, soil organic matter, management of insects and fungi, silviculture, stump harvesting, and production costs.[52, 53] Danish guidance documents classify sites according to the dominance of hardwoods or softwoods and recommend that "stand-wise evaluations" be completed prior to harvests and that forest residues are dried for at least two months during the spring or summer. Other recommendations focus on stands of special conservation value for flora and fauna, and others for which wood production is not a primary objective. Guidance recommends avoiding exposed forest edges, nature conservation areas, and rare forest types.

Danish forest policy generally suggests that nutrients lost in logging may be compensated for through fertilization, and that stumps are not to be removed.[52, 53] Forest policy also suggests that the maximum allowable amount of wood ash that should be applied over ten years ranges from 0.5 to 7.5 tons per hectare, although this depends on the specific chemical composition of the ash.

## 5D. THE UNITED KINGDOM

With the UK's biomass-based energy sector growing, the UK Forestry Commission has released a series of technical reference documents designed to help forest managers assess risks associated with biomass harvests.[41, 59, 57, 58] These documents cover slash removal and stump removal as well as the associated risks to soil fertility, soil organic matter, biodiversity and wildlife, hydrology and water quality, archaeological resources, cultural resources, recreational resources, and nature conservation.

The UK biomass harvesting guidance encourages managers to first classify sites according to their susceptibility to risks associated with biomass removal. In 2009, the UK Forestry Commission reevaluated the existing system of site classification used to assess the acceptability of biomass harvests. The previous classification had restricted the overall biomass supply by classifying large portions of the UK as sensitive forestland. The new classification was implemented to facilitate a more reliable biomass supply without adversely impacting natural resources.[58] The guidance classifies sites according to soil types as being of low, medium, or high risk and lists associated slash and stump removal management actions for each of these soil classifications. The assessment of site suitability for biomass harvests is to be based on the most sensitive soil type that covers greater than 20 percent of the site area. The guidelines suggest that site-specific risk assessments should be carried out before each harvest and should include a soil test. The guidance documents also recognize that there are significant uncertainties about the long-term sustainability of removing these materials and suggests that additional research is required to assess the full range of impacts, including net carbon balance.


Photo: UK Forestry Commission

In the UK, biomass harvests typically occur in conifer plantations where slash is windrowed and left for 3–9 months following final timber harvests. This material is subsequently bailed and collected.[58] Thinnings also supply biomass, but this volume is currently not significant. The guidelines suggest that thinnings pose less of an immediate risk to soil nutrient and base cation balance than do final clearcut harvests. In addition to removing timber harvest residues, there is increased interest in harvesting stumps. The UK Forestry Commission recently released interim guidance on stump removal, which states that in some instances the benefits of stump harvesting will outweigh the potential disadvantages, but that the removal of stumps very much requires a site-by-site evaluation. The report acknowledges that stump removal "poses a number of risks to the forest environment that can threaten both sustainable forest management and the wider environment," including soil compaction, rutting, sedimentation, soil carbon loss, removal of macro- and/or micronutrients, and loss of soil buffer capacity due to loss of base cations.[59]

It is important to note that the slash removal guidance states that residue removals are acceptable on all high risk soil types as long as compensatory applications of fertilizer or wood ash are used. The guidelines in turn warn that application of wood ash may induce either nitrogen deficiency on nutrient-poor soils, or leaching of nitrates and/or soil acidification on nitrogen-saturated sites. The guidelines also point out that the application of fertilizers and wood ash may not be acceptable under forest certification programs that have stringent standards for the application of chemicals.

## 6. OTHER ORGANIZATIONS AND CERTIFICATION SYSTEMS

### 6a. International Organizations

A number of international organizations have take up the issue of biomass harvest and retention. The International Energy Agency (IEA) conducts research through several programs. For example, Task 43 (feedstocks to energy markets) considers environmental issues, establishment of sustainability standards, exploration of supply chain logistics, and appropriate connections between harvesting standards and international trade and energy markets (www.ieabioenergy.com). The Global Bioenergy Partnership (GBEP) seeks to develop a common methodological framework to measure greenhouse gas emissions from biofuels and to developing science-based benchmarks and indicators for sustainable biofuel production. Throughout 2009, a GBEP task force was focused on the development of a set of relevant, practical, science-based, voluntary criteria and indicators as well as examples of best practices for biomass production. The criteria and indicators are intended to guide nations as they develop sustainability standards and to facilitate the sustainable development of bioenergy in a manner consistent with multilateral trade obligations (www.globalbioenergy.org). The Ministerial Conference on the Protection (MCPC) of Forests is a pan-European process to identify criteria and indicators for sustainability and adaptive management. In 2007, the MCPC initiated a special project to assess the need for sustainability criteria given the increased demand for biomass. The implications of carbon balances on biomass energy are also being explored and may impact the EU's 2009 Renewable Energy Directive (www.foresteurope.org).

### 6b. Federal Biomass Policy

U.S. federal policy on the use of woody biomass from forests has focused on how to define biomass and how or if sustainable should be legislated. Key areas of legislative focus are the type of wood that qualifies as renewable biomass, what kinds of ownerships can provide woody biomass, and the types of forest from which woody biomass can be procured. The following summary highlights aspects of federal law and proposed legislation that most directly influence the use of woody biomass from forests for energy.

- **Section 45 of the U.S. Internal Revenue Code** The tax code defines what kinds of biomass are eligible for producing energy that qualifies for federal tax incentives such as the federal renewable energy production tax credit and investment tax credit. "Closed-loop biomass" is defined as "any organic material from a plant which is planted exclusively for purposes of being used at a qualified facility to produce electricity," whereas "Open-loop biomass" includes a number of opportunity fuels, such as "any agricultural livestock waste nutrients," "any solid, nonhazardous, cellulosic waste material or any lignin material which is derived from…mill and harvesting residues, pre-commercial thinnings, slash, and brush," a variety of "solid wood waste materials," and agricultural biomass sources.

- **Farm Security and Rural Investment Act of 2002 Public Law 107–171—May 13, 2002** This law included both "trees grown for energy production" and "wood waste and wood residues" in its definition of biomass.

- **Energy Policy Act of 2005 Public Law 109–58—Aug. 8, 2005** The Energy Policy Act defined biomass to include "any of the following forest-related resources: mill residues, pre-commercial thinnings, slash, and brush, or non-merchantable material," as well as "a plant that is grown exclusively as a fuel for the production of electricity." This definition was more detailed than the previous 2002 Farm Bill and excluded material that would traditionally sell as timber.

- **The Energy Independence and Security Act of 2007 Public Law 110–140—Dec. 19, 2007** The Energy Independence and Security Act included the Renewable Fuels Standard (RFS) and provided the most detailed definition of biomass to date. One of the most important distinctions it made was to separate woody biomass from private and federal lands. Biomass from federal lands was excluded and could not be used to produce renewable fuels. However, an exception was provided for woody biomass removed from the "immediate vicinity of buildings" for fire protection. The RFS also excluded biomass from certain types of forests seen as rare: "ecological communities with a global or state ranking of critically imperiled, imperiled, or rare pursuant to a State Natural Heritage Program, old growth forest, or late successional forest." The RFS made an effort to discourage conversion of native forests to plantations by excluding woody biomass from plantations created after the enactment of the law. The RFS also established a subsidy of up to $20 per green ton of biomass delivered for facilities producing electric energy, heat, or transportation fuels.

- **Food, Conservation, and Energy Act of 2008 Public Law 110–246—June 18, 2008** The 2008 Farm Bill continued the trend toward great specification in the definition of renewable biomass. This time woody biomass from federal lands was included where it was the byproduct of preventive treatments to reduce hazardous fuels, contain disease or insect infestation; or restore ecosystem health. On private lands, the definition included essentially all trees and harvest residues. The exclusion for rare forests in the 2007 RFS was not included. The 2008 Farm Bill also initiated the **Biomass Crop Assistance Program (BCAP)** to improve the economics of establishing and transporting energy crops and collecting and transporting forest biomass. Regarding eligibility requirements for this program, forest lands producing biomass must be covered by a "forest management plan." The determination of what constitutes an "acceptable plan" is at the discretion of the State Forester.

Other legislation has been proposed that includes more specific provisions designed to ensure the sustainability of biomass production. For example, HR 2454 would require that biomass from federal land be "harvested in environmentally sustainable quantities, as determined by the appropriate Federal land manager." S 1733, introduced September 9, 2009, stipulates that biomass be produced while ensuring "the maintenance and enhancement of the quality and productivity of the soil" and promoting the "well-being of animals." The future fate of the federal biomass definition is likely to be part of the large climate-change legislation being debated in Washington. Climate-change legislation may include a national Renewable Energy Standard (i.e., a renewable portfolio standard) that would dictate what kind of woody biomass can be included to meet renewable electricity generation goals. Some proposals would shift the burden of sustainability to the states and require biomass harvesting guidelines or regulations that meet some federal oversight.

## 6c. FOREST STEWARDSHIP COUNCIL: U.S. NATIONAL FOREST MANAGEMENT STANDARD


Photo: Zander Evans

The FSC standards for the U.S. do not specifically address biomass or whole tree harvests. In other words, "biomass and whole tree harvests are addressed along with other types of removals."[23] The FSC U.S. National Standard covers biomass harvesting at a more general level than most state guidelines, since they are nationwide. The main sections that affect biomass harvest are Criterion 6.2 (habitat for rare species), 6.3 (ecological functions), and 6.5 (soils and water quality). For example, Indicator 6.3.f of the guidelines requires that "management maintains, enhances, or restores habitat components and associated stand structures, in abundance and distribution that could be expected from naturally occurring processes"; these habitat components include "live trees with decay or declining health, snags, and well-distributed coarse down and dead woody material." This proposed requirement would place some limits on biomass removal, but it is not specific about the amount of DWM that should be retained on-site. Indicator 6.5.c limits multiple rotations of whole tree harvesting to sites where soil productivity will not be harmed.

Since FSC guidelines are not focused solely on biomass harvests, they go beyond other biomass guidelines in areas such as habitat connectivity. By the same token, because FSC guidelines cover many different kinds of harvests in many different forest types with diverse forest management objectives, the standards do not contain many subtopics that are specific to biomass harvest (Appendix I).

The FSC standards are considered "outcome focused." Rather than prescribing how to achieve desired outcomes, they allow a variety of practices to be used, so long as the management objectives and the FSC standards are not compromised. For example, one element that shows up in some biomass guidelines is re-entry, but FSC does not include this. Missouri's guidelines advise, "Do not re-enter a harvested area [for the purposes of biomass harvesting] once the new forest has begun to grow," in order to reduce the risk of compaction, which is a recommendation echoed in the Minnesota and Pennsylvania guidelines. The FSC standards, however, do not specifically advise against re-entering a stand for the purpose of biomass harvesting. Instead, issues of compaction and the impacts of other soil disturbing activities are addressed in relation to all management activities under both 6.5 and 6.3.

### 6d. Other Voluntary Certification Systems

Other voluntary certification systems have standards which may influence forest biomass harvest and retention. For example, the Council for Sustainable Biomass Production (CSBP) released draft standards in 2009 and plans to release a preliminary standard in 2010.[14] The draft standards were open for stakeholder and expert review and comment. The CSBP standards address soil, biological diversity, water, and climate change. As with FSC standards, CSBP makes general recommendations such as "retain biomass materials required for erosion control and soil fertility" (1.1.S3), but do not provide specific guidance on retention of DWM or snags.

## 7. COMMON ELEMENTS OF BIOMASS HARVESTING GUIDELINES

Though the existing biomass guidelines cover different ecosystems, they share a number of important elements. The following sections assess the similarities and differences between the guidelines' recommendations on dead wood, wildlife and biodiversity, water quality and riparian zones, soil productivity, and silviculture. In addition, we compare the process used to develop each set of guidelines.

### 7a. Dead Wood

One of the central concerns in biomass removal is the reduction of the quantity of dead wood on-site. Maine's guidelines recommend leaving tops and branches scattered across the harvest area "where possible and practical." To ensure sufficient DWM debris is left on-site, Michigan's draft guidelines recommend retention of one-sixth to one-third of the residue less than four inches in diameter. Minnesota guidelines recommend leaving all preexisting DWM and to "retain and scatter tops and limbs from 20 percent of trees harvested." Wisconsin's guidelines recommend retaining all pre-harvest DWM and tops and limbs from 10 percent of the trees in the general harvest area, with a goal of at least 5 tons of FWM per acre. Wisconsin's guidelines also point out that "some forests lack woody debris because of past management," and that extra DWM should be left in those areas. Pennsylvania's guidelines suggest leaving 15 to 30 percent of "harvestable biomass" as DWM, while Missouri's suggest 33 percent of harvest residue (with variations for special locations such as stream sides).

Maine, Minnesota, Pennsylvania, and Wisconsin suggest leaving all snags possible. Except for some hazard exceptions, California requires retention of all snags. Missouri provides an example of clear and specific recommendations by suggesting 6 per acre in upland forests and 12 per acre in riparian corridors. Michigan does not have a specific recommendation for snag retention.

### 7b. Wildlife and Biodiversity

Many of the potential wildlife and biodiversity impacts stem from leaving too little dead wood on-site. The biomass guidelines reviewed here agree on the importance of avoiding sensitive sites for wildlife. These include areas of high biodiversity or high conservation value such as wetlands, caves, and breeding areas. Obviously, areas inhabited by threatened or endangered animals and plants receive special consideration. However, as the Minnesota guidelines point out, biomass harvesting may still be appropriate if management plans include specific strategies for maintaining habitat for rare species and/or to restore degraded ecosystems. Pennsylvania's guidelines suggest that biomass removal may be an opportunity to "develop missing special habitats, such as herbaceous openings for grouse and other species, through planting, cutting, or other manipulations." Additional suggestions from state guidelines include inventorying habitat features on the property, promoting individual trees and species that provide mast, and retaining slash piles that show evidence of use by wildlife. Missouri's guidelines make the case against forest conversion in terms of wildlife: "Do not convert natural forests into tree plantations or pasture; natural forests provide more wildlife food and habitat."

### 7c. Water Quality and Riparian Zones

Photo: Zander Evans

In general, water quality and riparian concerns do not change with the addition of biomass removals to a harvest plan. Streams and wetlands tend to be protected by existing regulation. For example, Maine's guidelines cite the existing laws governing water quality protection as well as the publication *Protecting Maine's Water Quality*. Where restrictions in wetlands and riparian zones are defined in terms of basal area, more specific guidance may be needed for biomass harvests, which can have a large ecological impact with a small change in basal area. An example of riparian recommendations from Minnesota's guidelines is to "avoid harvest of additional biomass from within riparian management zones over and above the tops and limbs of trees normally removed in a roundwood harvest under existing timber harvesting guidelines." Though the Missouri Watershed Protection Practice already includes requirements for stream and river management zones, the Missouri biomass guidelines reiterate how to protect streams and rivers during a harvest.

## 7D. SOIL PRODUCTIVITY

As with water quality, some aspects of soil productivity are usually included in standard forestry BMPs. For instance, Minnesota's biomass guidelines point readers to the state's timber harvesting guidelines, which contain sections titled "Design Outcomes to Maintain Soil Productivity" and "Minimizing Rutting." However, Minnesota's biomass guidelines do add warnings about harvesting biomass on bog soils and shallow soils (less than 8 inches) over bedrock. An appendix to Wisconsin's guidelines lists over 700 specific soil map units which are nutrient poor and unlikely to be able to support sustainable biomass removal. Maine's guidelines use the Briggs classification of soil drainage classes to identify sites that are more sensitive to biomass removals.9 Missouri's guidelines contain a specific section on sustaining soil productivity, especially on steep slopes and shallow soils. Michigan recommends leaving more than one-third of harvested tops on shallow, nutrient-poor or semi-organic soils. However, Michigan's guidelines suggest that the amount of retention can be reduced on jack pine stands on nutrient poor sites.

Another concern that arises with biomass harvest is removal of the litter layer or forest floor. Maine, Michigan, Minnesota, Pennsylvania, and Wisconsin's guidelines state that forest floor, litter layer, stumps, and root systems should all be left.

## 7E. SILVICULTURE

Many silvicultural prescriptions call for the removal of small, unhealthy, or poorly formed trees to open up more growing space for crop trees or regeneration, but these types of removals often cost money rather than generate income. By providing income from the removal of this material, biomass markets can help support good silviculture. At the same time, biomass removals raise some silvicultural concerns. The Minnesota guidelines point out that an increase in the amount of live vegetation removed may cause swamping, i.e., a decrease in transpiration and an increase in soil moisture. Swamping can kill seedlings and negatively impact regeneration. Removal of tree tops and branches may also remove seeds or cones, which may reduce the amount of natural regeneration. Biomass removals can help deal with forest insect problems, but removing the biomass material from the site must be timed to avoid contributing to pest problems such as bark beetles.

Some states have used biomass guidelines to make silvicultural recommendations that may improve stands but are not directly related to biomass harvesting. The Missouri biomass guidelines provide silvicultural suggestions for the number of crop trees per acre for stands in different stages of development. Pennsylvania's guidelines suggest that forest stewards "provide for regeneration each time harvests are made under the uneven-aged system," focus on the residual stand more than the trees being removed, and avoid high grading. Wisconsin's guidelines suggest retaining "reserve trees and patches at 5–15 percent crown cover or stand area" in even-aged regeneration cuts and three or more large-cavity trees, large mast trees, and trees that can become large trees in the future. Maine's guidelines recommend retention of cavity and mast trees while Wisconsin's guidelines recommend retaining five percent of the area unharvested in salvage operations following severe disturbances.

Another operational recommendation that Minnesota, Missouri, and Pennsylvania all make is to avoid re-entering a stand to remove biomass. Re-entering a site where timber was recently harvested can increase site impacts such as soil compaction and harm post-harvest regeneration. For this reason, the Missouri guidelines advise that "woody biomass should be harvested at the same time as sawlog timber to avoid re-entry." Maine's guidelines recommend that woody biomass removal be integrated with traditional forest operations where possible.

## 7F. BIOMASS GUIDELINES DEVELOPMENT

The process of developing guidelines can be as important as the specific recommendations. Most guidelines try to draw from the most recent forest science. Developing new biomass guidelines allows states to incorporate new research and ideas. Minnesota used funding from the University of Minnesota Initiative for Renewable Energy and the Environment to conduct a review of the scientific literature on biomass harvests. Other guidelines borrow from existing guidelines. For example, Pennsylvania's guidelines borrow extensively from Minnesota's guidelines and summarize the FSC's standards for the region.

The amount of stakeholder participation varies across the guidelines. While Pennsylvania's guidelines were created from within the DCNR, Minnesota, Missouri, and Wisconsin included public participation and a technical committee from the wider forestry community. Public participation can be unwieldy, but often generates greater public support for forestry projects.[20]

Some of the biomass guidelines, such as those from New Brunswick, Canada, focus on the identification of geographies where biomass harvesting is most appropriate. Wisconsin takes a complementary approach, identifying soil types where biomass removal is inappropriate. By mapping soil types, guidelines can highlight those areas where concerns about nutrient depletion are lowest. Suitability mapping also permits the consideration of the landscape-scale impacts of biomass harvesting. Pennsylvania's guidelines are notable because they consider the supply of biomass from forests as well as the appropriate scale of utilization. As mentioned previously, Pennsylvania's guidelines make a case for small-scale (less than 2,000 tons of biomass per year) biomass utilization facilities.

## 8. CONCLUSION

This revised assessment of biomass guidelines reviews a wide range of approaches to the sustainable use of biomass that can inform the development of guidelines in Massachusetts. The section on New York and New England may be the most helpful, because these states are dealing with similar timber types and land ownership patterns. However, there are number of other state-based approaches, such as those of Minnesota and Michigan, that can be readily transferable. Northern Europe has a long history of intensive biomass use, and while their harvesting systems and approach to forest management are currently very different, their approaches to ecological issues can be translated to concerns in Massachusetts. The sections on other organizations and federal policy provide insight into how Massachusetts guidelines might be influenced or integrated with other approaches.

The final section, which explores the common elements of biomass harvesting guidelines, offers a structure to develop guidelines tailored to Massachusetts. The Forest Guild has used that structure to develop a set of guidelines, *Biomass Retention and Harvesting Guidelines for the Northeast*, which is readily applicable to Massachusetts. These guidelines are included as a separate document.

The following recommendations for the development of future biomass guidelines in Massachusetts are based on the existing guidelines and available science, and will change as more is learned about biomass removals:

- Develop guidelines that are based on sound science and include wide stakeholder engagement. As the Minnesota guidelines describe it, “Provide the best scientific judgment, tempered by the consensus process among a broad group of forest management interests, related to practices that will sustain a high level of biodiversity.”
- Define “woody biomass” and other important terms clearly.
- Base biomass harvesting recommendations on local ecology. They should recognize state or local natural communities, disturbance regimes, and other ecological traits. Technical committees and scientific literature provide a firm base for harvest recommendations.
- Consider developing guidelines for each of the subtopics listed in Appendix I—though not all subtopics will be appropriate for every location.
- Make clear and specific recommendations for the retention of standing dead trees, existing CWM, CWM generated by the harvest, FWM, and forest floor and litter layer. Because reduction of dead wood is one of the key differences between biomass removal and traditional harvest, it should be a focus of future guidelines. Nutrients removed from the site should be replenished. For even-aged systems, nutrients should be replenished to adequate levels by the end of the rotation. Uneven-aged systems should maintain nutrient levels close to the optimum. Nutrient levels may be temporarily reduced after each entry, but should return to adequate levels by the next cutting cycle.
- Make biomass guidelines practical and easy to follow. Where biomass guidelines supplement existing forestry rules and guidelines, the new guidelines should provide clear references to the relevant sections of the existing rules and guidelines both for convenience and to increase the likelihood of implementation.
- Take advantage of the opportunity to create new forestry recommendations that encourage excellent forestry: forestry that goes beyond minimum BMPs and enhances the full suite of ecological values. For example, biomass guidelines may be an opportunity to suggest alternatives to high grading and other practices that damage the long-term health of the forest. Similarly, biomass guidelines can present the chance to advocate for appropriately scaled biomass utilization, as Pennsylvania guidelines already do.

## 9. ACKNOWLEDGMENTS

This report benefited from the comments of Don Arnosti, Amber Ellering, Kathryn Fernholz, Ehrhard Frost, Brad Hutnik, Ken Laustsen, Darcie Mahoney, Eunice Padley, Michael Palko, David Ray, Christopher Riely, Paul Trianosky, and Pieter van Loon.

Special thanks to Doug Enyart, Clearwater Forestry Consultants, LLC, for help with developing the section addressing the Missouri guidelines, Brian Titus, Research Scientist, Natural Resources Canada, for his help with the Canadian section, and to Hillevi Eriksson, Swedish Forest Agency for her help with the section that details activities in Europe.

## 10. REFERENCES

1 Aguilar, F., and H. E. G. Garrett. 2009. Perspectives of Woody Biomass for Energy: Survey of State Foresters, State Energy Biomass Contacts, and National Council of Forestry Association Executives. *Journal of Forestry* 107(6):297-306.

2 Ahtikoskia, A., J. Heikkila, V. Aleniusa, and M. Sirenc. 2008. Economic Viability of Utilizing Biomass Energy from Young Stands-the Case of Finland. *Biomass and Bioenergy* 32:988 - 996.

3 Aijala, O., K. M., and M. Halonen. 2005. Energy Wood Harvest from Clear Cuts, Guidelines. Quality Project of Energy Wood Harvest in Clear Cut. Feric Tapio Guidelines. Finland.

4 Andersson, G., A. Asikainen, R. Björheden, P. W. Hall, J. B. Hudson, R. Jirjis, D. J. Mead, and J. Nurmi. 2002. Production of Forest Energy. Pages Ch. 3. pp. 49-123 in G. F. Weetman, J. Richardson, R. Björheden, P. Hakkila, A. T. Lowe, and C. T. Smith, editors. *Bioenergy from Sustainable Forestry: Guiding Principles and Practice.* Kluwer Academic Publishers, The Netherlands.

5 Arnosti, D., D. Abbas, D. Current, and M. Demchik. 2008. Harvesting Fuel: Cutting Costs and Reducing Forest Fire Hazards through Biomass Harvest. Institute for Agriculture and Trade Policy, Minneapolis, MN.

6 Bauer, J. M., and P. J. Weisberg. 2009. Fire History of a Central Nevada Pinyon-Juniper Woodland. *Canadian Journal of Forest Research* 39(8):1589-1599.

7 Benjamin, J. G. 2010. Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine. Miscellaneous Publication 761, University of Maine, Maine

Agricultural and Forest Experiment Station, Orono, ME.

8 Berg, S. 2003. Harvesting Technology and Market Forces Affecting the Production of Forest Fuels from Swedish Forestry. *Biomass and Bioenergy* 24(4-5):381-388.

9 Briggs, R. D. 1994. Site Classification Field Guide. Maine Agricultural and Forest Experiment Station, Orono, ME.

10 Brown, J. K., Elizabeth D. Reinhardt, and K. A. Kramer. 2003. Coarse Woody Debris: Managing Benefits and Fire Hazard in the Recovering Forest. RMRS-GTR-105, US Forest Service, Rocky Mountain Research Station, Ogden, UT.

11 California. 2010. California Forest Practice Rules. *in Title 14, California Code of Regulations. Chapters 4, 4.5 and 10. Appendix Technical Rule Addendum # 2, B.*

12 Cassidy, G., J. Aron, and M. Tremblay. 2003. Rhode Island Conservation Management Practices Guide. Rhode Island Forest Conservator's Organization, Scituate, RI.

13 Chapman, C., G. Donovan, S. Fay, C. Foss, G. Jones, B. Leak, D. Merski, F. Mitchell, D. Publicover, M. Seeger, T. V. Ryn, and M. Yamasaki. 1997. Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire. New Hampshire Division of Forests & Lands and Society for the Protection of New Hampshire Forests, Concord, NH.

14 CSBP. 2009. Draft Standard. Council for Sustained Biomass Production, Dillon, CO.

15 CT DEP. 2007. Best Management Practices for Water Quality While Harvesting Forest Products. Connecticut Department of Environmental Protection, Bureau of Natural Resources, Division of Forestry, Hartford, CT.

16 Ellefson, P. V., and A. S. Cheng. 1994. State Forest Practice Programs: Regulation of Private Forestry Comes of Age. *Journal of Forestry* 92:34-37.

17 Ellefson, P. V., M. A. Kilgore, and J. E. Granskog. 2006. State Government Regulation of Forestry Practices Applied to Nonfederal Forests: Extent and Intensity of Agency Involvement. *Journal of Forestry* 104:401-406.

18 Elliot, C., editor. 2008. Biodiversity in the Forests of Maine: Guidelines for Land Management. University of Maine Cooperative Extension. Bulletin 7174, Orono, ME.

19 Evans, A. M., and A. J. Finkral. 2009. From Renewable Energy to Fire Risk Reduction: A Synthesis of Biomass Harvesting and Utilization Case Studies in Us Forests. *Global Change Biology Bioenergy* 1(3):211-219.

20 Evans, A. M., and G. McKinley. 2007. An Evaluation of Fuel Reduction Projects and the Healthy Forests Initiative. Forest Guild, Santa Fe, NM.

21 Fernholz, K., S. Bratkovich, J. Bowyer, and A. Lindburg. 2009. Energy from Woody Biomass: A Review of Harvesting Guidelines and a Discussion of Related Challenges. Dovetail Partners, Inc., Minneapolis, MN.

22 Flatebo, G., C. R. Foss, and S. K. Pelletier. 1999. Biodiversity in the Forests of Maine: Guidelines for Land Management. University of Maine, Cooperative Extension, Orono, ME.

23 FSC. 2009. Us Forest Management Standard Draft 8.1. Forest Stewardship Council, Washington, DC.

24 Hagan, J. M., and A. A. Whitman. 2006. Biodiversity Indicators for Sustainable Forestry: Simplifying Complexity. *Journal of Forestry* 104(4):203-210.

25 Hakkila, P. 2006. Factors Driving the Development of Forest Energy in Finland. *Biomass and Bioenergy* 30:281-288.

26 Herrick, S., J. Kovach, E. Padley, C. Wagner, and D. Zastrow. 2009. Wisconsin's Forestland Woody Biomass Harvesting Guidelines. PUB-FR-435-2009, WI DNR Division of Forestry and Wisconsin Council on Forestry, Madison, WI.

27 International Energy Agency. 2007. Bioenergy Report Finland. Paris, France.

28 Jacobson, G. L., Jr. 2000. Post-Glacial Changes in Vegetation and Climate in Northern New England. Rhodora 102(911):246-247.

29 Janowiak, M. K., and C. R. Webster. 2010. Promoting Ecological Sustainability in Woody Biomass Harvesting. *Journal of Forestry* 108:16-23.

30 Junginger, M., T. Bolkesj, D. Bradley, P. Dolzan, A. Faaij, J. Heinimo, B. Hektor, O. Leistad, E. Ling, M. Perry, E. Piacente, F. Rosillo-Calle, Y. Ryckmans, P. P. Schouwenberg, B. Solberg, E. Trømborg, A. D. S. Walter, and M. D. Wit. 2008. Developments in International Bioenergy Trade. *Biomass and Bioenergy* 32:717-729.

31 Lattimore, B., C. T. Smith, B. D. Titus, I. Stupak, and G. Egnell. 2009. Environmental Factors in Woodfuel Production: Opportunities, Risks, and Criteria and Indicators for Sustainable Practices. *Biomass and Bioenergy* 33(10):1321-1342.

32 Levin, R., and H. Eriksson. 2010. Good-Practice Guidelines for Whole-Tree Harvesting in Sweden: Moving Science into Policy. *Forestry Chronicle* 86(1):51-56.

33 Mallory, E. C. 2008. Collation of on-Going Canadian Research on Biomass Harvesting and Biodiversity. *in Proceeding of The Scientific Foundation for Sustainable Forest Biomass Harvsting Guidelines and Policies*. Sustainable Forest Management Network, Edmonton, AB.

34 MDC. 2008. Missouri Woody Biomass Harvesting Best Management Practices Manual. Missouri Department of Conservation, Jefferson City, MO.

35 MDNR. 2007. Sustainable Soil and Water Quality Practices on Forest Land. Michigan Department Of Natural Resources, Michigan Department Of Environmental Quality,, Lansing, MI.

36 MDNR. 2009. Michigan Woody Biomass Harvesting Guidance *Draft*. Michigan Department of Natural Resources, Forest, Mineral and Fire Management, Lansing, MI.

37 MFRC. 2007. Biomass Harvest Guidelines. Minnesota Forest Resources Council, St. Paul, MN.

38 MFS. 2004. Best Management Practices for Forestry: Protecting Maine's Water Quality. Maine Department of Conservation's Maine Forest Service, August, ME.

39 MFS. 2008. Maine Forestry Best Management Practices Use and Effectiveness 2006 - 2007. Maine Forest Service, Augusta, ME.

40 MFS, U of ME, and TCNF. 2008. Biomass Retention Guidelines for Timber Harvesting in Maine. Version 4. Maine Forest Service, University of Maine, and the Trust to Conserve Northeast Forestlands, Orono, ME.

41 Moffat, A., B. M. Jones, and B. Mason. 2006. Managing Brash on Conifer Clearfell Sites. Practice Note, UK Forestry Commission, Farnham, England.

42 New Brunswick DNR. 2008. Forest Biomass Harvesting. New Brunswick Department of Natural Resources, Fredericton, New Brunswick.

43 Nilsson, L. J., B. Johansson, K. Astrand, K. Ericsson, P. Svenningsson, and P. Borjesson. 2004. Seeing the Wood for the Trees: 25 Years of Renewable Energy Policy in Sweden. *Energy for Sustainable Development* 8(1).

44 Norton, G., S. Abraham, and A. Veneman. 2003. Memorandum of Understanding on Policy Principles for Woody Biomass Utilization for Restoration and Fuel Treatments on Forests, Woodlands, and Rangelands. U.S. Forest Service and Bureau of Land Management, Washington, DC.

45 NYSF. 2007. Best Management Practices for Water Quality. New York State Forestry, Albany, NY.

46 PA DCNR. 2008. Guidance on Harvesting Woody Biomass for Energy. Pennsylvania Department of Conservation and Natural Resources, Harrisburg, PA.

