DRAFT
Review of Studies that Estimated the Costs of CO2 Emission Reductions

Introduction

This Appendix presents a compilation of CO_2 abatement cost data to supplement the white paper titled “Cost-effectiveness Under the Global Warming Solutions Act A Brief Discussion of Potential Options”. The white paper addresses the requirements of AB32 regarding cost-effectiveness of proposed CO_2 regulations and four options for cost-effectiveness consideration, including the Cost of a Bundle of Strategies approach to evaluate and determine the cost-effectiveness of a regulation. The Cost of a Bundle of Strategies approach uses the range of cost-effectiveness of a number of strategies as background for establishing the reasonableness of a proposed regulation’s cost-effectiveness. The highest cost-effective strategy and the least cost-effective strategy form the range representing the bundle. These cost-effectiveness estimates are indicators for the reasonableness of the range rather than necessarily the range itself. A proposed ARB regulation falling within this range would be considered meeting the AB32 cost-effectiveness requirement.

The purpose of this document is to compile studies that estimated the cost and cost-effectiveness of CO_2 abatement strategies (dollar per ton of greenhouse gas emission reduction. The cost estimates in these studies may not be applicable to California. The thought is that the studies demonstrate cost ranges that could define a Cost of a Bundle of Strategies Approach (see the white paper). The studies present cost data for the following geographic areas: States, North America, and Worldwide. Industry cost data are also presented for specific industries.

An example of a study that developed a range of abatement costs is the State of California’s Climate Action Team (CAT). The lowest and highest dollar per ton cost estimate presented in CAT report can be thought of as indicators for the reasonableness of the range for the Cost of a Bundle of Strategies Approach. Members of the CAT used a consistent estimation methodology to calculate the costs of proposed CO_2 abatement strategies and the dollar per ton costs can be compared.

The other studies in this appendix present good indicators of the costs associated with CO_2 control strategies for geographic areas and specific industries. The cost data, however, may not be useful for direct comparison or to establish a lower or upper range as the studies used different methodologies and approaches. The studies also vary widely with respect to system boundaries, baseline, time period, subsectors included, completeness of mitigation measures included, and economic factors (e.g., costs and discount rates).

Appendix B, presents additional cost studies that were reviewed, but not included in the summary tables in the memorandum. These studies were out of date, not representative of California, or too broad in scope.

California, Arizona and New Mexico

Exhibit 1 presents summary information for the following five studies and includes a review of costs for CO_2 abatement strategies in the states of California, Arizona, and New Mexico.

Exhibit 1: Cost-effectiveness Range for California, Arizona & New Mexico

State	Cost-effectiveness Range $/ton CO2e	Tons Reduced MMT CO2e/yr
California (CAT)[1]	- 528 to 615	138.5 (2020)
California Non-CO2[2]	-50 to 52	31 (2020)
Cement[3] (California)	-20 to 37	(Cumulative 2005 – 2025) 47
Arizona[4]	- 90 to 65	69.4 (2020)
New Mexico[5]	- 120 to 105	35.4 (2020)

Source:
1. Climate Action Team Updated Macroeconomic Analysis of Climate Strategies, Presented in the March 2006 Climate Action Team Report, October 2007.
2. California Energy Commission, *Emission Reduction Opportunities for Non-CO2 Greenhouse Gases in California*, July 2005, ICF.
3. Center for Clean Air Policy, *Reducing CO2 Emissions from California's Cement Sector*, October 14, 2005.
4. Arizona Climate Change Advisory Group, *Climate Change Action Plan*, August 2006.
5. New Mexico Climate Change Advisory Group, Final Report, December 2006.

1. California Climate Action Team [1]

In recognition of the risks associated with climate change, on June 1, 2005, Governor Schwarzenegger signed Executive Order S-3-05. This Executive Order established Statewide climate change emission reduction targets:

- By 2010, reduce emissions to 2000 levels;
- By 2020, reduce emissions to 1990 levels;
- by 2050, reduce emissions to 80 percent below 1990 levels.

The Executive Order placed Cal/EPA as the lead coordinating State agency. The Secretary of Cal/EPA created a multi-agency team, the Climate Action Team (CAT), to meet the directives in the Executive Order.

The Executive Order also directed the Secretary for Environmental Protection to prepare a report to the Governor and the Legislature by January 2006 that defines actions necessary to meet the Governor's targets. This effort was coordinated with other key agencies to ensure the targets are met. The Climate Action Team developed a list of emission reduction strategies that could meet the Governor's targets.

The CAT proposed about 40 GHG reduction strategies developed by ARB and several other state agencies. The costs associated with the implementation of these strategies were first estimated in 2005, and subsequently updated in 2007 using a consistent estimation methodology. The CAT abatement strategies and dollar per ton cost are shown in Exhibit 2. The latest estimates of the strategies' cost per ton ranges from a negative $528 (i.e., savings) to $615 per ton of CO_2eq. The strategies include many energy efficiency, forestry, renewable energy sources, refrigeration,

---

[1] *Climate Action Team Updated Macroeconomic Analysis of Climate Strategies*, Presented in the March 2006 Climate Action Team Report, September 2007. http://www.climatechange.ca.gov/events/2007-09-14_workshop/final_report/2007-10-15_MACROECONOMIC_ANALYSIS.PDF

vehicular, and land use measures. The total GHG reduction from the strategies is about 138 $MMTCO_2$ eq.

Exhibit 2: Net Cost Estimates for 2020 for the Updated Climate Strategies Included in the 2006 CAT Report (2006 $)

Updated Strategy in This Report	Agency	Net Cost ($/ton of CO_2e)	
		Without Criteria Air Pollutant Values	With Criteria Air Pollutant Values
Vehicle Climate Change Standards	ARB	-$177.05	-$177.71
Diesel Anti-Idling	ARB	-$180.82	-$486.27
Other New Light Duty Vehicle Technology Improvements	ARB	$39.64	$38.92
HFC Reduction Strategies	ARB	$8.61	$8.44
Transport Refrigeration Units (on and off road)	ARB	$400.00	-$510.26
Shore Electrification	ARB	$56.36	-$407.61
Manure Management	ARB	$36.00	$36.00
PFC Emission Reduction for Semiconductor Manufacturers	ARB	$50.94	$50.94
Alternative Fuels: Biodiesel Blends	ARB	(c)	(c)
Alternative Fuels: Ethanol	ARB	$365.13	$365.13
Heavy-Duty Vehicle Emission Reduction Measures	ARB	-$178.41	-$473.58
Reduced Venting and Leaks in Oil and Gas Systems	ARB	$0.30	$0.30
Hydrogen Highway*	ARB	(a)	(a)
Achieve 50% Statewide Recycling Goal	IWMB	$27.33	$27.33
Landfill Methane Capture	IWMB	-$41.35	-$41.35
Zero Waste—High Recycling	IWMB	$23.00	$23.00
Conservation Forest Management	Forestry	$1.70	$1.70
Forest Conservation	Forestry	$37.50	$37.50
Fuels Management/Biomass	Forestry	-$86.10	-$86.38
Urban Forestry	Forestry	$150.00	$149.85
Afforestation/Reforestation	Forestry	$10.61	$10.61
Water Use Efficiency	DWR	-$525.49	-$528.09
Building Energy Efficiency Standards in Place	CEC	-$188.32	-$190.31
Appliance Efficiency Standards in Place	CEC	-$218.75	-$221.05
Fuel-Efficient Tire Program	CEC	-$259.85	-$260.60
Cement Manufacturing	CEC	-$5.00	-$5.00
Comprehensive Municipal Utility Program	CEC	-$16.60	-$17.47
Alternative Fuels: Non-Petroleum Fuels*	CEC	(a)	(a)

Exhibit 2 (con't): Net Cost Estimates for 2020 for the Updated Climate Strategies Included in the 2006 CAT Report

Updated Strategy in This Report	Agency	Net Cost ($/ton of CO_2e) Without Criteria Air Pollutant Values	With Criteria Air Pollutant Values
Measures to Improve Transportation Energy Efficiency and Smart Land Use and Intelligent Transportation	BTH	$0.00	-$16.06
Conservation tillage/cover crops*	Food/Ag	(a)	(a)
Enteric Fermentation	Food/Ag	$3.00	$3.00
Green Buildings Initiative	SCSA	$0.00	-$2.03
Transportation Policy Implementation*	SCSA	(a)	(a)
Accelerated RPS to 33% by 2020	CPUC	$12.20	$12.20
California Solar Initiative	CPUC	$617.39	$614.78
IOU Energy Efficiency Programs	CPUC	-$54.37	-$56.57
IOU Additional Energy Efficiency Programs	CPUC	-$17.86	-$20.00
IOU CHP (Self Generation Incentive Program)	CPUC	(b)	(b)
IOU Electricity Sector Carbon Policy (including SB 1368 Implementation for IOUs)	CPUC	(b)	(b)
Total		**-$47.55**	**-$62.22**

a. Net cost not calculated because emission impacts are not estimated.
b. Costs, savings, and emission impacts remain to be determined.
c. Net cost not calculated because costs and benefits are not estimated.
* The 2006 CAT Report did not include emission reduction estimates, costs, or savings for the strategies marked with an asterisk.
Multiple newly developed strategies that were not in the 2006 CAT Report are not included in this analysis. Examples include the Low Carbon Fuel Standard and other strategies being considered for early action and for the Scoping Plan. Many of the strategies are continuing to be refined.

2. California Energy Commission

Emission Reduction Opportunities For Non-CO_2 Greenhouse Gases in California[2]

Two other California specific GHG control costs studies were located. The CEC study, presented in this section, was funded in 2005 and was conducted by ICF. Control costs were constructed for non-CO_2 GHG. The Center for Clean Air Policy developed CO_2 abatement strategies and cost estimates for the California cement industry. This work is presented in section 3.

The results of the CEC study showed that a number of cost-effective mitigation options have the potential to reduce non-CO_2 greenhouse gas emissions in California. Non-CO_2 gases included in the study were methane (CH_4), hydrofluorcarbon (HFC), perfluorcarbon (PFC), and

[2] *Emission Reduction Opportunities for Non-CO 2Greenhouse Gases in California*, California Energy Commission, July 2005. Prepared by ICF.
http://www.energy.ca.gov/2005publications/CEC-500-2005-121/CEC-500-2005-121.PDF

sulfurhexafluoride (SF_6). Overall, this study analyzed 59 mitigation options in seven source categories including: Petroleum Systems, Natural Gas Systems, Landfills, Manure Management, Electric Power Systems, Semiconductor Manufacture, and Refrigeration/Air Conditioning.