47 Raison, R. J., P. Hakkila, D. G. Neary, J. A. Burger, P. Angelstam, G. Mikusinski, and M. Breuss. 2002. Effects of Very Intensive Forest Biomass Harvesting on Short and Long Term Site Productivity. in J. Richardson, R. Björheden, P. Hakkila, A. T. Lowe, and C. T. Smith, editors. *Bioenergy from Sustainable Forestry: Guiding Principles and Practice*. Kluwer Academic Publishers, Hingham, MA.

48 Ralevic, P., J. Karau, T. Smith, and J. Richardson. 2008. Iea Bioenergy Task 31 Country Report: Canada. International Energy Agency, Ottawa, Canada.

49 Raulund-Rasmussen, K., I. Stupak, N. Clarke, I. Callesen, H.-S. Helmisaari, E. Karltun, and I. Varnagiryte-Kabasinskiene. 2008. Effects of Very Intensive Forest Biomass Harvesting on Short and Long Term Site Productivity. Pages 29-78 in D. Röser, A. Asikainen, K. Raulund-Rasmussen, and I. Stupak, editors. *Sustainable Use of Forest Biomass for Energy. Springer Netherlands*.

50 Röser, D., A. Asikainen, K. Raulund-Rasmussen, and I. Stupak, editors. 2008. *Sustainable Use of Forest Biomass for Energy—a Synthesis with Focus on the Baltic and Nordic Region*. Springer.

51 Shepard, J. P. 2006. Water Quality Protection in Bioenergy Production: The Us System of Forestry Best Management Practices. *Biomass and Bioenergy* 30(4):378–384.

52 Stupak, I., A. Asikainen, M. Jonsell, E. Karltun, A. Lunnan, D. Mizaraite, K. Pasanen, H. P. rn, K. Raulund-Rasmussen, D. R. ser, M. Schroeder, I. Varnagiryte, L. Vilkriste, I. Callesen, N. Clarke, T. Gaitnieks, M. Ingerslev, M. Mandre, R. Ozolincius, A. Saarsalmi, K. Armolaitis, H.-S. Helmisaari, A. Indriksons, L. Kairiukstis, K. Katzensteiner, M. Kukkola, K. Ots, H. P. Ravn, and P. Tamminen. 2007. Sustainable Utilisation of Forest Biomass for Energy—Possibilities and Problems: Policy, Legislation, Certification, and Recommendations and Guidelines in the Nordic, Baltic, and Other European Countries. *Biomass and Bioenergy* 31:666–684.

53 Stupak, I., T. Nordfjell, and P. Gundersen. 2008. Comparing Biomass and Nutrient Removals of Stems and Fresh and Predried Whole Trees in Thinnings in Two Norway Spruce Experiments. *Canadian Journal of Forest Research* 38(10):2660–2673.

54 Sverdrup, H., and K. Rosen. 1998. Long-Term Base Cation Mass Balances for Swedish Forests and the Concept of Sustainability. Forest Ecology and Management 110(1-3):221-236.

55 Titus, B. D., S. M. Berch, D. M. Morris, R. L. Fleming, P. W. Hazlett, D. Pare, and P. A. Arp. 2008. Synopsis of on-Going Canadian Research on Biomass Harvesting and Site Productivity. *in Proceeding of The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies.* Sustainable Forest Management Network, Edmonton, AB.

56 Titus, B. D., C. T. Smith, D. Puddister, J. R. Richardson, and C. Young. 2008. Notes from Facilitated Discussions. *in Proceeding of The Scientific Foundation for Sustainable Forest Biomass Harvsting Guidelines and Policies*. Sustainable Forest Management Network, Edmonton, AB.

57 UK Forestry Commission. 2009. *Forests and Soils Guidelines Consultation Draft, July 2009*. Forest Research, the Research Agency of the UK Forestry Commission. http://www.forestry.gov.uk/pdf/FCGL008consultation.pdf/$FILE/FCGL008consultation.pdf

58 UK Forestry Commission. 2009. *Guidance on Site Selection for Brash Removal*. Forest Research, the Research Agency of the UK Forestry Commission. http://www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/BEC_TECHNICAL/BEST%20PRACTICE/BRASH_RESIDUE_PROTOCOL-1.PDF

59 UK Forestry Commission. 2009. *Stump Harvesting: Interim Guidance on Site Selection and Good Practice*. Forest Research, the Research Agency of the UK Forestry Commission. http://www.biomassenergycentre.org.uk/pls/portal/docs/PAGE/BEC_TECHNICAL/BEST%20PRACTICE/FC_STUMP_HARVESTING_GUIDANCE_APRIL09.PDF

60 VT DFPR. 1987. Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont. Department of Forests, Parks, and Recreation, Waterbury, VT.

61 Walmsley, J. D., D. L. Jones, B. Reynolds, M. H. Price, and J. R. Healey. 2009. Whole Tree Harvesting Can Reduce Second Rotation Forest Productivity. *Forest Ecology and Management* 257(3):1104-1111.

62 Woodall, C. W., and V. J. Monleon. 2008. Sampling Protocol, Estimation, and Analysis Procedures for the Down Woody Materials Indicator of the Fia Program. NRS-GTR-22, U.S. Forest Service, Newtown Square, PA.

# 11. APPENDIX I

# SUMMARY TABLE OF BIOMASS GUIDELINES

| | ME | MN | MO | PA | WI | FSC |
|---|---|---|---|---|---|---|
| **Dead Wood** | | | | | | |
| Coarse woody material | √ | √ | √ | √ | √ | √ |
| Fine woody material | √ | √ | √ | √ | √ | √ |
| Snags | √ | √ | √ | √ | √ | √ |
| **Wildlife and Biodiversity** | | | | √ | | |
| Wildlife | √ | √ | √ | √ | √ | √ |
| Sensitive wildlife species | √ | √ | √ | √ | √ | √ |
| Biodiversity | √ | √ | √ | √ | √ | √ |
| Plants of special concern | √ | √ | √ | √ | √ | √ |
| Sensitive areas | √ | √ | √ | √ | √ | √ |
| **Water Quality and Riparian Zones** | | | | | | |
| Water quality | √ | √ | √ | √ | √ | √ |
| Riparian zones | √ | √ | √ | √ | √ | √ |
| Non-point source pollution | √ | √ | √ | √ | √ | √ |
| Erosion | √ | √ | √ | √ | √ | √ |
| Wetlands | √ | √ | √ | √ | √ | √ |
| **Soil Productivity** | | | | | | |
| Chemical (Nutrients) | √ | √ | √ | √ | √ | √ |
| Physical (Compaction) | √ | √ | √ | √ | √ | √ |
| Biological (Removal of litter) | √ | √ | | √ | √ | |
| **Silviculture** | | | | | | |
| Planning | √ | √ | √ | √ | | √ |
| Regeneration | | √ | | √ | √ | √ |
| Residual stands | √ | √ | √ | √ | √ | √ |
| Aesthetics | | | √ | √ | √ | √ |
| Post operations | √ | √ | √ | √ | √ | |
| Re-entry | | √ | √ | √ | | |
| Roads and skid trail layout | √ | √ | √ | √ | √ | √ |
| **Disturbance** | | | | | | |
| Insects | | √ | √ | √ | √ | √ |
| Disease | | | √ | √ | √ | √ |
| Fire | | √ | √ | √ | | √ |
| Fuel reduction | | √ | | √ | | √ |
| Pesticides | | √ | | √ | | |
| Invasives | | √ | √ | √ | | |
| Conversion from forest | | | √ | √ | | √ |

# 12. APPENDIX II

## LINKS TO BIOMASS HARVESTING GUIDELINES

- Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine http://www.maine.gov/doc/mfs/pubs/biomass_retention_guidelines.html

- Minnesota: Biomass Harvesting Guidelines for Forestlands http://www.frc.state.mn.us/FMgdline/BHGC.html

- Missouri: Best Management Practices for Harvesting Woody Biomass http://mdc4.mdc.mo.gov/applications/MDCLibrary/MDCLibrary2.aspx?NodeID=2055

- Pennsylvania: Guidance on Harvesting Woody Biomass for Energy http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf

- Wisconsin Council on Forestry: Use of Woody Biomass http://council.wisconsinforestry.org/biomass/

- Forest Stewardship Council http://www.fscus.org/standards_criteria/

- Canada: The Scientific Foundation for Sustainable Forest Biomass Harvesting Guidelines and Policies http://www.sfmnetwork.ca/html/biomass_workshop_e.html

- New Brunswick: Forest Biomass Harvesting Policy http://www.gnb.ca/0078/Policies/FMB0192008E.pdf

# APPENDIX 4–C

# FOREST BIOMASS RETENTION AND HARVESTING GUIDELINES FOR THE NORTHEAST

## TABLE OF CONTENTS

## 1. INTRODUCTION AND BACKGROUND

Interest in removing wood with a historically low economic value from forests has increased because of rising fossil fuel costs, concerns about carbon emissions from fossil fuels, and the risk of catastrophic wildfires. Even as federal, state and regional programs encourage the utilization of forest biomass, there are concerns about its potential adverse effects on biodiversity, soil productivity, wildlife habitat, water quality, and carbon storage. At the same time, biomass removal and utilization have the potential to provide a renewable energy source, promote the growth of higher-value trees and forest products, reduce forest fire risk, support the removal of invasive species, and help to meet the economic development goals of rural communities. These guidelines are designed to encourage protection of soils, wildlife habitat, water, and other forest attributes when biomass or other forest products are harvested in the Northeastern United States.

### Our Principles

**1. The well-being of human society is dependent on responsible forest management that places the highest priority on the maintenance and enhancement of the entire forest ecosystem.**

**2. The natural forest provides a model for sustainable resource management; therefore, responsible forest management imitates nature's dynamic processes and minimizes impacts when harvesting trees and other products.**

**3. The forest has value in its own right, independent of human intentions and needs.**

**4. Human knowledge of forest ecosystems is limited. Responsible management that sustains the forest requires a humble approach and continuous learning.**

**5. The practice of forestry must be grounded in field observation and experience as well as in the biological sciences. This practical knowledge should be developed and shared with both traditional and non-traditional educational institutions and programs.**

**6. A forester's or natural resource professional's first duty is to the forest and its future. When the management directives of clients or supervisors conflict with the Mission and Principles of the Guild, and cannot be modified through dialogue and education, a forester or natural resource professional should disassociate**

## THE FOREST GUILD GUIDELINES

The Forest Guild guidelines are designed to augment and enhance existing Best Management Practices (BMPs) or new state-based biomass guidelines that may, in some cases, leave managers and policy makers looking for more detailed recommendations. While these guidelines were developed to address biomass harvesting, they also are intended to inform all harvests in northeastern forests. We developed these guidelines to assist several audiences: field foresters, loggers, state-based policy makers charged with developing biomass guidelines and standards, biomass facilities wishing to assure sustainability, third party certifiers, and members of the public interested sustainable forest management.

These guidelines are based on the Forest Guild's principles (see text box). Forest Guild members are concerned with reconciling biomass removals with the principles of excellent forestry—forestry that is ecologically, economically, and socially responsible. Excellent forestry exceeds minimum best management practices and places the long-term viability of the forest above all other considerations. It uses nature as a model and embraces the forest's many values and dynamic processes. Excellent forestry maintains the functions, structures, and composition that support the health of the entire forest ecosystem. Excellent forestry is different in each ecoregion, but is guided by science, place-based experience, and continuous learning.

Forest Guild members acknowledge their social responsibilities as forest stewards to address climate change and mitigate the buildup of atmospheric carbon. In addition, we understand how renewable fuels derived from well-managed forests can provide energy security and enhance rural communities. At the same time, we have an ecological imperative to ensure that all our harvests—including biomass harvests—maintain or enhance the ecological values of the forest.

### Creating the Guidelines

Our working group consisted of 23 Forest Guild members representing public and private field foresters and resource managers, academic researchers and members of major regional and national environmental organizations. The process was led by Forest Guild staff and was supported by two Forest Guild reports: *Ecology of Dead Wood in the Northeast 4 and An Assessment of Biomass Harvesting Guidelines*.5 Wherever possible we base our recommendations on peer-reviewed science. However, in many cases research is inadequate to connect practices, stand level outcomes, and ecological goals. Where the science remains inconclusive, we rely on field observation and professional experience. The guidelines provide both general guidance and specific targets that can be measured and monitored. These guidelines should be revisited frequently, perhaps on a three-year cycle, and altered as new scientific information and results of field implementation of the guidelines become available.

## "Sustainability" and Biomass Harvesting

Using a common definition, sustainable biomass harvests would "meet the needs of the present without compromising the ability of future generations to meet their needs" (Brundtland Commission 1987). Crafting a more precise definition of sustainable forest management is inherently complex because forest ecosystems are simultaneously intricate, dynamic, and variable. Sustainable forest management must integrate elements of ecology, economics, and societal well being. These guidelines primarily pertain to issues of sustaining ecological function and productivity; they are not meant to replace a comprehensive assessment of forest sustainability.

In general, the sustainability of managed forests must be judged on timelines that span generations. Individual trees can persist for centuries and management decisions made today will have important implications well beyond the tenure of any one manger. The indigenous focus on the impact of decisions seven generations into the future is more appropriate. Similarly, sustainability must be judged on scales larger than that of the individual forest stand. For example, large mammal home ranges, water quality, and a viable forestry industry all depend on landscapes that encompass multiple stands. Due to the difficulties of defining appropriate time frames and spatial scales, the concept of forest sustainability is best thought of as an adaptive process that requires regular monitoring and recalibration. Consequently, these guidelines are presented not as static targets to be maintained at all times in all places, but rather as guideposts on a path to sustainability.

## Definitions

### Biomass

In a scientific context, the term "biomass" includes all living or dead organic matter. In common parlance, biomass usually refers to woody material that has historically had a low value and was not considered merchantable in traditional markets. Biomass harvesting can also involve the removal of dead trees, downed logs, brush, and stumps, in addition to tops and limbs. Changing markets and regional variations determine which trees are considered sawtimber or pulpwood material and which are relegated to the biomass category. This report does not discuss biomass from agricultural lands and short-rotation woody biomass plantations.

In this report, the term biomass refers to *vegetation removed from the forest, usually logging slash, small-diameter trees, tops, limbs, or trees not considered merchantable in traditional markets*. Similarly we use the phrase **biomass harvesting** to refer to the *removal of logging slash, small-diameter trees, tops, or limbs*.

Biomass can be removed in a number of ways. Some harvests remove only woody biomass, some combine the harvest of sawtimber or other products with biomass removal, and some remove biomass after other products have been removed. This report focuses on post-harvest forest conditions and not on the type of harvest. The goal is to ensure the forest can support wildlife, maintain biodiversity, provide clean water, sequester carbon, protect forest soil productivity, and continue to produce income after a biomass harvest or repeated harvests. In some regions, current wood utilization is such that very little woody material is available for new markets such as energy. For these high-utilization areas, application of these guidelines may result in more biomass being left in the forest.

### Downed Woody Material

Woody material is sometimes divided into coarse woody material (CWM) and fine woody material (FWM). CWM has been defined as more than 6 inches in diameter at the large end and FWM that is less than 6 inches in diameter at the large end.17 The USDA Forest Service defines CWM as downed dead wood with a small-end diameter of at least 3 inches and a length of at least 3 feet, and FWM as having a diameter of less than 3 inches.25 FWM has a higher concentration of nutrients than CWM. Large downed woody material, such as logs greater than 12 inches in diameter, is particularly important for wildlife. In this report, we use the term **downed woody material (DWM)** to encompass all three of these size classes, but in some circumstances we discuss a specific size of material where the piece size is particularly important.

## 2. GUIDELINES FOR BIOMASS RETENTION AND HARVESTING FOR ALL FOREST TYPES

The following recommendations are applicable across a range of forest types in the Northeast. However, different forest types naturally develop different densities of snags, DWM, and large downed logs. Unfortunately, even after an exhaustive review of the current science there is too much uncertainty to provide specific targets for each forest type. The recommendations in this section set minimum retention targets necessary for adequate wildlife habitat and to maintain the integrity of ecological process such as soil nutrient cycling. Wherever possible, exceed the targets as a buffer against the limitations of current research. Section 3 presents research that may help landowners and foresters interested in additional tree, snag, and DWM retention tailored to specific forest types.

## Site Considerations to Protect Rare Forests and Species

- Biomass harvests in critically imperiled or imperiled forest types (i.e., globally recognized or listed as S1 or S2 in a State National Heritage Program) should be avoided unless necessary to perpetuate the type. Management of these and other rare forest types (for example, those ranked S3 by state Natural Heritage Programs) should be based on guidance from the local Natural Heritage Program and/or other local ecological experts.

- Biomass harvesting may be appropriate in sensitive sites to control invasive species, enhance critical habitat, or reduce wildfire risk. However, restoration activity should be guided by ecological goals and not designed solely to supply biomass. It is unlikely that restored sites will contribute to the long-term wood supply, because biomass removals for restoration may not be repeated at regular intervals.

- Old growth forest stands with little or no evidence of harvesting are so rare in the Northeast that they should be protected from harvesting, unless necessary to maintain their structure or ecological function. Areas with scattered old growth trees or late-successional forest characteristics should be carefully managed to ensure retention of their ecological functions. Biomass generally should not be removed from these areas.

### Retention of Downed Woody Material

Though CWM represents a large pool of nutrients in some ecosystems, it likely plays a relatively small role in nutrient cycling for managed Northeastern forests. A review of scientific literature suggests that biomass harvesting is unlikely to cause nutrient problems when both sensitive sites (including low-nutrient sites) and clearcutting with whole-tree removal are avoided (see Evans and Kelty 2010 for a more detailed discussion of the relevant scientific literature). However, there is no scientific consensus on this point because of the limited range of treatments and experimental sites.

### Maintenance of Soil Fertility

Biomass harvesting on low-nutrient sites is a particular concern. For example, Hallett and Hornbeck note that "red oak and white pine forests growing on sandy outwash sites are susceptible to nutrient losses due to inherently low-nutrient capitals and/or nutrient depletion by past activities such as farming, fire, and intensive harvesting."9 Maine's *Woody Biomass Retention Guidelines*1 list shallow-to-bedrock soils, coarse sandy soils, poorly drained soils, steep slopes, and other erosion-prone sites as sensitive to biomass removals. We encourage states to identify low-nutrient soil series where biomass harvesting should not occur and those soil series where biomass harvests require particular caution. Wisconsin's *Forestland Woody Biomass Harvesting Guidelines* is an excellent example.11

In areas that do not qualify as low-nutrient sites, where 1/3 of the basal area is being removed on a 15- to 20-year cutting cycle, it is our professional judgment that retaining 1/4 to 1/3 of tops and limbs will limit the risk of nutrient depletion and other negative impacts in most forest and soil types. Additional retention of tops and limbs may be necessary when harvests remove more trees or harvests are more frequent. Similarly where the nutrient capital is deficient or the nutrient status is unknown, increased retention of tops, branches, needles, and leaves is recommended. Conversely, if harvests remove a lower percentage of basal area, entries are less frequent, or the site is nutrient-rich, then fewer tops and limbs need to be retained on-site.

## Guidelines for DWM Retention

- In general, when 1/3 of the basal area is being removed on a 15 to 20 year cycle, retain 1/4 to 1/3 of the slash, tops, and limbs from harvest (i.e., DWM).
- Three main factors influence the percentage of tops and limbs that should be left onsite:
  - number of live trees left on-site,
  - time between harvests, and
  - available soil nutrients.
- As harvesting intensity increases (and the three preceding factors decrease) more slash, tops, and limbs from harvests should be left on-site
- As harvesting intensity decreases (and the three factors increase) less slash, tops, and limbs from harvests are required to protect site productivity.
- Avoid harvesting on low-nutrient sites or adjust retention of tops, branches, needles, and leaves.
- Retain DWM of all sizes on-site including FWM, CWM and large downed logs.
- In general, leave DWM distributed across the harvest site. However, there may be cases where piles of DWM provide habitat, or redistribution of DWM collected at the landing would cause excessive damage to soil or regeneration.
- Minimize the removal of needles and/or leaves by harvesting in winter, retaining FWM on-site, or leaving felled trees on-site to allow for needle dro

## Retention of Forest Structures for Wildlife and Biodiversity

- Leave and protect litter, forest floor, roots, stumps, and large downed woody material.
- Leave and protect live cavity trees, den trees, other live decaying trees, and snags (i.e., dead standing trees >10"). Individual

snags that must be felled for safety requirements should not be removed from the forest.

**Table 1. General Guidelines for Retaining Forest Structures**

| Structure | Minimum Target (per acre) | | Considerations |
|---|---|---|---|
| | Number | Basal area ($ft^2$) | |
| Live decaying Trees 12 –18 inches DBH | 4 | 3–7 | Where suitable trees for retention in these size classes are not present or may not reach these targets due to species or site conditions, leave the largest trees possible that will contribute toward these targets. |
| Live decaying trees >18 inches DBH | 1 | 2 | |
| Snags >10 inches DBH | 5 | 3 | Worker safety is top priority. Retain as many standing snags as possible, but if individual snags must be felled for safety reasons, leave them in the forest. |

Table 1 is based on the scientific literature review in *The Ecology of Dead Wood in the Northeast*4 as well as other biomass harvesting and retention guidelines[5]. These guidelines are not meant to be attained on every acre, at all times. Rather, they are average targets to be applied across a stand, harvest block, or potentially an ownership.

- If these forest structures do not currently exist, select and identify live trees to become these structures in the future. Retaining live decaying trees helps ensure sufficient snags in the future. Similarly, both decaying trees and snags can eventually become large downed logs.
- If forest disturbances such as hurricanes, ice storms, and insect infestations create large areas of dead trees, leaving all snags or decaying trees may be impractical. If an area is salvage logged, leaving un-salvaged patches totaling 5% to 15% of the area will provide biological legacies important to wildlife. However, the potential for insect populations to build up in dead trees may prohibit retention of unsalvaged patches in some situations.
- Since there are differences in decay rates and wildlife utilization, retain a variety of tree species as snags, DWM, and large downed logs.
- In areas under even-aged management, leave an uncut patch within or adjacent to every 10 acres of regeneration harvest. Uncut patches, including riparian buffers or other set-asides within the management unit, should total 5% to 15% of the harvest area.
- Build retention patches around large legacy trees, den or cavity trees, large snags, and large downed logs, to maximize structural and habitat diversity.
- Marking retention trees will help ensure that sufficient numbers are retained during the current harvest, and that and they will not be removed in subsequent harvests.
- Management that maintains multiple vegetation layers, from the overstory canopy to the midstory, shrub, and ground layers will benefit wildlife and plant species diversity.

## WATER QUALITY AND RIPARIAN ZONES

In general, water quality and riparian concerns do not change with the addition of biomass removals to a harvest plan. Refer to state water quality best management practices (BMPs) and habitat management guidelines for additional measures to protect streams, vernal pools, and other water bodies (see Appendix I for a list of these BMPs and habitat management guidelines).

- DWM retention described above is also important for water quality, because DWM reduces overland flow and holds water.
- Leave and protect existing woody material in streams, ponds, and lakes. DWM in riparian systems provides sites for vegetation colonization, forest island growth and coalescence, and forest floodplain development.
- Leave and protect live decaying trees (e.g., cavity/den trees), snags, and large downed logs in riparian or stream management zones.
- Keep vernal pools free of slash, tops, branches, and sediment from forestry operations. If slash falls into the pool during the breeding season, it is best to leave it in place to avoid disturbing egg masses or other breeding activity that may already be occurring.
- Within 100 feet of the edge of a vernal pool, maintain a shaded forest floor to provide deep litter and woody debris around the pool. Also avoid ruts, bare soil, or sources of sediment near vernal pools.
- Extra care should be taken working in or around forested wetlands because of their importance for wildlife and ecosystem function. Wetlands are often low-fertility sites and may support rare natural communities, so removal of DWM may be inappropriate.

## HARVESTING AND OPERATIONS

Most concerns about the operational aspects of biomass harvesting are very similar to all forestry operations. However, some key points are worth emphasizing:

- Protect forest land from conversion to non-forest use and native forest from conversion to plantations.
- Involve a professional forester (or a licensed forester in states where available) in development of a long-term management plan and supervision of harvests.
- Engage a certified logger from the Master Logger Certification Program or other similar program when harvesting.
- Follow all best management practices (BMPs) for the state or region.
- Plan and construct roads and skid trails based on professional advice and BMPs.
- Integrate biomass harvesting with other forest operations. Re-entering a site where timber was recently harvested to remove

biomass can increase site impacts such as soil compaction and may harm post-harvest regeneration.

- Use low impact logging techniques such as directional felling or use of slash to protect soil from rutting and compaction from harvest machines.
- Use appropriate equipment matched to site and operations.

## 3. RELEVANT RESEARCH FOR NORTHEASTERN FOREST TYPES

Although there is too much scientific uncertainty to provide specific targets for each forest type, the research described below may help landowners and foresters interested in additional tree, snag, and DWM retention tailored to specific forest types. We hope the need to better quantify decaying tree, snag, and DWM retention requirements will catalyze new research efforts and the retention target can be updated based on new science.

### Measurements of Downed Woody Material

Most of the scientific research measures DWM in terms of dry tons per acre rather than percentage of DWM retained after harvest. Tons per acre may not currently be a useful measurement unit for forester and loggers, but we present data in those units here because of their prevalence in scientific literature. This measurement unit may become more prevalent as biomass harvesting increases. Field practitioners typically have not paid a great deal attention to volumes of DWM. Measurement techniques are available to integrate DWM sampling into forest inventories; over time, field practitioners will develop an awareness of volumes-per-acre of DWM, similar to standing timber volumes. The Natural Fuels Photo Series illustrates various levels of DWM and can be used to assist this process (http://depts.washington.edu/nwfire/dps/).

In general, stands have the most DWM when they are young (and trees are rapidly dying from competition) or when they are old (and trees are in various states of decline). Healthy, intermediate-aged stands tend to have less DWM. The following table represents a target range for the mass of DWM left on-site after harvest (including both existing and harvest-generated DWM). The table is based on a number of studies that documented the ranges of observed DWM in managed and unmanaged stands in the Northeast (see Evans and Kelty 2010 for more details). The selected target ranges reflect measurements from unmanaged stands more than those from managed stands and take into account patterns of DWM accumulation during stand development.

**Table 2. DWM Ranges by Forest Type**

| | Northern HW | Spruce-Fir | Oak-Hickory | White and Red Pine |
|---|---|---|---|---|
| Tons of DWM per acre* | 8–16 | 5–20 | 6–18 | 2–50 |

** Includes existing DWM and additional material left during harvesting to meet this target measured in dry tons per acre.*

### SPRUCE–FIR FORESTS

Research data on DWM in Maine's spruce-fir forest include 3.4 tons per acre10 and a range from 22 to 117 tons per acre.[20] The low estimate of 3.4 tons per acre is from a survey that includes intensively-managed lands that may not have enough DWM to maintain ecosystem processes and retain soil nutrients,10 while the higher estimates come from unmanaged lands.[20]

The basal area of dead trees from a survey of paper birch-red spruce-balsam fir and red spruce-balsam fir stands ranged from 11 to 43 percent of stand basal area.[23] The Canadian province of Newfoundland and Labrador requires retention of 4 snags per acre, while Maine recommends retaining 3 snags and/or cavity trees greater than 14 inches DBH and one greater than 24 inches DBH.[6, 19] Smith and colleagues recommend retention and recruitment of white birch snags to ensure sufficient snag and DWM density.19 Other guidelines recommend between 5 and 6 snags per acre greater than 8 inches DBH and an additional 4 to 6 potential cavity trees at least 10 inches DBH.[26]

### NORTHERN HARDWOOD FORESTS

Measures of the DWM in northern hardwood forests are as low as 3.1 tons per acre (Roskoski 1977), but 16 other measurements from 6 scientific articles average 17 tons per acre, with a low of 8 tons per acre.[18, 21, 8, 14, 16, 2] Dead trees made up 3 to 14 percent of the basal area in five hemlock-yellow birch stands and 5 to 34 percent of basal area in sugar maple-beech-yellow birch stands.[23] Other research suggests retention of between 5 and 17 snags per acre.[7, 15, 13] Tubbs and colleagues recommend leaving between one and ten live decaying trees per acre at least 18 inches DBH.[24] Research has documented a range of 7 to 25 to cavity trees per acre in unmanaged stands.[7, 13]

### TRANSITIONAL HARDWOOD /OAK-HICKORY FORESTS

Measures of the DWM in transitional hardwood forests, i.e., oak-hickory forests of southern New England, range from 5.8 to 18 tons per acre.22, 12 Out of seven oak stands in Connecticut, the number of dead trees ranged from 19 to 44 per ac or 5 to15 percent of basal area.[23]

### WHITE AND RED PINE FORESTS

Estimates of the volume of downed dead wood in white and red pine forests range from 1.6 to 50 tons per acre of DWM.3, 10 Unmanaged red pine stands in the Great Lakes area had 30 snags per acre while a managed forest had 6.9 per acre.[3] Many of the red oak and white pine stands on sandy outwash sites are susceptible to nutrient losses because of a combination of low-nutrient capital and past nutrient depletion.[9]

## 4. CARBON CONSIDERATIONS AND GUIDELINES

To date, forestry or biomass harvesting BMPs have not included guidelines for the management of carbon. However, climate change has the potential to fundamentally change both forests and forestry over the next century. Moreover, climate change has added carbon management to the responsibilities of forest managers and landowners (Forest Guild Carbon Policy Statement 2010). Protecting forests from conversion to other land uses is the most important forest management measure to store carbon and mitigate climate change. Biomass harvests may reduce the incentive to convert forests to other uses by providing additional income to forest landowners, and maintaining the forest industry and availability of markets.

The extent to which forest biomass can serve as a low-carbon alternative to fossil fuels is currently the subject of intense debate. In 2010, the Forest Guild is engaged in a comprehensive study commissioned by the Massachusetts Department of Energy Resources and led by Manomet Center for Conservation Sciences. Together with Manomet and other partners, we are investigating the impact of various forest practices on atmospheric carbon between managed and unmanaged forests. The results of this study will be available by June 2010 and will be used to expand this section on the carbon considerations for biomass harvesting. The Manomet study will model different biomass harvest scenarios to help determine which forest practices have less of an impact on the accumulation of atmospheric carbon.

In the interim, the following sections offer suggestions based on research that is currently available. It is important to recognize that in some cases a practice that contributes to a significant reduction in atmospheric carbon may be, or may appear to be, in conflict with considerations regarding biodiversity or long-term site productivity, as outlined in previous sections of this document. For example, while utilizing logging slash for energy may prove important in a scenario designed to reduce atmospheric carbon, the retention of some logging slash post harvest may also be important for the maintenance of forest productivity. In such cases, as in many areas of forestry, divergent goals must be balanced for the specific operating unit or ownership. As discussed in previous sections, the guidelines in this report are primarily intended to support decision making about the maintenance of ecological function and value in a forest management context.

### Strategies that Improve the Carbon Budget on Managed Forests

Some forest management strategies can increase carbon sequestration rates and store more carbon over time than others. Silviculture that encourages the development of structural complexity stores more carbon than silvicultural methods that create homogenous conditions. Uneven-aged management is often used to promote a structurally complex forest and can sequester more carbon than less structurally complex forests managed with even-age methods. Even-aged management systems periodically remove most of the forest carbon. When used in existing mature forests they may have a greater negative carbon impact, particularly since near-term carbon emission reductions are most important. Where even-aged management systems are appropriate, encouraging advance regeneration, or retaining residual components of the original stand, may be the fastest way to build up or maintain forest carbon. Extending rotation length will also result in an increased mean carbon stocking volume and a potential increase in carbon in harvested wood products stored offsite.

The use of logging slash for energy production has a lower carbon impact than the use of live trees for energy because logging slash will decay and emit carbon and other greenhouse gases, while live trees will continue to sequester carbon. Similarly, since trees naturally die, decay, and emit carbon, harvests that focus on suppressed trees likely to die in the near future produce fewer carbon emissions overall than the harvest of trees that are healthier, sequester carbon faster, and have long life expectancies. By using biomass harvests to remove suppressed trees with shorter life expectancies, the remaining healthier trees, "crop trees," can grow faster and larger and produce higher-value products. These more valuable products have the potential to store carbon off-site longer than products with a shorter life cycle, such as paper or shipping pallets. These products also will meet human needs while emitting less carbon than alternatives such as steel or concrete. However, the harvest of future crop trees for energy is the worst case scenario: such a harvest reduces on-site carbon, probably limits the economic productivity of the stand, and reduces the opportunity to produce higher-value products that provide long-term carbon storage and displace more carbon-intensive products.

### Determining the Carbon Impact of Biomass Harvesting

While the use of forest biomass for energy production can be helpful in mitigating climate change, accounting procedures for carbon mitigation programs must accurately account for all of the impacts of the proposed biomass use. The accounting should be based on a life cycle analysis that evaluates the effects of forest management and biomass removals on forest carbon . In order to determine the carbon impact of a biomass harvest, the analysis must include the following elements:

1. The amount of carbon removed from the site.

2. The amount of carbon used to grow, remove and transport the material to utilization.

3. The efficiency and carbon emissions of the use of forest biomass for energy, compared to business-as-usual (i.e., no biomass harvest) alternatives.

4. Future carbon sequestration rate for the site.

5. The impact of biomass removals on the site's capacity to grow forest products that store carbon or replace other carbon-intensive products.

6. The time required to re-sequester the carbon removed from the site and the time required to re-sequester the carbon that would have been sequestered in the business-as-usual scenario.

7. The business-as-usual scenario which includes

   a. Predicted harvest rates for the forest type and site in question

   b. Carbon emissions factors for the production, transportation, and use of the business-as-usual fuel, most likely a fossil fuel.

A full accounting that includes these elements can help answer complex questions regarding forest management and carbon impacts. For example, logging slash plays a number of functions. It is a valuable source of nutrients, provides biodiversity habitat, stores carbon on-site and is a potential source of renewable energy. Biomass retention guidelines provide targets for how much to retain for ecological reasons. But how much to remove as a renewable fuel versus how much to leave for on-site carbon storage can only be answered by comprehensive modeling of carbon flows over time.

### GUIDELINES FOR CARBON STORAGE

- When managing for shade-tolerant and mid-tolerant species, a shift from even-aged to uneven-aged management will increase the retention of carbon on-site.
- When appropriate to the tree species, a shift to regeneration methods that encourage advanced regeneration, such as from clearcut to shelterwood, will retain carbon on-site for longer periods.
- Retain reserve trees or standards or delay their removal.
- Delay regeneration harvests or lengthen harvest cycles to grow trees for longer times and to larger sizes.
- Encourage rapid regeneration.
- Capture natural mortality as efficiently as possible while retaining adequate numbers of snags, decaying trees, and DWM.
- Use biomass harvests to concentrate growth on healthy crop trees that can be used to manufacture products that hold carbon for long periods or replace carbon-intensive products.

## 5. RESOURCES AND REFERENCES

### BMPs and Other State Guides

- Maine's Woody Biomass Retention Guidelines http://www.maine.gov/doc/mfs/pubs/biomass_retention_guidelines.html
- Biodiversity in the Forests of Maine: Guidelines for Land Management http://www.maine.gov/doc/mfs/pubs/pdf/biodiversity_forests_me.pdf
- Vernal Pool Habitat Management Guidelines (Maine) http://www.maine.gov/doc/mfs/pubs/pdf/vernal_pool_hmg.pdf
- Good Forestry in the Granite State: Recommended Voluntary Forest Management Practices for New Hampshire http://extension.unh.edu/resources/files/Resource000294_Rep316.pdf
- Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont http://www.vtfpr.org/watershed/documents/Amp2006.pdf
- Massachusetts Forestry Best Management Practices Manual http://www.mass.gov/dep/water/drinking/forstbmp.pdf
- Connecticut Best Management Practices for Water Quality while Harvesting Forest Products http://www.ct.gov/dep/cwp/view.asp?A=2697&Q=379248
- Northeast Master Logger Certification Program http://www.masterloggercertification.com/
- Natural Fuels Photo Series http://depts.washington.edu/nwfire/dps/

### Forest Guild Reports

- Ecology of Deadwood in the Northeast
- www.forestguild.org/publications/research/2010/ecology_of_deadwood.pdf
- An Assessment of Biomass Harvesting Guidelines www.forestguild.org/publications/research/2009/biomass_guidelines.pdf
- Synthesis of Knowledge from Biomass Removal Case Studies www.forestguild.org/publications/research/2008/Biomass_Case_Studies_Report.pdf
- A Market-Based Approach to Community Wood Energy: An Opportunity for Consulting Foresters www.forestguild.org/publications/research/2008/Market_Based_CWEP_Approach.pdf

## REFERENCES

1 Benjamin, J. G. 2010. *Considerations and Recommendations for Retaining Woody Biomass on Timber Harvest Sites in Maine*. Miscellaneous Publication 761, University of Maine, Maine Agricultural and Forest Experiment Station, Orono, ME

2 Bradford, J., P. Weishampel, M.-L. Smith, R. Kolka, R. A. Birdsey, S. V. Ollinger, and M. G. Ryan. 2009. Detrital Carbon Pools in Temperate Forests: Magnitude and Potential for Landscape-Scale Assessment. *Canadian Journal of Forest Research* 39(4):802–813

3 Duvall, M. D., and D. F. Grigal. 1999. Effects of Timber Harvesting on Coarse Woody Debris in Red Pine Forests across the Great Lakes States, USA. *Canadian Journal of Forest Research* 12(29):1926-1934

4 Evans, A. M., and M. J. Kelty. 2010. *The Ecology of Dead Wood in the Northeast*. Forest Guild, Santa Fe, NM

5 Evans, A. M., and R. T. Perschel. 2009. *An Assessment of Biomass Harvesting Guidelines*. The Forest Guild, Santa Fe, NM

6 Flatebo, G., C. R. Foss, and S. K. Pelletier. 1999. *Biodiversity in the Forests of Maine: Guidelines for Land Management*. University of Maine, Cooperative Extensive, Orono, ME

7 Goodburn, J. M., and C. G. Lorimer. 1998. Cavity Trees and Coarse Woody Debris in Old Growth and Managed Northern Hardwood Forests in Wisconsin and Michigan. *Canadian Journal of Forest Reseach* 28:427–438

8 Gore, J. A., and W. A. Patterson, III,. 1986. Mass of Downed Wood in Northern Hardwood Forests in New Hampshire: Potential Effects of Forest Management. *Canadian Journal of Forest Research* 16(2):335-339

9 Hallett, R. A., and J. W. Hornbeck. 2000. Managing Oak and Pine Stands on Outwash Sands: Protecting Plant Nutrients. *Northern Journal of Applied Forestry* 17(2):57-61

10 Heath, L. S., and D. C. Chojnacky. 2001. *Down Dead Wood Statistics for Maine Timberlands*, 1995. RB-NE-150, Forest Service, Northeastern Research Station, Newtown Square, PA

11 Herrick, S., J. Kovach, E. Padley, C. Wagner, and D. Zastrow. 2009. *Wisconsin's Forestland Woody Biomass Harvesting Guidelines*. PUB-FR-435-2009, WI DNR Division of Forestry and Wisconsin Council on Forestry, Madison, WI

12 Idol, T. W., R. A. Figler, P. E. Pope, and F. Ponder. 2001. Characterization of Coarse Woody Debris across a 100 Year Chronosequence of Upland Oak-Hickory Forests. *Forest Ecology and Management* 149(1-3):153-161

13 Kenefic, L. S., and R. D. Nyland. 2007. Cavity Trees, Snags, and Selection Cutting: A Northern Hardwood Case Study. *Northern Journal of Applied Forestry* 24(3):192-196

14 McCarthy, B. C., and R. R. Bailey. 1994. Distribution and Abundance of Coarse Woody Debris in a Managed Forest Landscape of the Central Appalachians. *Canadian Journal of Forest Research* 24(7):1317–1329

15 McGee, G. G. 2001. Stand-Level Effects on the Role of Decaying Logs as Vascular Plant Habitat in Adirondack Northern Hardwood Forests. *The Journal of the Torrey Botanical Society* 128(4):370-380

16 McGee, G. G., D. J. Leopold, and R. D. Nyland. 1999. Structural Characteristics of Old-Growth, Maturing, and Partially Cut Northern Hardwood Forests. *Ecological Applications* 9(4):1316-1329

17 MFRC. 2007. *Biomass Harvest Guidelines*. Minnesota Forest Resources Council, St. Paul, MN

18 Roskoski, J. P. 1977. *Nitrogen Fixation in Northern Hardwoods Forests*. Yale University, New Haven, CT

19 Smith, C. Y., M. T. Moroni, and I. G. Warkentin. 2009. Snag Dynamics in Post-Harvest Landscapes of Western Newfoundland Balsam Fir-Dominated Boreal Forests. *Forest Ecology and Management* 258(5):832-839

20 Taylor, A. R., J. R. Wang, and H. Y. H. Chen. 2007. Carbon Storage in a Chronosequence of Red Spruce (Picea Rubens) Forests in Central Nova Scotia, Canada. *Canadian Journal of Forest Research* 37(11):2260–2269

21 Tritton, L. M. 1980. *Dead Wood in the Northern Hardwood Forest Ecosystem*. Yale University, New Haven, CT

22 Tritton, L. M., C. W. Martin, J. W. Hornbeck, and R. S. Pierce. 1987. Biomass and Nutrient Removals from Commercial Thinning and Whole-Tree Clearcutting of Central Hardwoods. *Environmental Management* 11(5):659-666

23 Tritton, L. M., and T. G. Siccama. 1990. What Proportion of Standing Trees in Forests of the Northeast Are Dead? *Bulletin of the Torrey Botanical Club* 117(2):163-166

24 Tubbs, C. H., R. M. DeGraaf, M. Yamasaki, and W. M. Healy. 1987. *Guide to Wildlife Tree Management in New England Northern Hardwoods*. GTR-NE-118, US Forest Service, Northeastern Forest Experiment Station, Broomall, PA

25 Woodall, C. W., and V. J. Monleon. 2008. *Sampling Protocol, Estimation, and Analysis Procedures for the Down Woody Materials Indicator of the Fia Program*. NRS-GTR-22, U.S. Forest Service, Newtown Square, PA

26 Woodley, S. 2005. Snag and Cavity Tree Retention. Pages 61-64 in M. G. Betts and G. J. Forbes, editors. *Forest Management Guidelines to Protect Native Biodiversity in the Greater Fundy Ecosystem*. New Brunswick Co-operative Fish and Wildlife Research Unit, University of New Brunswick, Fredericton, NB

# APPENDIX 5

# SUMMARY OF PUBLIC INPUT TO STUDY

The intent of the public meeting held on December 17, 2009 in Holyoke, Massachusetts was:

1) to share information about the study and the questions it will address; and

2) solicit public input about additional questions the research team should consider (within the scope of the DOER RFP).

Nearly 200 people attended the public meeting. Following an overview presentation, those that were interested in providing input were broken into to small groups where the questions and comments were recorded and reported out. Those questions and comments are contained in the table below. The team reviewed these inputs and addressed those that were relevant to the study and within the scope of what DOER asked the team to assess. Additional input was solicited via the internet. The internet site was meant to be a venue for the submission of additional comments and not a forum for discussion with the study team. Maintaining an ongoing public dialogue during the study was outside the scope and budget of the study commissioned by DOER.

Outside of the public meeting, many additional submissions of comments, opinion, technical resources, and relevant articles were also submitted to the team and distributed to the appropriate subject matter expert. Submissions were made by a range of concerned citizens, organizations, and technical experts.

| Comments/Questions developed during small group breakout sessions at December 17, 2009 input meeting in Holyoke, MA (note: several submissions were illegible) | |
|---|---|
| | |
| **Comment** | **Category** |
| Why weren't researchers working on this issue in west included on panel? | Comments/Questions to DOER |
| Will each of these questions be explicitly dealt with in a public way? | Comments/Questions to DOER |
| Why aren't they looking at emissions/pollution? | Comments/Questions to DOER |
| How is study being coordinated with adjacent states? | Comments/Questions to DOER |
| If we gave this level of scrutiny to every other power producer, would anything get built? | Comments/Questions to DOER |
| Are new technologies (such as combined heat and power) being encouraged for existing power plants? | Comments/Questions to DOER |
| Can (we) guarantee exactly what emissions are emitted? | Comments/Questions to DOER |
| Sustainable communities - where is power going? (local or distant) | Comments/Questions to DOER |
| What happens when the wood runs out, will you turn to waste? Trash? And are there adequate standards in place to govern trash? | Comments/Questions to DOER |
| What if your assumptions and study results are wrong and the biomass plants are built? | Comments/Questions to DOER |
| What if your assumptions are based on sustainable harvesting and there is no enforcement after the plants are built, and illegal clearcuts are rampant? | Comments/Questions to DOER |
| Why isn't this being run as a MEPA Study? | Comments/Questions to DOER |
| Will you also consider water resources needed for biomass electric? | Comments/Questions to DOER |
| Are they delaying biomass plants until these studies are done? If not, what is the purpose of these studies? Can't this be studied in lab or research? What if state is [?] without proper data? | Comments/Questions to DOER |
| What is states statutory authority to ban issuance of new qualifications for REC and effect on ongoing biomass projects? Need explanation of RPS in MA and neighbors. Address electricity market fundamentals as it drives biomass. | Comments/Questions to DOER |
| Adequacy of DCR to oversee forest cutting on private lands and state & capacity to expand question to other states. | Comments/Questions to DOER |
| What can be done to prevent invasive species transfer with increasing wood transport of other tree parts? | Comments/Questions to DOER |
| Why won't the state halt existing permitting process for biomass while study in progress instead of issuing permits in environment of uncertainty? | Comments/Questions to DOER |

| | |
|---|---|
| How can the state prevent clustering of incinerators? | Comments/Questions to DOER |
| When are sociological impacts of biomass to be studied? | Comments/Questions to DOER |
| Why are there four proposals at this time for biomass plants? | Comments/Questions to DOER |
| What are the impacts of biomass plants on river ecology and water resources? | Comments/Questions to DOER |
| How can you be permitting the plants before the sustainability has been determined? | Comments/Questions to DOER |
| Is there a regional solution to biomass plants? | Comments/Questions to DOER |
| This is all second growth forest, why cut and destroy the best carbon sequesters we have (which don't charge)? | Comments/Questions to DOER |
| The wind blows for free, how much do you charge? | Comments/Questions to DOER |
| If 1/3 of biomass in MA is proposed to use construction and demolition debris, then why are we only studying woody forest biomass? | Comments/Questions to DOER |
| Will you examine the impact of increased biomass harvesting on the economics of tourism and recreation that exists in western MA? | Comments/Questions to DOER |
| Please consider the possibility of a statewide referendum in 2012 to stop all logging on public lands. | Comments/Questions to DOER |
| Why do we need biomass? | Comments/Questions to DOER |
| Carbon accounting of corporate energy consumption vs. future energy consumption. | Comments/Questions to DOER |
| What will harvesting of forests do to tourism industry? | Comments/Questions to DOER |
| What are the consequences of continued over-reliance on fossil fuels vs. various biomass scenarios? | Comments/Questions to DOER |
| With overall electric consumption projected to go down, why do we need biomass plants? | Comments/Questions to DOER |
| Why not put subsidies to conservation or non-emission technologies? | Comments/Questions to DOER |
| Will Governor be able to take wood from private lands by eminent domain? | Comments/Questions to DOER |
| How can we allow biomass combustion when we cannot remove particulate matter < 2.5? | Comments/Questions to DOER |
| Concern if RECs for sustainable forestry for biomass, then we'll lose control of forest. | Comments/Questions to DOER |
| Who will answer the question about human health? | Comments/Questions to DOER |
| 90% of the energy used in MA is from fossil fuels, 4.5% from hydro. Wind and solar are minimal. If we can't use biomass, then how will we get to the 10% RPS? What's the solution for getting off fossil fuels? | Comments/Questions to DOER |
| When and how, if at all, will the state address it's August, 2009 decision to only include waste sources in the renewable fuel standard? What about non-food energy crops? Cellulosic ethanol? Algae and direct-to-fuel microbes and processes? Is this study going to be the main input to the state's stance on biofuel feedstocks? If so, then why is the focus only on forests and wood? What about fallow lands? Non-thermal transformation of feedstocks and other advanced technologies? | Comments/Questions to DOER |
| Have they considered the ballot initiative where sufficient signatures were just collected fort the 2010 ballot and the fact that if it passes, incinerators will not be eligible for renewable energy credits and how this will impact the economics of the biomass effort? Related: citizen consideration of a similar ballot in 2012 for prohibition of all logging on public lands? | Comments/Questions to DOER |
| Will the research address the advisability of any biomass harvesting or removal first? All other questions follow. | Comments/Questions to Team |
| What is the definition of clearcutting (is it prohibited, is it proceeding?)? | Comments/Questions to Team |
| Are you aware state not FSC cert and has not been since April 10th? And there are serious conditions open on their forestry practices? | Comments/Questions to Team |

| | |
|---|---|
| Water quality and hydrology issue? | Comments/Questions to Team |
| How much non-renewable energy is used to produce renewable energy? | Comments/Questions to Team |
| Clean wood vs. construction/demo wood | Comments/Questions to Team |
| Alternative transportation of wood opportunities. | Comments/Questions to Team |
| Nitrogen cycles/methane cycles. How are they affected by biomass harvesting? | Comments/Questions to Team |
| How will biomass harvesting (removal of organic matter) affect acid rain impacts on forest soil? | Comments/Questions to Team |
| Where will you get your information on the technological aspects of burning biomass? | Comments/Questions to Team |
| How will biomass harvesting contribute to the spread of invasive species? | Comments/Questions to Team |
| Silvicultural perspective - what markets other than biomass are there for low grade wood? | Comments/Questions to Team |
| Is there a realistic time frame for the scope of study? Is there a way to address the time issue? | Comments/Questions to Team |
| How are they defining "forest health" and "forest sustainability"? | Comments/Questions to Team |
| Where will the displaced animals go? | Comments/Questions to Team |
| Incentives to landowners? | Comments/Questions to Team |
| Shifting balance of renewable? | Comments/Questions to Team |
| Will you consider energy security of local fuel? | Comments/Questions to Team |
| What are the positions of the Audubon Society and other environmental groups on biomass energy? | Comments/Questions to Team |
| Need to consider project finance implications in order to avoid considering unfeasible options or recommendations. | Comments/Questions to Team |
| Will DOER-funded SFBI studies be considered/utilized? | Comments/Questions to Team |
| Look at long experience with biomass energy in New England (especially southern NH). | Comments/Questions to Team |
| Look at other uses of biomass (ethanol etc.). | Comments/Questions to Team |
| Are BMPs required to be followed on public land? Concern they have not been followed in the past consistently. | Comments/Questions to Team |
| Where are you drawing the circle for supply of biomass per plant? Is it limited to 50 mile radius for each plant? Are you looking at a limit on plants with regard to supply (e.g., when several new plants are proposed and there are existing plants)? | Comments/Questions to Team |
| Are they considering pyrolysis as an alternative technology? | Comments/Questions to Team |
| Are you comparing biomass to other renewables or only to carbon based fuels? | Comments/Questions to Team |
| Are they starting with an hypothesis or asking questions without an hypothesis? What method are they using - published sources - for answering questions? Are they bringing a bias that they are trying to prove as true? | Comments/Questions to Team |
| Whate about the impact on wood prices? Are the changes in prices being considered in the economic impact analysis? The mix of biomass sources could change in price and so could carbon. | Comments/Questions to Team |
| Is there representation on the team from agricultural interests? Look at impacts on farmland. | Comments/Questions to Team |
| What about non-forest biomass resources? Are they being considered? | Comments/Questions to Team |
| What about infrastructure limits? (e.g., we have XX tons/day - but no way to get it to where [facilities are]). | Comments/Questions to Team |
| Are the total scope of impacts being considered? Co-firing issue needs to be taken into account more fully. | Comments/Questions to Team |

| | |
|---|---|
| NY study - How will their results affect our study? Or be taken into account as we embark on this? | Comments/Questions to Team |
| What is the geography being studied - just within Massachusetts? | Comments/Questions to Team |
| Are other pollutants being considered besides carbon (e.g., black carbon)? | Comments/Questions to Team |
| Are you factoring in the impacts of climate change over the next 50 years when evaluating the resource? | Comments/Questions to Team |
| BMPs are based on historical records. | Comments/Questions to Team |
| Are you considering energy to dry biomass? | Comments/Questions to Team |
| Why wasn't the study done prior to permitting plants? | Comments/Questions to Team |
| Are you looking at all scale technologies (e.g., home wood stoves) or only on larger-scale institutional level? | Comments/Questions to Team |
| Are you considering that biomass may not be sustainable or a good idea for harvesting for energy at all? | Comments/Questions to Team |
| After you establish the baseline, could you then create a model that would examine the impact of a biomass plant within 50-75 miles radius of the plant and compare the environmental impact of biomass to the other fuel sources used within that region, like wind, hydro, coal, oil, etc., and not include areas with no proposed biomass plants? | Comments/Questions to Team |
| Will this report dive right in or preface with layperson friendly terms and fundamental terms? Providing something accessible to public including life cycle of a tree and forest as it relates to carbon sequestration. | Comments/Questions to Team |
| Will they share report on progress or black box final issue? | Comments/Questions to Team |
| Existing Pine Tree Biomass already burning biomass. Are they addressing the draw of biomass plants to pull in new wood products? Do we need additional constraints on any plant? Need to address impossibility of ensuring fuel specifications. | Comments/Questions to Team |
| Will baseline study - look at each energy source, compare sustainability, renewability and carbon consequences including conservation, solar, efficiency, wind. | Comments/Questions to Team |
| See how more advanced country (Japan, Scandinavia, etc.) have dealt with biomass reducing fossil fuel. | Comments/Questions to Team |
| Climate models see MA as warmer - more erratic weather. Potential of drought to kill forest if too dense. Will model consider drought effect on unmanaged forest? | Comments/Questions to Team |
| Can the team openly address skepticism toward state and skepticism about panel members' past activities as a delay tactic. Biomass developers have applauded this study. | Comments/Questions to Team |
| Address biochar benefits/feasibility. | Comments/Questions to Team |
| When studying levels of carbon sequestration in between managed and unmanaged forest, distinguish "poorly managed forest" from "well managed forest". | Comments/Questions to Team |
| Will you study different biomass harvesting systems (i.e., cut-to-length vs. whole tree) in terms of stand damage, soil nutrient levels, and democratizing access to biomass markets (i.e., allowing all loggers to participate in the market, not just those with expensive logging/chipping systems) - This would require new biomass plants to accept round wood. | Comments/Questions to Team |
| Assessing amount of clean wood waste generated (i.e., tree trimming; ice storm wood; sawmill remains; waste pallets; secondary manufacturing waste; roadside trimming). | Comments/Questions to Team |
| Full transparency of funding sources of the members of the study group. | Comments/Questions to Team |
| Define "biomass". Is it woody biomass? | Comments/Questions to Team |
| Consider pyrolysis as technology. | Comments/Questions to Team |
| Consider methane production from natural forest decomposition. | Comments/Questions to Team |
| Assess the impact of residential use of biomass vs. commercial use of biomass. | Comments/Questions to Team |

| | |
|---|---|
| Will MA DFW goals of early successional habitat creation be considered? | Comments/Questions to Team |
| Regulations by basal area. Is this the best way to regulate whole tree harvesting? | Comments/Questions to Team |
| Are you considering that management on stand land may change? | Comments/Questions to Team |
| What capacity of mechanized operators will be required? | Comments/Questions to Team |
| It is not just a question of "sustainability". Is it a good idea to burn forests when we have too much pollution, too much carbon in the atmosphere, and already stressed forests. | Comments/Questions to Team |
| What is the impact of biomass market on incentives for private forest landowners? Will this help keep forest land in forests? | Comments/Questions to Team |
| Add other indicators of forest health. | Comments/Questions to Team |
| What were the positions of the consultants on biomass prior to being commissioned for this study? | Comments/Questions to Team |
| Research Question 2 may want to factor in diesel and gasoline truck transportation of forest fuels to the biomass plants as that relates to sustainability. | Comments/Questions to Team |
| How many invasive species will come to visit when we truck in wood from the whole northeast? Worcester has had to euthanize a whole bunch of its trees. | Comments/Questions to Team |
| Will you look at the impact of increased wood harvesting for biomass on the market for firewood? A concern in Franklin County is that the wood market will drive up the price of firewood for people who rely on it to heat. | Comments/Questions to Team |
| How is waste biomass byproduct factored into biomass equation? | Comments/Questions to Team |
| More clarification on assumptions in study. | Comments/Questions to Team |
| Why so many men on the study team? | Comments/Questions to Team |
| Will efficiency of different biomass energy technologies be taken into consideration? | Comments/Questions to Team |
| What are environmental and economic impacts of inefficient combustion of biomass? | Comments/Questions to Team |
| Will building/construction of power plants be factored into LCA? | Comments/Questions to Team |
| Will biomass harvesting be like strip mining and how do we prevent it? | Comments/Questions to Team |
| Consider indirect impacts in addition to land impacts. | Comments/Questions to Team |
| Balance effect of development and managed forests. | Comments/Questions to Team |
| Is construction and demolition material included in the study? | Comments/Questions to Team |
| Will the policy address the need for innovation in bioenergy and recognize new technologies such as gas pyrolysis and alternative feedstockes such as wastewood, construction debris, etc. | Comments/Questions to Team |
| Is construction and demolition material included in the consideration for the study? | Comments/Questions to Team |
| How much trucking will there be and how will that affect local traffic patterns and the quality of life? What is the energy impact of the trucking and will that be considered as part of the life-cycle analysis? Why are four plants so close together all being proposed at the same time and where will the wood come from? | Comments/Questions to Team |
| Indirect impacts – in addition to the land impacts, what is the environmental cost of the "growth induced impacts"? (such as the growth of the local economy? | Comments/Questions to Team |
| How can we balance the effect of development versus managed forests. What will be the land ownership incentive? The incentive to hold land in private hands? If we become too restrictive, then people will not be able to earn income from their land and have to sell off to developers. Concern about incentives for land ownership. Also, concern if REC's for sustainable forestry for biomass are impacted, then we will lose control of our forests. | Comments/Questions to Team |

| | |
|---|---|
| Request to include long-term anthropological perspective of human forest use in the area and how social and economic situations, values, etc. affect the use of forest. Going all the way back to native American Indians; through colonial times, to industrialization to the present. (editor comment: are we so vain as to think we will leave no heritage)? | Comments/Questions to Team |
| What is the H2O content of the wood being considered? | Comments/Questions to Team |
| Are we going to include extreme scenarios in the baseline such as a complete cut-off of foreign oil (i.e. middle east nuclear scenario) and the ability of the state (and the country) to continue to function? Will an extreme case be included in the baseline? | Comments/Questions to Team |
| How will more smaller plants with more lax air quality regulations and controls affect health? | Public Health Concerns |
| Look at health issues. | Public Health Concerns |
| Will you be looking at the broadest range possible of forest health indicators? Should make sure to also overlay analysis with the other detailed biodiversity planning in state, including Woodlands and Wildlands and TNC Ecoregional Plans. | Public Health Concerns |
| Call on state to address the medical society's statement that biomass incinerators pose unacceptable health risks. | Public Health Concerns |
| Why propose biomass within city limits or in a valley with a high percentage of respiratory illness? Are you mad? | Public Health Concerns |
| Air quality changes from biomass. | Public Health Concerns |
| Fine particulate given off by large trucks and impact on air quality. | Public Health Concerns |
| Other emissions from biomass combustion (other health impacts). | Public Health Concerns |
| What will happen to remnants from burning – the ash? Will there be environmental problems from it? | Public Health Concerns |
| Who will answer the question about human health and local environments? These plants are in low-lying valleys with poor air circulation and bad air quality already. What about the local climate and weather and current health issues (such as already high cancer rates)? | Public Health Concerns |

# ATTACHMENT B

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions | fact sheet

# Land-use Changes and Biofuels

*The changing landscape of low-carbon fuel risks and rewards*

Recent studies of the impact that land conversion has on the global warming pollution created by crop-based biofuels are changing the science of measuring biofuel risks and rewards. These studies demonstrate that when crop-based biofuels contribute to deforestation or other damaging land conversions, the pollution benefits can be compromised or even eliminated, potentially producing a net *increase* in pollution. The science behind these calculations is new, and the numbers can be expected to change as the science matures, but we can already conclude that biofuels must use both land and energy efficiently to ensure these fuels play a constructive role in addressing global warming.

Some biofuels can be produced without harmful changes in land use, and these have great potential to reduce global warming pollution. Examples include fuels made from biomass waste products or native perennials grown on land not currently used for or well suited to food crops. On the other hand, there are types of land that should certainly not be used for biofuel production, especially forests high in stored carbon and rich in biodiversity. Converting a forest to cropland can result in much more global warming pollution than the amount that can be reduced by the biofuels grown on that land.

## The Science of Land-use Changes

A recent paper estimated that if peatlands in Southeast Asia were converted to palm oil plantations to make biodiesel, it would take 423 years to pay back the "carbon debt" from the land-use change.[1]

In the United States today, biofuels are mainly produced from corn and soybeans grown on existing agricultural land, so there is not necessarily a direct land-use change. But there can be an indirect land-use effect when the corn and soy are taken out of the market for food and animal feed.[2] This increases corn and soy prices, stimulating land conversion in other parts of the world. A study by Searchinger et al. of this indirect effect used agricultural economics models to estimate how global markets respond to the increased use of corn for biofuels.[3] They used these models and historical data on land conversion to estimate where new crops will be planted, what land will be converted, and what emissions will result. Based on these estimates they calculated that expanded use of corn ethanol will produce almost twice as much global warming pollution as gasoline.

The federal energy bill passed in 2007 includes a Renewable Fuel Standard (RFS) that significantly accelerates use of biofuels including ethanol—from about 6 billion gallons in 2007 to 36 billion gallons in 2022. The RFS requires most renewable fuels to reduce global warming pollution, including pollution from indirect land conversion, but exempts corn

---

[1] Fargione, J., et al. 2008. Land clearing and the biofuel carbon debt. *Science* 319(5867):1235–1238.

[2] Some by-products of ethanol production can be used as animal feed and therefore replace some of the corn and soy used for fuel. This displacement is accounted for in the life cycle analysis.

[3] Searchinger, T., et al. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319(5867):1238–1240.

ethanol produced in existing plants or plants that were under construction prior to the law's enactment. This loophole undermines the standard's intended benefits. If the estimates of indirect land-use impacts by Searchinger et al. are accurate, the emissions from roughly 12 billion gallons of corn ethanol exempt from pollution limits set by the RFS could wipe out the benefits derived from the remaining 24 billion gallons of renewable fuels over the lifetime of the RFS.[4]

## A Sensible Approach to Biofuel Production

The Union of Concerned Scientists' Principles for Bioenergy Development (online at *http://www.ucsusa.org/assets/documents/clean_energy/ucs-bioenergy-principles.pdf*) suggest how biofuels and bioenergy can be a productive part of a broader strategy to address climate change. Below, we offer additional recommendations that address land-use issues specifically and suggest how to avoid harmful unintended consequences, which can prevent biofuels from achieving their potential.

***Performance-based policies should reward reductions in global warming pollution over a fuel's full life cycle, based on the best available information and vetted in an open and transparent process.*** The rule making currently under way for the federal RFS and the California low-carbon fuel standard (LCFS) will determine how global warming pollution is measured for compliance with these standards; their success requires that all significant inputs and impacts, including indirect land-use changes, be considered. Because the science of global warming pollution and indirect effects is still evolving, and new studies will improve our understanding over time, both standards must also include a mechanism to ensure that life cycle emissions metrics used for compliance can be improved accordingly, and that the process is open, transparent, and based on the best peer-reviewed science.

***Biofuel life cycle analysis should include a non-zero estimate, based on the best available science, of emissions associated with indirect land-use changes.*** While there is no scientific consensus about the exact magnitude of indirect land-use effects, and details of the methodology used to measure these effects are debated, scientists generally agree that the impact is real and significant. Because the federal RFS and California LCFS will be implemented before a firm consensus on these details can be reached, both standards should take effect with a non-zero default value. The U.S. Environmental Protection Agency and the California Air Resources Board are developing models fundamentally similar to Searchinger et al. in their use of global economic agricultural models; both agencies should use their best estimates and set a schedule for updating them as the science improves. Even an indirect land-use value of one-fourth that predicted by Searchinger et al. could have significant implications for near-term policy decisions, and setting that value to zero will send the wrong signal.