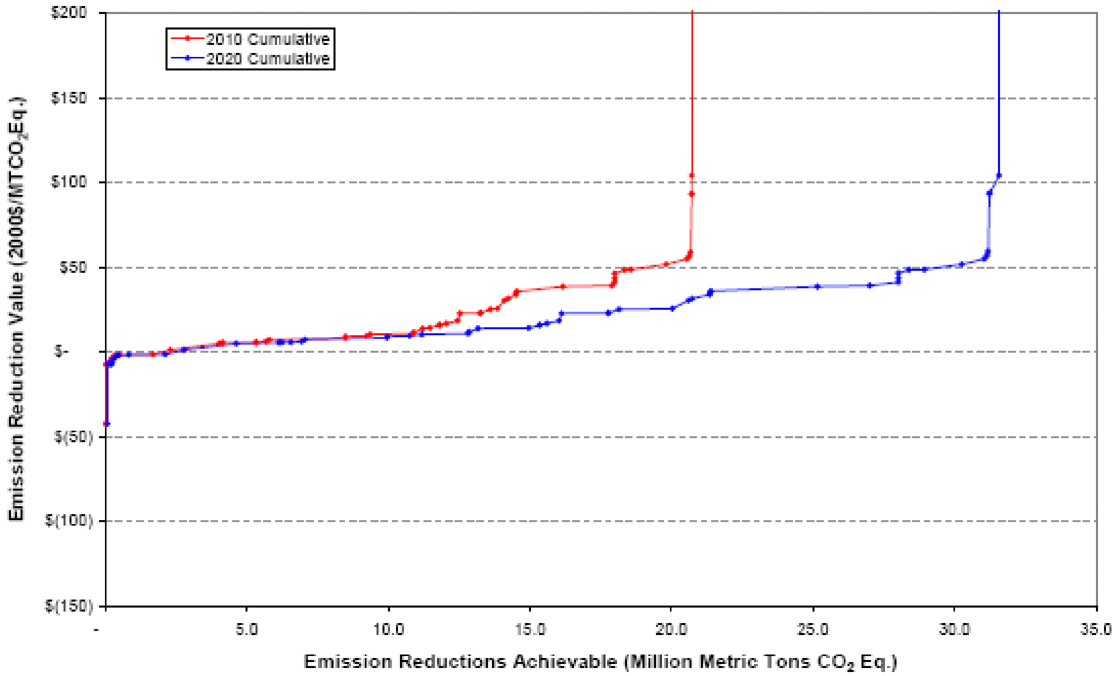
The results are presented for two scenarios that use alternative discount and tax rate assumptions: Scenario A uses a 4 percent discount rate and a 0 percent tax rate, while Scenario B uses a 20 percent discount rate and a 40 percent tax rate. The parameters of Scenario A were chosen to approximate the costs from a societal perspective, and Scenario B was designed to reflect private costs.

Results for 2010 and 2020 are discussed for Scenario B, as these Scenario B assumptions were thought to be more representative of business costs. Overall, costs were lower for Scenario A, as would be expected with lower discount and tax rates.

The results, presented in Exhibit 3, show the cumulative tons that can be reduced at the break-even price for specified cumulative tons of CO2 eq. reduced. The term break-even price refers to the price at which an entity (e.g., plant, manufacturer, utility) can be expected to be financially indifferent as to whether to institute an option. For example, at a break-even price of zero, an entity can install a retrofit or institute an alternative gas for an amount exactly equal to the energy or other savings that would be realized; the break-even price of zero is therefore considered to represent the reductions that can be achieved with no net cost. At negative breakeven prices, entities are expected to experience net savings while reducing emissions simultaneously. For these reasons, the emission reductions achievable at break-even prices equal to or less than zero are of particular interest. At positive break-even prices, on the other hand, an option might only be considered worthwhile if some external value were “attached” to the emission reduction. This value might be in the form of tax relief, rebates, emission reduction credits, or other government-offered incentives.

Exhibit 3 presents achievable reductions and marginal abatement costs for the years 2010 and 2020 for a discount rate of 20 percent and a tax rate of 40 percent.

Exhibit 3: Control Costs for Non-CO2 Emissions in California (DR =20%, TR =40%)



For Scenario B, net cost savings were identified for natural gas systems, landfills, manure management, and refrigeration/AC. In total, these options represent 1.7 MMTCO_2 eq. of potential reductions in 2010, and 2.1 MMTCO_2 Eq. in 2020. Options for reducing emissions from landfills account for the majority (70 percent and 60 percent, respectively) of these reductions. For a break-even price of less than \$20/MTCO_2 Eq., an additional 10.8 MMTCO2 Eq. can be reduced in 2010, and 13.9 MMTCO2 Eq. in 2020. In total, by implementing all options with a break-even price of less than \$20/MTCO2 Eq., 12.4 MMTCO2 Eq. can be reduced in 2010, and 16.0 MMTCO2 Eq. in 2020. At \$50/MTCO2 Eq., nearly all of the options included in this analysis can be implemented. At this level, cumulative reductions of 18.6 MMTCO2 Eq. in 2010 and 28.9 MMTCO2 Eq. in 2020 are estimated. (Note: Total non-CO2 GHG emissions in California were approximately 135 MMTCO2E in 2004.)

It is useful to identify points on the cost curve before a drastic increase in break-even price. Recognition of these points can help policymakers decide which suite of options can be implemented with a relatively low net cost per reduction. In 2010, 10.9 MMTCO2 Eq. can be reduced by implementing all options below \$11.48/MTCO2 Eq., at which point, the curve turns steeply upward. In 2020, 15.0 MMTCO2 Eq. can be reduced by implementing options below \$14.09/MTCO2 Eq**.** A similar point exists at \$39.05/MTCO2 Eq. At break-even prices slightly below these levels, a significant amount of potential reductions are lost for very little decrease in cost. At break-even prices somewhat above these levels, relatively small amounts of additional reductions can be achieved.

3. Center for Clean Air Policy

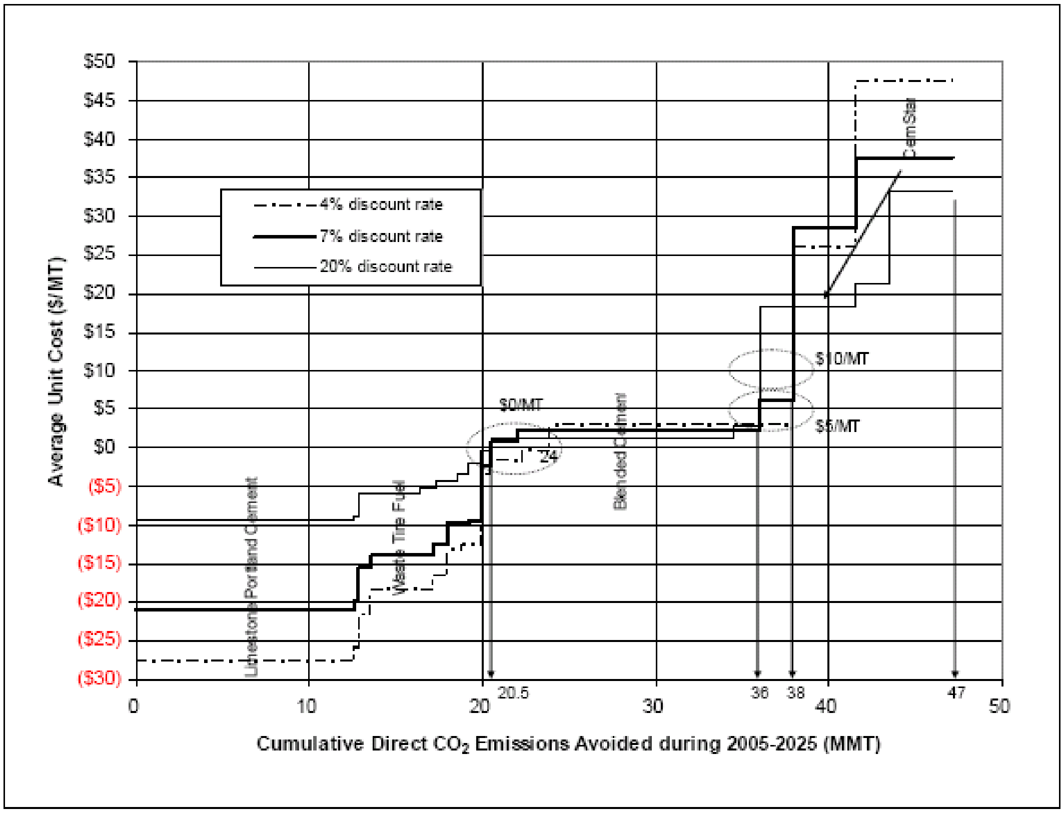
Reducing CO_2 Emissions from California's Cement Sector[3]

According to the ARB's GHG inventory, CO_2 emissions from California cement production was 6.04 MMT CO_2 Eq. in 2004. The Center for Clean Air Policy reviewed CO_2 abatement strategies

[3] *Reducing CO2 Emissions from California's Cement Sector***,** Center for Clean Air Policy, October 14, 2005. http://www.ccap.org/domestic/State/cement.pdf

that could be adopted by the California cement industry. The center also estimated emission reduction and abatement costs for these CO2 control strategies. Exhibit 4 presents the control cost and emission reductions.

Exhibit 4: Abatement-Cost Curve for Cumulative Direct CO_2 Emissions from California's Cement Sector during 2005–2025



Method
Information was collected on the benefits, costs, and technical potentials of energy-efficiency (EE) and other measures to reduce energy consumption and CO2 emissions in clinker and cement production. Data on these measures were largely taken from various publicly available reports by Lawrence Berkeley National Laboratory (LBNL). Because these reports did not contain California specific data, some of their data were altered when appropriate to better comport with conditions in California's cement sector (e.g., its higher-than-average energy efficiency). In the case of California-specific technical potentials, data from a recent draft report by LBNL for the Energy Commission, as well as from industry representatives, were used in the analysis. Because benefits of the measures were given in energy per unit of clinker or cement, they were translated into monetary benefits via projected future energy prices from *AEO 2005*. Also, to the extent that a measure displaced some amount of clinker production (e.g., blended cement), the measure received fuel, electricity, limestone, and cost credits for the clinker displacement. Finally, for some of the largest capital-intensive measures, additional down time beyond scheduled maintenance was assumed to occur in 2005; this resulted in additional costs from lost production, as well as reduced energy consumption and CO2 emissions, in 2005. All prices and costs were denominated in constant 2003 dollars, whether as originally cited in source documents (e.g., *AEO 2005*) or subsequently adjusted by CCAP.

Potential cumulative reductions in energy consumption and CO2 emissions from measure implementation and their cumulative net costs were computed from the above baselines and measures data. To set a likely upper limit on potential emissions reductions, all measures, except maintenance items and limestone Portland cement, were implemented at their technical potentials in 2005 for reductions during 2006–2025; the exceptions were implemented during 2006–2025 for same-year reductions. A measure's cumulative net cost was calculated by discounting its 2005–2025 stream of projected annual total costs back to 2005 at an annual rate of 7%. To assess the effect of discount rate, rates of 4% and 20% were also used. Cumulative net costs could be positive (cost), zero, or negative (savings), and could vary with discount rate.

Abatement-cost curves for cumulative direct CO2 emission reduction were constructed from the above potential cumulative CO2-emissions reductions and net costs of the measures considered. These curves indicate the quantity of cumulative CO2 emissions avoided by each measure relative to the baseline at its average unit (abatement) cost. A measure's average unit cost was calculated by dividing its cumulative net cost by its cumulative CO2-emissions reduction. Relative to the 7% discount rate, the 4% rate tended to increase the magnitude of average unit cost whereas the 20% rate tended to decrease it.