***The United States should promote biofuels that use both land and energy efficiently.*** Current life cycle accounting does a good job accounting for a fuel's energy inputs, but the recent literature suggests we have not accounted for land use adequately. In spite of the uncertainty, however, we can state with relative certainty that biofuels that use land more efficiently, such as those derived from agricultural, forest-product, and municipal waste

---

[4] For more information, see: UCS. The 2007 Renewable Fuel Standard. Online at *http://www.ucsusa.org/clean_vehicles/solutions/advanced_vehicles_and_fuels/2007-renewable-fuel.html*.

streams, are a better bet than food-based biofuels from a land-use perspective. And bioenergy crops that improve land currently considered unsuitable for agriculture are likely to be the best bet of all. While these resources appear beneficial from a climate perspective, their broader impact must be considered before moving forward with their use, as outlined in the UCS Principles for Bioenergy Development.

***Additional funding should be directed to areas of research that can improve our ability to measure land-use changes globally.*** Satellite and aerial imagery, for example, can be used to accurately and objectively measure changes in land use and estimate the impact on carbon cycling, nitrogen and methane cycling, and carbon sequestration. Also, economic modeling of the impact biofuel production will have on land-use decisions worldwide (and how this affects food prices and availability, global warming pollution, deforestation, nutrient runoff, water use, and other important outcomes) will be critical to biofuel life cycle accounting and climate policy in general.

***A long-term commitment to biofuels must be tempered by realistic expectations about the scope of biomass production.*** Biofuels derived from many resources can play a role in reducing global warming pollution. The federal RFS calls for 21 billion gallons of advanced ethanol, which would require about 300 million tons of biomass. Based on current estimates, this amount of biomass can be obtained from waste products such as agricultural residues, forestry residues, and municipal and construction waste.[5] Any significant expansion beyond this level, however, must be based on a sound scientific determination that the required volume of biomass can be produced in a sustainable manner. Biofuels will have to compete for biomass with electrical power generation, biogas and chemical production, and traditional agricultural uses such as food, feed, and fiber. Unexploited biomass production systems such as forests and prairies also play an important role in supporting needed ecosystem services including water purification, carbon sequestration, nutrient cycling, biodiversity, and recreation. If we over-utilize these resources to make fuel, we risk transforming a potential solution to our fuel challenges into a major problem for food supplies and ecosystem services. We need to ensure that renewable resource policies account for this risk and strike the right balance.

*For further background on this topic, see our list "Further Reading on Biofuels" (online at* http://www.ucsusa.org/assets/documents/clean_vehicles/Further-Reading-on-Biofuels.pdf*). For more information, contact Jeremy Martin or Eli Hopson at (202) 223-6133.*

*Revised October 2008*

---

[5] Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply.* TM-2005-66. Oak Ridge, TN: Oak Ridge National Laboratory, U.S. Department of Energy.

ATTACHMENT C

Critical Review

# Environmental and Sustainability Factors Associated With Next-Generation Biofuels in the U.S.: What Do We Really Know?

PAMELA R. D. WILLIAMS,*,† DANIEL INMAN,‡
ANDY ADEN,‡ AND GARVIN A. HEATH§

*E Risk Sciences, LLP, 4647 Carter Trail, Boulder, Colorado 80301, National BioEnergy Center, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado, and Strategic Energy Analysis Center, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, Colorado*

*Received January 23, 2009. Revised manuscript received April 26, 2009. Accepted May 6, 2009.*

In this paper, we assess what is known or anticipated about environmental and sustainability factors associated with next-generation biofuels relative to the primary conventional biofuels (i.e., corn grain-based ethanol and soybean-based diesel) in the United States during feedstock production and conversion processes. Factors considered include greenhouse (GHG) emissions, air pollutant emissions, soil health and quality, water use and water quality, wastewater and solid waste streams, and biodiversity and land-use changes. Based on our review of the available literature, we find that the production of next-generation feedstocks in the U.S. (e.g., municipal solid waste, forest residues, dedicated energy crops, microalgae) are expected to fare better than corn-grain or soybean production on most of these factors, although the magnitude of these differences may vary significantly among feedstocks. Ethanol produced using a biochemical or thermochemical conversion platform is expected to result in fewer GHG and air pollutant emissions, but to have similar or potentially greater water demands and solid waste streams than conventional ethanol biorefineries in the U.S. However, these conversion-related differences are likely to be small, particularly relative to those associated with feedstock production. Modeling performed for illustrative purposes and to allow for standardized quantitative comparisons across feedstocks and conversion technologies generally confirms the findings from the literature. Despite current expectations, significant uncertainty remains regarding how well next-generation biofuels will fare on different environmental and sustainability factors when produced on a commercial scale in the U.S. Additional research is needed in several broad areas including quantifying impacts, designing standardized metrics and approaches, and developing decision-support tools to identify and quantify environmental trade-offs and ensure sustainable biofuels production.

## Introduction

Modern liquid biofuels are promoted in the United States (U.S.) as a means of achieving national energy independence and security and reducing greenhouse gas (GHG) emissions (*1–5*). First-generation (i.e., conventional) biofuels in the U.S. are produced primarily from major commercial crops such as corn (*Zea mays, L.*)-grain ethanol and soybean (*Glycine mix, L.*) biodiesel (*6, 7*). Under the U.S. Energy and Independence Security Act of 2007, conventional biofuel production is permitted to increase through 2015 up to the 15 billion gallon per year cap set on corn-grain ethanol (*4*). However, issues of sustainability and environmental impacts have been raised in response to the wide-scale production and use of conventional biofuels. For example, traditional intensive corn-grain and soybean production practices are associated with high rates of chemical (e.g., fertilizer, pesticide) inputs, extensive water consumption in some regions, and many deleterious environmental effects such as soil erosion, surface water pollution, air pollution, and biodiversity losses (*8–13*). Furthermore, recent studies suggest that increased biofuel production, particularly conventional biofuels, could result in a substantial "carbon debt" because the quantity of carbon dioxide ($CO_2$) released from direct and indirect land-use changes will be far greater than the GHG reductions from the displacement of fossil fuels (*14, 15*). Although some have been critical of these studies (*16, 17*), and advances in agronomy and biofuel conversion efficiencies have been noted (*12, 18, 19*), the expansion of conventional annual crops for biofuels may still have negative long-term environmental consequences unless more sustainable practices are employed (*10, 20*).

The desire for more diverse and sustainable fuel sources has led to greater attention being focused in the U.S. on second- and third-generation (i.e., next-generation) liquid biofuels which are produced through a variety of feedstocks and conversion technologies (*7, 21–25*). Although the literature suggests that next-generation biofuels have the potential to avoid many of the environmental challenges that face conventional biofuels (*9, 10, 15, 26–28*), few attempts have been made to synthesize and document the current state-of-knowledge on how the production of next-generation biofuels compares to conventional biofuels. The purpose of this paper is 2-fold: (1) qualitatively summarize the literature in regard to what is known or anticipated about environ-

---

* Corresponding author phone: 303-284-1935; e-mail: pwilliams@erisksciences.com.
† E Risk Sciences, LLP.
‡ National BioEnergy Center.
§ Strategic Energy Analysis Center.

10.1021/es900250d CCC: $40.75

mental and sustainability factors associated with next-generation biofuels relative to the primary conventional biofuels in the U.S. from a high-level perspective; and (2) quantitatively estimate environmental emissions, water consumption, and waste streams during selected feedstock production and ethanol conversion processes using life-cycle assessment (LCA) and systems engineering modeling tools as illustrative examples. We focus on biofuels in the U.S. context, though many of the research findings are applicable to other locations. Environmental and sustainability factors considered here include GHG emissions, air pollutant emissions, soil health and quality, water use and water quality, wastewater and solid waste streams, and biodiversity and land-use changes. Note that these factors relate primarily to environmental releases rather than impacts, because the available data and modeling tools are insufficient to adequately characterize the ultimate outcomes (e.g., human morbidity or mortality, species loss) associated with next-generation biofuels. As part of our review and analysis, we also identify several key data gaps and important areas for future research.

Our reference point for comparison is U.S.-based conventional liquid biofuels (i.e., corn-grain ethanol and soybean biodiesel); comparison to petroleum-based fuel is beyond the scope of this study. Additionally, the current paper is specifically focused on feedstock production and fuel conversion because these two life-cycle stages are considered the most significant overall with regard to environmental implications and are likely to result in the greatest differences between conventional and next-generation biofuels. In this study, next-generation feedstocks are categorized as follows: (1) the cellulosic components of municipal solid waste (e.g., tree trimmings, yard waste, paper products), (2) forest residues and thinnings (e.g., logging residues from commercial forests), (3) annual crop residues (e.g., corn stover), (4) dedicated herbaceous perennial energy crops (e.g., switchgrass, Miscanthus, native prairie grasses), (5) short-rotation woody crops (e.g., hybrid poplar, willow shrubs, eucalyptus), and (6) microalgae. These feedstocks can produce a variety of liquid transportation fuels (e.g., ethanol, biodiesel, jet fuel, green gasoline, green diesel), although feedstock categories 1−5 are typically associated with the production of ethanol while category 6 is generally associated with the production of biodiesel. Other oil-bearing feedstocks such as Jatropha (*Jatropha curcus L.*), grease and cooking waste oil, and animal fats, are not included in this study because they are of greater international interest or are not considered capable of making a significant contribution to the U.S. biofuel market (*29*−*31*). Two next-generation conversion technologies are considered in this study: (1) ethanol produced via a biochemical (enzymatic or acid hydrolysis) process, and (2) ethanol produced via a thermochemical (gasification) process. Algae-based biodiesel conversion is not discussed because transesterification is a mature and well-known process (*32*). Advanced hybrid conversion platforms and pyrolysis technologies are also not discussed due to limited access to information on these technologies. Factors related to net energy, feedstock and conversion yields, socio-economic impacts, and public policy are outside the scope of the current paper.

## Methods

This study employed two strategies: (1) a qualitative high-level review of the current literature and (2) quantitative illustrative estimates of environmental emissions, waste streams, and water consumption based on modeling. The literature review portion of this study was conducted using standard search techniques such as Boolean searches of relevant databases (e.g., Web of Science, Agricola). In addition to reviewing the peer-reviewed literature, federal government reports, presentations, and workshop materials were gathered. Personal interviews were conducted with relevant experts within the federal government, national laboratories, and selected universities. Meetings held by the interagency Biomass R&D Board, which was created by Congress in 2000 to coordinate federal activities and promote the development and adoption of biobased fuels and products in the U.S., as well as its working groups on Sustainability and Feedstock Production, were also routinely attended. Additionally, feedstock field trials and cellulosic pilot and/or proposed commercial biorefineries were toured. Based on the information gathered from these sources, next-generation biofuels are qualitatively summarized and compared to the primary conventional biofuels in the U.S. across a range of environmental and sustainability factors. Quantitative estimates are also presented in some instances to provide greater context, but precise values were not deemed to be feasible for most factors due to the paucity of data on different feedstocks, technologies, and scenarios and the difficultly in making comparisons among diverse studies. Life-cycle stages considered during feedstock production include the production of farm or field inputs, field preparation activities, planting and establishment activities, and feedstock harvesting and collection. Life-cycle stages considered during ethanol conversion include the amount and source of energy used in the biorefinery, the production of chemical and other biorefinery inputs, and the conversion process itself.

The second portion of this study utilized certain modeling tools to illustratively estimate and compare potential environmental emissions, waste streams, and water consumption associated with feedstock production and ethanol conversion. These modeling approaches are briefly described below, with a more detailed description presented in the online Supporting Information. For feedstock production, the SimaPro (v. 7.1.8) LCA model (www.pre.nl/simapro/) is used to make comparisons between three next-generation feedstocks (corn stover, switchgrass, and forest residues) and corn grain. The life-cycle stages included in this modeling are the same as those considered in the literature review. Factors assessed during feedstock production are GHGs, air pollutants, water use, and water quality metrics. For ethanol conversion, the Advanced Simulator for Process Engineering Plus (AspenPlus) model (www.aspentech.com/core/aspen-plus.cfm) is used to make predictions for biochemical and thermochemical conversion platforms for the same three next-generation feedstocks. Corn-grain ethanol is not modeled due to the lack of a comparable AspenPlus model for this feedstock. The only life-cycle stage included in this modeling is the conversion process itself (i.e., other stages were not assessed because the AspenPlus model is a mass-balance, not a LCA, model). Factors assessed during ethanol conversion are GHGs, air pollutants, water use, wastewater, and solid waste streams. Note that the modeling performed in this study is not intended to be comprehensive, but rather is for illustrative purposes and to provide more quantitative and comparative information than a traditional literature review (i.e., the modeling allows for more direct, quantitative comparisons using standardized platforms and consistent system boundaries and assumptions).

## Results

The following sections summarize the current state-of-knowledge of environmental and sustainability factors associated with next-generation biofuels relative to conventional biofuels based on our qualitative review of the literature and quantitative modeling analyses. Results are provided separately for feedstock production and conversion stages.

**Feedstock Production—Literature Review.** Overall, the production of next-generation feedstocks is expected to fare better than conventional biofuel feedstock production on most environmental and sustainability factors. The specific comparisons focused on here are between next-generation feedstocks and conventional feedstocks that are currently associated with the same biofuel in the U.S.; i.e., municipal solid waste (MSW), forest residues and thinnings, crop residues, dedicated herbaceous perennial energy crops, and short-rotation woody crops (SRWC) are compared to conventional corn-grain production, while microalgae is compared to conventional soybean production. However, because none of the next-generation feedstocks are currently produced or collected on a commercial scale, there is significant uncertainty regarding their potential positive or negative environmental implications. In particular, the sustainability of any feedstock is dependent on many factors including prior and future land use, production and management practices, temporal and spatial considerations, and prevailing environmental conditions (e.g., soils, climate) (*10, 33, 34*). There is also considerable debate about whether or how to allocate life-cycle environmental burdens between products, and the choice of allocation method can have a significant influence on the results of a study (*35, 36*). For example, in one LCA of ethanol derived from MSW, none of the environmental burdens associated with the processes and products that generated the MSW were allocated to MSW because it was assumed that MSW was a waste that needed to be disposed of (*37*). On the other hand, in LCAs of ethanol produced from corn stover, allocation schemes have ranged from attributing all life-cycle burdens of producing corn grain to the corn stover (*38*) to attributing none of these burdens to corn stover (*39*). While these are all important issues, an in-depth discussion of influential factors and allocation methodologies for different feedstocks is beyond the scope of this paper.

**GHG Emissions.** The production of next-generation feedstocks is generally expected to result in fewer overall GHG emissions compared to conventional corn-grain or soybean production in the U.S (*9, 10, 26, 27, 40*). In particular, next-generation feedstocks such as waste biomass and biomass grown on uncultivated land (i.e., unutilized arable or marginal land) are projected to incur little or no carbon debt (*14*). Anticipated reductions in GHG emissions compared to conventional feedstocks are driven primarily by the following: (1) less significant land-use/conversion impacts; (2) greater carbon sequestration in soil, plant, and root systems; (3) fewer fertilizer and pesticide inputs; and (4) less energy-intensive management practices. Reduced nitrogen fertilizer use is particularly beneficial because of reduced nitrous oxide ($N_2O$) emissions, which are 310× more potent than $CO_2$ as a GHG, and $N_2O$ releases can easily offset carbon sequestration gains (*12, 41*).

Depending on how upstream environmental burdens are allocated, the collection of waste biomass and residues for use as feedstocks may be especially promising because they are not produced *per se*, but rather are diverted from waste streams that might be disposed of in different ways. For example, because MSW is often destined for landfills, using the biological fraction of MSW as a feedstock for biofuels has the potential to emit significantly lower GHGs than conventional corn-grain production which generally requires significant amounts of land, energy, and chemical inputs (*37, 42*). Life-cycle GHG emissions from MSW-based ethanol are estimated to be approximately 60−80% less than that of conventional corn-grain ethanol, and presorting of marketable aluminum, glass, steel, and plastic materials can reduce GHG emissions by approximately 50% compared to unsorted MSW-based ethanol (*37*). It is currently unclear to what extent the allocation of potential upstream burdens associated with MSW (e.g., grass clippings produced from fertilized lawns) might offset these GHG reductions.

Similarly, using forest residues and thinnings from existing commercial logging operations as a feedstock has the potential for much lower GHG emissions compared to conventional corn-grain production because these feedstocks are considered nonmerchantable products of existing forest production systems. The collection of forest residues and thinnings has the added benefit of avoiding GHG emissions related to intentional burnings (i.e., forest residues are often disposed of through burnings) and forest wildfires (i.e., removing thinnings may reduce the frequency and intensity of wildfires) (*43−46*). Although logging activities (e.g., felling, skidding, delimbing) and residue processing (e.g., loading, chipping) are energy-intensive, total fossil fuel consumption and $CO_2$ emissions are likely to be much lower per ton of feedstock than corn-grain production given the large volumes of potentially available biomass. Additionally, even if some of the potential upstream burdens due to conventional commercial forestry (e.g., intensive land preparation, energy-intensive machinery, large pesticides and fertilizer inputs) are allocated to forest residues and thinnings, such burdens only need to be considered during forest seeding and re-establishment phases (i.e., once every 40−75 years) (*47*).

The use of crop residues, such as corn stover, as a feedstock is also expected to result in lower GHG emissions relative to conventional corn-grain production because these residues are a coproduct of existing crop production systems (although the magnitude of such GHG reductions is dependent on allocation method). However, some research suggests that the removal of corn stover could increase the net rate of $CO_2$ emissions during agricultural activities unless “best practices” are used because crop residues provide cover that allows for greater soil carbon retention rates (*48*). Additional fertilizer (e.g., 16 pounds of nitrogen per ton of dry matter) may also be required to replace nutrients during stover harvesting (*38, 49*). GHG emissions may also occur during the collection of crop residues after corn harvesting unless equipment capable of performing a single-pass harvest becomes commercially available (*38, 45*).

The production of dedicated perennial herbaceous energy crops is expected to result in lower GHG emissions than conventional corn-grain production, particularly if these crops are grown on uncultivated land, because it is anticipated that such production will require fewer pesticide and fertilizer inputs and less intensive tillage practices (*9, 10, 26, 45, 50−58*). The production of these crops on currently cultivated agricultural land, however, could result in additional GHG emissions from indirect land-use changes (*15*). Some dedicated herbaceous energy crops that are intensively managed as a monoculture may also require significant pesticide and fertilizer inputs and research suggests that these crops could be grown more sustainably as polycultures (*9, 10, 51, 53, 59*). Because dedicated herbaceous energy crops are grown for durations as long as a decade or more per rotation, they provide year-round soil cover and develop deep and complex root systems that sequester significant amounts of carbon underground (*54, 57, 60*). For example, carbon sequestration rates have been found to be as high as 20−30× greater for perennial grasses such as switchgrass compared to annual row crops like corn (*57*), and experiments with mixtures of native grassland perennials have shown that low-input high-diversity plots can result in 30× greater $CO_2$ sequestration in soil and roots relative to monoculture plots (*53*). Additionally, if nitrogen fertilizer is applied to perennial energy crops it has the potential to be less susceptible to denitrification and $N_2O$ emissions than conventionally grown corn that is irrigated because the use of irrigation is minimal or nonexistent for these crops (i.e., water mediates denitrification) and there is a longer time frame during which fertilizer can be applied (i.e., this allows for better timing of fertilizer applications to drier conditions). Relative to corn, switchgrass

(*Panicum Virgatum*, L.), miscanthus (*Miscanthus x giganteus*), and native prairie grasses have higher nitrogen-use efficiency (i.e., amount of nitrogen taken up and used in the plant per amount applied) because plant nitrogen is translocated to the roots during senescence where it is stored over winter; this results in less nitrogen fertilizer applied and therefore less potential for $N_2O$ emissions (*9, 51, 54, 55, 57, 61, 62*). Studies indicate that switchgrass production requires approximately 25−50% less total nitrogen use than conventional corn-grain production, although actual nitrogen application rates will vary depending on region and desired yields (*57, 59, 63, 64*). GHG emissions related to the production of SRWC are expected to be similar to those of dedicated herbaceous energy crops for the reasons mentioned above (*9, 26, 52, 65, 66*). Research also suggests that SRWC can store substantial amounts of carbon in roots and soil (*66*). As with forest residues, the harvesting and processing of SRWC is fossil fuel-intensive, but GHGs emitted during these activities are likely to be outweighed by the GHG emission reductions associated with SRWC production relative to conventional corn-grain production.

The cultivation of microalgae is expected to use approximately 100−300× less land area per unit yield than conventional soybean production, and it is anticipated that microalgae production will not require arable land or land applications of pesticides and fertilizers for open ponds or closed bioreactors (obviating indirect land-use GHG emissions) (*9, 26, 29, 30, 67*−*70*). Unlike most other crop-based feedstocks, microalgae may also be able to utilize nutrient-laden wastewater for cultivation, thus negating the need for fertilizers produced using fossil energy and avoiding the need to treat said wastewater (*29, 71*). Furthermore, studies indicate that $CO_2$ fixation (i.e., the capacity to absorb $CO_2$ in biomass) is approximately 10−50× greater for microalgae than terrestrial plants (*29, 71, 72*). Microalgae require $CO_2$ to grow, which could be provided by local industrial $CO_2$ sources (e.g., power plants), thus providing a GHG emission mitigation option for those sources (*9, 30, 67, 71, 73, 74*). However, some studies have shown that microalgae harvesting and separating is very energy intensive and requires significant chemical inputs (*69, 71, 75*). On balance, based on the current state-of-knowledge, potential GHG emissions from microalgae operational activities are likely to be outweighed by the GHG emission reductions associated with the production efficiency and sequestration potential of microalgae relative to conventional soybean production.

**Air Pollutant Emissions.** The production of most next-generation feedstocks is expected to result in fewer direct air pollutant emissions (or secondary transformation products) than conventional corn-grain or soybean production due to the use of waste products and less intensive agricultural production practices, particularly if grown on uncultivated land (see prior discussion). However, according to a recent LCA study, MSW-based ethanol is estimated to result in 44% greater volatile organic compound (VOC) emissions, 5−6% greater carbon monoxide (CO) emissions, 13−38% greater $NO_x$ emissions, 18% greater particulate matter ($PM_{10}$) emissions, and 32−141% greater sulfur oxide ($SO_x$) emissions compared to corn-grain ethanol, but it is unclear what proportion of these emissions is attributable to feedstock production relative to other life-cycle stages (*37*). Because they are typically treated as waste products, the use of forest residues and thinnings is likely to decrease overall air pollutant emissions compared to conventional corn-grain production (except perhaps during forest seeding and re-establishment), and some studies suggest that the collection of forest residues and thinnings can reduce local and regional air pollution by avoiding the intentional burning of logging residues and reducing the frequency and intensity of wildfires, respectively (*45, 46*). Similarly, depending on allocation method, using crop residues as a feedstock is generally expected to result in lower air pollutant emissions relative to corn-grain production, although additional fertilizer may be required to replace removed nutrients (see above). Note that in one LCA of ethanol produced from corn stover, this feedstock was found to yield 9× higher nitrogen oxide ($NO_x$) emissions compared to conventional gasoline, primarily due to emissions from cultivated soil (*38*).

The production of dedicated herbaceous energy crops and SRWC is also likely to result in lower air pollutant emissions than conventional corn-grain production due to anticipated lower pesticide, fertilizer, and tillage requirements. A recent study found that growing perennial biomass crops on land currently in the U.S. Conservation Reserve Program (CRP) results in lower fine particulate matter ($PM_{2.5}$) concentrations than corn grown conventionally in the same region because of lower fossil fuel and fertilizer inputs (*58*). Additionally, large-scale switchgrass production has the potential to reduce regional concentrations of sulfur dioxide ($SO_2$) and nitrogen dioxide ($NO_2$) because more efficient uptake of nitrogen by switchgrass compared to corn means lower fertilizer demand and fewer field applications (*39*).

Although exact future production methods are highly uncertain, the cultivation of microalgae is expected to emit only carbon and hydrogen, thus greatly reducing air emissions of sulfur and nitrogen-containing compounds compared to conventional soybean production (*68*). Several microalgae species have also been found to tolerate moderate levels (up to 150 ppm) of $SO_x$ and $NO_x$ present in industrial flue gas, which is a potential source of $CO_2$ needed by the microalgae (*71*).

**Soil Health and Quality.** Soil organic carbon (SOC) and soil erosion potential are important measures of soil health and quality. Soil properties such as cation exchange capacity, water holding capacity, soil structure, and root penetration are directly affected by SOC levels (*76*−*78*). Soil erosion reduces productivity through the loss of water-holding capacity and nutrients (*79*). Most studies show that these measures of soil health are affected by crop management practices (e.g., tillage, rotation, fertilization), although recent research suggests SOC levels for the entire soil profile (>1m) are not significantly different between tillage practices (*76, 79*−*82*). While there is currently debate regarding the relationship between tillage and SOC, there are other compelling reasons to practice conservation tillage, such as reduced erosion potential and lower fossil fuel use. In general, SOC levels are highest for forest lands and the lowest for croplands, with dedicated herbaceous energy crops and SRWCs falling between these extremes (*78*).

Crop residues notwithstanding, next-generation feedstocks are expected to have much less of an adverse impact on soil quality and health than conventional corn-grain or soybean production. For example, the collection of MSW is likely to have little to no direct adverse affect on soil quality and health. The collection of forest residues and thinnings is also likely to have minimal direct adverse effects on soil quality and health, although some concerns have been raised regarding potential depletion of nutrients and compaction of soil during the removal of thinnings from forests if these activities are poorly managed (*45, 46*). It is currently unclear how potential upstream environmental burdens associated with MSW and forest residues may affect soil quality and health.

Compared to conventional corn-grain production, the collection of crop residues has the potential for greater detrimental impacts on soil quality and health. Specifically, the excessive removal (i.e., above tolerable limits) of crop residues such as corn stover can result in significant loss of source carbon (e.g., 800 pounds per ton harvested), reduced soil fertility, increased erosion, reduced microbial life, reduced water retention capacity, and increased weed growth relative to conventional corn-grain production (*10, 20, 38, 39, 45, 48, 51, 77, 83*). Although several studies have attempted to define sustainable removal rates for corn stover by controlling for erosion and water retention, current estimates of the amount of residue that should be left on the cornfield vary widely (i.e., 25−100% of the total available corn residue) and depend on crop, farming system, rotation, climate, soils, and other factors (*38, 39, 76, 83, 84*). Recent research also suggests that the amount of stover needed to maintain SOC is a greater constraint on sustainable removal rates than that needed to control soil moisture and erosion (*76*).

The production of most dedicated herbaceous energy crops is expected to have minimal negative impacts on soil quality and health for the reasons mentioned above (e.g., low chemical inputs, less intensive tillage) and could potentially improve local soil conditions depending on previous land use. Specifically, because of their deep root systems and year-round cover, perennial herbaceous energy crops have the potential to reduce soil erosion rates, sequester and enhance SOC, and increase soil fertility over time relative to annual corn-grain production (*9, 45, 50, 54, 56, 57, 60, 62*). For example, data from controlled switchgrass plots in the U.S. indicate approximately 30× lower soil erosion during the first year and more than 600× lower erosion by the second and third years of establishment compared to the historical production of annual crops (*56*). A study of established switchgrass stands and newly cultivated cropland also shows that SOC is approximately 10−20% greater for switchgrass than cropland sites at soil depths of 0−5 and 60−90 cm on a concentration basis (*60*). Additionally, measured SOC from annually harvested perennial grasses was not found not to differ significantly from an undisturbed native grassland, suggesting that perennial feedstocks will not adversely affect soil quality (*85*). Studies show that dedicated herbaceous energy crops may also improve soil conditions if grown on marginal land and when strategically placed as buffer strips to reduce soil erosion and chemical runoff associated with conventional cropping systems (*56*). Similarly, few chemical inputs are needed to produce most SRWC, and these crops can improve soil conditions because of their extensive fine root systems (*66*). For example, compared to conventional corn-grain production, SRWC can enhance SOC storage, reduce soil erosion and nonpoint source pollution, and improve soil quality on certain lands (*65, 66*).

Although there are perhaps greater uncertainties associated with the production of microalgae than other feedstocks, its cultivation in open ponds or closed reactors is not likely to have detrimental effects on the health and quality of the surrounding soil so long as the ponds are properly lined.

**Water Use and Quality.** Crop irrigation currently dominates U.S. water withdrawals, accounting for approximately 70% of total withdrawals (*86−88*). The percentage of existing cultivated cropland needing irrigation to supplement rainfall supply is regionally dependent and can range anywhere from 2−100% for corn and 0−30% for soybeans (with most irrigation occurring in western states) (*88*). However, the total amount of water used to irrigate these crop is locally and nationally significant (e.g., 11,830,000 acre-feet/yr and 4,409,000 acre-feet/yr for U.S. production of corn and soybeans, respectively) (*86, 88*). Additionally, although research suggests that there will be sufficient water resources to meet future biofuel feedstock production demands on a national level, water shortages could still be locally significant across the U.S. due to variations in climate and geology (*86, 88, 89*). Agricultural pesticide and fertilizer use associated with conventional crop production has also long been associated with significant adverse effects such as eutrophication of fresh and ocean waters caused by phosphorus and nitrogen runoff as well as elevated nitrate levels in groundwater associated with nitrate leaching (*86*). The hypoxic zone in the Gulf of Mexico is an example of how historical agricultural practices have contributed to significant water pollution impacts in the U.S. (*8, 90*).

Depending on allocation method, the production of most next-generation feedstocks is likely to have lower water demand and less adverse impacts on water quality compared to conventional corn-grain or soybean production. For example, the collection of MSW is not expected to directly consume water or to have negative water quality impacts (*42*). Similarly, the collection of forest residues and thinnings is projected to have minimal direct water demands relative to conventional corn-grain production, and some research suggests that reducing forest stand density by removing small diameter trees may decrease water loss from evapotranspiration and increase the amount of water stored in snowpack (*46*). Although water quality could be affected if the collection of forest residues and thinnings increases sediment loadings to streams (*46*), these impacts are likely to be offset by water quality benefits from a decrease in forest residue burnings and intensive wildfires, which can lead to soil erosion and sediment loadings. The harvesting of crop residues such as corn stover, is also expected to have lower total water demands than conventional corn-grain production which can be very water-intensive in certain regions. However, the replacement of nutrients removed with biomass may necessitate additional fertilizer input, which could exacerbate water quality impacts attributed to conventional corn-grain cropping systems (*48, 88*), and the removal of crop residues may increase soil erosion if not done at sustainable rates, thereby resulting in greater sediment runoff into waterways (*86*). In one LCA study, corn stover collected at a maximum allowable rate (based on controlling erosion) resulted in a 21% increase in eutrophication potential due to increased leaching of total nitrogen and phosphorus compared to traditional corn−soybean rotation production (*39*).

Overall, the production of dedicated herbaceous energy crops and SRWC is expected to have much lower total water demands than the production of corn-grain crops because of minimal irrigation requirements, although SRWC may have greater water demand than herbaceous energy crops (*64, 88, 91*). However, some research suggests that if these crops (like any crop) are grown on marginal land or as monocultures, substantial irrigation may be required to ensure their economic viability (*10, 92*). Other potential benefits are that certain dedicated herbaceous energy crops, such as switchgrass, may be much more water efficient and heat and drought tolerant than annual row crops such as corn (*50, 55*), and much research has focused on using municipal and/or industrial wastewater for the irrigation of these crops which could reduce local freshwater demand (*9*). Neither dedicated herbaceous energy crops nor SRWC are likely to have a significant adverse impact on water quality because of their minimal use of pesticides and fertilizers (*45, 86, 91*), and the production of these crops has the potential to improve water quality relative to conventional corn-grain production by reducing off-site transport of agricultural chemicals if planted as buffer zones between surface waterways and conventional crops (*45, 65, 91*). Dedicated herbaceous energy crop production is also likely to result in less nitrogen loading to surface and groundwater because of lower overall nitrogen requirements and more efficient nitrogen uptake and use by the crop as compared to corn (*57*). For example, data from controlled switchgrass plots in the U.S. indicated approximately 2−3× lower nitrate loss from soil during the second and third years of establishment, even when compared to no-till corn production (*56*).

Although the cultivation of microalgae requires significant volumes of makeup water due to evaporative losses from open ponds or cooling water demands for closed microalgae

**TABLE 1. Comparison of Predicted Air Emissions, Water Use, and Water Quality Metrics From the Production of Next Generation Feedstocks Relative to Corn Using a LCA Model**

| | | % change relative to corn production (per metric ton) | | |
|---|---|---|---|---|
| | | forest residues | switchgrass | corn stover |
| GHG emissions | carbon dioxide ($CO_2$) | −93 | −90 | −23 |
| | dinitrogen monoxide ($N_2O$) | −99 | −56 | −23 |
| | methane ($CH_4$) | −98 | −83 | −23 |
| air pollutant emissions | carbon monoxide (CO) | −85 | −89 | −23 |
| | lead (Pb) | −87 | −88 | −23 |
| | nitrogen oxides ($NO_x$) | −75 | −86 | −23 |
| | ozone ($O_3$) | −99 | −89 | −23 |
| | particulates <2.5 mm ($PM_{2.5}$) | −94 | −87 | −23 |
| | particulates <10 mm ($PM_{10}$) | −90 | −90 | −23 |
| | sulfur dioxide ($SO_2$) | −90 | −92 | −23 |
| water use | groundwater | −100 | −100 | −23 |
| water quality | atrazine loadings[a] | −100 | −99 | −23 |
| | biological oxygen demand (BOD) | −85 | −86 | −23 |
| | chemical oxygen demand (COD) | −87 | −86 | −23 |
| | nitrate loadings | −100 | −100 | −23 |
| | phosphorus loadings | −100 | −100 | −23 |

[a] Note that this pesticide is not currently registered for use on all feedstocks.

reactors (*29, 30, 67, 68*), microalgae production is expected to use substantially less fresh water compared to conventional soybean production because many species have been found to grow well in brackish or salt water (*9, 26, 29, 68, 70, 73*). The utilization of wastewater has also been proposed for microalgae cultivation, although this could cause contamination problems or complicate downstream processing (*69, 71−73*).

**Biodiversity and Land-Use Changes.** Increased production of biofuel feedstocks can require vast amounts of land. However, the extent to which large-scale land-use changes can negatively impact biodiversity and ecosystem services depends on the type of land that is used for feedstock production (e.g., degraded versus fertile land) and the method by which these feedstocks are grown (e.g., polycultures versus monocultures) (*9, 10*). Compared to meeting U.S. biofuels mandates with increased conventional corn-grain and soybean production, the production of certain next-generation feedstocks is expected to result in fewer land-use changes and biodiversity impacts, whereas others are likely to result in much greater effects on land-use or have the potential for larger biodiversity impacts.

Depending on allocation method, the use of waste products or residues as next-generation feedstocks can significantly reduce land requirements and ecological footprints compared to conventional corn-grain or soybean production. For example, the collection of MSW will have virtually no direct effect on land use or biodiversity, except perhaps a positive impact due to less material sent to landfills (*42*). The collection of forest residues and thinnings is also likely to result in minimal direct land-use and biodiversity changes because this feedstock is located on existing forest lands. Some research suggests that the removal of forest thinnings can even indirectly improve forest growth and ecosystem functioning due to less frequent and intensive wildfires (*43, 46*). However, detrimental impacts are anticipated if excessive amounts of forest thinnings are removed due to a variety of causes (e.g., machine damage to trees and tree scarring, changes in stand structure, habitat fragmentation and wildlife disturbances, introduction of non-native plants) (*10, 45, 46*). Similarly, harvesting of crop residues is likely to result in minimal land-use changes and effects on biodiversity because these materials are produced as co-products of existing agricultural systems on land already in production. However, pheasants and other wildlife that feed on grain left in corn fields may be adversely affected by excessive corn stover removal (*93*).

Compared to conventional corn-grain production which occurs on land already in use, dedicated herbaceous energy crops and SRWC are expected to result in greater land-use changes and potential positive or negative biodiversity impacts (*9, 10, 28, 66*). For example, several studies have found that the planting of dedicated herbaceous energy crops and SRWC can improve marginal land by promoting landscape restoration and diversity and enhancing species biodiversity and natural habitats (*51−53, 65, 66*). Certain dedicated herbaceous energy crops, such as switchgrass and miscanthus, can also provide wildlife cover and habitat for birds and other species (and harvesting can be timed to occur after birds have fledged) (*62, 93−95*), while prairie grasses can offer additional ecosystem services such as supporting pollinators (*9, 50, 51, 53*). Additional research suggests that some SRWC can enhance landscape diversity, provide good foraging and nesting habitat for a variety of bird species, and increase forest interior habitats or serve as corridors between forest patches if they are planted adjacent to natural forests (*65, 91*). However, adverse biodiversity effects could occur if dedicated herbaceous energy crops and SRWC are grown as monocultures or if high carbon lands (e.g., forests) are converted for their production (*9, 10, 28, 66*). Some research also suggests that certain next-generation crops could impact wildlife habitat and biodiversity preservation due to their spatial pattern of production (*51*). Additional concerns have been raised regarding the invasive potential of some of these crops, especially if they are genetically modified or not native to the region, although the utilization of native plants such as switchgrass and sterile cultivars of species such as miscanthus can alleviate concerns of invasiveness (*9, 28, 61, 62, 96*).

The cultivation of microalgae is estimated to potentially produce 10−100× more lipids per acre than plants such as soybeans, thereby requiring much less total land area (*29, 30, 67, 69, 70*). Open ponds or closed reactors can also be sited on marginal land, although there may be some constraints on the exact location of microalgae cultivation facilities because of the need for a continuous source of $CO_2$ and water (*26, 29, 73, 74*). It is currently unclear to what extent the production of microalgae, particularly in open ponds, might have an effect on local biodiversity.

**Feedstock Production—LCA Modeling.** Comparative analyses using LCA modeling generally confirm the findings reported above from the published literature (see Table 1). Specifically, the production of all three next-generation feedstocks modeled (forest residues, switchgrass, and corn stover) is estimated to fare better than corn-grain production

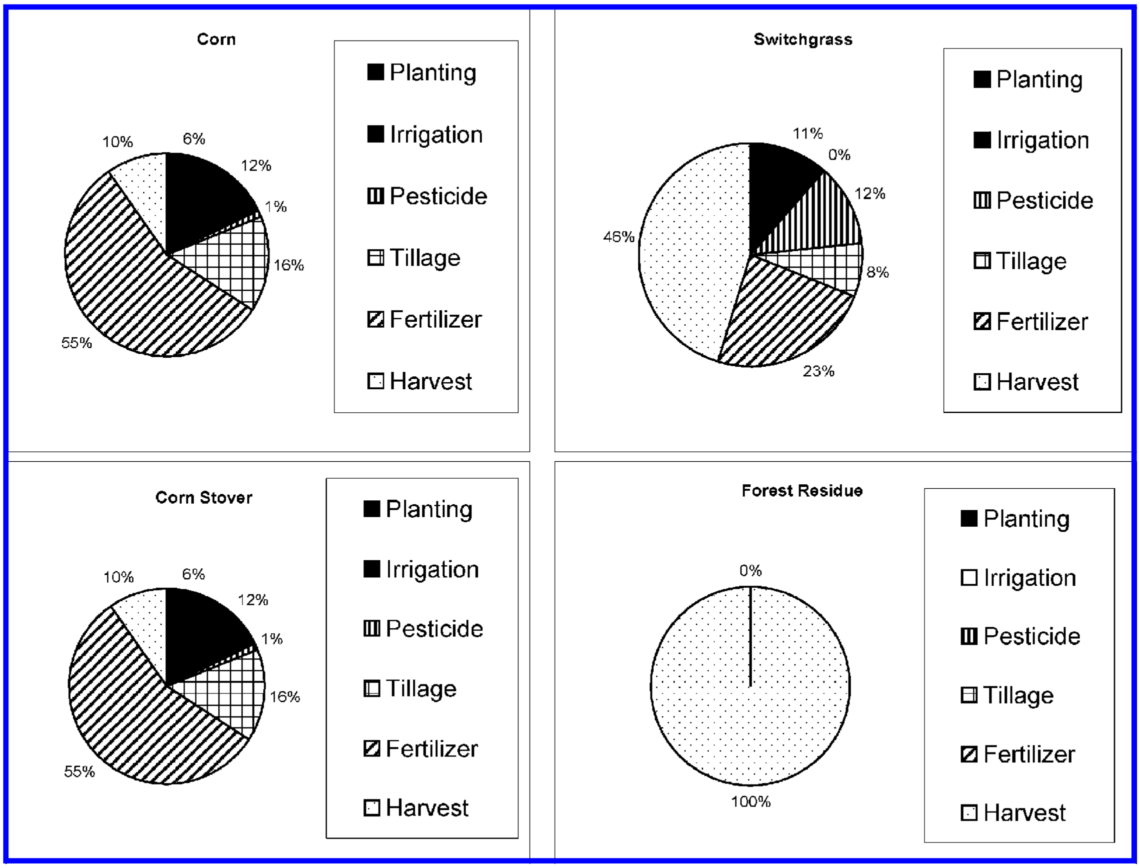


**FIGURE 1. Source contribution for carbon dioxide ($CO_2$) emissions during feedstock production.**

on all of the factors evaluated. Based on the modeling assumptions related to the allocation of environmental burdens for all three next-generation feedstocks (see Supporting Information), the production/collection of forest residues, switchgrass, and corn stover are estimated to result in approximately 93%, 89%, and 23% lower $CO_2$ emissions, respectively, than corn-grain production per ton of feedstock. However, the relative contribution of different sources to $CO_2$ emissions varies among feedstocks, with the production and application of fertilizers accounting for the greatest $CO_2$ emissions for corn grain and corn stover, whereas harvesting activities account for the greatest $CO_2$ emissions for switchgrass and forest residues (see Figure 1). During production processes, forest residues and switchgrass are also estimated to result in approximately 75−99% lower air pollutant emissions and a 100% reduction in water consumption and pesticide/fertilizer loadings to water on a per ton basis relative to corn-grain production. Corn stover is estimated to fare approximately 23% better than corn grain on a per ton basis on all factors. Note that our modeling does not assume any "credit" for avoided emissions, waste streams, or other environmental burdens (e.g., reduced air pollutant emissions from avoided burning of forest residues that are common current practices), so the actual reductions associated with production of next-generation feedstocks relative to corn-grain production may be much greater than the estimates provided here.

**Ethanol Conversion—Review of Literature.** Currently, the U.S. produces ethanol from corn grain by a dry grind or wet mill process (*6, 19, 22, 97, 98*). In a conventional ethanol biorefinery, corn starch is converted to sugars by cooking it at high temperature and using amylase enzymes to facilitate carbohydrate depolymerization to monomeric glucose. The glucose sugars are then fermented to produce ethanol and $CO_2$. Distillation separates the ethanol from the water and stillage downstream. The dominant proposed processes for conversion of next-generation cellulosic feedstocks to ethanol utilize biochemical (*99*) and thermochemical (*100*) platforms. The biochemical conversion platform uses yeast or bacteria, isolated enzymes, or strong acids to break down cellulose into fermentable sugars before operating in a manner similar to a corn-grain ethanol plant (*19, 21−23, 99, 101*). In contrast, the thermochemical conversion platform entails reacting feedstocks under conditions of limited oxygen and very high temperatures to create a synthesis gas (syngas), which is then converted to ethanol via a catalytic alcohol synthesis process after syngas cleaning and conditioning (*22, 23, 100*). It should be noted, however, that neither of the cellulosic conversion processes have been demonstrated on a commercial scale. Today's designs assume the existence of several plants using the same technology in order to eliminate the potential price spikes that might occur from "overengineering" a first-of-a-kind facility (*19, 99, 100*). Pioneer cellulosic ethanol biorefineries are therefore likely to be less efficient and produce greater emissions and waste streams than the optimized "$n^{th}$" plant designs.

**GHG Emissions.** Conventional ethanol biorefineries have become much more energy efficient over the last two decades, but these facilities are still dependent on fossil fuels (e.g., natural gas, coal) for heat and power (*6, 18, 19, 97, 98*). Cellulosic ethanol biorefineries are expected to rely on biomass instead of fossil fuels as an energy source by burning lignin residues generated during biochemical conversion processes and using a diverted portion of syngas produced during thermochemical processes (*19, 99, 100*). Cellulosic ethanol biorefineries are therefore expected to result in fewer total GHG emissions than conventional ethanol biorefineries because of their underlying source of heat and power. On the other hand, GHG emissions from conversion operations (e.g., scrubbing units, flue gas) are likely to be similar between conventional and cellulosic ethanol biorefineries (*102*). Additionally, it is currently unclear how cellulosic ethanol biorefineries will fare relative to conventional ethanol biorefineries in regards to GHG emissions associated with the production of various process inputs (e.g., ammonia, lime, sulfuric acid, enzymes). Note that $CO_2$ generated during conventional or cellulosic ethanol conversion can be collected and exported as a coproduct, thereby potentially mitigating or offsetting $CO_2$ emissions from these facilities (*6, 19*).

Total GHG emissions for cellulosic ethanol biorefineries are not expected to differ significantly between biochemical and thermochemical conversion platforms, but the proportionate contribution of different sources may vary. For biochemical conversion, the greatest $CO_2$ emissions are projected to occur from flue gas due to the burning of byproduct streams and combustion of lignin-rich residue in the boiler system (*38, 99*). Relatively small amounts of methane ($CH_4$) and $N_2O$ are also predicted to be released from this source (*99*). Smaller quantities of $CO_2$ are estimated to be released during fermentation, in which $CO_2$ (which is a byproduct of the fermentation process) is collected and sent through a scrubber to separate the organics prior to venting (*38, 99*). For thermochemical conversion, the greatest $CO_2$ emissions are projected to occur from flue gas due to the combustion of char and the slipstream of syngas to provide heat to power the refinery (*100*). Relatively small amounts of $CH_4$ and $N_2O$ are also predicted to be released from flue gas due to combustion processes (*100*). Smaller quantities of $CO_2$ are estimated to be released during gasification, in which $CO_2$ is vented to the atmosphere from the amine acid-gas scrubbing unit operations and during gas cleanup and conditioning after the removal of $CO_2$ from the cooled syngas (*100*). Although outside the scope of the current paper, these GHG emissions should be balanced against sequestration during the feedstock production stage (and added to emissions from all other stages) in a complete life-cycle accounting analysis.

**Air Pollutant Emissions.** Ethanol plants can emit significant amounts of VOCs, $SO_x$, $NO_x$, hazardous air pollutants, and particulate matter (*103*). The primary sources of air pollutant emissions from conventional corn-grain ethanol plants include the grain handling units, boilers, dried distillers grain with solubles (DDGS) dryers, fermentation, and distillation units (*103*). Although air pollution problems from the drying of distiller's grains have been associated with corn-grain ethanol plants in the past (*13*), most of these facilities have been retrofitted with thermal oxidizers to address these problems (*23*). However, cellulosic ethanol biorefineries are still expected to result in fewer total air pollutant emissions than conventional biorefineries due to the anticipated use of biomass instead of fossil fuels as an energy source. The only exception may be for $SO_x$ emissions, which may be greater for some biochemical cellulosic ethanol biorefineries than conventional ethanol biorefineries (see discussion below) (*38*).

In general, biochemical and thermochemical cellulosic ethanol biorefineries are projected to produce similar emissions of air pollutants. An exception is $SO_x$ emissions, which are likely to be greater during biochemical conversion processes if sulfuric acid is used as a pretreatment catalyst (i.e., residual sulfur can be present in the downstream lignin if the pretreatment mixture is not completely neutralized, thereby leading to $SO_x$ formations during lignin burning). The sources of air pollutant emissions may also differ by conversion platform. For biochemical conversion, air pollutant emissions are expected to occur mainly from two sources in the process: scrubbed fermentation offgas and flue gas from the biomass fluidized bed combustor (*99*). Specifically, gaseous ethanol and VOCs are produced during fermentation, while $SO_x$, $NO_x$, and particulates are generated during the combustion of lignin residue (*99*). For thermochemical conversion, air pollutant emissions are expected to be produced in significant quantities only by the char and syngas combustor (*100*).

**Water Use.** Biorefineries require a significant amount of water to convert biomass to fuel (*86*). Water demands are primarily for process and cooling purposes, with some of the greatest consumptive losses from boiler blowdown and evaporation in the cooling tower (*19, 86, 100, 104*). Although the total amount of water consumed during ethanol conversion is projected to be small compared to that during feedstock production, biofuel conversion facilities can still stress local water supplies (*86*). Sources of fresh water used during ethanol conversion processes can vary depending on where a biorefinery is sited. For example, the primary source of fresh water for most existing corn-grain ethanol plants is from local groundwater aquifers, and some of these aquifers are not readily recharged (*100, 104*). Water sources for future cellulosic ethanol biorefineries are likely to be more diverse than for conventional ethanol biorefineries, perhaps comprising a mix of groundwater and surface water sources, due to their expected geographic diversity.

Overall, cellulosic ethanol biorefineries are expected to have water requirements similar to those of conventional ethanol biorefineries. Corn-grain ethanol plants have historically used more than 15 gal. of water per 1 gal. of ethanol produced, but newly built corn-grain ethanol dry mills use an average of 3.5 gal. of fresh water to produce 1 gal. of ethanol (*6, 18, 104, 105*). By comparison, biochemical cellulosic ethanol biorefineries are expected to use approximately 6 gal. of fresh water per 1 gal. of ethanol produced, whereas thermochemical cellulosic ethanol biorefineries are expected to use approximately 2 gal. of fresh water per 1 gal. of ethanol produced (*99, 100, 104, 105*). Biochemical conversion processes have greater projected water requirements than thermochemical conversion processes because the former platform is based on a design technology that was not optimized for water use, while the latter platform minimized water usage by using forced-air cooling in place of water in some locations (*99, 104, 106*). However, because a tar reforming catalyst is not yet commercially available for thermochemical conversion systems (*107*), pioneer thermochemical biorefineries will likely require greater volumes of process water to wash the tar than what is predicted by the optimized process design.

**Wastewater.** Wastewater at biofuel conversion facilities is mostly composed of unrecycled stillage with high organic content. A small amount of wastewater is also periodically generated from salt buildup in cooling towers and boilers from evaporation and scaling and brine effluent from water purification (*86*). Because water containing organic compounds is not allowed to be discharged into rivers, wastewater produced at biofuel conversion facilities must be treated either onsite or off-site at a local wastewater treatment facility (*18*). Although corn-grain ethanol plants have produced large amounts of wastewater in the past (*13*), newer ones are typically designed to have a high degree of water recycling and "zero wastewater discharge" (i.e., up to about 10,000 gallons per year) (*18, 19, 86, 100*).

Both biochemical and thermochemical cellulosic ethanol biorefineries are also designed for zero wastewater discharge and are expected to have virtually all process water recycled through a series of onsite separation, evaporation, and anaerobic and aerobic wastewater treatment steps (*99, 100, 104*). However, scrubbing water generated during thermochemical conversion processes may require off-site wastewater treatment to economically treat the tars and other organic contaminants scrubbed from the syngas.

**Solid Waste.** Conventional ethanol biorefineries generate very little solid waste. In contrast, cellulosic ethanol biorefineries are expected to generate solid waste from several sources, including the boiler and conditioning tanks. The

**TABLE 2. Predicted Air Emissions, Water Use, and Waste Streams From Ethanol Conversion Based on Next-Generation Feedstocks and Cellulosic Conversion Technologies Using a Process Engineering Model**

| | | model estimates (kg per L of ethanol)[c] | | | | | |
|---|---|---|---|---|---|---|---|
| | | forest residues | | switchgrass | | corn stover | |
| | | biochemical | thermochemical | biochemical | thermochemical | biochemical | thermochemical |
| GHG Emissions | carbon dioxide ($CO_2$)[a] | 0.75 | 0.85 | 0.75 | 0.85 | 0.75 | 0.82 |
| | carbon dioxide ($CO_2$)[b] | 2.74 | 3.50 | 2.89 | 3.68 | 2.11 | 3.63 |
| | methane ($CH_4$)[b] | 0.00003 | 0.00 | 0.0001 | 0.00 | 0.0001 | 0.00 |
| air pollutant emissions | carbon monoxide (CO)[b] | 0.002 | 0.00 | 0.003 | 0.00 | 0.002 | 0.00 |
| | nitrogen oxides ($NO_x$)[b] | 0.002 | 0.005 | 0.003 | 0.027 | 0.002 | 0.033 |
| | sulfur dioxide ($SO_2$)[b] | 0.003 | 0.0003 | 0.004 | 0.003 | 0.003 | 0.002 |
| water use | fresh (make-up) | 7.20 | 2.56 | 8.61 | 2.17 | 6.16 | 2.67 |
| waste water | treated (off-site) | 0.00 | 0.03 | 0.00 | 0.03 | 0.00 | 0.03 |
| solid waste | ash/sand | 0.03 | 0.03 | 0.16 | 0.37 | 0.14 | 0.05 |
| | gypsum waste | 0.23 | 0.00 | 0.28 | 0.00 | 0.24 | 0.00 |
| | sulfur | 0.00 | 0.0002 | 0.00 | 0.002 | 0.00 | 0.001 |

[a] Emissions from scrubbed $CO_2$ vent. [b] Emissions from flue gas. [c] kg per ton (dry) assuming 2000 dry metric tonnes per day and 15% moisture content of feedstock.

composition of the solid waste streams is also expected to differ between biochemical and thermochemical conversion platforms due to different chemical inputs and production processes. For example, biochemical conversion processes are expected to generate large amounts of gypsum if lime is used as a conditioning agent (*99*). Research is currently underway using ammonium hydroxide as an alternative hydrolysate conditioning agent, which will eliminate this solid waste stream (*106*). Thermochemical conversion processes are expected to generate small amounts of elemental sulfur from the scrubbed syngas (*100*). Both biochemical and thermochemical conversion processes are expected to generate varying amounts of boiler ash depending on the ash content of the cellulosic feedstock.

**Ethanol Conversion—Process Engineering Modeling.** Comparative analyses using a process engineering model generally confirm findings reported in the published literature (see Table 2). For example, both conversion platforms are predicted to have similar estimated $CO_2$ and air pollutant emissions from two primary streams ($CO_2$ vent and flue gas). However, the biochemical conversion platform is estimated to produce approximately 2−10× greater $SO_x$ emissions than the thermochemical conversion platform, while the thermochemical conversion platform is estimated to produce approximately 2 to 17× greater $NO_x$ emissions than the biochemical conversion platform. Also, as expected, the biochemical conversion platform (which was not optimized for water use) is estimated to use 2−4× more water than the thermochemical conversion platform. Only the thermochemical conversion platform is predicted to produce wastewater requiring off-site treatment, while the solid waste streams are projected to differ by conversion platform (i.e., large amounts of gypsum are generated from the biochemical conversion platform, while small amounts of sulfur are generated from the thermochemical conversion platform). Note that these comparisons assume a dilute acid pretreatment process to break down hemicellulose in the biochemical conversion platform. Although there are many other alternative pretreatment technologies in development, preliminary modeling by the National Renewable Energy Laboratory (NREL) show little difference in overall emissions or effluent streams if hot water or ammonia-based processes are used instead (the use of lime has not yet been adequately studied).

## Discussion

The current paper summarizes the state-of-knowledge of what is known or anticipated about environmental and sustainability factors associated with next-generation biofuels relative to conventional biofuels during feedstock production and conversion processes in the U.S. Based on our review of the available literature and modeling analyses, we find that next-generation biofuels are expected to fare better on most of these factors compared to conventional biofuels, but the magnitude of these differences may vary significantly and will depend on many factors (e.g., prior land use, management practices). Although environmental releases can also occur during other stages of the biofuels supply chain (i.e., feedstock logistics, fuel distribution, and vehicle operation), GHG and air pollutant emissions are projected to be insignificant during these stages when compared to feedstock production and conversion steps, except for air pollutant emissions from vehicle operations (*27, 38, 108−112*). However, vehicle operation-related emissions would not vary substantially between conventional and next-generation biofuels because the properties of the biofuel (e.g., ethanol) will remain nearly the same regardless of underlying feedstock. Despite the generally positive expectations associated with next-generation biofuels, there is significant uncertainty regarding how well these biofuels will fare on different environmental and sustainability factors when produced on a commercial scale. To fill important data gaps and ensure that next-generation biofuels are produced in the U.S. in a sustainable manner, additional research is needed in the following five general areas:

(1) Studies utilizing medium- and large-scale, multiacre field trials and modeling efforts that reflect geographical differences as well as alternative feedstock production and management practices. These studies should evaluate the influence of site-specific conditions (e.g., climate, rainfall, soil type, proximity to water sources) on soil and water quality and water demands for different next-generation feedstocks. These studies should also examine the extent to which different types of management practices (e.g., no-till farming, advanced fertilizer application technologies, cover crops and riparian plantings, crops grown as polycultures) can influence stored carbon levels and improve water quality and ecosystem services. Additional research is needed to assess the potential environmental effects of new feedstock varieties or cultivars that are genetically modified for specific traits (e.g., stress and drought resistance, water and nutrient use efficiency, pest control). Moreover, future research in this area should target a broad spectrum of potential next-generation feedstocks, rather than a selected subset, with a particular focus on those that have received relatively little research attention

but which may have few negative environmental implications (e.g., MSW, microalgae, native prairie grasses).

(2) Research on the potential environmental effects of major land-use changes in the U.S. associated with the production of next-generation biofuels. In particular, this research should attempt to better characterize how the use of different types of land for feedstock production may impact GHG emissions, soil carbon levels, water quality and demand, biodiversity losses, and land use function. For example, standardized approaches and analytical tools are needed to better quantify GHG emissions from direct and indirect land use changes due to the production of different feedstocks. More research is needed to determine whether using marginal or unutilized arable land to produce different feedstocks will result in significant biodiversity losses or require sizable inputs of nutrients, pesticides, and water. Ideally, research on potential land-use changes should emphasize a systems approach that focuses on ecosystems services and considers environmental effects on several spatial and temporal scales (*10, 34, 45*).

(3) Research to optimize the efficiencies of next-generation conversion technologies. In particular, this research should focus on alternative ways to reduce energy consumption and transfer heat at cellulosic ethanol biorefineries, which can lead to fewer emissions, lower water consumption, and reduced waste streams. For the biochemical conversion platform, ongoing research should continue to explore opportunities for optimal water use and advanced pretreatment and consolidated processing steps (*21, 22, 99, 106*) that considers potential environmental releases associated with different processes. For the thermochemical conversion platform, additional research is needed to commercialize catalyst technologies for tar reforming and mixed alcohol synthesis (*100, 107*). More research is also needed to assess the potential benefits of hybrid techniques that integrate biochemical and thermochemical conversion technologies (*28, 100, 113*). Future research in this area should evaluate other advanced conversion technologies, such as pyrolysis, that can be used to produce a variety of renewable and advanced fuels (e.g., green gasoline, green diesel, jet fuel) and which can use existing infrastructure (*114, 115*).

(4) Research on the ultimate environmental and health impacts of biofuels across all life-cycle stages and standardized approaches for assessing sustainable biofuels production. This research should focus on modeling and analytical tools that move beyond initial *inventory* assessments that track environmental flows and releases, to more quantitative *impact* assessments that characterize direct and indirect environmental and health outcomes due to these releases (*57, 116*). As part of this effort, more research is needed to standardize systems boundaries and allocation methods for quantifying life-cycle environmental burdens between products and coproducts. A related research topic should be the development of universally accepted metrics for evaluating and comparing environmental and health impacts associated with biofuels across multiple scales (*34, 45, 117*). Note that efforts are currently underway in the U.S. and abroad to develop science-based criteria and indicators for sustainable biofuels production, including a white paper being prepared by the Sustainability Interagency Working Group of the Biomass R&D Board. International governmental and nongovernmental organizations, such as the Global Bioenergy Partnership and Roundtable on Sustainable Biofuels (*118*), are also developing standards, benchmarks, and principles and criteria for assessing sustainable biofuels production. However, these national and international organizations will need to work together to develop globally agreed upon sustainability metrics, especially if they are to be used for certification schemes or mandatory trade guidelines for biofuels. Data and modeling limitations also hinder our ability to identify, measure, and evaluate many environmental indicators and research will be necessary to address these shortcomings and ensure the most appropriate benchmarks and metrics are adopted (*117*).

(5) Research on environmental and sustainability trade-offs associated with the production of different biofuels and the influence of different technology and management choices using new decision-support modeling tools. This research area should focus on the development of analytical tools that are capable of identifying, quantifying, and weighing uncertainties and potential trade-offs (e.g., minimizing GHG emissions vs increasing aqueous effluent) associated with different biofuels production decisions. This research will likely entail utilizing geographic information system (GIS) information and linking process-oriented models and sector models to develop a consistent framework that explicitly considers such trade-offs and other unintended consequences (*10, 45*). These tools are necessary to ensure that the most optimal technology, management, and policy decisions are made regarding biofuel production, including which next-generation feedstocks should be produced in a specific location, what feedstock management practices should be used, and where cellulosic biorefineries should be sited.

## Acknowledgments

This work was performed while P.R.W. was an employee at the U.S. Environmental Protection Agency (EPA), Office of Research and Development, on detail to the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy. All other authors affiliated with DOE's National Renewable Energy Laboratory (NREL) received financial support under DOE contract DE-AC36-08GO28308. Any views or opinions expressed herein are those of the authors only and do not necessarily reflect those of the EPA, DOE, or NREL. We thank Zia Haq, Alison Goss Eng, John Ferrell, and Jacques Beaudry-Losique with DOE's Office of Biomass Program for their review of the scope and content of this manuscript. We also thank Alan Hecht and George Gray (EPA), Dale Gardner (NREL), and Virginia Dale and Keith Kline (ORNL) for their helpful comments on this manuscript and insight regarding sustainable biofuels production. Additionally, we acknowledge Kelly Tiller (University of Tennessee), William Davis and John Cuzens (BlueFire Ethanol), and Mitch Mandich and Bud Klepper (RangeFuels) for providing site tours and information on biofuels produced from switchgrass, MSW, and forest residues, respectively.

## Supporting Information Available

Additional information regarding the modeling tools, data sources, and assumptions used to estimate potential environmental emissions, waste streams, and water consumption associated with feedstock production and ethanol conversion. This information is available free of charge via the Internet at http://pubs.acs.org.

## Literature Cited

(1) Pacala, S.; Socolow, R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. *Science* **2004**, *305*, 968–972.
(2) Biomass Research and Development Act of 2000. Public Law 106-224.
(3) Energy Policy Act of 2005. Public Law 109-58.
(4) Energy and Independence Security Act of 2007. Public Law 110-140.
(5) Biomass Research and Development Board. *National Biofuels Action Plan*; BR&Di: Washington, DC, 2008; http://www1.eere.energy.gov/biomass/pdfs/nbap.pdf.
(6) Wu, M. *Analysis of the Efficiency of the U.S. Ethanol Industry 2007*; Argonne National Laboratory: Argonne, IL, 2008.

(7) Biomass Research and Development Board. *Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications and the Role of Research*; BR&Di: Washington, DC, 2008. Available at http://www.brdisolutions.com/Site%20Docs/Increasing%20Feedstock_revised.pdf.

(8) Donner, S. D.; Kucharik, C. J. Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. *Proc. Natl. Acad. Sci. U.S.A*. **2008**, *105*, 4513–4518.

(9) Groom, M. J.; Gray, E. M.; Townsend, P. A. Biofuels and biodiversity: principles for creating better policies for biofuel production. *Conserv. Biol*. **2008**, *22*, 602–609.

(10) Robertson, G. P.; Dale, V. H.; Doering, O. C.; Hamburg, S. P.; Melillo, J. M.; Wander, M. M.; Parton, W. J.; Adler, P. R.; Barney, J. N.; Cruse, R. M.; Duke, C. S.; Fearnside, P. M.; Follett, R. F.; Gibbs, H. K.; Goldemberg, J.; Mladenoff, D. J.; Ojima, D.; Palmer, M. W.; Sharpley, A.; Wallace, L.; Weathers, K. C.; Wiens, J. A.; Wilhelm, W. W. Sustainable biofuels redux. *Science* **2008**, *322*, 49–50.

(11) Engelhaupt, E. Biofueling water problems. *Environ. Sci. Technol*. **2007**, *41*, 7593–7595.

(12) Hill, J. Environmental costs and benefits of transportation biofuel production from food-and lignocellulose-based energy crops. A review. *Agron. Sustain. Dev*. **2007**, *27*, 1–12.

(13) Pimentel, D.; Patzek, T. W. Ethanol production using corn, switchgrass, and wood; biodiesel production using soybean and sunflower. *Nat. Resour. Res*. **2005**, *14*, 65–76.

(14) Fargione, J.; Hill, J.; Tilman, D.; Polasky, S.; Hawthorne, P. Land clearing and the biofuel carbon debt. *Science* **2008**, *319*, 1235–1237.