Results
Sector measures for reducing energy consumption and CO2 emissions during the period could achieve cumulative direct reductions of up to 47 MMTCO2 by 2025 relative to the baseline (Exhibit 4). The corresponding average annual reduction during the period would be up to 2.2 MMTCO2. Of this cumulative (annual) amount, 38 (or 1.8 per year), 36 (or 1.7 per year), and 20 (or 1.0 per year) MMTCO2 would cost ≤ $10/MT, ≤ $5/MT, and ≤ $0/MT, respectively (7% discount rate; Exhibit 4, heavy solid line.

With regard to future sector-wide emissions, undertaking all measures considered that cost ≤ $5/MT would result in 2010 and 2020 emissions of 9.6 and 11.8 MMTCO2, respectively. Similarly, undertaking those costing ≤ $10/MT would result in 2010 and 2020 emissions of 9.5 and 11.7 MMTCO2, respectively.

4. Other Western States: Arizona and New Mexico

The states of Arizona and New Mexico also developed CO2 mitigation strategies and abatement costs. Exhibit 5 summarizes the cost of CO2 abatement strategies for four sectors for Arizona and New Mexico. The cost represents the weighted average cost of reduced CO2 from policy options for which quantitative estimates of both costs and savings were prepared. The four sectors were developed by the Advisory Groups of Arizona and New Mexico.

Exhibit 5: New Mexico & Arizona, Cost by Sector, $/tCO2e (2007 - 2020)

Sector	New Mexico	Arizona
Residential, Commercial, Industrial	-18.0	-30.0
Energy Supply	7.0	20.57
Transportation & Land Use	-36.0	-32.
Agricultural & Forestry	-5.0	-0.5

Arizona[4]

In February 2005, Governor Janet Napolitano signed Executive Order 2005-02 establishing the Climate Change Advisory Group (CCAG). Appointed by the Governor, the 35-member CCAG comprised a diverse group of stakeholders who brought broad perspective and expertise to the topic of climate change in Arizona. The Governor's Executive Order directed the CCAG, under the coordination of the Arizona Department of Environmental Quality (ADEQ), to:

- Prepare an inventory and forecast of Arizona greenhouse gas (GHG) emissions; and
- Develop a Climate Change Action Plan with recommendations for reducing GHG emissions in Arizona.

The recommendations adopted by the CCAG underwent two levels of screening. First, a potential policy option being considered by a technical work group was accepted as a "priority for analysis" and developed for full analysis only if it had a supermajority of support from CCAG members (with a "supermajority" defined as five or fewer "no" votes or objections). Second, after the analyses were conducted, only policy options that received at least majority support from CCAG members were adopted as recommendations by the CCAG and included in this report. Of the 49 policy recommendations adopted by the CCAG, 45 received unanimous consent, two (2) received a supermajority of support, and two (2) received a majority of support.

The costs for Arizona Strategies range from savings of $90 per ton to a cost of $65 per ton. Exhibit 6 presents the cost-effectiveness range for Arizona. Exhibit 7 summarizes the results of the 49 policy options by presenting aggregate data for four sectors: agricultural and forestry; residential, commercial and industrial; transportation and land use; and energy supply. Specific, mitigation strategies (and their associated GHG reduction and costs) for each of the four sectors are subsequently presented in Exhibit 8 (agricultural and forestry), Exhibit 9 (Residential, Commercial and Industrial), Exhibit 10 (Transportation and Land Use), and Exhibit 11 (Energy Supply).

[4] *Climate Change Action Plan,* Arizona Climate Change Advisory Group, August 2006. http://www.azclimatechange.gov/download/O40F9347.pdf

Exhibit 6: Arizona's Recommended Policy Options, Cost per Ton GHG Removed

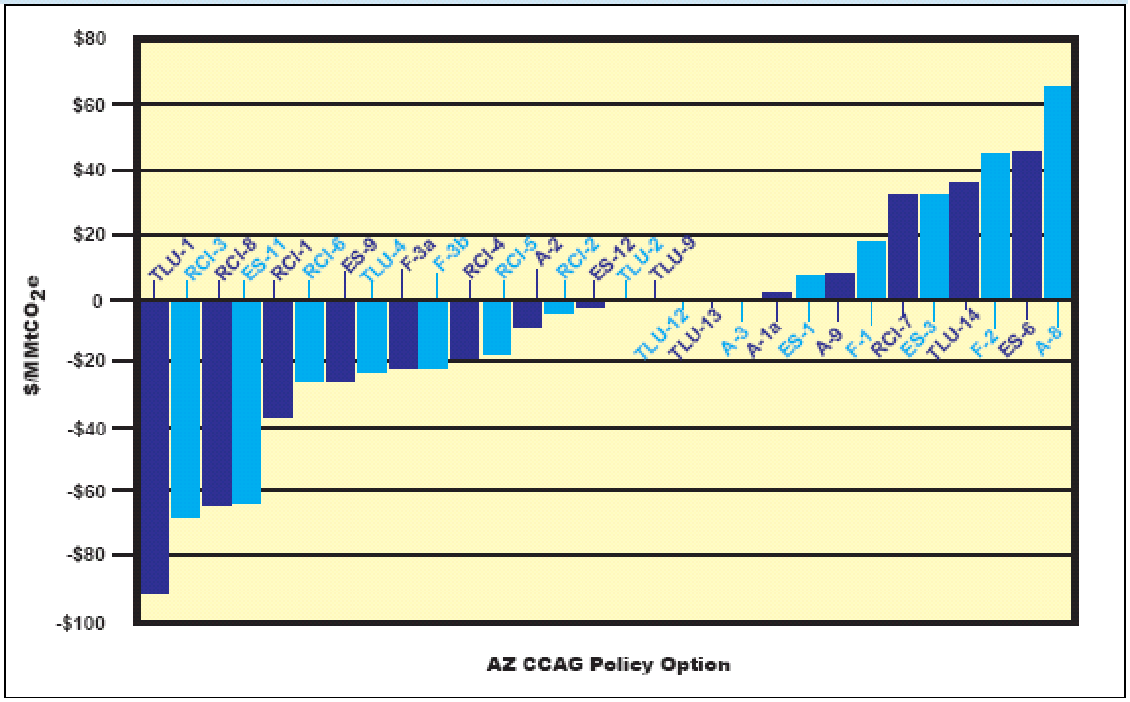


Exhibit 7: Arizona GHG Emission Reduction and Cost by Sectors 2020

Sector	Annual GHG Reduction (MMtCO2e) (2020)	Cost or Cost Savings per metric ton GHG Removed ($/tCO2e) (2007- 2020)
Agricultural & Forestry	5.9	- 0.5
Residential, Commercial & Industrial	31.1	-30.
Transportation & Land Use	14.5	-32.
Energy Supply	17.9	20.57
Total	69.4	-12.74

The Agricultural and Forestry Sector

The Agriculture and Forestry (AF) sector (Exhibit 8) includes emissions and mitigation opportunities related to use of biomass energy, protection, and enhancement of forest and agricultural carbon sinks, control of agricultural methane emissions, production of renewable fuels, and reduction of transport emissions from imported agricultural commodities. The CCAG recommends a set of 11 policy options for the AF sector that offer the potential for major GHG emissions reductions from the reference projection. As summarized in the Exhibit, these 11 policy recommendations could lead to emissions savings from reference case projections of 5.9 MMtCO2e per year by 2020 and cumulative savings of 51 MMtCO2e from 2007 through 2020. The weighted average cost of avoided carbon from the policy options for which quantitative estimates of both costs and savings were prepared was -$0.5 per metric ton of CO2 equivalent. http://www.azclimatechange.gov/download/O40F9289.pdf

Exhibit 8: Summary of Arizona's Policy Recommendations for the Agricultural and Forestry Sector

#	Policy Name	Estimated 2010 GHG Savings ($MMtCO_2e$)	Estimated 2020 GHG Savings ($MMtCO_2e$)	Estimated Costs or Cost Savings Per Ton ($/$tCO_2e$)	Cumulative 2007-2020 GHG Savings ($MMtCO_2e$)	Level of CCAG Support
A-1	Manure Management – Manure Digesters	0.2	0.5	$1	3.8	Unanimous
A-2	Biomass Feedstocks for Electricity or Steam/Direct Heat	0.05	0.1	-$8	4.5	Unanimous
A-3	Ethanol Production and Use	0.5	4.0	$0	28	Unanimous
A-7	Convert Land to Forest or Grassland	Not Quantified	Not Quantified	Not Quantified	Not Quantified	Unanimous
A-8	Reduce Permanent Conversion of Farm and Rangelands to Developed Uses	0.1	0.2	$65	1.6	Unanimous
A-9	Programs to Support Local Farming / Buy Local	0.01	0.02	$6	0.1	Unanimous
F-1	Forestland Protection from Developed Uses	0.3	0.3	$17	3.7	Unanimous
F-2	Reforestation/Restoration of Forestland	0.02	0.1	$44	0.7	Unanimous
F-3a	Forest Ecosystem Management – Residential Lands	0.5	0.5	-$21	6.4	Unanimous
F-3b	Forest Ecosystem Management – Other Lands	0.2	0.2	-$21	2.9	Unanimous
F-4	Improved Commercialization of Biomass Gasification and Combined Cycle	Not quantified[a]		Not quantified[a]		Unanimous

[a] Not quantified due to overlap of biomass energy resource with Option F3a and F3b.

The Residential, Commercial and Industrial Sector

The Residential, Commercial and Industrial (RCI) sector (Exhibit 9) includes emissions and mitigation opportunities related to electricity use by residential, commercial, and industrial consumers, as well as to the on-site combustion of natural gas, oil, and coal, the release of CO2 and fluorinated gases (HFCs, PFCs) during industrial processes, and the leakage of HFCs from refrigeration and related equipment. The CCAG recommends a set of 13 policy options for the RCI sector that offer the potential for major GHG emissions reductions from the reference projection. As summarized in the Exhibit, these 13 policy recommendations could lead to net emissions savings from reference case projections of 31.1 MMtCO2e per year by 2020 and cumulative savings of 222 MMtCO2e from 2007 through 2020. The weighted average cost of saved carbon from the policy options for which quantitative estimates of both costs and savings were prepared was minus $30 per metric ton of CO2 equivalent, meaning that there is a net savings to the Arizona economy in implementing these options.