(15) Searchinger, T.; Heimlich, R.; Houghton, R. A.; Fengxia, D.; Elobeid, A.; Gabiosa, J.; Tokgoz, S.; Hayes, D.; Yu, T. H. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* **2008**, *319*, 1238–1240.

(16) Kline, K. L.; Dale, V. H. Biofuels: effects on land and fire. *Science* **2008**, *321*, 199.

(17) Morris, D. *Ethanol and Land Use Changes*; ILSR: Washington, DC, 2008. Available at http://www.newrules.org/sites/newrules.org/files/images/ethanol-and-land-use.pdf.

(18) Shapouri, H.; Gallagher, P. *USDA's 2002 Ethanol Cost-of-Production Survey*; USDA: Washington, DC, 2005.

(19) McAloon, A.; Taylor, F.; Yee, W.; Ibsen, K.; Wooley, R. *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks*; NREL: Golden, CO, 2000.

(20) Kline, K. L.; Oladosu, G. A.; Wolfe, A. K.; Perlack, R. D.; Dale, V. H.; McMahon, M. *Biofuel Feedstock Assessment for Selected Countries: To Support the DOE Study of Worldwide Potential to Produce Biofuels with a Focus on U.S. Imports*; ORNL: Oak Ridge, TN, 2008.

(21) U.S. Department of Energy. *Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda. A Research Roadmap Resulting from the Biomass to Biofuels Workshop*; DOE: Washington, DC, 2006.

(22) U.S. Environmental Protection Agency. *Biomass Conversion: Emerging Technologies, Feedstocks, and Products*; EPA: Washington, DC, 2007.

(23) Granada, C. B.; Zhu, L.; Holtzapple, M. T. Sustainable liquid biofuels and their environmental impact. *Environ. Prog*. **2007**, *26*, 233–250.

(24) Perlack, R. D.; Wright, L. L.; Turhollow, A. F.; Graham, R. L.; Stokes, B. J.; Erbach, D. C. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion Ton Annual Supply*; ORNL: Oak Ridge, TN, 2005.

(25) Kim, S.; Dale, B. E. Global potential bioethanol production from wasted crops and crop residues. *Biomass Bioenergy* **2004**, *26*, 361–375.

(26) Holzman, D. C. The carbon footprint of biofuels: can we shrink it down to size in time. *Environ. Health Perspect*. **2008**, *116*, A246–A252.

(27) Farrell, A. E.; Plevin, R. J.; Turner, B. T.; Jones, A. D.; O'Hare, M.; Kammen, D. M. Ethanol can contribute to energy and environmental goals. *Science* **2006**, *311*, 506–508.

(28) Sims, R. H.; Hastings, A.; Schlamadinger, B.; Taylor, G.; Smith, P. Energy crops: current status and future prospects. *Global Change Biol*. **2006**, *12*, 2054–2076.

(29) Campbell, M. M. Biodiesel: algae as a renewable source for liquid fuel. *Guelph Eng. J*. **2008**, *1*, 2–7.

(30) Chisti, Y. Biodiesel from microalgae. *Biotechnol. Adv*. **2007**, *25*, 294–306.

(31) Kumar, N.; Sharma, P. B. *Jatropha curcus* - a sustainable source for production of biodiesel. *J. Sci. Ind. Res*. **2005**, *64*, 883–889.

(32) Van Gerpen, J.; Gray, A.; Shanks, B. H. *Convergence of Agriculture and Energy: III. Considerations in Biodiesel Production*; CAST: Ames, IA, 2008.

(33) Kim, H.; Kim, S.; Dale, B. E. Biofuels, land use change, and greenhouse gas emissions: some unexplored variables. *Environ. Sci. Technol*. **2009**, *43*, 961–967.

(34) Dale, V. H.; Wright, L. L.; Kline, K. L.; Perlack, R. D.; Graham, R. L.; Downing, M. E. Interactions between bioenergy feedstock choices, landscape dynamics, and land use. *Ecol. Applications* 2009,In Review.

(35) Kodera, K. Analysis of Allocation Methods of Bioethanol LCA; Vrije Universiteit, Amsterdam, 2007. Available at http://www.leidenuniv.nl/cml/ssp/students/keiji_kodera/analysis_allocation_methods_bioethanol.pdf.

(36) Kim, S.; Dale, B. E. Allocation Procedure in Ethanol Production System from Corn Grain. *Int. J. LCA* **2002**, *7*, 237–243.

(37) Kalogo, Y.; Habibi, S.; Maclean, H. L.; Joshi, S. V. Environmental implications of municipal solid waste-derived ethanol. *Environ. Sci. Technol*. **2007**, *41*, 35–41.

(38) Sheehan, J.; Aden, A.; Paustian, K.; Killian, K.; Brenner, J.; Walsh, M.; Nelson, R. Energy and environmental aspects of using corn stover for fuel ethanol. *J. Indust. Ecol*. **2004**, *7*, 117–146.

(39) Powers, S. E. *Quantifying Cradle-to-Farm Gate Life-Cycle Impacts Associated with Fertilizer Used for Corn, Soybean, and Stover Production*; NREL: Golden, CO, 2005.

(40) Scharlemann, J. P. W.; Laurance, W. F. How green are biofuels? *Science* **2008**, *319*, 43–44.

(41) Conant, R. T.; Paustian, K.; Del Grosso, S. J.; Parton, W. J. Nitrogen pools and fluxes in grassland soils sequestering carbon. *Nutr. Cycling Agroecosyst*. **2005**, *71*, 239–248.

(42) Li, A.; Khraisheh, M. Municipal solid waste used as bioethanol sources and its related environmental impacts. *Int. J. Soil, Sed., Water* **2008**, *1*, 1–5.

(43) Leinonen, A. *Harvesting Technology of Forest Residues for Fuel in the USA and Finland*; VTT: Helsinki, Finland, 2004. Available at http://www.vtt.fi/inf/pdf/tiedotteet/2004/T2229.pdf.

(44) Hollenstein, K.; Graham, R. L.; Shepperd, W. D. Biomass flow in the western forests: simulating the effects of fuel reduction and presettlement restoration treatments. *J. Forestry* **2001**, *99*, 12–19.

(45) Graham, R. L. Forecasting the magnitude of sustainable biofeedstock supplies: the challenges and the rewards. *Biofuels, Bioprod. Biorefin*. **2007**, *1*, 255–263.

(46) Graham, R. L.; Huff, D. D.; Kaufmann, M. R.; Shepperd, W. D.; Sheehan, J. Bioenergy and watershed restoration in the mountainous regions of the west: what are the environmental/community issues? *BioEnergy'98: Expanding BioEnergy Partnerships* **1998**, 1262–1271.

(47) National Renewable Energy Laboratory. *U.S. Life-Cycle Inventory Database*; NREL: Golden, CO, 2009. Available at http://www.nrel.gov/lci/.

(48) Lal, R. Soil and environmental implications of using crop residues as biofuel feedstock. *Int. Sugar J*. **2006**, *108*, 161–167.

(49) Edwards, W. *Estimating a Value for Corn Stover*. Iowa State University: Ames, IA, 2007.

(50) Wright, L. *Historical Perspective on How and Why Switchgrass was Selected as a "Model" High-Potential Energy Crop*; ORNL: Oak Ridge, TN, 2007.

(51) Hill, J.; Nelson, E.; Tilman, D.; Polasky, S.; Tiffany, D. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proc. Natl. Acad. Sci. U.S.A*. **2006**, 11206–11210.

(52) Junginger, M.; Faigg, A.; Rosillo-Calle, F.; Wood, J. The growing role of biofuels - opportunities, challenges, and pitfalls. *Int. Sugar. J*. **2006**, *108*, 618–629.

(53) Tilman, D.; Hill, J.; Lehman, C. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* **2006**, *314*, 1598–1600.

(54) McLaughlin, S. B.; Kszos, L. A. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass Bioenergy* **2005**, *28*, 515–535.

(55) Parrish, D. J.; Fike, J. H. The biology and agronomy of switchgrass for biofuels. *Crit. Rev. Plant Sci*. **2005**, *24*, 423–459.

(56) McLaughlin, S. B.; De La Torre Ugarte, D. G.; Garten, C. T., Jr.; Lynd, L. R.; Sanderson, M. A.; Tolbert, V. R.; Wolf, D. D. High-value renewable energy from prairie grasses. *Environ. Sci. Technol*. **2002**, *36*, 2122–2129.

(57) McLaughlin, S. B.; Walsh, M. E. Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass Bioenergy* **1998**, *14*, 317–324.

(58) Hill, J.; Polasky, S.; Nelson, E.; Tilman, D.; Huo, H.; Ludwig, L.; Neumann, J.; Zheng, H.; Bonta, D. Climate change and health costs of air emissions from biofuels and gasoline. *Proc. Natl. Acad. Sci. U.S.A*. **2009**, *106*, 2077–2082.

(59) Perrin, R.; Vogel, K.; Schmer, M.; Mitchell, R. Farm-scale production cost of switchgrass for biomass. *Bioenergy Res*. **2008**, *1*, 91–97.

(60) Liebig, M. A.; Johnson, H. A.; Hanson, J. D.; Frank, A. B. Soil carbon under switchgrass stands and cultivated cropland. *Biomass Bioenergy* **2005**, *28*, 347–354.

(61) Heaton, E. A.; Dohleman, F. G.; Long, S. P. Meeting US biofuel goals with less land: the potential of Miscanthus. *Global Change Biol*. **2008**, *14*, 2000–2014.

(62) Lewandowski, I.; Scurlock, J. M. O.; Lindvall, E.; Christou, M. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. *Biomass Bioenergy* **2003**, *25*, 335–361.

(63) U.S. Department of Agriculture. *NASS Agricultural Chemical Usage 2005 Field Crops Summary*; USDA: Washington, DC, 2006. Available at http://www.nass.usda.gov.

(64) Sokhansanj, S.; Mani, S.; Turhollow, A.; Kumar, A.; Bransby, D.; Lynd, L.; Laser, M. Large-scale production, harvest and logistics of switchgrass (*Panicum virgatum* L.) - current technology and envisioning a mature technology. *Biofuels, Bioprod. Biorefin*. **2009**, *3*, 124–141.

(65) Volk, T. A.; Abrahamson, L. P.; Nowalk, C. A.; Smart, L. B.; Tharakan, P. J.; White, E. H. The development of short-rotation willow in the northeastern United States for bioenergy and bioproducts, agroforestry and phytoremediation. *Biomass Bioenergy* **2006**, *30*, 715–727.

(66) Keoleian, G. A.; Volk, T. A. Renewable energy from willow biomass crops: life cycle energy, environmental and economic performance. *Crit. Rev. Plant Sci*. **2005**, *24*, 385–406.

(67) Darzins, A. *Algal-Derived Oil Feedstock R&D at NREL: Beyond the Aquatic Species Program*; NREL: Golden, CO, 2008.

(68) Darzins, A. Personal communication; NREL: Golden, CO, 2008.

(69) Dismukes, G. C.; Carrieri, D.; Bennette, N.; Ananyev, G. M.; Posewitz, M. C. Aquatic phototrophs: efficient alternatives to land-based crops for biofuels. *Curr. Opin. Biotechnol*. **2008**, *19*, 235–240.

(70) Sheehan, J. H.; Dunahay, T.; Benemann, J.; Roessler, P. *A Look Back at the U.S. Department of Energy's Aquatic Species Program - Biodiesel from Algae: Close-Out Report*; NREL: Golden, CO, 1998.

(71) Wang, B.; Li, Y.; Wu, N.; Lan, C. Q. $CO_2$ bio-mitigation using microalgae. *Appl. Microbiol. Biotechnol*. **2008**, *79*, 707–718.

(72) Patil, V.; Tran, K. Q.; Giselrod, H. R. Towards sustainable production of biofuels from microalgaev. *Int. J. Mol. Sci*. **2008**, *9*, 1188–1195.

(73) Hu, Q.; Sommerfeld, M.; Jarvis, E.; Ghiradi, M.; Posewitz, M.; Seibert, M.; Darzins, A. Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances. *Plant J*. **2008**, *54*, 621–639.

(74) Li, Q.; Du, W.; Liu, D. Perspectives of microbial oils for biodiesel production. *Appl. Microbiol. Biotechnol*. **2008**, *80*, 749–756.

(75) Reijnders, L. Do biofuels from microalgae beat biofuels from terrestrial plant? *Trends Biotechnol*. **2008**, *26*, 349–350.

(76) Wilhelm, W. W.; Johnson, J. M. F.; Karlen, D. L.; Lightle, D. T. Corn stover to sustain soil organic carbon further constrains biomass supply. *Agronomy J*. **2007**, *99*, 1665–1667.

(77) Johnson, J. M. F.; Allmaras, R. R.; Reicosky, D. C. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agron. J*. **2006**, *98*, 622–636.

(78) Andress, D. *Soil Carbon Changes for Bioenergy Crops*; DOE: Washington, DC, 2002.

(79) Pimentel, D.; Harvey, C.; Resosudarmo, P.; Sinclair, K.; Kurtz, D.; McNair, M.; Crist, S.; Sphritz, L.; Fitton, L.; Saffouri, R.; Blair, R. Environmental and economic costs of soil erosion and conservation benefits. *Science* **1995**, *276*, 1117–1123.

(80) Blanco-Canqui, H.; Lal, R. No-tillage and soil-profile carbon sequestration: An on-farm assessment. *Soil Sci. Soc. Am. J*. **2008**, *72*, 693–701.

(81) Baker, J. M.; Ochsner, T. E.; Ventera, R. T.; Griffis, T. J. Tillage and soil carbon sequestration - what do we really know? *Agric. Ecosyt. Environ*. **2007**, *118*, 1–5.

(82) Dolan, M. S.; Clapp, C. E.; Allmaras, R. R.; Baker, J. M.; Molina, J. A. E. Soil organic carbon and nitrogen in a Minnesota soil as related to tillage, residue and nitrogen management. *Soil Till. Res*. **2006**, *89*, 221–231.

(83) Graham, R. L.; Nelson, R.; Sheehan, J.; Perlack, R. D.; Wright, L. L. Current and potential U.S. corn stover supplies. *Agron. J*. **2007**, *99*, 1–11.

(84) Varvel, G. E.; Vogel, K. P.; Mitchell, R. B.; Follett, R. F.; Kimble, J. M. Comparison of corn and switchgrass on marginal soils for bioenergy. *Biomass Bioenergy* **2008**, *32*, 18–21.

(85) Mikhailovaa, E. A.; Bryanta, R. B.; Vassenevb, I. I.; Schwagerc, S. J.; Posta, C. J. Cultivation effects on soil carbon and nitrogen contents at depth in the Russian chernozem. *Soil Sci. Soc. Am. J*. **2000**, *64*, 738–745.

(86) National Research Council. *Water Implications of Biofuels Production in the U.S*; The National Academies Press: Washington, DC, 2008.

(87) Berndes, G. Bioenergy and water - the implications of large-scale bioenergy production for water use and supply. *Global Environ. Change* **2002**, *12*, 253–271.

(88) Pellegrino, J.; Antes, M.; Zotter, B.; Andres, H.; Scher, C. *Water Impacts from Increased Biofuels Production: An Analysis of Water Issues Based on Future Feedstock Production Scenarios*; NREL: Golden, CO, 2007.

(89) King, C.; Webber, M. E. Water intensity of transportation. *Environ. Sci. Technol*. **2008**, *42*, 7866–7872.

(90) U.S. Environmental Protection Agency. *Hypoxia in the Northern Gulf of Mexico*; EPA: Washington, DC, 2009. Available at http://epa.gov/msbasin/pdf/sab_report_2007.pdf.

(91) Graham, R. L.; Downing, M.; Walsh, M. E. A framework to assess regional environmental impacts of dedicated energy crop production. *Environ. Manage*. **1996**, *20*, 475–485.

(92) Fingerman, K.; Kammen, D.; O'Hare, M. *Integrating Water Sustainability into the Low Carbon Fuel Standard*; University of California: Berkeley, CA, 2008. Available at http://rael.berkeley.edu/files/Fingerman_WaterSust.pdf.

(93) Murray, L. D.; Best, L. B.; Jacobsen, T. J.; Braster, M. L. Potential effects on grassland birds of converting marginal cropland to switchgrass biomass production. *Biomass Bioenergy* **2003**, *25*, 167–175.

(94) Semere, T.; Slater, F. M. Ground flora, small mammal and bird species diversity in miscanthus (*Miscanthus* × *giganteus*) and reed canaray-grass (*Phalaris arundinacea*) fields. *Biomass Bioenergy* **2007**, *31*, 20–29.

(95) Roth, A. M.; Sample, D. W.; Ribic, C. A.; Paine, L.; Undersander, D. J.; Bartelt, G. A. Grassland bird response to harvesting switchgrass as a biomass energy crop. *Biomass Bioenergy* **2005**, *28*, 490–498.

(96) DiTomaso, J. M.; Barney, J. N.; Fox, A. M. *Biofuel Feedstocks: The Risk of Future Invasions*; CAST: Ames, IA, 2007.

(97) Renewable Fuels Association. *How Ethanol Is Made*; RFA: Washington, DC, 2009. Available at http://www.ethanolrfa.org/resource/made/.

(98) Eggeman, T.; Verser, D. The importance of utility systems in today's biorefineries and a vision for tomorrow. *Appl. Biochem. Biotechnol*. **2006**, *130*, 361–381.

(99) Aden, A.; Ruth, M.; Ibsen, K.; Jechura, J.; Neeves, K.; Sheehan, J.; Wallace, B.; Montague, L.; Slayton, A.; Lukas, J. *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*; NREL: Golden, CO, 2002.

(100) Philips, S.; Aden, A.; Jechura, J.; Dayton, D.; Eggeman, T. *Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass*; NREL: Golden, CO, 2007.

(101) Gray, K. A. Cellulosic ethanol - state of the technology. *Int. Sugar J*. **2007**, *109*, 146–151.

(102) Foust, T. D.; Aden, A.; Dutta, A.; Phillips, S. A rigorous comparison of biofuels conversion processes for near and long term scenarios. *Cellulose* 2009,In Review.

(103) U.S. Environmental Protection Agency. *Environmental Laws Applicable to Construction and Operation of Ethanol Plants*; EPA: Kansas City, KS, 2007. Available at http://www.epa.gov/Region7/priorities/agriculture/ethanol_plants_manual.pdf.

(104) Aden, A. Water usage for current and future ethanol production. *Southwest Hydrol*. **2007**, (Sept./Oct.), 22–23.

(105) Wu, M.; Mintz, M.; Wang, M.; Arora, S. *Consumptive Water Use in the Production of Bioethanol and Petroleum Gasoline*; ANL: Argonne, IL, 2008.

(106) Aden, A. *Biochemical Production of Ethanol from Corn Stover: 2007 State of Technology Model*; NREL: Golden, CO, 2008.

(107) Carpenter, D. L.; Deutch, S. P.; French, R. J. Quantitative measurement of biomass gasifier tars using a molecular-beam mass spectrometer: Comparison with traditional impinger sampling. *Energy Fuels* **2007**, *21*, 3036–3043.

(108) Wang, M. *Well-to-Wheels Energy and Greenhouse Gas Emission Results of Fuel Ethanol*; USDA: Washington, DC, 2008.

(109) Wu, M.; Wu, Y.; Wang, M. Energy and emission benefits of alternative transportation liquid fuels derived from switchgrass: a fuel life cycle assessment. *Biotechnol. Prog.* **2006**, *22*, 1012–1024 .

(110) Dias de Oliviera, M. E.; Vaughan, V. B.; Rykiel, E. J. Ethanol as fuel: energy, carbon dioxide balances, and ecological footprint. *BioSci.* **2005**, *55*, 593–602.

(111) Niven, R. K. Ethanol in gasoline: environmental impacts and sustainability review article. *Renewable Sustainable Energy Rev.* **2005**, *9*, 535–555.

(112) Spatari, S.; Zhang, Y.; MacLean, H. L. Life cycle assessment of switchgrass- and corn stover-derived ethanol-fueled automobiles. *Environ. Sci. Technol.* **2005**, *39*, 9750–9758.

(113) Schmidt, L. D.; Daunhauer, P. J. Hybrid routes to biofuels. *Nature* **2007**, *447*, 914–915.

(114) Hsu, D.; Bain, R. L.; Elliott, D. C.; Butner, S. Life cycle assessment of the pyrolysis of corn stover into hydrotreated gasoline and diesel; presentation at AIChe annual meeting, Nov. 19, 2008.

(115) Kalnes, T.; Marker, T.; Shonnard, D.; Koers, K. *Life Cycle Assessments for Green Diesel Production*; The World Congress on Industrial Biotechnology & Bioprocessing, 2008.

(116) Zah, R.; Böni, H.; Gauch, M.; Hischler, R.; Lehmann, M.; Wäger, P. *Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels*; Empa: Gallen, Switzerland, 2007. Available at http://www.globalbioenergy.org/bioenergyinfo/bioenergy-and-climate-change/detail/en/news/3966/icode/7/.

(117) Hecht, A. D.; Shaw, D.; Bruins, R.; Dale, V.; Kline, K.; Chen, A. Good policy follows good science: using criteria and indicators for assessing sustainable biofuel production. *Ecotoxicology* **2008**, *18*, 1–4.

(118) Roundtable on Sustainable Biofuels. *Version Zero - Global Principles and Criteria for Sustainable Biofuels Production*; RSB, 2008. Available at http://cgse.epfl.ch/page79931.html.

ES900250D

ATTACHMENT D

# Should Construction and Demolition Wood Be Burned?

## An Evaluation of NESCAUM's May 2006 Report

by

Ellen Moyer, Ph.D., P.E.

December 20, 2007

# TABLE OF CONTENTS

# TABLES

# FIGURES

# Executive Summary

The report issued by the Northeast States for Coordinated Air Use Management ("NESCAUM") in 2006 titled Emissions from Burning Wood Fuels Derived from Construction and Demolition ("C&D") Debris was critically evaluated. This evaluation indicates that the report's conclusions are not supported by the data NESCAUM reviewed, and that the NESCAUM report should not be relied upon in developing any public policies relative to the burning of C&D wood.

The NESCAUM report is seriously flawed. NESCAUM based its conclusions on a very small data set, and those sparse data do not support NESCAUM's conclusions. In addition, the quality of much of the data is questionable. Furthermore, no specific data were available regarding a number of expected air toxics, leaving significant data gaps. The NESCAUM report contained significant errors and never defined key terms.

Contrary to NESCAUM's conclusions, the data NESCAUM reviewed indicated that air emissions are higher when C&D wood is included in the fuel, at least as far as arsenic and dioxin are concerned. According to the data cited by NESCAUM, concentrations of arsenic and dioxin were doubled and quadrupled, respectively, when burning 50% C&D wood/50% forest biomass compared to burning 100% forest biomass.

Copper-chromium-arsenic-treated ("CCA-treated") wood, painted wood, and fines are included in the C&D wood fuel. NESCAUM says it is critical to eliminate CCA-treated wood from the fuel, but does not say how this could be accomplished. Literature indicates that this is a challenge because CCA-treated wood cannot always be identified visually. In addition, NESCAUM says it is critical to minimize fine-grained particles in the fuel, but does not say to what extent this is necessary. In addition, data indicate that painted wood has relatively high concentrations of toxic chemicals such as arsenic, copper, and dioxin, yet NESCAUM does not suggest that painted wood should be minimized or eliminated.

C&D wood is inherently contaminated with a variety of hazardous chemicals. NESCAUM provides no basis for its conclusion that requirements for comprehensive fuel testing will assure that fuel quality will be maintained, nor does it provide any guidance on what level of fuel testing would be adequate.

NESCAUM only evaluated air. Ash is a significant concern that was not addressed. In contrast to forest biomass plants, ash from C&D wood burning facilities must be disposed of in lined landfills due to high concentrations of heavy metals. In addition, toxic chemicals in the C&D wood present material handling issues that NESCAUM did not address.

Dispersion modeling of the stack gas concentrations from several C&D test burns indicated that ambient air concentrations of arsenic and dioxin would be below applicable guidelines. However, the modeling used flawed data and only evaluated direct inhalation. It did not consider another more indirect route of exposure from contaminant deposition onto soil and surface water, followed by subsequent uptake in the food chain. Thus, a realistic and comprehensive assessment of risks to human health and the environment from burning C&D wood has not been carried out.

# Introduction

At the request of Ridgewood Power Management (www.ridgewoodpower.com), the report issued in May 2006 by NESCAUM titled Emissions from Burning Wood Fuels Derived from Construction and Demolition Debris (2006, http://www.nescaum.org/activities/major-reports) was critically evaluated. This evaluation indicates that the report's conclusions and recommendations are not supported by the data NESCAUM relied upon.

The NESCAUM report discussed current and future C&D wood generation in the Northeast, the current status of use of C&D wood for energy generation in the region, and air emission requirements in the region. The report then briefly summarized the results of C&D wood test burns at three facilities in Maine, as well as a Best Available Control Technology ("BACT") determination to predict emissions from a fourth facility, which at the time was proposed to be developed in Maine. The report ended with a number of conclusions, and recommendations arising from the conclusions, suggesting that it is safe to burn C&D wood for energy as long as fuel and air emissions are properly managed. Several key conclusions of the report will be examined in this evaluation, namely:

- "A review of the data shows that the use of appropriately processed C&D wood is similar in its emission profile to that of virgin wood."
- "The critical element in minimizing air emissions, especially air toxics, is the elimination of copper-chromium-arsenic-treated ("CCA-treated") and penta-chlorophenol-treated ("penta-treated") wood from the fuel and minimizing fines."
- "Requirements for comprehensive testing and sampling of the fuel at both the processing facility and the location of the end user will assure that the fuel quality is maintained."

The most definitive way to evaluate the environmental impacts of burning C&D wood is to examine the actual performance of facilities that have done so. To evaluate emissions, it is necessary to review concentration data. The NESCAUM report did not provide much detail about the aforementioned test burns. Therefore, in preparing this evaluation, concentration data relative to the test burn fuel, air emissions, and ash were reviewed and are summarized below.

This evaluation provides a brief background on C&D wood and then evaluates the test burn data in some detail. The BACT determination described in the NESCAUM report is briefly discussed, and several additional concerns besides air emissions and ash are mentioned. Then each of the three conclusions above is evaluated in light of the data NESCAUM reviewed, and conclusions and recommendations of this evaluation are presented.

# Background

C&D debris is a mixture that may contain wood, drywall, brick, roofing, concrete, plastics, metals, and fines (NESCAUM, 2006). C&D wood may be treated or painted and can contain heavy metals such as copper, chromium, arsenic, cadmium, lead, mercury, zinc, and beryllium, and organic contaminants such as creosote, pentachlorophenol, dioxin, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, solvents, and volatile organic compounds (USEPA, 1999). Processing facilities attempt to separate out the wood fraction from the C&D debris and remove creosote-, penta-, and CCA-treated wood, primarily through visual inspection. The remaining wood, which also contains some fines (small particles), plastic, and non-burnable materials, is then chipped to produce the combustion fuel. Additional fines are generated in the chipping process. Fines may be comprised of disproportionate amounts of paint and other coatings containing toxic chemicals.

CCA is the most common waterborne preservative and it represented over 90% of the U.S. waterborne preservative market until 2004, when it was banned for residential use due to its toxicity (Wu et al., 2006). The amount of CCA-treated wood entering the waste stream is expected to peak around 2015 (Tom, 2001). Simple visual sorting is ineffective for distinguishing CCA-treated wood from untreated wood (Holton, 2001; Solo-Gabriele et al., 2000); stains that react with copper can be used as an aid for identifying CCA-treated wood. Data from the University of Florida (Wu et al., 2006), which are summarized in Table 1, indicate that CCA-treated wood and its ash contain high concentrations of copper, chromium, and arsenic compared to untreated wood. A University of Maine study (Humphrey, 2005) measured arsenic concentrations in CCA-treated wood at 2,010 to 2,409 milligrams per kilogram (mg/kg), approximately double the concentration of 1,200 mg/kg reported by Wu et al. (2006). Copper, chromium, and arsenic in CCA-treated wood are somewhat leachable. Toxicity Characteristic Leaching Procedure ("TCLP") concentrations of arsenic at 8 milligrams per liter (mg/l) as reported by Wu et al. (2006, Table 1 below) would classify the CCA-treated wood as "hazardous" were it not granted a specific exemption under the federal Resource Conservation and Recovery Act (see 40 Code of Federal Regulations 261.4).

## Table 1
## Metals in CCA-Treated Wood and Ash

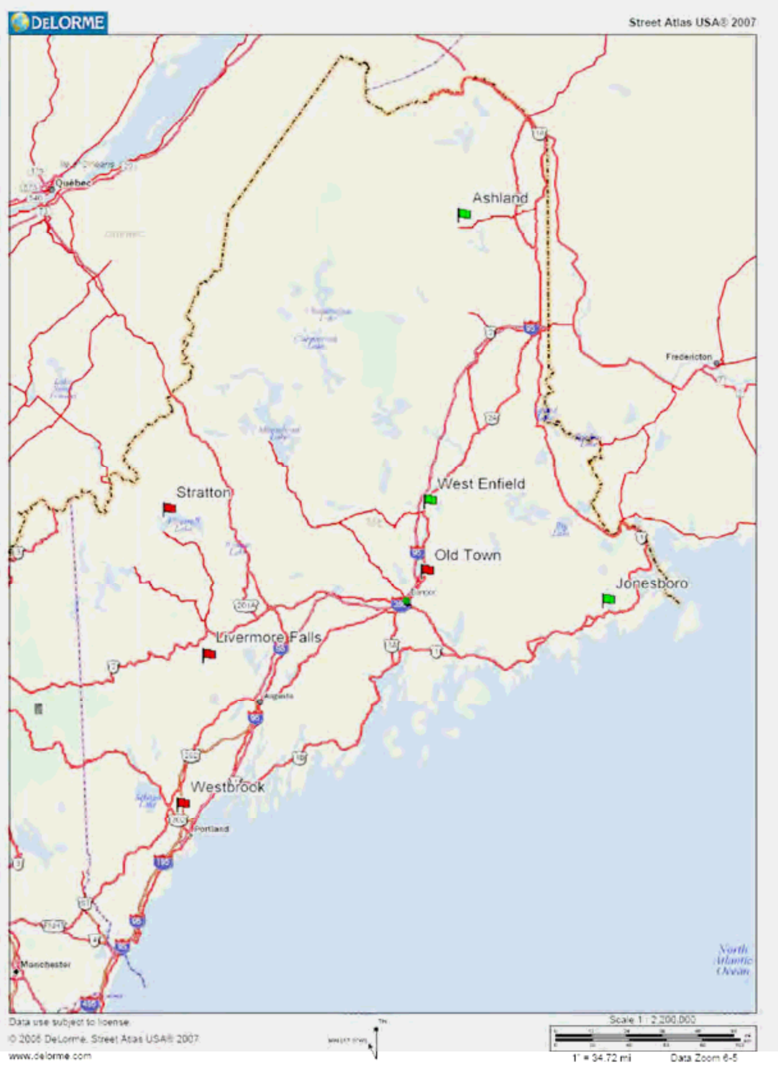
| **Metal** | **CCA-Wood** | **Untreated Wood** | **TCLP Limit** |
|---|---|---|---|
| Arsenic (mg/kg) | 1,200 | 2 | NA |
| Chromium (mg/kg) | 2,100 | 7 | NA |
| Copper (mg/kg) | 1,100 | 4 | NA |
| TCLP Arsenic (mg/l) | **8** | 0.1 | **5** |
| **Metal** | **CCA-Wood Ash** | **Untreated Wood Ash** | **TCLP Limit** |
| Arsenic (mg/kg) | 33,000 | 67 | NA |
| Chromium (mg/kg) | 16,000 | 51 | NA |
| Copper (mg/kg) | 22,000 | 120 | NA |
| TCLP Arsenic (mg/l) | **180** | 0.2 | **5** |

CCA = copper-chromium-arsenic
mg/kg = milligrams per kilogram
mg/l = milligrams per liter
TCLP = toxicity characteristic leaching procedure
NA = not applicable

*Source: Wu, Chang-Yu, Timothy Townsend, Helena Solo-Gabriele, Anadi Misra, and Brajesh Dubey. 2006. Evaluation for Thermal Processes for CCA Wood Disposal in Existing Facilities, Florida Center for Solid and Hazardous Waste Management, Contract 00053522*

Connecticut (except for two grandfathered exceptions) and New Hampshire are New England states that have banned the burning of C&D wood. In addition, Rhode Island has excluded C&D wood from its Renewable Energy Standards. As of this writing, there are three facilities in New England that currently burn C&D wood, all located in Maine: a 40 megawatt ("MW") wood-burning facility in Stratton owned by Boralex Energy, Inc. ("Boralex"); a 34 MW wood-burning facility in Livermore Falls, also owned by Boralex; and a 20 MW wood-burning facility in Old Town owned by Red Shield that had been closed and re-started operation in December 2006 (Dolloff, 2006). Two other facilities have conducted test burns of C&D wood but do not currently burn C&D wood: a 9 MW wood-burning facility in Hopkinton, New Hampshire, owned by Bio-Energy Corporation (also known as Regenesis), and a 62.5 MW wood-burning facility in Westbrook, Maine, owned by South African Paper Products, Inc. ("SAPPI"). The locations of the facilities in Maine are shown on Figure 1, along with three facilities in Ashland, Jonesboro, and West Enfield that burn only forest biomass.

**Figure 1. Wood Burning Facilities in Maine**
(Used with permission)



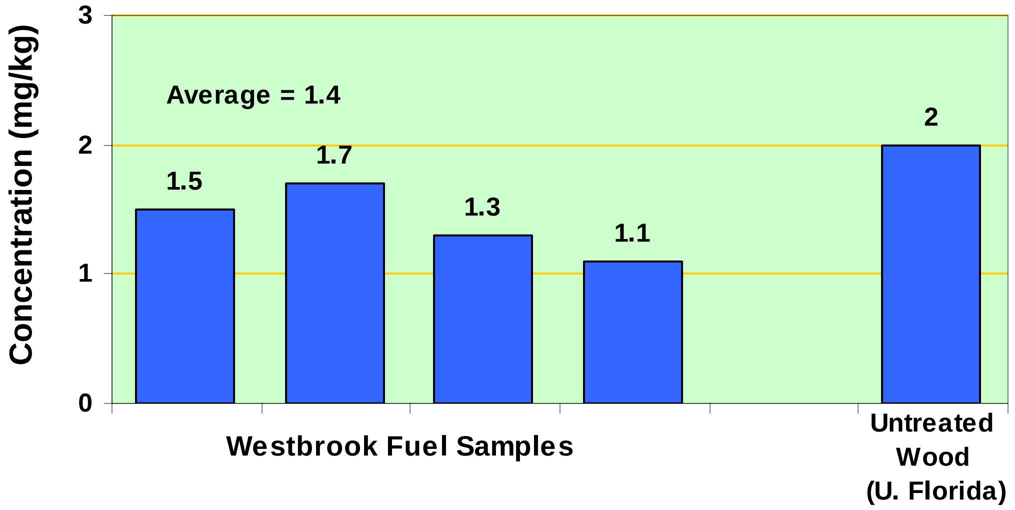
# Test Burns Considered by NESCAUM

This section presents information on the test burns discussed in the NESCAUM report. They took place in 2005 at the facilities in Westbrook, Stratton, and Livermore Falls, Maine. (The Hopkinton, New Hampshire facility is somewhat atypical, which is perhaps why NESCAUM did not review the test burn that was conducted there.)

## Fuel

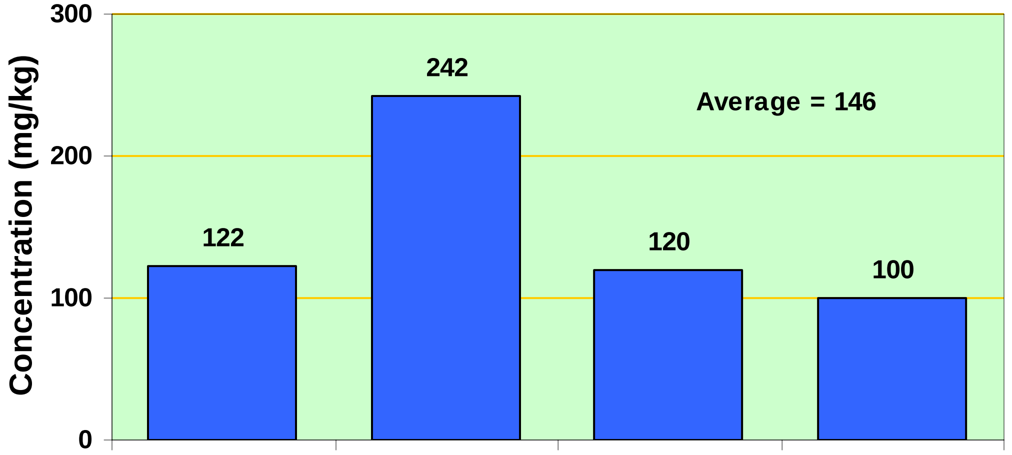
Fuel burned in the test at Westbrook consisted of approximately 50% forest biomass and 50% C&D wood (McMullin, 2006). Fuel samples were tested for 25 total metals and 8 TCLP metals (S.D. Warren Company, 2005). Total metals results for arsenic and lead are shown on Figures 2a and 2b. Arsenic and lead are of special interest because C&D wood can contain significant arsenic from CCA-treated wood and lead from lead-painted wood. Westbrook arsenic concentrations were relatively low, similar to concentrations in untreated wood reported by Wu et al., (2006). For additional perspective, it is worth noting that the arsenic concentrations are also well below the limit of 50 mg/kg for arsenic specified in the Maine Department of Environmental Protection ("Maine DEP") rules for burning C&D wood that were issued shortly after the NESCAUM report (Maine DEP, 2006). Westbrook lead concentrations illustrate the variability of concentrations in C&D wood fuel, and incidentally are also well below the 375 mg/kg limit for lead specified in the Maine rules.

**Figure 2a. Arsenic in Fuel for the Westbrook Test Burns**



*Source: S.D. Warren Company. 2005. "Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler," submitted to Maine DEP.*

**Figure 2b. Lead in Fuel for the Westbrook Test Burns**



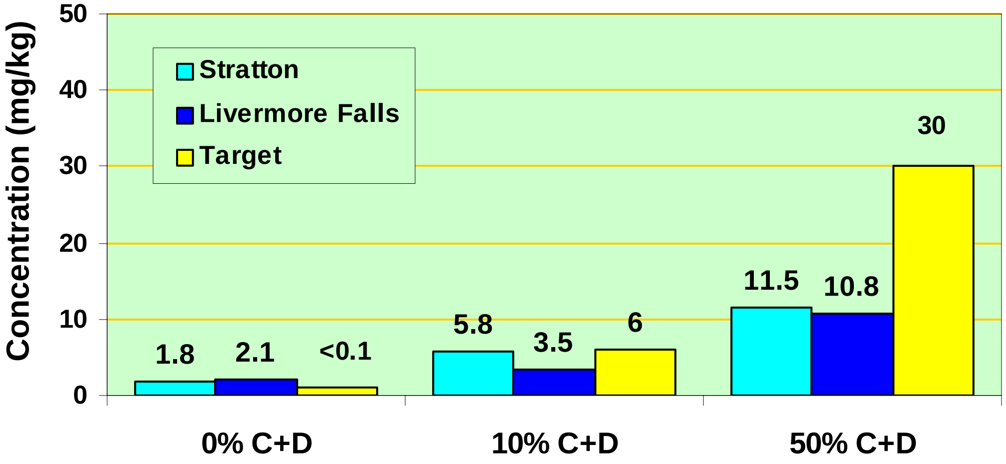
*Source: S.D. Warren Company. 2005. "Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler," submitted to Maine DEP.*

As a University of Maine research project, three blends of fuel were tested at each of the facilities in Stratton and Livermore Falls: 0% C&D wood (i.e., 100% forest biomass, "0% test"), 10% C&D wood/90% forest biomass ("10% test"), and 50% C&D wood/50% forest biomass ("50% test") (Humphrey, 2005). Some (less than 1% by mass) penta-treated wood was also added to the latter two fuels. The NESCAUM report erroneously stated that the last blend was 50% C&D wood and 50% penta-treated wood, whereas the mixture consisted of 50% C&D wood and only 1% penta-treated wood, the balance consisting of forest biomass.

Samples of the C&D wood for the Stratton test burns, which was received from three commercial and five municipal sources, were first evaluated. The volume of each sample was approximately 15 gallons. One sample from each commercial source and two samples from each municipal source were sorted visually and the various fractions were weighed. The composition of individual samples ranged as follows: 0.1 to 5.4% CCA-treated wood, 12.1 to 43.4% fines (material passing through a #4 sieve with 0.187-inch square openings), 2.1 to 13.5% painted wood, 0.1 to 1.6% plastics (such as plastic laminates and synthetic carpets), 0.1 to 4.8% non-burnable materials (such as nails, stones, and wire), and 48.1 to 74.9% non-painted non-CCA wood and paper. The average composition of the municipal samples and the commercial samples was found to be generally similar. However, as indicated above, there was a great deal of variability among samples. Much variability was seen even among duplicate samples from the same municipal source. The data also indicate the C&D "wood" may contain significant quantities of materials other than wood, with the maximum percentage of non-painted non-CCA wood in any sample being only 74.9%.

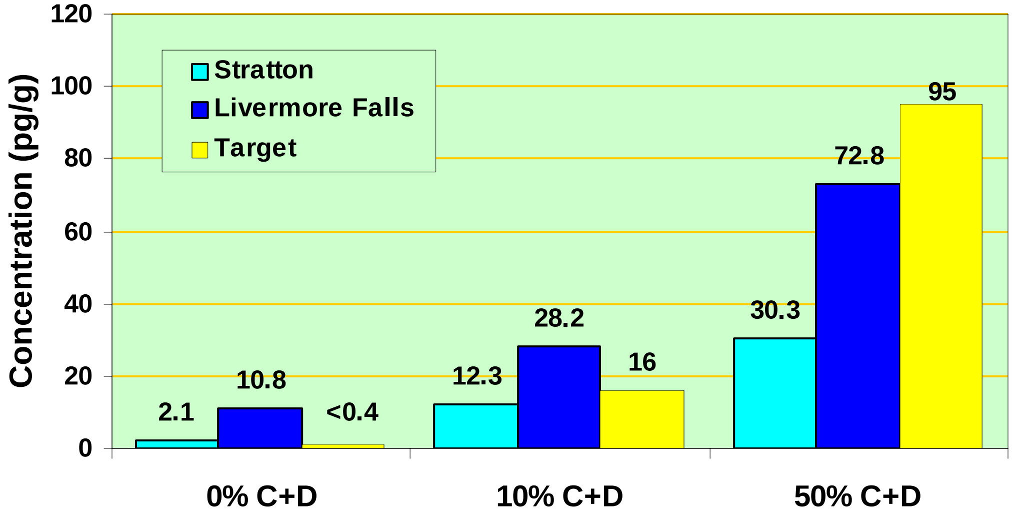
The above-described sample fractions and the three fuel blends to be test burned at each facility were then chemically analyzed, but only for total arsenic, polychlorinated dibenzo-p-dioxin/furan ("PCDD/F," or "dioxin/furan," hereafter abbreviated as "dioxin" for simplicity), copper, and chlorine. (This evaluation will focus mainly on arsenic and dioxin, because air samples were not analyzed for copper or chlorine.) Average results (for duplicate samples) for the fuel blends are shown on Figures 3a and 3b. (Results for the C&D wood sample fractions are discussed later.) Arsenic concentrations for the 50% test were less than half of the target level, which may indicate difficulty in testing or blending of the non-homogeneous fuel mixture. Arsenic concentrations are also well below the limit currently specified in the Maine rules (Maine DEP, 2006). Dioxin concentrations were also lower than target levels for the 50% test.

**Figure 3a. Arsenic in Fuel for the Stratton and Livermore Falls Test Burns**



*Source: Humphrey, Dana. 2005. <u>Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc.</u>, May 27.*

**Figure 3b. Dioxin in Fuel for the Stratton and Livermore Falls Test Burns**

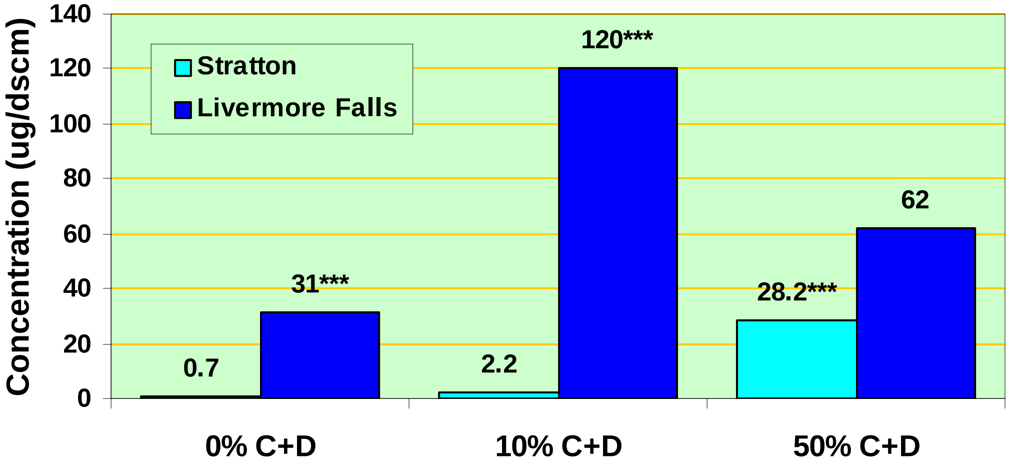


*Source: Humphrey, Dana. 2005. Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc., May 27.*

## Air

Each test burn at Stratton and Livermore Falls lasted approximately nine hours. Stack gas samples were analyzed for arsenic and dioxin. Average concentrations (for triplicate samples) are shown on Figures 4a and 4b. Arsenic and dioxin concentrations were two to forty times higher when C&D wood was included in the fuel than when it was not, with the exception of the dioxin concentrations from the Stratton 10% test which were similar to the dioxin concentrations from the 0% test at the same facility. Arsenic results did not follow the pattern expected, i.e., lowest concentrations from the 0% test, intermediate concentrations from the 10% test, and highest concentrations from the 50% test. For example, Livermore Falls air samples from the 10% test had twice the concentration of arsenic as from the 50% test. One possible explanation for this that was given in the University of Maine report was that one of the three Livermore Falls electrostatic precipitator ("ESP") fields was off during the 10% test. Since dioxin may be consumed or generated during the combustion process, a similar pattern would not necessarily be expected for this chemical.

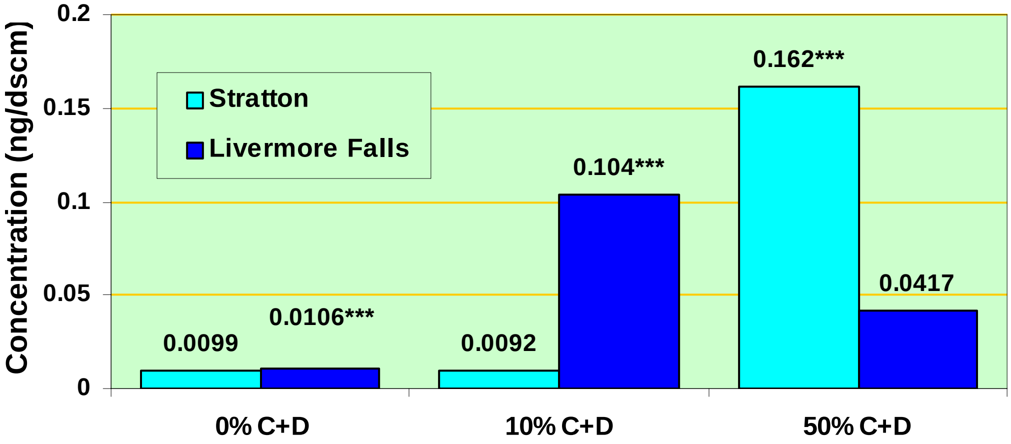
Figure 4a. Arsenic in Stack Gas for Stratton and Livermore Falls Test Burns



*** An ESP field may have been off

*Source: Humphrey, Dana. 2005. Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc., May 27.*

Figure 4b. Dioxin in Stack Gas for Stratton and Livermore Falls Test Burns



*** An ESP field may have been off

*Source: Humphrey, Dana. 2005. Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc., May 27.*

Air samples from the Livermore Falls 0% test had 15 times the arsenic concentrations as air samples from the Stratton 10% test and a somewhat higher arsenic concentration than from the Stratton 50% test. The University of Maine report states that one of the three Livermore Falls ESP fields may have been off during the 0% test, and the above data would seem to corroborate this. It is not clear, because the report says “The hand-written logs of precipitator field operation could indicate that field #1 was off for the control *[i.e., 0%]* run on May 26, 2004 and that field #3 was off for the low *[i.e. 10%]* run on June 16, 2004. However, Mr. Michael Daigle from the Livermore Falls plant states that to the best of his knowledge for May 26, 2004, the precipitator ‘was operating under normal parameters.’”

At Stratton, one of four ESP fields was intentionally turned off during the last three hours of the 50% test in an attempt to demonstrate compliance with Stratton’s particulate matter limit while operating in a three-field configuration. (The report does not say whether or not compliance was demonstrated.) Non-functioning ESP fields may help explain some of the variability and deviation from the expected pattern that is apparent in the air emissions results. It introduces an element of lack of experimental control because one cannot tell how much of the differences in concentrations were due to differences in the fuel and how much they were due to differences in operation of the air pollution control equipment. This complication renders some, but not all, of the data unusable, as explained below.

All three ESP fields were operational during the 50% test at Livermore Falls. For the 50% test, the arsenic concentrations were doubled and the dioxin concentrations were quadrupled compared to the 0% Livermore Falls test, even though one of the ESP three fields may not have been operational for the 0% test. This would certainly indicate that air emissions are higher when C&D wood is present in the fuel than when it is not. A similar comparison of 50% and 0% test concentrations is not appropriate for Stratton since an ESP field was off part of the time for the 50% test, which by itself could account for any increase in concentration.

For both the Stratton 0% and 10% tests, all four ESP fields were operating, thus the concentration data may be compared. The 10% test had three times the arsenic concentration of the 0% test, providing more evidence that air emissions are higher when C&D wood is present in the fuel, while the dioxin concentration was slightly lower for the 10% test. Because of the uncertainty as to whether all ESP fields were operating for the 0% test at Livermore Falls, a similar comparison of 0% and 10% test concentrations is not appropriate here, because the non-operational ESP field in the 10% test could by itself account for any increase in concentration if all fields were in fact operational for the 0% test.

As inferred in the University of Maine report, when any of the ESP fields are not operating, the air emissions tend to be higher, and the data bear this out. Despite the complications caused by some ESP fields being off, the report does say that a general trend is that as the arsenic and dioxin input in the fuel increases, the output in stack gas and ash (which is discussed below) increases.

Other operational problems occurred during the Stratton and Livermore Falls test burns. At Livermore Falls, the forced draft fan discharge pressure was recorded as zero for the entire 0% test and all but the last hourly reading of the 10% test. The University of Maine report says that it is possible that this sensor was malfunctioning. Another problem was that one page of the hourly combustion parameters records for Livermore Falls was missing; this page dealt with precipitator and stack gas parameters.

Air dispersion modeling was performed on the maximum Stratton and Livermore Falls test burn concentrations to predict the concentrations of arsenic and dioxin in air some distance from the stack where people would be breathing the air. These modeled concentrations were compared to Maine Ambient Air Guidelines ("MAAGs," Maine Bureau of Health, 2004) and found to be below the MAAGs.[1] Modeled ambient arsenic concentrations were 30% and 3.5% of arsenic MAAGs, and modeled dioxin concentrations were 0.47% and 0.24% of dioxin MAAGs, for the Stratton and Livermore Falls 50% and 10% tests, respectively. The Stratton modeled ambient arsenic concentration is troubling in light of the fact that the arsenic concentration in the 50% test fuel was only 10.8 mg/kg, approximately 36% of the target level of 30 mg/kg intended for the test burn. Had the fuel target level been achieved, modeled ambient arsenic concentrations could be projected to have been more like 30% divided by 0.36, or 83% of the MAAG (assuming a linear relationship). However, the situation is again complicated by the fact that one of the Stratton EPS fields was turned off for the last third of the 50% test.

Furthermore, MAAGs only deal with one route of potential exposure. MAAGs are established such that there is a 1 in 100,000 incremental lifetime cancer risk for a person breathing the MAAG concentration for 70 years. However, some pollutants that are released into the air are subsequently deposited onto soil and water and can make their way into the food chain and bioaccumulate. Recent U.S. Environmental Protection Agency (USEPA) guidance (2007) on metals risk assessment states that "deposition processes represent an important route of exposure for plants, animals, and humans." Therefore, compliance of modeled concentrations of two air toxics of concern with MAAGs, dealing with only one route of exposure, does not necessarily mean that the air emissions are safe for human health and the environment.

The NESCAUM report erroneously stated that the Stratton and Livermore Falls report (incorrectly attributed to Maine DEP rather than University of Maine) "concluded that an electrostatic precipitator was an effective control technology for lead removal." The University of Maine report (Humphrey, 2005) said nothing about lead. It also did not state that an ESP was an effective control technology for any other chemical. NESCAUM does seem to be referencing the University of Maine report (Humphrey, 2005), but this is not entirely certain. One problem throughout the NESCAUM report is that it is not always entirely clear what documents are being referred to, and citations are not given in a number of instances.

Westbrook average air emissions of heavy metals (from triplicate samples) are summarized both as concentrations and as emission rates in Table 2 (SAPPI Westbrook, 2005). There was no 0% test at Westbrook with which to compare the results. Compared to Stratton arsenic concentrations, the Westbrook arsenic concentration exceeded concentrations from the 0% and 10% tests but was less than the concentration from the 50% test (during which an ESP field was turned off part of the time). The Westbrook arsenic concentration was much less than concentrations from all three Livermore Falls tests.

---

[1] The MAAG for arsenic is 0.002 micrograms per dry standard cubic meter ("ug/dscm"), and the MAAG for dioxin is 0.0003 nanograms per dry standard cubic meter ("ng/dscm").

**Table 2**
**Westbrook Metals in Air Samples**
(averages of three samples)

| **Metal** | **Concentration (ug/dscm)*** | **Emission Rate (pounds/hour)** |
|---|---|---|
| Arsenic | 3.79 | 0.002664 |
| Cadmium | 0.24 | 0.000169 |
| Chromium | 1.78 | 0.001248 |
| Copper | 2.40 | 0.001689 |
| Lead | 20.98 | 0.014712 |
| Manganese | 5.38 | 0.0037362 |
| Mercury | <1.79 | <0.001256 |

***** ug/dscm = micrograms per dry standard cubic meter

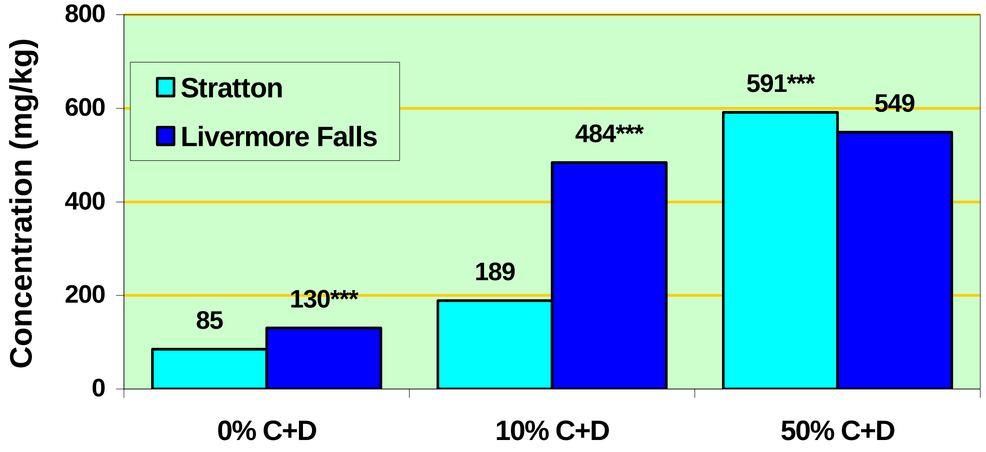
*Source: SAPPI Westbrook. 2005. "Summary of Multi-Metals." One page table of analytical results for air samples during stack testing, received from Robert Hartley of Maine DEP.*

## Ash

Although NESCAUM did not discuss ash in its report, ash is important because toxic chemicals present in the wood may end up in the air and/or in the ash. Fly ash samples from the Stratton and Livermore Falls test burns were analyzed for arsenic and dioxin. Average results (for duplicate samples) are summarized in Figures 5a and 5b. Unlike the arsenic air emissions data, the arsenic ash data did follow the expected pattern (i.e., lowest concentrations for the 0% tests, intermediate concentrations for the 10% tests, and highest concentrations for the 50% tests). Dioxin ash data did not follow this pattern but would not be expected to, as noted earlier.

Average fly ash data for Westbrook (S.D. Warren Company, 2005), Stratton (50% test), and Livermore Falls (50% test) are summarized on Figures 6a, 6b and 6c, along with fly ash data for two facilities that burn 100% forest biomass in West Enfield and Jonesboro, Maine (Maine Environmental Laboratory, 2005). Arsenic, lead, and mercury concentrations were much higher in ash from the facilities that burn C&D wood than in ash from the facilities that do not. It is unclear why the arsenic concentrations in the 0% tests at Stratton and Livermore Falls (85 and 130 mg/kg, see Figure 5a) are so much higher than the arsenic concentrations at West Enfield and Joneboro (4 and 6 mg/kg). Since air pollution control equipment captures most but not all of the fly ash, the ash concentration data have implications for air emissions. Given two facilities emitting the same amount of particulate matter, one burning C&D wood and the other burning forest biomass, the data indicate that particulate matter from the C&D burning facility will contain relatively more arsenic, lead, and mercury.

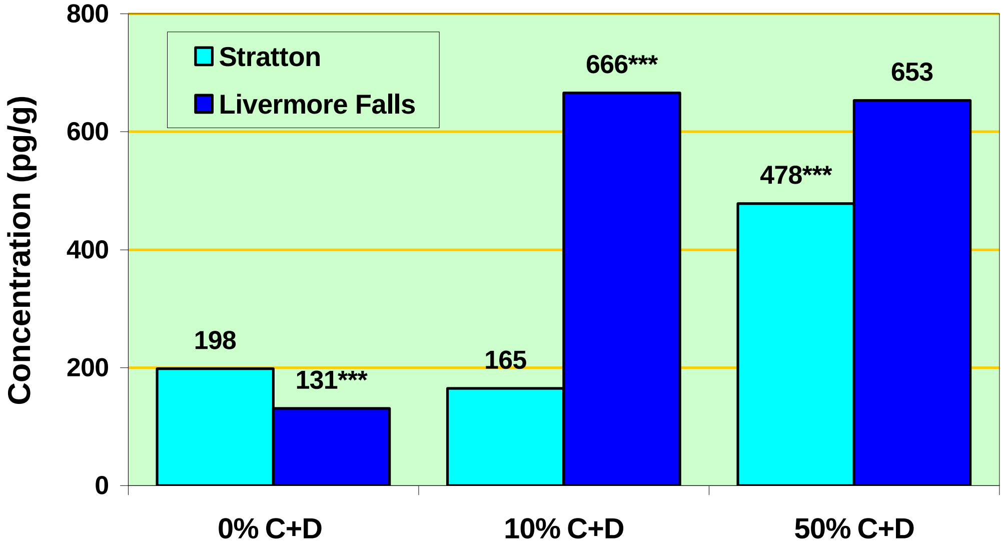
**Figure 5a. Arsenic in Fly Ash for the Stratton and Livermore Falls Test Burns**



*** An ESP field may have been off

*Source: Humphrey, Dana. 2005.* *__Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc.__*, *May 27.*

**Figure 5b. Dioxin in Fly Ash for the Stratton and Livermore Falls Test Burns**

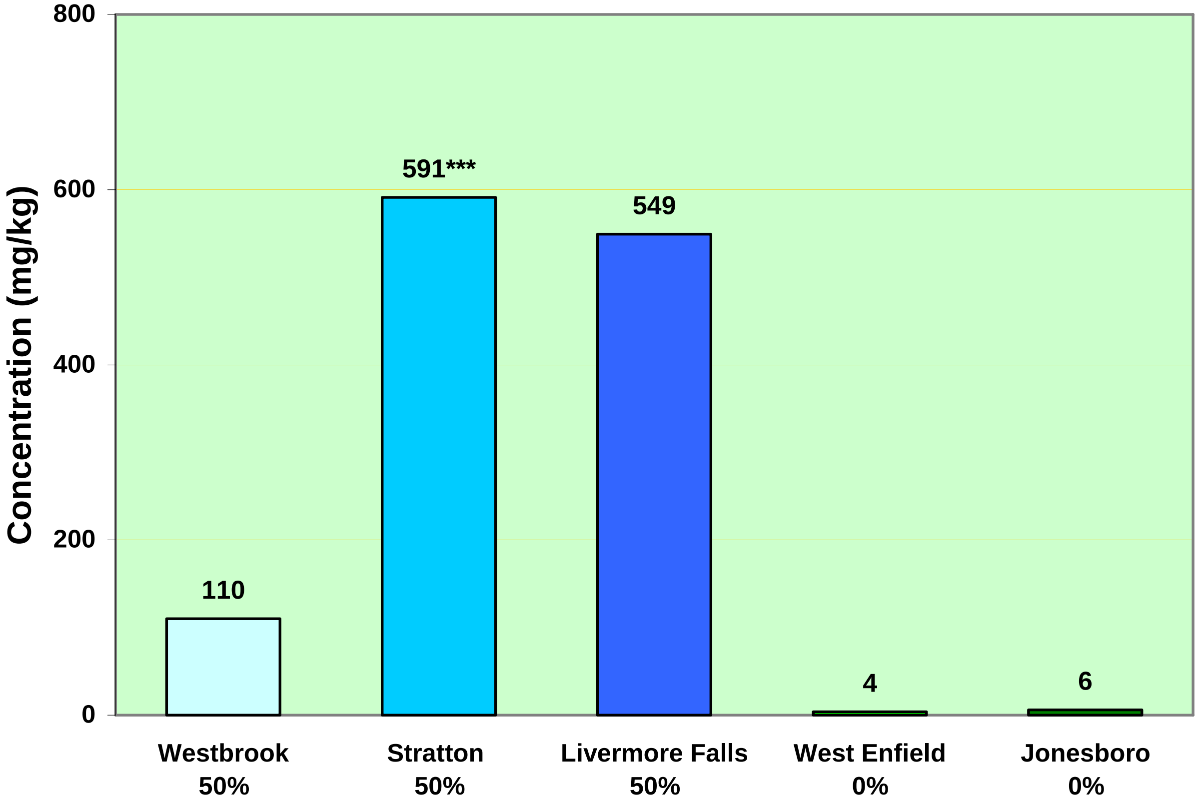


*** An ESP field may have been off

*Source: Humphrey, Dana. 2005.* *__Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc.__*, *May 27.*

Ash from facilities that burn C&D wood is typically not classified as "hazardous" (i.e., it does not exceed TCLP limits); however, it must be disposed of in a secure lined landfill. By contrast, ash from facilities burning only forest biomass may be reused beneficially in a number of ways, provided it meets applicable standards and appropriate permits are obtained (McMullin, 2007). It may be spread on agricultural fields to raise the pH, used as a component of aggregate for road construction, added to sludge as a thickener, used as a filter medium for leachate treatment, or used for landfill capping (Irving, 2006).