Exhibit 9: Summary of Arizona's Policy Recommendations for the Residential, Commercial and Industrial Sector

#	Policy Name	GHG Savings ($MMtCO_2e$)	Cost-Effectiveness ($/t$CO_2e$)	Level of CCAG Support
RCI-1	Demand-Side Efficiency Goals, Funds, Incentives, and Programs	2010: 3.1 2020: 15.1	- $36	Unanimous
RCI-2	State Leadership Programs	2010: 0.04 2020: 0.4	- $4	Unanimous
RCI-3	Appliance Standards	2010: 0.2 2020: 1.0	- $66	Unanimous
RCI-4	Building Standards/Codes for Smart Growth	2010: 0.3 2020: 2.2	- $18	Unanimous
RCI-5	"Beyond Code" Building Design Incentives and Programs for Smart Growth	2010: 0.2 2020: 3.1	- $17	Unanimous
RCI-6	Distributed Generation/Combined Heat and Power	2010: 0.4 2020: 2.7	- $25	Unanimous
RCI-7	Distributed Generation/Renewable Energy Applications	2010: 0.1 2020: 2.1	$31	Unanimous
RCI-8	Electricity Pricing Strategies	2010: 1.1 2020: 1.5	-$63	Unanimous
RCI-9	Mitigating High Global Warming Potential (GWP) Gas Emissions (HFC, PFC)	Not Quantified		Unanimous
RCI-10	Demand-Side Fuel Switching	2010: 0.1 2020: 1.2	Not estimated	Unanimous
RCI-11	Industrial Sector GHG Emissions Trading or Commitments	See ES-4	See ES-4	Unanimous
RCI-12	Solid Waste Management	2010: 2.2 2020: 3.7	Not estimated	Unanimous
RCI-13	Water Use and Wastewater Management	2010: 0.2 2020: 0.8	Not estimated	Unanimous

The Transportation and Land Use Sector

The Transportation and Land Use sector (Exhibit 10) includes GHG mitigation opportunities related to vehicle technologies, fuel choices, transit options, and demand for transportation services. The CCAG recommends a set of 13 policy options for the TLU sector that offer the potential for major GHG emissions reductions from the reference projection. As summarized in the Exhibit below, these 13 policy recommendations could lead to emissions savings from reference case projections of 14.5 MMtCO2e per year by 2020 and cumulative savings of 91 MMtCO2e from 2007 through 2020. The weighted average cost of saved carbon from the policy options for which quantitative estimates of both costs and savings were prepared was minus $32 per metric ton of CO2 equivalent, meaning that there is a net savings to the Arizona economy in implementing these options.

Exhibit 10: Summary of Arizona's Policy Recommendations for the Transportation and Land Use Sector

#	Policy Name	Estimated 2010 GHG Savings ($MMtCO_2e$)	Estimated 2020 GHG Savings ($MMtCO_2e$)	Estimated Costs or Cost Savings Per Ton ($\$/tCO_2e$)	Cumulative 2007–2020 GHG Savings ($MMtCO_2e$)	Level of CCAG Support
TLU-1	State Clean Car Program	0.3	5.6	-$90	32.5	Unanimous
TLU-2	Smart Growth Bundle	1.5	4.0	$0 (Net savings)	26.7	Unanimous
TLU-3	Promoting Multimodal Transit	Not available (included in TLU-2)				Unanimous
TLU-4	Reduction of Vehicle Idling	0.7	1.3	-$22	11.8	Unanimous
TLU-5	Standards for Alternative Fuels	Not available (enabling policy for TLU-12 and A-3)				Unanimous
TLU-7	Hybrid Promotion and Incentives	Not available (included in TLU-1)				Unanimous
TLU-8	Feebates	Not available				Super-majority
TLU-9	Pay-As-You-Drive Insurance	0	2.8	$0 (Zero Net cost)	12.3	Unanimous
TLU-10	Low Rolling Resistance Tires	0.0	0.8	Not available	4.8	Unanimous

Exhibit 10 (con't): Summary of Arizona's Policy Recommendations for the Transportation and Land Use Sector

TLU-11	Accelerated Replace-ment/ Retirement of High-emitting Diesel Fleet	0.2	0.03	Not available	1.2	Unanimous
TLU-12	Biodiesel Implemen-tation	0.1	1.1	$0 (Zero Net cost)	6.2	Unanimous
TLU-13	State Lead-By-Example (via Procure-ment and SmartWay)	0.03	0.04	$0 (Zero Net cost)	0.4	Unanimous
TLU-14	60 mph Speed Limit for Commercial Trucks	0.3	0.5	$35	5.2	Super-majority

The Energy Supply Sector

The Energy Supply (ES) sector (Exhibit 11) includes emissions mitigation opportunities related to electrical energy supply options, including the generation, transmission, and distribution of electricity, whether generated through the combustion of fossil fuels or by renewable energy sources, and whether generated in a centralized power station or distributed generation facilities. Arizona has little oil and gas production, so the CCAG made no oil and gas recommendations.

Three policies are quantified as ES options that Arizona can implement on its own, including ES-1, Environmental Portfolio Standard/Renewable Energy Standard and Tariff; ES-6, Carbon Intensity Targets; and ES-12, Integrated Resource Planning. Because the purpose of ES-12 would largely be accomplished by (i.e., overlap with) the activities that would be undertaken to satisfy ES-1 and ES-6, only the results from ES-1 and ES-6 are included in the totals. Further, because either ES-1 or ES-6 would exhaust all available wind, biomass, and geothermal generation capacity within Arizona, GHG reductions from these resources are included only in ES-6 in order to avoid double-counting.

These policy recommendations could lead to emissions savings from reference case projections of 17.9 MMtCO2e per year by 2020 and cumulative savings of 120.6 MmtCO2e from 2007 through 2020. The weighted average cost of saved carbon from the policy options for which quantitative estimates of both costs and savings were prepared was $20.57 per metric ton of CO2 equivalent.

Exhibit 11: Summary of Arizona's Policy Recommendations for the Energy Supply Sector

#	Policy Name	Estimated 2010 GHG Savings ($MMtCO_2e$)	Estimated 2020 GHG Savings ($MMtCO_2e$)	Estimated Costs or Cost Savings Per Ton ($/$MMtCO_2e$)	Cumulative 2007-2020 GHG Savings ($MMtCO_2e$)	Level of CCAG Support
ES-1	Environ-mental Portfolio Standard / Renewable Energy Standard and Tariff	*The quantification below reflects the results provided by ES-1 when* ***integrated into the comprehensive package*** *of approved CCAG policy options.*				Majority
		3.0	8.7	$3.54	70.3	
		The quantification below reflects the results provided by ES-1 when ***isolated as a single, stand-alone*** *policy option.*				
		4.19	16.4	$6.48	116	
ES-3	Direct Renewable Energy Support (including Tax Credits and Incentives, R&D, and siting / zoning)	*This option is quantified under RCI-7, Distributed Generation / Renewable Energy Applications. Values are shown below for completeness, but not included in cumulative totals to prevent double-counting.*				Unanimous
		0.1	*2.1*	*$31*	*10*	
ES-4	GHG Cap and Trade	*Quantification for an aggressive national cap and trade scenario (Cap-Trade 4) as it would apply to Arizona's power sector is shown below. These values reflect the results of this scenario were it to be* ***integrated into the comprehensive package*** *of approved CCAG policy options.*				Unanimous
		0.12	*12.2*	*$18.45*	*63.2*	
		Four national cap and trade scenarios were modeled as they would apply to Arizona's power sector in order to gauge their impact if implemented ***as an isolated, single, stand-alone policy option****. Ranges of results are shown below. These values are not included in cumulative figures.*				
		-0.28 – 0.18	*2.0 – 18.5*	*$7.29 – $18.52*	*7 – 88*	

Exhibit 11 (con't): Summary of Arizona's Policy Recommendations for the Energy Supply Sector

ES-6	Carbon Intensity Targets	*The quantification below reflects the results provided by ES-6 when* ***integrated into the comprehensive package*** *of approved CCAG policy options.*				Majority
		0.0	9.2	$44.33	50.3	
		The quantification below reflects the results provided by ES-6 when ***isolated as a single, stand-alone*** *policy option.*				
		0.0	14.0	$44.56	70	
ES-9	Reduce Barriers to Renewables and Clean DG	*This option is quantified under RCI-6, Distributed Generation / Combined Heat and Power. Values are shown below for completeness, but not included in cumulative totals to prevent double-counting.*				Unanimous
		0.4	*2.7*	*-$25*	*16*	
ES-10	Metering Strategies	*ES-10 is an enabling policy for RCI-6 and RCI-7; its quantification is incorporated into those options.*				Unanimous
ES-11	Pricing Strategies	*This option is quantified under RCI-8, Electricity Pricing Strategies. Values are shown below for completeness, but not included in cumulative totals to prevent double-counting.*				Unanimous
		1.1	*1.5*	*-$63*	*16*	
ES-12	Integrated Resource Planning	*The quantification below reflects the results ES-12 would provide if* ***implemented as a single, stand-alone*** *policy option. When* ***integrated into the comprehensive package*** *of CCAG-approved policy options, however, it would target the same activities as ES-1 and ES-6, so its reductions and savings would not be included in order to avoid double-counting.*				Unanimous
		0.06	5.4	-$2.50	28	
Total All Options		**3.0**	**17.9**	**$20.57**	**120.6**	*Note: Total includes onlyES-1 and ES-6.*

New Mexico[5]

Governor Bill Richardson signed Executive Order 05-33 in June 2005, establishing the New Mexico Climate Change Advisory Group (CCAG). The Governor directed the CCAG to prepare a report that includes a projection of the State's future GHG emissions and policy recommendations for reducing New Mexico's total greenhouse gas emissions to 2000 levels by the year 2012, 10% below 2000 levels by 2020 and 75% by 2050.

The New Mexico Environment Department (NMED) organized the process on behalf of the Governor. NMED assembled 37 stakeholders, representing a broad range of interests and

[5] New Mexico Climate Change Advisory Group, Final Report, December 2006. http://www.nmclimatechange.us/ewebeditpro/items/O117F10150.pdf

expertise, and the CCAG met six times from July 2005 to October 2006. During this same period, five sector-based technical work groups (TWGs) of the CCAG developed initial recommendations in the areas of: Energy Supply (ES); Residential, Commercial, Industrial and Waste Management (RCI); Transportation and Land Use (TLU); Agriculture and Forestry (AF); and Cross-Cutting Issues (CC). The CCAG developed 69 policy recommendations to the Governor to help meet the GHG emissions goals in Executive Order 05-33.

The costs for New Mexico Strategies range from savings of about $120 to costs of about $105 per ton. Exhibit 12 presents the cost-effectiveness range for New Mexico. Exhibit 13 summarizes the results of the 69 policy options by presenting emission reduction and cost data for four sectors: agricultural and forestry; residential, commercial and industrial; transportation and land use; and energy supply. Specific, mitigation strategies (and their associated GHG reduction and costs) for each of the four sectors are subsequently presented in Exhibit 14.

Exhibit 12: New Mexico Policy Recommendations Ranked by Dollars per Ton

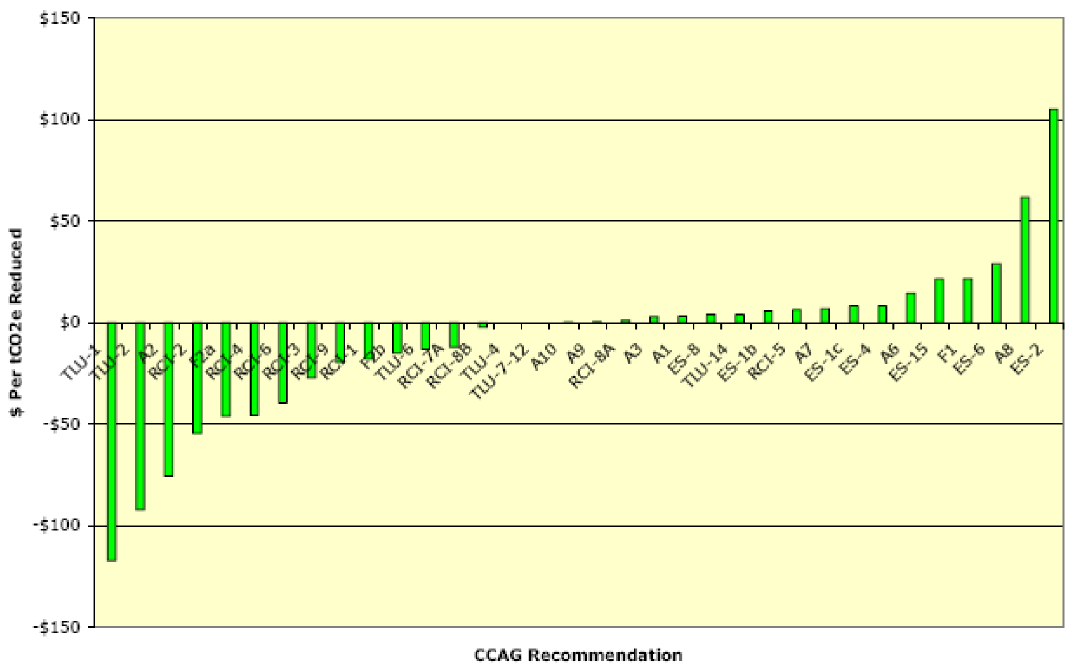


Exhibit 13: New Mexico GHG Emission Reduction and Cost by Sectors 2020

Sector	Annual GHG Reduction (MMtCO2e) (2020)	Cost or Cost Savings per ton GHG Removed ($/tCO2e) (2007- 2020)
Agricultural & Forestry	4.9	- 5.0
Residential, Commercial & Industrial	9.4	-18.0
Transportation & Land Use	6.8	-36.0
Energy Supply	14.3	7.0
Total	35.4	--

Exhibit 14: Summary of New Mexico's Policy Recommendations by Sector

Explanatory Note on "Level of Support" column: UC=Unanimous Consent. Majority=Simple majority. Obj's=number of objections. Total number of options=69 due to counting both ES-1b and ES-1c.

	Policy Option	GHG Reductions ($MMtCO_2e$)			Net Present Value 2007–2020 (Million $)	Cost-Effective-ness ($/$tCO_2e$)	Level of Support
		2012	2020	Total 2007-2020			
	CROSS-CUTTING ISSUES						
CC-1	State Greenhouse Gas Reporting	*Non-quantified enabling policy*					UC
CC-2	State Greenhouse Gas Registry	*Non-quantified enabling policy*					UC
CC-3	State Climate Public Education and Outreach	*Non-quantified enabling policy*					UC
	RESIDENTIAL, COMMERCIAL AND INDUSTRIAL						
RCI-1	Demand Side Management (DSM) Programs, Energy Efficiency Funds,and/or Energy Efficiency Requirements for Electricity	0.2	1.0	5.5	-$98	-$18	UC
RCI-2	Demand Side Management (DSM) Programs, Energy Efficiency Funds, and/or Energy Efficiency Requirements for Natural Gas and Other Fuels	0.03	0.2	1.0	-$55	-$55	UC
RCI-3	Regional Market Transformation Alliance	0.1	0.5	2.9	-$79	-$27	UC
RCI-4	State Appliance Standards	0.1	0.3	2.1	-$97	-$46	UC
RCI-5	Green Power Purchasing	0.3	0.1	2.3	$15	$7	UC
RCI-6	Rate Design (Including Time of Use Rates, Increasing Block Rates, and Seasonal Use Rates)	0.3	0.3	3.6	-$141	-$40	UC
RCI-7A	Improved Building Codes	0.9	2.4	16.6	-$200	-$12	UC
RCI-7B	Solar Hot Water-ready and Solar-PV-ready Codes for New Buildings	*Not quantified*					UC
RCI-7C	Solar Hot Water Systems as an Element of Building Codes for New Buildings	*Not quantified*					UC
RCI-8A	Building Energy Performance Requirements for State-funded and Other Government Buildings ("Reach Codes")	0.01	0.04	0.2	0.2	$1	UC
RCI-8B	Building Energy Performance Promotion and Incentives for Energy Performance Enhancements (Attaining "Reach Codes") in Non-Government Buildings (Including Existing Buildings)	0.3	1.3	7.4	-$16	-$2	UC
RCI-9	Government Agency Requirements and Goals (including procurement) -- Focus on operations	0.04	0.2	0.9	-$18	-$20	UC

Exhibit 14 (con't): Summary of New Mexico's Policy Recommendations by Sector

	Policy Option	GHG Reductions ($MMtCO_2e$) 2012	2020	Total 2007-2020	Net Present Value 2007–2020 (Million $)	Cost-Effective-ness ($/$tCO_2e$)	Level of Support
RCI-10	Education and Outreach for Building Professionals	*Not quantified*					UC
RCI-11	Consumer Education Programs	*Not quantified* *Jointly considered with CC TWG*					UC
RCI-12	Increased Emphasis on Energy and Environmental Consideration in Higher Education						UC
RCI-13	Incentives and Promotion for Renewable Energy and Clean Combined Heat and Power	*Jointly considered with Energy Supply TWG*					UC
RCI-14	Regulatory/Legislative Grid, Pricing, and other Policies to Support Distributed Generation						UC
RCI-16	Participation in Regional (or National) Industry Emissions Cap and Trade Programs	*Jointly considered with Energy Supply TWG*					UC
RCI-17	Voluntary Emissions Targets	0.3	0.7	4.6	*Not quantified*		UC
RCI-18	Use of Alternative Gases (Non-Energy Emissions, Indus. Process Gases)	*Not quantified*					UC
RCI-19	Solid Waste Recycling, Source Reduction, and Composting						UC
	Scenario A: Financial/Technical Support	0.2	0.5	3.6	*Not quantified*		UC
	Scenario B: Financial/Technical Support and Mandatory Recycling	0.5	1.1	8.4	*Not quantified*		UC
	ENERGY SUPPLY						
ES-1	Mandate(s) for Renewable Energy (RPS, etc.)						
	Scenario B: 10% in 2011, 1% increase/year to 2021	1.1	2.6	17.8	$102	$6	UC
	Scenario C: 10% in 2011, 2% increase/year to 2021	*See ES-4 below*					Majority (9 Obj's)
ES-2	Financial Incentives for Distributed Renewables	0.02	0.4	1.6	$164	$105	UC
ES-3	Renewable Energy Transmission and Storage	*Not quantified*					UC
ES-4	RPS with Financial Incentives for Centralized Renewables	1.2	4.2	26.0	$215	$8	UC
ES-5	R&D including Energy Storage	*Not quantified*					UC
ES-6	Advanced Coal/Fossil Technologies (e.g., IGCC with carbon capture)	0.8	4.3	22.7	$650	$29	UC
ES-7	Nuclear Power	*Not quantified*					UC
ES-8	Incentives and Barrier Reductions for Combined Heat & Power (CHP)	0.3	0.9	6.1	$26	$4	UC

Exhibit 14 (con't): Summary of New Mexico's Policy Recommendations by Sector

	Policy Option	GHG Reductions ($MMtCO_2e$) 2012	2020	Total 2007-2020	Net Present Value 2007–2020 (Million $)	Cost-Effective-ness ($/$tCO_2e$)	Level of Support
ES-9	Demand-Side Management, Energy Efficiency, and Integrated Resource Planning (IRP)	*Jointly considered with RCI TWG (RCI-1)*					
ES-10	Transmission Capacity and Corridors	*Not quantified*					UC
ES-11	CO2 Capture and Storage or Reuse (CCSR) in Oil and Gas Operations	1.6	3.0	25.1	*Not quantified*		UC
ES-12	Methane Reduction in Oil and Gas Operations: BMPs and PROs	2.7	3.4	35.3	*Not quantified*		UC
ES-13	CO2 Reduction from Fuel Combustion in Oil and Gas Operations	0.6	1.4	10.6	*Not quantified*		UC
ES-14	GHG Cap and Trade	*Not quantified*					UC
ES-15	Generation Performance Standard	1.2	3.8	24.3	$522	$21	Majority (9 Obj's)
ES-16	Clean Energy Development for Electric Cooperatives	*Non-quantified enabling policy*					UC
	TRANSPORTATION AND LAND USE						
TLU-1	State Clean Car Program	0.4	1.9	10.4	-$1,207	-$117	UC
TLU-2	Low Rolling Resistance Tires	0.5	0.6	5.5	-$506	-$92	UC
TLU-3	Low-GHG Operation of State Fleet Vehicles	*Not quantified*					UC
TLU-4	Pay-As-You-Drive Insurance	0.2	1.0	5.0	Zero net cost		UC
TLU-5	Incentive/Disincentive Options Bundle	*Not quantified*					UC
TLU-6	Alternative Fuels Use	0.4	1.7	9.1	-$119	-$13	UC
VMT Reduction Bundle TLU-7 to TLU-11							
TLU-7	Infill, Brownfield Re-development	1.2	1.3	13.4	*Zero net costs or positive cost savings*		UC
TLU-8	Transit-Oriented Development						UC
TLU-9	Smart Growth Planning, Modeling, Tools						UC
TLU-10	Multimodal Transportation Bundle						UC
TLU-11	Promote LEED for Neighborhood Development						UC
TLU-12	Targeted Open Space and Croplands Protection	*Considered in Agriculture and Forestry TWG (F-1 and A-8)*					
TLU-13	Diesel Retrofits	*Incorporated as part of TLU-5*					
TLU-14	Truck Stop Electrification/Anti-Idling	0.4	0.7	6.3	$23	$4	UC

Exhibit 14 (con't): Summary of New Mexico's Policy Recommendations by Sector

	Policy Option	GHG Reductions ($MMtCO_2e$) 2012	2020	Total 2007-2020	Net Present Value 2007–2020 (Million $)	Cost-Effectiveness ($/$tCO_2e$)	Level of Support
TLU-15	Intermodal Freight Initiatives	0.1	0.5	2.6	*Not quantified*		UC
TLU-16	Lower Speed Limits	0.2	0.3	2.8	*Not quantified*		UC
	AGRICULTURE AND FORESTRY						
F-1	Forestland Protection from Developed Uses	0.1	0.1	1.2	$46	$22	UC
F-2a	Forest Health & Restoration - Residential Lands	0.2	0.2	2.5	-$115	-$46	UC
F-2b	Forest Health & Restoration – Other Lands	0.5	0.5	6.3	-$92	-$15	UC
A-1	Manure Energy Utilization	0.3	0.8	6.3	$29	$3	UC
A-2	Biomass Feedstocks for Electricity or Steam Production	0.2	0.3	2.6	-$198	-$76	UC
A-3	Ethanol Production	0.5	1.0	7.5	$20	$3	UC
A-6	Conservation Tillage/No-Till	0.1	0.1	0.6	$14	$15	UC
A-7	Convert Agricultural Land to Grassland or Forest	0.4	0.4	4.0	$27	$7	UC
A-8	Reduce Permanent Conversion of Agricultural Land and Rangeland to Developed Uses	0.1	0.2	1.6	$97	$62	UC
A-9	Programs to Support Organic Farming	0.2	0.4	4.4	$2	$0.5	UC
A-10	Programs to Support Local Farming/Buy Local	0.3	1.1	5.9	$1	$0.2	UC
A-11	Biodiesel Production	0.1	0.3	2.3	*Not quantified*		UC
	TOTAL AFTER ADJUSTING FOR OVERLAPS AND RECENT POLICY ACTIONS	16	35	267	-$2,239		n/a

5. McKinsey & Company [6]

McKinsey & Company (http://www.mckinsey.com/) is a management consultant company that advises companies, governments, and institutions worldwide. In December 2007, McKinsey & Company released the report, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost*? [7] Emission control strategies and their dollar per ton costs were developed for the regions of U.S and for the U.S.