**Figure 6a. Arsenic in Fly Ash of Several Facilities**



*** An ESP field may have been off

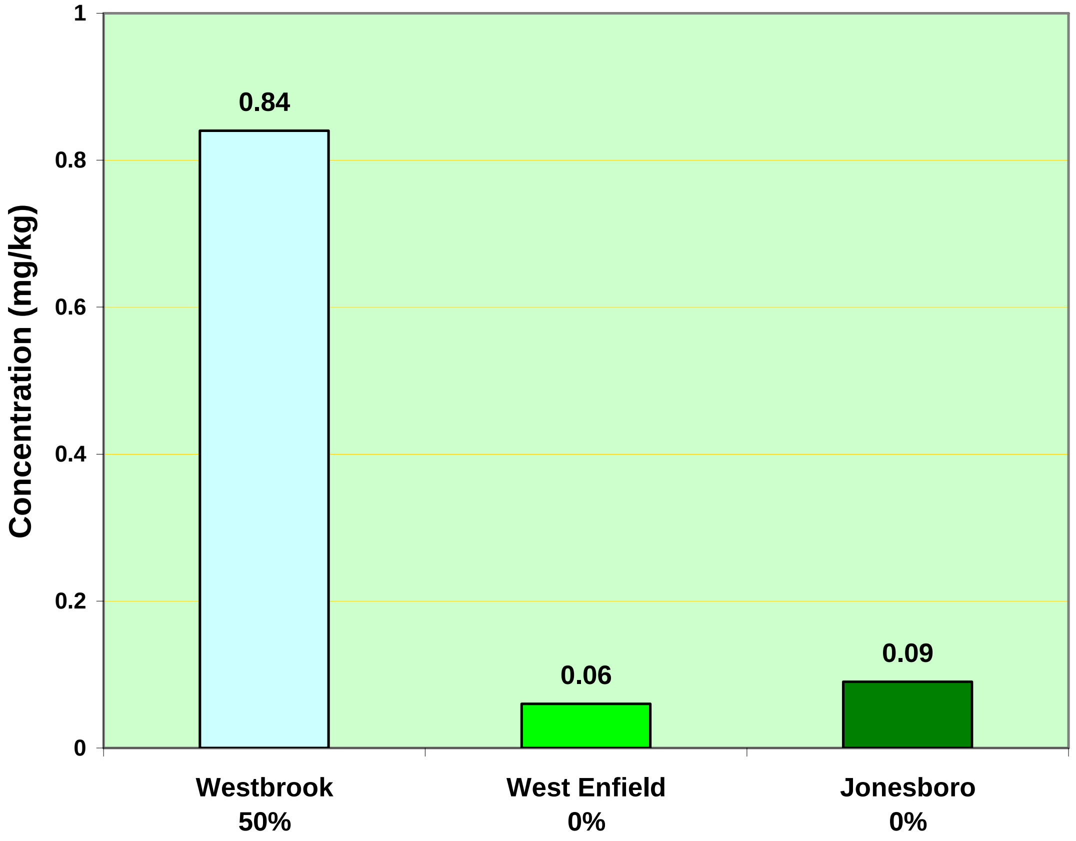
*Sources:*

*S.D. Warren Company. 2005. "Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler," submitted to Maine DEP.*

*Humphrey, Dana. 2005. Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc., May 27.*

*Maine Environmental Laboratory. 2005. Laboratory analytical reports for ash samples collected November 14 from biomass plants in West Enfield and Jonesboro, Maine.*

# Figure 6b. Mercury in Fly Ash of Several Facilities

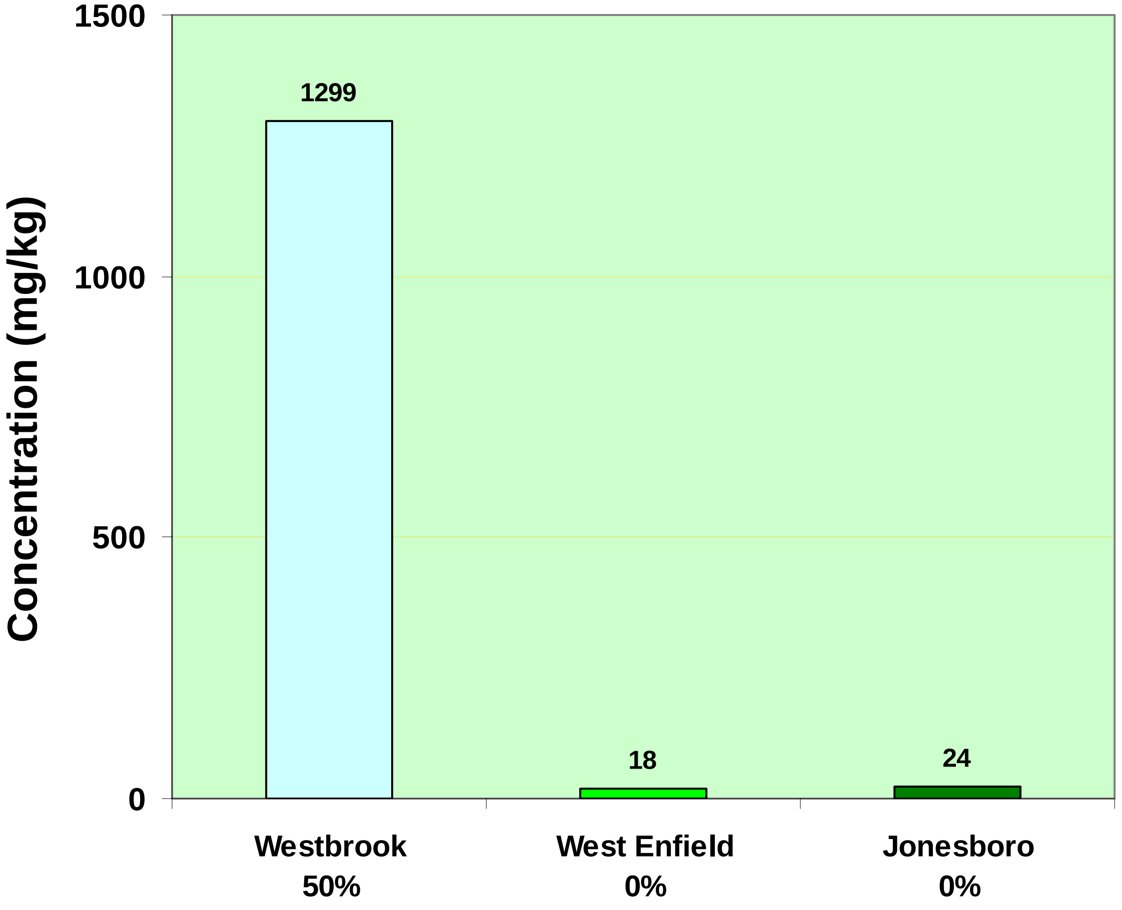


***Sources:***

*S.D. Warren Company. 2005. "Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler," submitted to Maine DEP.*

*Maine Environmental Laboratory. 2005. Laboratory analytical reports for ash samples collected November 14 from biomass plants in West Enfield and Jonesboro, Maine.*

Figure 6c.  Lead in Fly Ash of Several Facilities



*Sources:*

*S.D. Warren Company. 2005. "Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler," submitted to Maine DEP.*

*Maine Environmental Laboratory. 2005. Laboratory analytical reports for ash samples collected November 14 from biomass plants in West Enfield and Jonesboro, Maine.*

## Mass Balance Evaluation at Stratton and Livermore Falls

University of Maine researchers performed calculations on the fuel, air, and ash data in an attempt to perform a mass balance on arsenic and dioxin.  (They also attempted mass balances on copper and chlorine in fuel and ash.) Mass balance calculations are predicated on the assumption that the amount of arsenic and dioxin coming out of the facility in the stack gas and ash should equal the amount going into the facility in the fuel. This should be the case for arsenic, which is an element that cannot be created or destroyed. Because dioxin can be generated or consumed during the combustion process, mass balance would not necessarily be expected for dioxin. Mass balance on arsenic was not achieved for 5 of the 6 test burns, which calls into question either the sampling and analytical methods used or the calculations performed.

Other evidence of potential sampling and analysis problems was noted in the University of Maine report. For example, two composite samples were created for each of the three runs at the Stratton and Livermore Falls facilities, "Fly Ash A" and "Fly Ash B." The composites were made by alternately depositing scoops of fly ash into the A and B containers, so they were essentially taken over the same time period. Yet on analysis, Fly Ash A had nearly twice the arsenic concentration as Fly Ash B for the 10% test at Livermore Falls. The report said that "there is no ready explanation for the difference between the arsenic concentrations in the Fly Ash A and B samples."

# BACT Determination Considered by NESCAUM

In addition to the test burns discussed above, NESCAUM reviewed a BACT analysis prepared by GenPower for their proposed Athens, Maine, facility. NESCAUM summarized proposed BACT limits for the GenPower facility and compared them with emission limits for forest biomass plants and with emissions limits for facilities burning other types of fuel. Table 4-4 of the NESCAUM report indicates that GenPower proposed a BACT level of 0.01 pounds of particulates per million British Thermal Units (“lb/MMBtu”), compared to a 0.025 lb/MMBtu level given for a forest biomass burning plant. The last forest biomass burning biomass plant in the Northeast (i.e., in Ashland, Maine) went into service in 1993, and the design was likely set in the late 1980s. To compare a modern design for a C&D wood burning facility with an older design for a forest biomass burning plant is to compare apples and oranges, because air emissions are more tightly restricted today than in the past. Table 4-4 of the NESCAUM report thus merely suggests that C&D burning facilities designed today would utilize more advanced combustion and/or emissions control technologies than forest biomass plants designed nearly two decades ago. Because the C&D wood burning facility uses fuel containing more heavy metals than a forest biomass burning facility, heavy metals emissions would be expected to be greater regardless of the BACT level.

NESCAUM concluded that GenPower would emit no more pollution than facilities burning other types of fuel. However, this is based on general criteria pollutant emission rates, and no data were presented regarding specific air toxics such as arsenic and lead that would be of particular concern with C&D wood. The analysis ignores the fact that, as demonstrated above, the particulate matter from combusting C&D wood contains relatively more heavy metals due to the increased heavy metal content of the fuel. Therefore, NESCAUM’s conclusion, at least with respect to metals, is not supported by data.

# Evaluation of NESCAUM Report Conclusions

Key conclusions of the NESCAUM report are revisited below. In summary, the first conclusion is not based on sufficient data and is actually refuted by the scant data that NESCAUM did review. The second conclusion is vague, incomplete, and potentially infeasible. Finally, no data at all are presented to support the third conclusion.

## NESCAUM's Conclusion Regarding Similar Air Emissions

> "A review of the data shows that the use of appropriately processed C&D wood is similar in its emission profile to that of virgin wood."

Too few data were reviewed to support a blanket statement such as this. The air data described above (Westbrook, Stratton, and Livermore Falls test burns) and the Athens BACT analysis were the only information upon which NESCAUM based its assessment. This small handful of analyses is inadequate because of inherent heterogeneities in C&D wood and variations in C&D wood burning facility equipment and operational parameters. The variability in both the fuel and the facilities would demand that a much larger data set be reviewed in order to evaluate whether air emissions are generally similar or different.

The analyte list was very limited. Only seven heavy metals were evaluated in all media in the Westbrook 50% test, and there was no Westbrook 0% test with which to compare the results. Only arsenic and dioxin were evaluated in all media in the Stratton and Livermore Falls tests, with no information developed for a number of other air toxics of potential concern such as lead, cadmium, chromium, mercury, antimony, nickel, selenium, and vanadium. (These are analytes that were included in later stack tests at Stratton and Livermore Falls that were not reviewed by NESCAUM.)

Furthermore, much of the data were of limited quality and usefulness. The test burns at Stratton and Livermore Falls were flawed in that two variables were changed at the same time (the fuel and the operation of the ESP fields), thus the experiment was not well controlled. In addition, the quality of the data is questionable because mass balance of arsenic inputs and outputs was not achieved in the study. Other analytical problems were noted as well.

The fuel tested apparently had lower than expected concentrations of arsenic. In the Westbrook 50% test, arsenic concentrations were similar to literature values for untreated wood. In the Stratton and Livermore Falls 10% and 50% tests, arsenic concentrations were less than the study target concentrations. Thus, the range of conditions that was intended to be tested apparently was not tested, thereby limiting the usefulness of the results.

The Stratton and Livermore Falls test burns provided the only information comparing emissions of any air toxics that result from burning C&D wood versus 100% forest biomass. The air concentrations of the only chemicals evaluated, arsenic and dioxin, were two to forty times higher from the 50% tests compared to the 0% tests. The only similar concentrations were the dioxin concentrations from the 0% and 10% tests at Stratton. Some of the variation in air concentrations of arsenic and dioxin at Stratton and Livermore Falls may be explained by non-functioning ESP fields during the tests as opposed to variations in the fuel burned. What can be gleaned from the University of Maine data, taking into account the variably operating ESP fields, during the 50% test at Livermore Falls (with three of three ESP fields operating) at a minimum, arsenic concentrations were doubled and dioxin concentrations were quadrupled compared to the 0% test (with either two or three ESP fields operating). During the 10% test at Stratton (with four of four ESP fields operating), arsenic concentrations were tripled compared to the 0% test (again with four of four ESP fields operating), while dioxin concentrations were similar. Thus the preponderance of the few available data that may be compared indicates that the air emissions are **not** similar when burning C&D wood versus forest biomass, in direct contradiction to NESCAUM's conclusion. Air emissions are in fact higher.

NESCAUM did not compare the air toxics emissions of C&D wood test burns with air toxics emissions of other facilities that burn only forest biomass, other than the above-mentioned Stratton and Livermore Falls 0% tests (Rector, 2006). Facilities that do not burn C&D wood, at least in New England, are not typically required to test for air toxics such as heavy metals.

It should be noted that NESCAUM never defines the term "appropriately processed C&D wood." One would have to presume that NESCAUM considered the C&D wood containing fuels tested at Westbrook, Stratton, and Livermore Falls as "appropriate processed" since NESCAUM based its conclusions on the data from these test burns and little else.

Finally, NESCAUM did not say that air emissions are similar when burning C&D wood versus forest biomass; it said the "air emissions profiles" are similar. "Air emissions profile" is another key term that NESCAUM does not define. If "similar air emissions profiles" means that both the chemicals and their concentrations are similar from burning C&D wood and from burning forest biomass, then the data described above contradict that claim.

## NESCAUM's Conclusion Regarding Fuel Processing

> "The critical element in minimizing air emissions, especially air toxics, is the elimination of CCA-treated and penta-treated wood from the fuel and minimizing fines."

There are several problems with this conclusion. One issue is whether in reality CCA-treated and penta-treated wood can be eliminated from the fuel and whether fines can be adequately minimized. It may be unrealistic to think that CCA-treated wood can be completely eliminated because, as discussed previously, visual inspection is not a reliable method for identifying CCA-treated wood. In addition, NESCAUM does not say to what extent fines should be minimized in order to have acceptable air emissions. The Maine rules for burning C&D wood (Maine DEP, 2006) allow in the C&D wood portion of the fuel (which can be up to 50% of the total, the remainder being forest biomass) up to 1.5% CCA-treated wood and 10 to 20% fines by weight.

Another issue is whether NESCAUM has accurately identified the problematic components of C&D wood that need to be addressed during fuel processing. In speaking of the University of Maine study, NESCAUM stated: "The study concluded that, the fines in the fuel had the highest concentrations of metals and dioxin." This is believed to be a misunderstanding as the University of Maine report did not state this conclusion, and NESCAUM appears to have based the conclusion above relative to fuel processing at least partly on this misunderstanding. To the contrary, the University of Maine analytical data for the visually sorted sample fractions of C&D wood for the Stratton test burns indicate that CCA-treated wood had the highest average concentrations of the only two metals tested, arsenic and copper, in both the commercial and the municipal samples. Painted wood had the second highest average arsenic and copper concentrations in the municipal samples, while fines had the second highest average arsenic concentration and plastic had the second highest average copper concentration in the commercial samples.

Fines had the highest average dioxin concentrations in both the commercial and municipal samples, while painted wood had the second highest average dioxin concentrations in both the commercial and municipal samples. (Dioxin concentrations in the plastic fraction were not reported in the University of Maine report due to analytical difficulties; it is unknown whether such data would change either of the above statements.) Thus NESCAUM's statement about the fines containing the highest concentrations of metals and dioxin may be true with respect to dioxin but it is not true with respect to the data for the only two metals (copper and arsenic) included in the University of Maine report.

In addition, because the analyte list was limited to a small subset of the contaminants expected to be found in C&D wood, the number of samples was small, and the results were highly variable, it is difficult to see how NESCAUM could draw general conclusions about the composition of C&D wood from such limited data. Furthermore, the University of Maine data indicate that painted wood also contains relatively high arsenic, copper, and dioxin concentrations, which suggests that painted wood should also be eliminated or minimized, yet NESCAUM makes no such suggestion.

## NESCAUM's Conclusion Regarding Fuel Testing

> "Requirements for comprehensive testing and sampling of the fuel at both the processing facility and the location of the end user will assure that the fuel quality is maintained."

NESCAUM offers no evidence to support this statement. This assertion is not even discussed in the report; it is simply stated in the NESCAUM report conclusions. NESCAUM provides no basis for its conclusion that requirements for comprehensive fuel testing will assure that fuel quality will be maintained, nor does it provide any guidance on what level of fuel testing would be adequate. Sampling and analyzing this heterogeneous material for the array of hazardous constituents of concern that may be present could be seen as a major challenge, especially if it is to be both thorough and economical. Yet NESCAUM simply glosses over this issue.

# Additional Concerns

## Fuel Management Issues

NESCAUM's focus is on air, so it is understandable that NESCAUM did not evaluate other issues relative to burning C&D wood that do not involve air. However, human health and the environment are affected by all media, so it is worth at least mentioning other concerns regarding burning C&D wood.

Ash issues were discussed above in connection with the test burns NESCAUM reviewed. Dust generated by C&D sorting and fuel and ash handling or, if the fuel or ash is stored outdoors, wind, may be a concern, particularly for facility workers. Splinters of CCA-wood are also a worker safety concern (Florida Center for Solid and Hazardous Waste Management and Florida Department of Environmental Protection, 2005). In addition, if fuel or ash is exposed to precipitation during transportation or storage, runoff may contaminate groundwater or surface water. At some facilities, fuel is stored outdoors, for example, at one of the two Boralex C&D burning facilities in Maine.

## Disincentive to Reduce, Reuse, and Recycle

Allowing C&D wood to be burned provides a disincentive to reduce, reuse, and recycle. There are a number of alternatives for dealing with C&D wood that do not involve combustion. It is beyond the scope of this evaluation to discuss these in any detail, but it is worth noting that some wood may be reused as dimensional lumber (O'Connor, 2006), or made into particle board and fiber board (McQuade, 2006).

# Conclusions and Recommendations of this Evaluation

This evaluation has examined three key conclusions of the NESCAUM report on burning C&D wood for energy, namely:

- "A review of the data shows that the use of appropriately processed C&D wood is similar in its emission profile to that of virgin wood."
- "The critical element in minimizing air emissions, especially air toxics, is the elimination of CCA-treated and penta-treated wood from the fuel and minimizing fines."
- "Requirements for comprehensive testing and sampling of the fuel at both the processing facility and the location of the end user will assure that the fuel quality is maintained."

The NESCAUM report ends with two recommendations: 1) "States should establish fuel specifications and fuel management procedures for C&D wood if they plan to support the use of C&D wood for energy generation"; and 2) Existing biomass plants may need to upgrade emission controls if they wish to burn C&D wood." The recommendations suggest that burning C&D wood can be done safely and that states should go ahead, as long as they manage the fuel and air emissions properly. However, NESCAUM's analysis was not sufficient to support the conclusions on which these recommendations are predicated, as summarized below.

The NESCAUM report is seriously flawed. NESCAUM based its conclusions on a very small data set, and those sparse data do not support NESCAUM's conclusions. In addition, the quality of much of the data is questionable. Furthermore, no specific data were available regarding a number of expected air toxics, leaving significant data gaps. The NESCAUM report contained significant errors and never defined key terms such as "appropriately processed C&D wood" and "air emissions profile."

Air emissions are higher when C&D wood is included in the fuel. Contrary to NESCAUM's conclusions, the data NESCAUM reviewed indicated that air emissions are higher when C&D wood is included in the fuel, at least as far as arsenic and dioxin are concerned. Livermore Falls data indicate that concentrations of arsenic and dioxin are doubled and quadrupled, respectively, when burning 50% C&D wood compared to burning forest biomass.

CCA-treated wood, painted wood, and fines are included in the C&D wood fuel. NESCAUM says it is critical to eliminate CCA-treated and penta-treated wood from the fuel, but does not say whether this is feasible. Literature indicates that eliminating CCA-treated wood is a challenge because it cannot always be identified visually. In addition, NESCAUM says it is critical to minimize fines in the fuel, but does not say to what extent this is necessary nor to what extent it is feasible. In addition, data indicate that painted wood has relatively high concentrations of toxic chemicals such as arsenic, copper, and dioxin, yet NESCAUM does not suggest that painted wood should be minimized or eliminated.

There is no basis for saying that testing will assure fuel quality. C&D wood is inherently contaminated with a variety of hazardous chemicals. NESCAUM provides no basis for its conclusion that "requirements for comprehensive fuel testing at both the processing facility and at the location of the end user will assure that the fuel quality is maintained." That assertion is simply stated in the NESCAUM report conclusions. NESCAUM does not say what the testing requirements are or should be, let alone evaluate whether or not they are adequate.

NESCAUM only evaluated air. Ash is a significant concern that was not addressed by NESCAUM. Ash from facilities that do not burn C&D wood may be reused in several beneficial ways. By contrast, ash from C&D wood burning facilities must be disposed of in lined landfills due to high concentrations of heavy metals. In addition, arsenic, lead, and other toxic chemicals in the C&D wood present material handling issues. Dust, splinters, and contaminated surface water runoff are among the potential concerns. NESCAUM did not address any of these issues.

Assessment of risks to human health and the environment is incomplete. Although dispersion modeling of the stack gas concentrations at Stratton and Livermore Falls indicated that ambient air concentrations of arsenic and dioxin would be below MAAGs, the stack gas concentration data that were modeled are sparse and of questionable quality, as explained above. In addition, the modeling only evaluated one route of exposure to two chemicals, namely direct inhalation of arsenic and dioxin. It did not consider another more indirect route of exposure from contaminant deposition onto soil and surface water, followed by subsequent uptake in the food chain. Nor have risks from dust and contaminated runoff from fuel piles been considered. Thus, a realistic and comprehensive assessment of risks to human health and the environment from burning C&D wood has not been carried out.

Recommendation: The NESCAUM report should not be relied upon in developing any public policies relative to the burning of C&D wood.

---

*Author Information: Ellen Moyer has a B.A. in Anthropology, an M.S. in Environmental Engineering, and a Ph.D. in Civil Engineering. She is a registered professional engineer in Connecticut, Massachusetts, and New Hampshire, with over 20 years of environmental engineering experience. She is also a U.S. Green Building Council Leadership in Energy and Environmental Design ("LEED") Accredited Professional. She can be reached at ellenmoyer@em-green.com.*

# References

Doloff, Aimee. 2006. “Old Town: Ex-G-P Mill Site Produces Power.” Bangor Daily News, December 16.

Florida Center for Solid and Hazardous Waste Management and Florida Department of Environmental Protection. 2005. Guidance for the Management and Disposal of CCA-Treated Wood, 15 pp.

Holton, W. Conrad. 2001. “Special Treatment: Disposing of CCA-Treated Wood,” Environmental Health Perspectives, 109:6:3 pp.

Humphrey, Dana. 2005. Fate of Dioxin and Arsenic from the Combustion of Construction and Demolition Debris and Treated Wood: A Study for Boralex Energy, Inc., May 27.

Irving, John. 2006. McNeil Station Plant Manager, Burlington, Vermont. Personal communication October 30.

Maine Bureau of Health. 2004. “Maine Bureau of Health Ambient Air Guidelines,” April.

Maine DEP. 2006. “Maine Solid Waste Management Rules – Chapter 418 – Beneficial Use of Solid Wastes. Updated June 16, 2006. www.maine.gov/sos/cec/rules/06/096/096c418.doc.

Maine Environmental Laboratory. 2005. Laboratory analytical reports for ash samples collected November 14 from biomass plants in West Enfield and Jonesboro, Maine.

McMullin, Randy. 2006/2007. Maine DEP. Personal communication November 13 and December 5, 2006, and January 3, 2007.

McQuade, James. 2006. Massachusetts Department of Environmental Protection. Personal communication November 1.

Northeast States for Coordinated Air Use Management. 2006. Emissions from Burning Wood Fuels Derived from Construction and Demolition Debris. May 2006. http://www.nescaum.org/activities/major-reports.

O’Connor, Marge. 2006. “The Story Behind the Wood,” Eco-Structure, December, pp.50-53. www.eco-structure.com.

Rector, Lisa. 2006. Northeast States for Coordinated Air Use Management. Personal communication November 1 and December 4.

S.D. Warren Company. 2005. “Application for Beneficial Use of Wood Chips from Construction/Demolition Debris as a Fuel in #21 Boiler,” submitted to Maine DEP.

SAPPI Westbrook. 2005. “Summary of Multi-Metals.” One page table of analytical results for air samples during stack testing, received from Robert Hartley of Maine DEP.

Solo-Gabriele, Helena, Monika Kormienko, and Kelvin Gary. 2000. Alternative chemicals and Improved Disposal-End Management Practices for CCA-treated Wood, State University System of Florida, Florida Center for Solid and Hazardous Waste Management, Report #00-03 Final Draft.

Tom, Patricia-Anne. 2001. “Good Wood Gone Bad: The Effects of Arsenic Leaching from CCA-Treated Wood are Creating Very Real Concerns for the Waste Industry,” Waste Age, August.

USEPA. 1999. Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup, Second Edition. EPA 542-B-99-009.

USEPA. 2007. Framework for Metals Risk Assessment. EPA 120/R-07/001, 171 pp.

Wu, Chang-Yu, Timothy Townsend, Helena Solo-Gabriele, Anadi Misra, and Brajesh Dubey. 2006. Evaluation for Thermal Processes for CCA Wood Disposal in Existing Facilities, Florida Center for Solid and Hazardous Waste Management, Contract 00053522.

ATTACHMENT E

BIOMASS MAGAZINE
The World of Biomass at Your Fingertips

From the April 2009 Issue

# The Politics of 'Dirty' Wood

Pressure-treated and painted, or what is commonly referred to as "dirty" wood, is often off limits for productive reuse and relegated to landfills. Stakeholders in the construction and demolition industries talk about the politics and economics holding back the potential these prolific waste streams possess in the renewable energy sector and, more importantly, what can be done to make use of this resource.

by Ron Kotrba

New Hampshire banned the use of construction and demolition (C&D) waste, whether it's clean, unadulterated wood waste generated at construction sites or "dirty" wood—the pressure-treated and painted variety of lumber. In Massachusetts there is a moratorium on using C&D waste. In Portland, Ore., the city prohibits any use of painted or pressure-treated woods except in "incidental" quantities. In New York, the state court of appeals shot down an appeal from a biomass plant that wanted to burn clean wood chips in the case of Laidlaw Energy & Environmental Inc. v. Town of Ellicottville. The appellate court upheld the trial court's refusal to accept the biomass plant status in permitting as being "carbon neutral" because the company did not have a "sustainable fuel source management plan" in place; and the court argued that the distance the chips had to be transported hadn't been considered in the company's revelation of the plant's carbon footprint. Obstacles exist prohibiting the use of dirty wood—and in the Laidlaw case clean wood—in local and state regulations across the United States. Despite these prohibitions on the combustion or burning of these types of materials, the C&D industries keep generating it. So what should be done with all this wood?

According to Jim Taylor, president and chief executive officer of Taylor Biomass Energy LLC and head of the Construction Materials Recycling Association, the material received by a C&D facility, where sorting and separating mixed debris occurs, on average is about one-third clean and unadulterated wood; one-third glued and pressed boards; and one-third pressure-treated and painted woods. For Taylor, the politics behind the limited outlets for dirty wood are more than just regulatory in nature. As a businessman, Taylor has personal politics to contend with, and as president of the CMRA he must consider the politics of the industry he represents.

His company is expecting to break ground this spring on a state-of-the-art biomass gasification plant in Montgomery, N.Y. Unlike the oxygen-rich combustion of dirty wood for energy in a boiler or incinerating it at a burn plant, gasification holds a lot of promise for increased utilization of dirty woods. The anaerobic or oxygen-free environment significantly reduces emissions, which is much less costly than controlling emissions at the back end of the plant. "I know many of my industry counterparts are capable of burning or combusting painted or pressure-treated wood," he says. Even so, Taylor says he's made a personal choice not to use dirty wood to fuel his new gasification facility. "We wanted to develop the most environmentally sound process out there today and, by keeping pressure-treated and painted woods out, we believe we can do that," Taylor says. "From our approach, we are voluntarily staying out of the pressure-treated and painted woods market." He says it's not a decision based on regulations, or policy. "It's a personal decision," Taylor tells Biomass Magazine. "Our waste chronology is to reduce, reuse, recycle and recover the energy content, and landfill or incinerate last. That's how I drive my business."

## Dangerous Emissions?

Shane Carpenter with Continental Biomass Industries Inc., a company in New Hampshire that engineers and sells industrial biomass processing equipment, says even though emissions from gasification are much less abundant and dangerous than effluent from combustion or incineration, there is a deficiency in gasification technologies proven to work on a large enough scale to process more than a thousand tons a day. And, with a growth-stunting recession in full swing, the cost is definitely a concern. Tad Wollenhaupt, president of Massachusetts-based Air One Inc., a company that develops industrial dust and odor control systems, says to build a 200-plus ton per day gasification plant it could cost more than $100 million. "For these projects it is about economics—that's my opinion," Wollenhaupt says. Carpenter adds to this, saying, "Economics is a big factor, yes, but we probably have not focused enough on the politics involved, the local politics. People are saying, 'I don't want this stuff being burned in my backyard.' I think there's this feeling that the emissions coming from utilizing this type of dirty wood are very dangerous."

In September 2007, the University of New Hampshire published a comprehensive paper on the life-cycle analyses of C&D woods, in which the authors leveraged existing research along with data from Greg Wirsen of Green Seal Environmental Inc. to profile the emissions from clean and dirty C&D woods in different applications. "A facility with an advanced air pollution control system combusting 10 percent C&D derived biomass mixed with virgin wood had lower dioxin emissions than a facility combusting 100 percent virgin wood," the authors wrote. "Furthermore, the levels of arsenic and dioxin emissions were well below levels found at municipal solid waste combustors and below all applicable regulations."

Arsenic is used when manufacturing pressure-treated wood, and is one of the concerns about using that material. In addition, the UNH study cited University of Maine test data that compared emissions from burning three different concoctions of fuel: 100 percent clean wood; 90 percent clean wood with 10 percent C&D wood and "penta (PCP)-treated" wood; and 50 percent "penta (PCP)-treated" wood and 50 percent C&D wood. "In all cases, the stack emissions during the trial burns were far below Maine's ambient air guidelines and New Hampshire stack emission limits," the UNH paper states. A facility equipped with an advanced emissions control system combusting 10 percent C&D wood with 90 percent virgin wood had levels of arsenic and dioxin emissions "well below" levels detected at municipal solid waste (MSW) combustion plants "and below all applicable regulations."

"From a [British thermal unit] basis, you need 2 tons of whole tree chips per 1 ton of C&D," Wirsen says. "So there's actually the potential for more emissions using whole tree chips," because twice as much needs to be burned to produce the same amount of energy.

## New Ways to Use an Old Problem

Taylor, who has decided to exclude pressure-treated and painted woods from his commercial-scale gasification plant once it is operational, says he will still use woods with creosote and glue, and he has a plan to deal with the dirty wood. "We're going to find new uses for pressure-treated and painted wood in a new wood product," he says. "We're finding another recycling avenue for pressure-treated and painted woods." When asked for specifics, Taylor says, "Talk with me again in three months." Perhaps one avenue for these materials is to chip them up and, with the application of glue, make press board.

In places like Maine, where Wirsen says some pulp and paper mills with the right pollution controls can burn dirty wood—"hogged fuel" as it's called because the wood is ground up in a "hog" grinder—the solution could very well be dilution. Wollenhaupt backs this up in reference specifically to MSW-to-energy plants. "You could mix C&D wood into these trash-to-energy plants and gain some energy value out of it," Wollenhaupt says.

"That's a whole different industry," Carpenter says, referring to MSW plants. "Maybe they're slow in wanting to commingle their solid waste with the wood we're talking about but I think a mixture would be great. And I think it would really alleviate a lot of questions as to where this wood should go. Ultimately we could really sort of loosen up some of the restrictions and get some of these MSW plants onboard—and there's like 70 or 80 of them around the country. If we started looking at what they could do with some of this material, it would help to alleviate some of the strain these C&D process facilities have on them; specifically the transportation costs that are included with having to get rid of this material—it's huge. But we're not there yet. It would be great to create some conversation between these waste-to-energy facilities and the recycling associations—the CMRA—about creating a fuel that would make sense for both entities."

*Ron Kotrba is a Biomass Magazine senior writer. Reach him at rkotrba@bbiinternational.com or (701) 738-4942.*