[6] *Designing an Effective GHG Regulatory System for CA – Abatement Opportunities Lessons Learned from Europe*, McKinsey & Company, presented to ARB staff 2/13/07.

7 Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost? McKinsey & Company, December 2007. http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf

McKinsey and Company also publish *The McKinsey Quarterly.* In a recent quarterly publication entitled, *A Cost Curve for Green House Gas Reduction*[8], McKinsey presented global CO2 control costs for a wide array of abatement measures beyond "business as usual" measured in GtCO2e.

The control strategies and their associated abatement costs will be presented first for the U.S., followed by the Western U.S., and then Global.

- United States -

In December 2007, McKinsey & Company released the report, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost*?[9]

The report centered on CO2e abatement strategies that can be undertaken for less than $50/ton.

McKinsey developed three scenarios or levels of national commitment. (A level of commitment is like turning up the dial, it increases the intensity of the action)

- Low-range case 1.3 gigaton/yr of abatement potential (2030) this would represent an incremental effort from current business practices

- Mid-range case 3.0 gig/yr of abatement potential. It would take a concerted action across the economy (full energy efficiency potential and CCS)

- High-range 4.5 gig/yr of abatement potential. This represents aggressive measures, sense of great urgency, national mobilization.

A summary of emission control strategies and their costs for the U.S. are presented in this section.

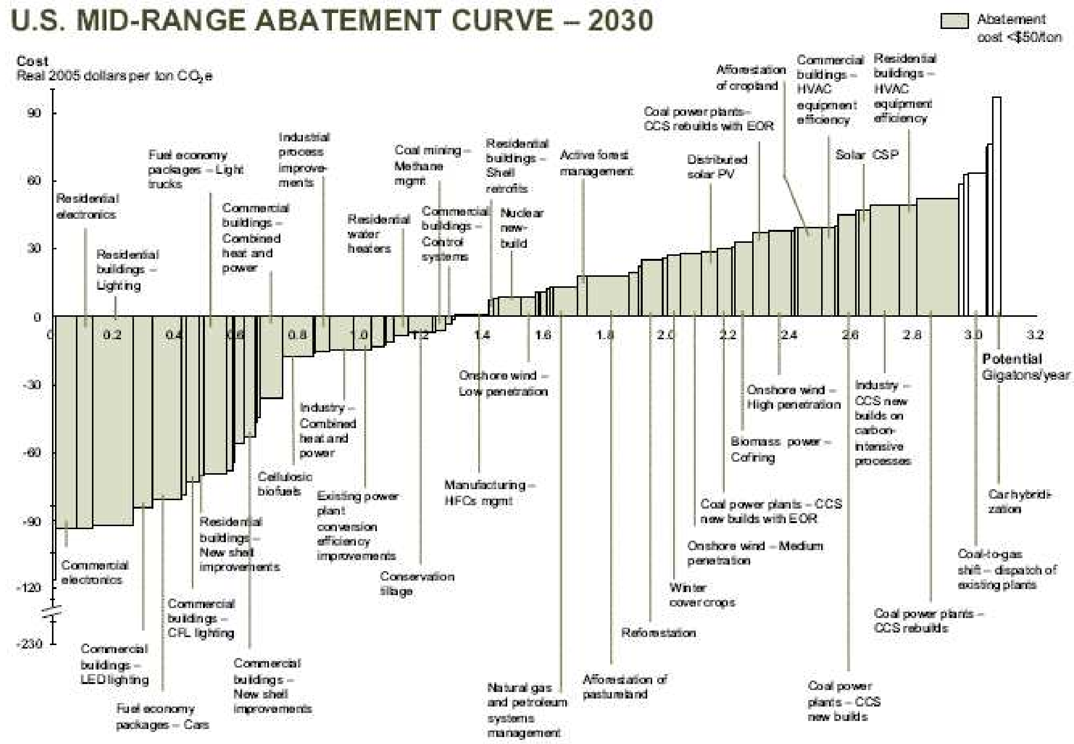
From a U.S. perspective, Exhibit 15 presents the cost of control for 42 abatement measures, and specifically identifies abatement measurers with marginal costs between $ -93/ tCO2e (commercial electronics) to $91/ tCO2e (car hybridization). The 42 abatement strategies (plus others) are estimated to reduce GHG in the U.S. by approximately 3.1 gigatons/year by the year 2030.

---

[8] *A Cost Curve for Greenhouse Gas Reduction,* The McKinsey Quarterly, *Fall 2007.*

[9] *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost*? McKinsey & Company, December 2007. http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf

Exhibit 15:

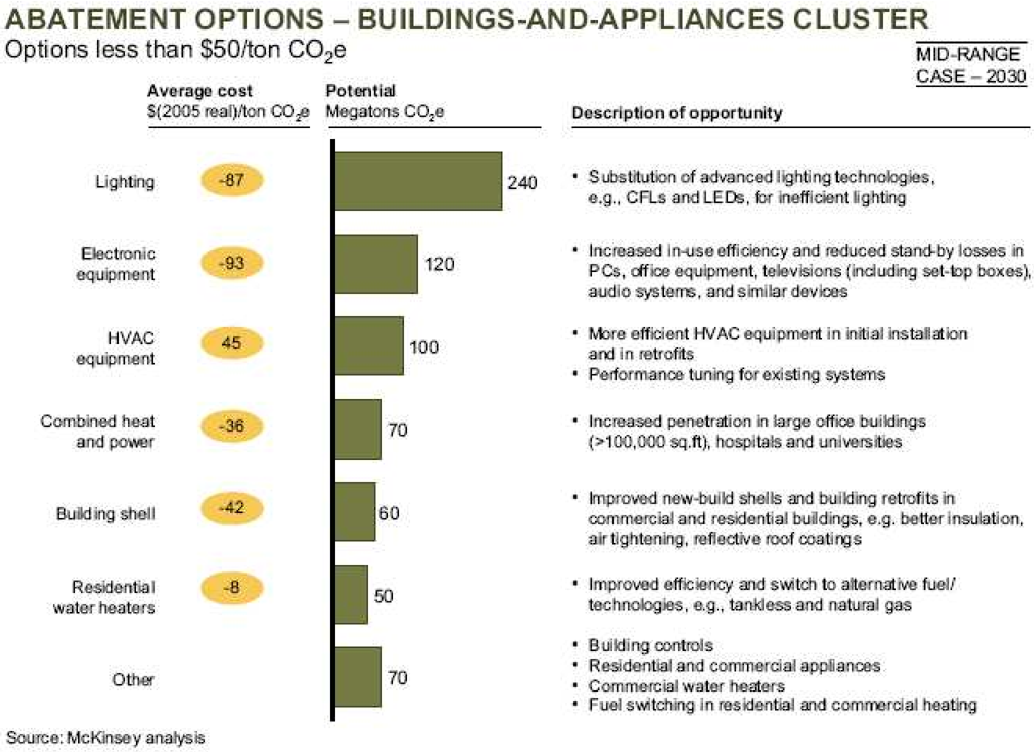


Source: McKinsey analysis

McKinsey also estimated abatement potentials and costs for five sectors in the economy. The sectors are presented in order from least to highest cost and represent the mid-range case of national (U.S.) commitment.

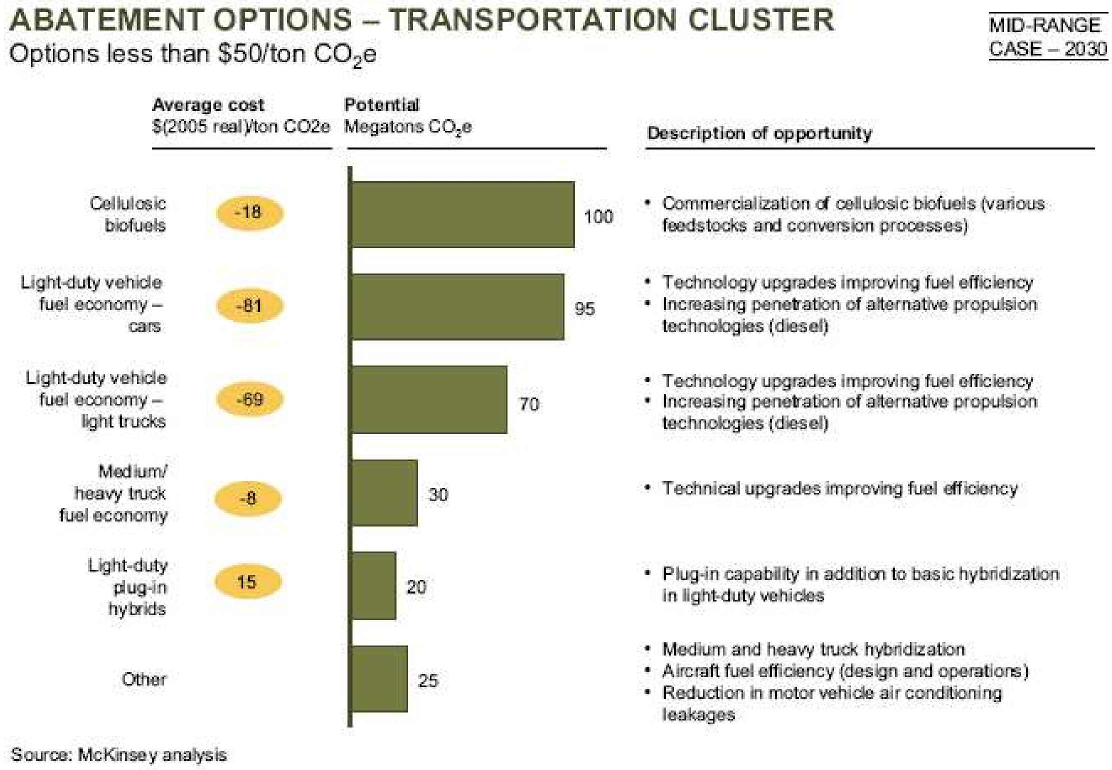
The Buildings & Appliances sector (Exhibit 16) has the potential to reduce CO2 e emissions by .7gigaton/year by 2030. Strategies range from electronic equipment at $ -93/ton to residential water heaters at $-8/ton.

Exhibit 16:



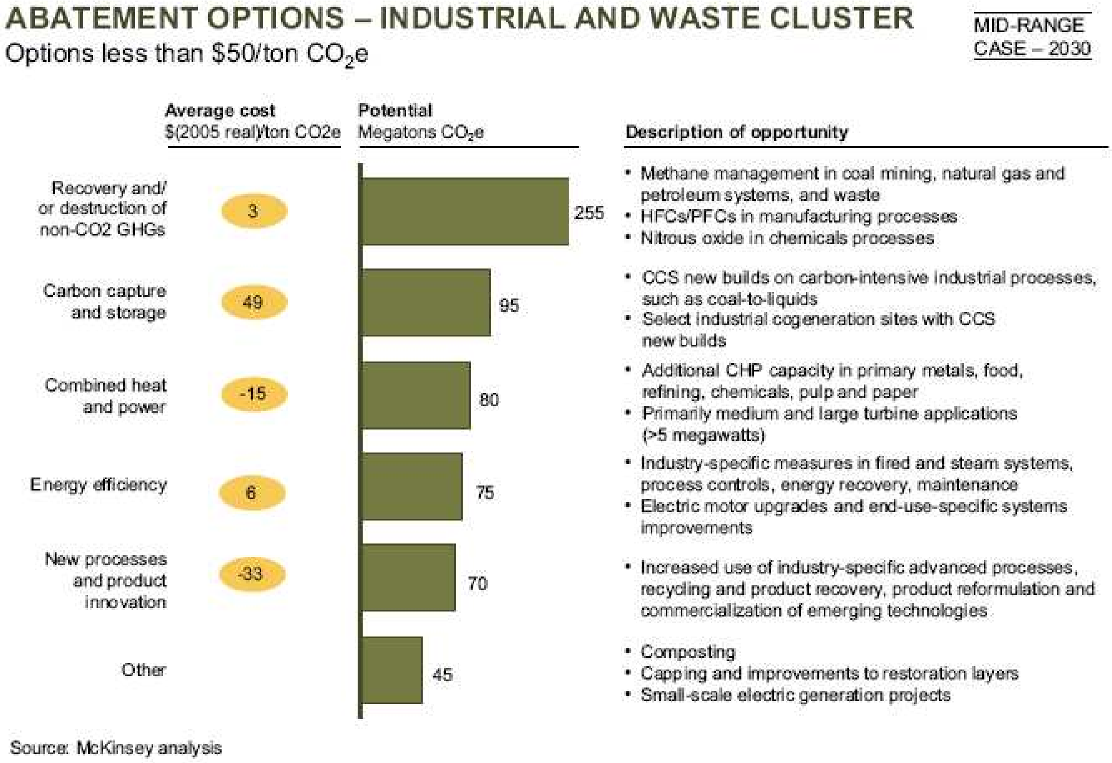
The Transportation sector (Exhibit 17) has the potential to reduce CO2 e emissions by .3 gigaton/year by 2030. Strategies range form light duty vehicle fuel economy at $-81/ton to Light-Duty Plug-in Hybrids at $15/ton.

Exhibit 17:



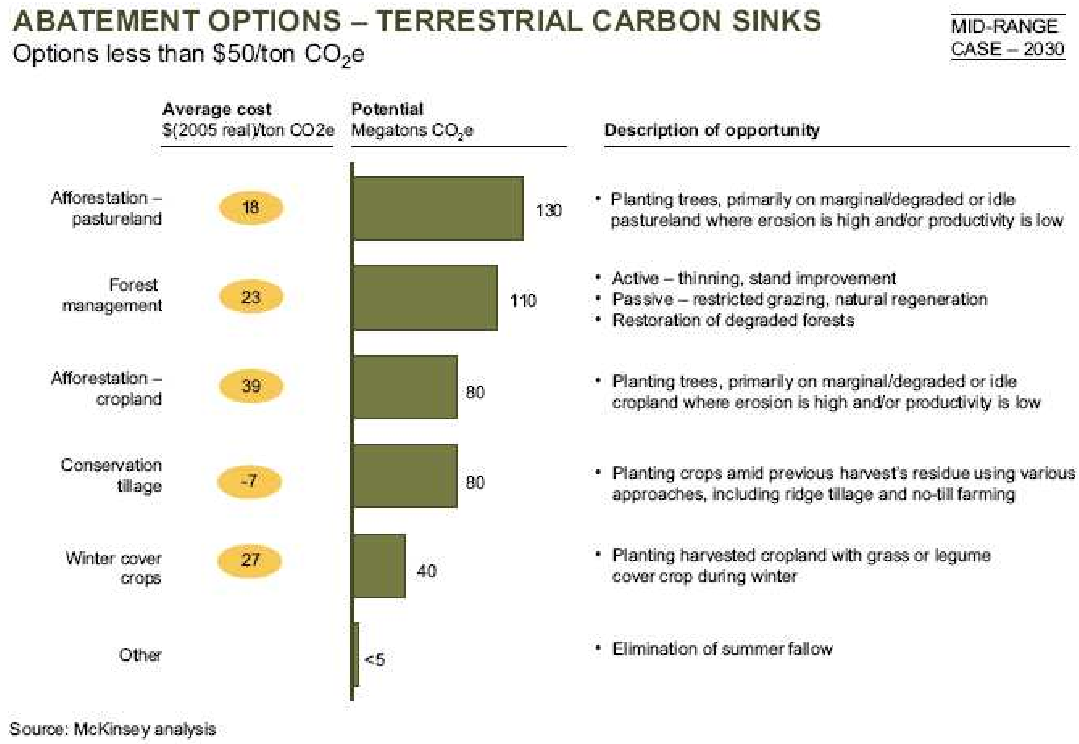
The Industrial & Waste sector (Exhibit 18) has the potential to reduce CO2 e by .6 gigaton/year by the year 2030. Strategies range from new processes and product innovation (in the heavy industries) at $-33/ton to carbon capture and storage at $49/ton.

Exhibit 18:



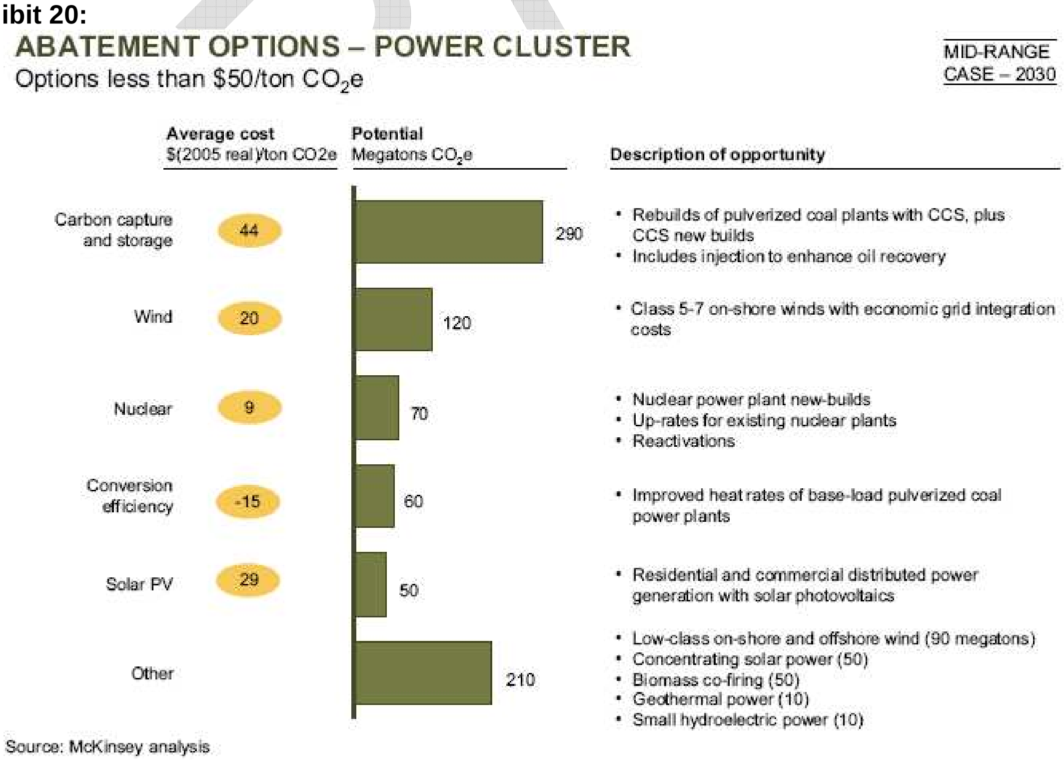
The Terrestrial Carbon Sinks sector (Exhibit 19) has the potential to reduce CO2 e by .5 gigaton/year. Strategies range from conservation tillage at $ -7/ton to winter cover crops at $27/ton.

Exhibit 19:



The Power Generation sector (Exhibit 20) has the potential to reduce CO2 e by .8 gigatons/year by 2030. Strategies range from conversion efficiency at $-15/ton to carbon capture and storage at $44/ton.

Exhibit 20:

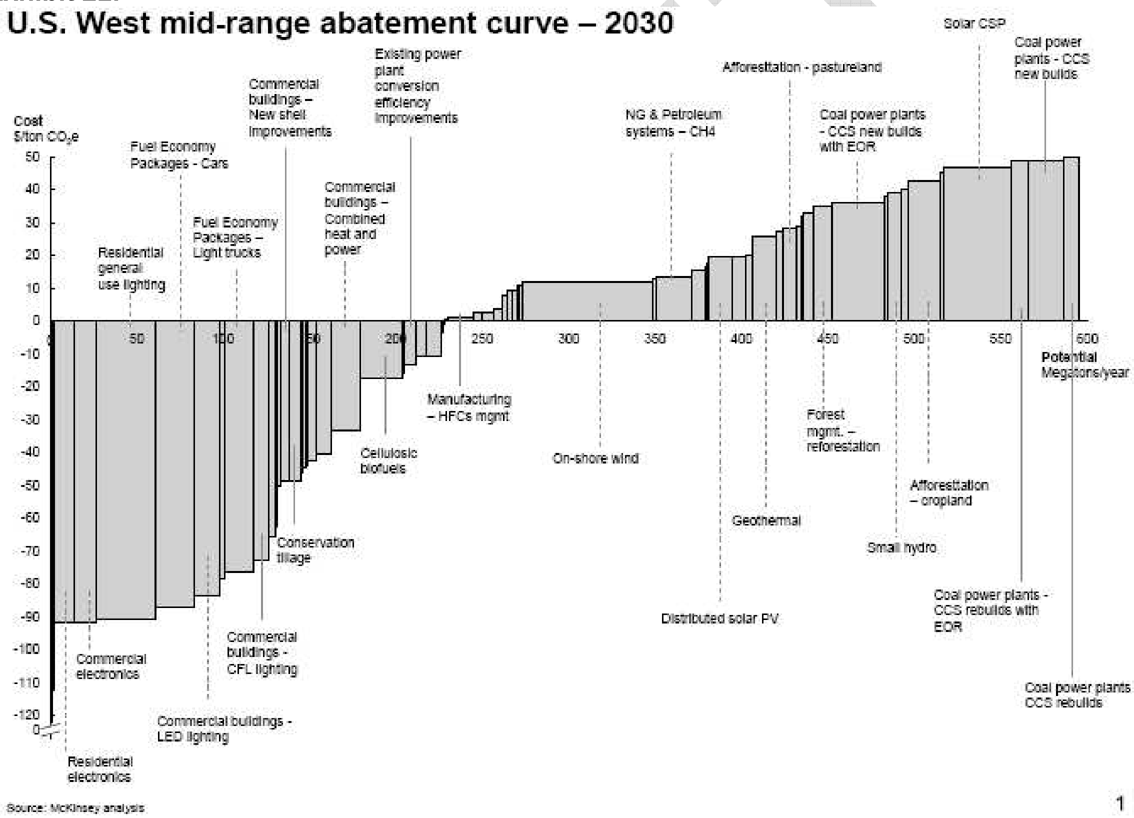


-Western U.S.-

McKinsey estimated abatement strategies and costs for the western U.S. The western U.S. includes the states of Alaska, California, Oregon, Washington, Idaho, Nevada, Montana, Wyoming, Utah, Colorado, Arizona, New Mexico, and Hawaii.

From a western U.S. perspective, Exhibit 21 presents the cost of control for 26 abatement measures, and specifically identifies abatement measurers with marginal costs between $-90/tCO2e (residential electronics) to $50/tCO2e (carbon capture rebuilds for coal power plants). The 26 abatement strategies (plus others) are estimated to reduce GHG in the western U.S. by approximately 600 megatons/year by the year 2030.

Exhibit 21:



-Global-

McKinsey and Company also publish *The McKinsey Quarterly.* In a recent quarterly publication of *The McKinsey Quarterly,* McKinsey and Company[10] presented <u>global</u> CO2 control costs for a wide array of abatement measures beyond "business as usual" measured in GtCO2e. The global control strategies and costs are presented in this section.

---

[10] *A Cost Curve for Greenhouse Gas Reduction,* The McKinsey Quarterly, *Fall 2007.*

Exhibit 22 presents summary (global) information which is presented in more detail in Exhibits 23 – 26. Note: Cost data in Exhibits 23 -26 is presented in Euros per ton of CO2 eq.

Exhibit 22: Cost-effectiveness for Global, All Sectors, Power, Transport, & Building 2030

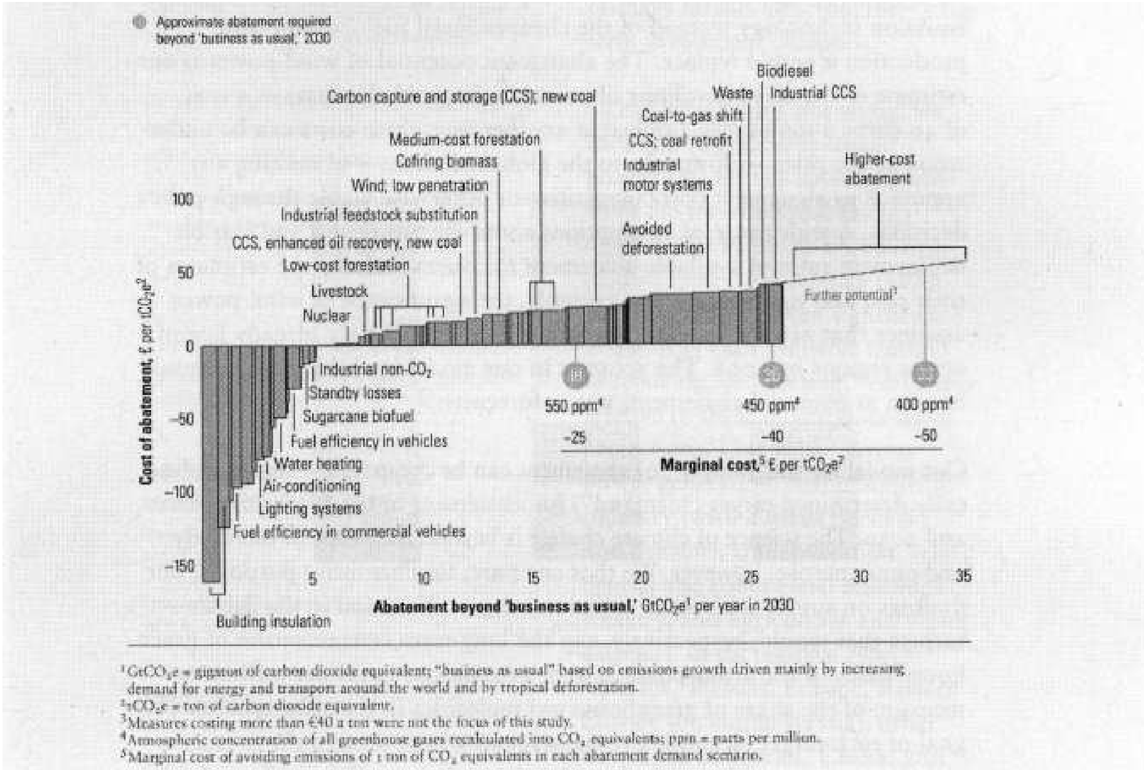
Global	Cost-effectiveness Range $/ton CO2eq	Tons Reduced GTCO2eq
Global (All Sectors)[1]	-225 to 91	26
Air-conditioning	-106	0.5
Water heating	-70	0.4
Sugarcane biofuel	-14	1.0
Avoided deforestation	49	3.0
Waste	63	1.0
Power[2]	21 to 70	12.5
Transport[2]	-144 to 561	0.003
Building[2]	-281 to -14	3.75

Source: 1. The McKinsey Quarterly, *A Cost Curve for Greenhouse Gas Reduction,* Fall 2007.
2. McKinsey & Company, Designing an Effective GHG Regulatory System for CA – Abatement Opportunities, Lessons Learned from Europe, presented to ARB staff 2/13/0707

Exhibit 23 presents global cost curve for greenhouse gas abatement measures beyond "business as usual", measured in GtCO2e. McKinsey developed a cost curve with the 450-parts-per-million global scenario (in the midrange of the targets put forward by advocates). Under this scenario, reductions of 26 gigatons a year would need to occur by 2030. Assuming that measurers are implemented in order of increasing cost, the marginal cost per ton of emissions avoided would be 40 euros (1 euro = $1.4076, 9/21/07) or $56.30 tCO2e.

Also, from a global perspective, Exhibit 16 presents the cost of control for 26 abatement measures, and specifically identifies abatement measurers with marginal costs between $ -225/ tCO2e (building insulation) to $91/ tCO2e (industrial carbon capture and storage).

Exhibit 23: Global Cost Curve for Greenhouse Gas Abatement Measures Beyond "Business as Usual" GHG Measured in GtCO2e[1]

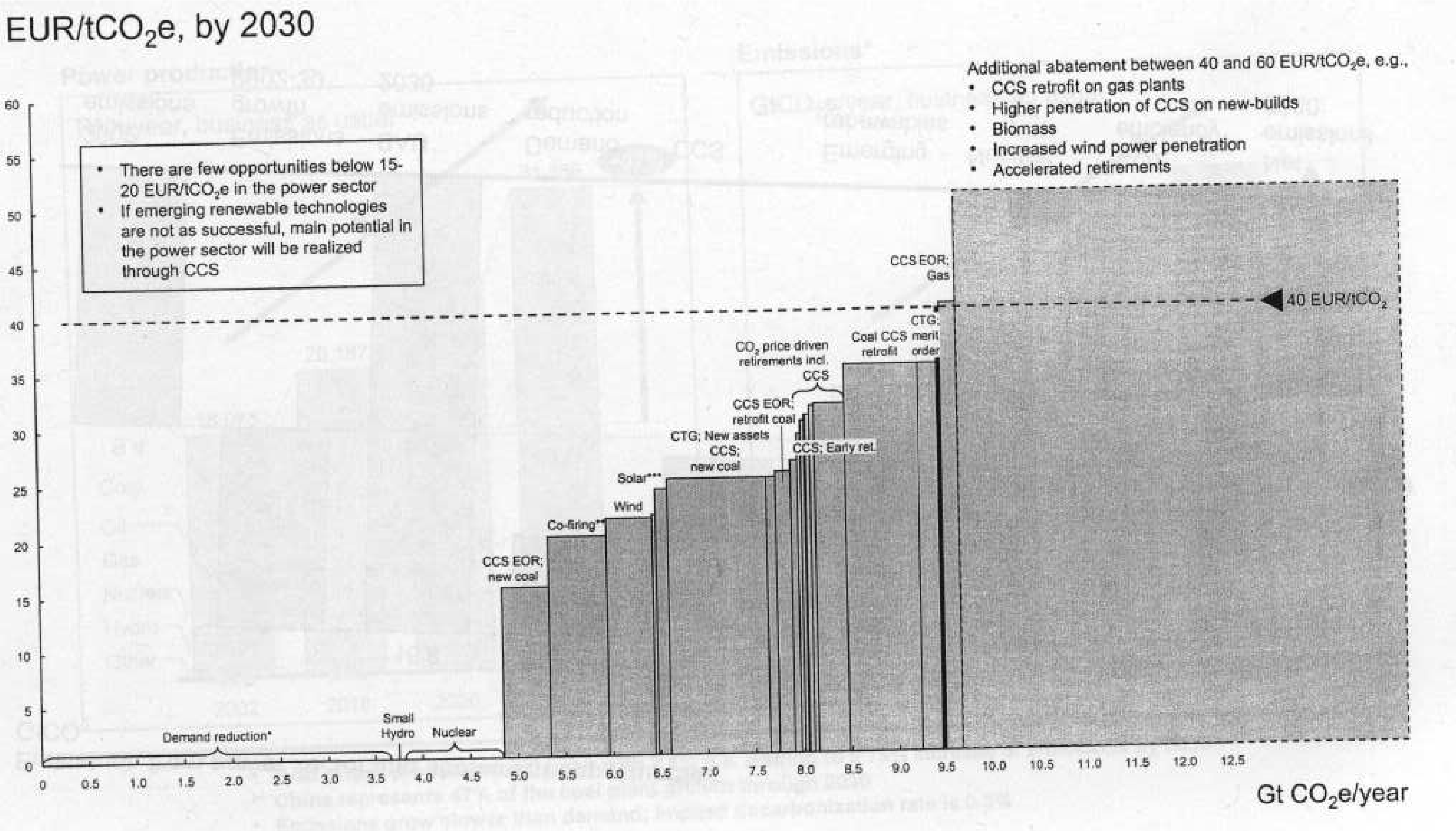


In February 2007, the staff from McKinsey & Company made a presentation to ARB economics' staff. The presentation covered, in part, the global CO2 abatement costs for three major sectors of CO2 emissions: power sector, transportation, and building. Exhibit 17 presents the abatement strategies and global costs for the power sector. Exhibit 18 presents transportation abatement strategies and global costs, and Exhibit 19 mitigation strategies for the building sector and global cost.

Global Power Sector

Exhibit 24 presents abatement measures and their associated control costs for the global power sector for 2030. The cost measures range from about 15 euros (carbon capture and storage-coal) to 50 euros (biomass, wind power), or \$21 to \$70/ tCO2e reduced (12.5 Gt CO2 e/year by 2030 @\$70/ tCO2e).

Exhibit 24: Marginal Abatement Cost Curve for the Global Power Sector 2030



* Demand reduction is not zero cost but allocated rather to respective sector

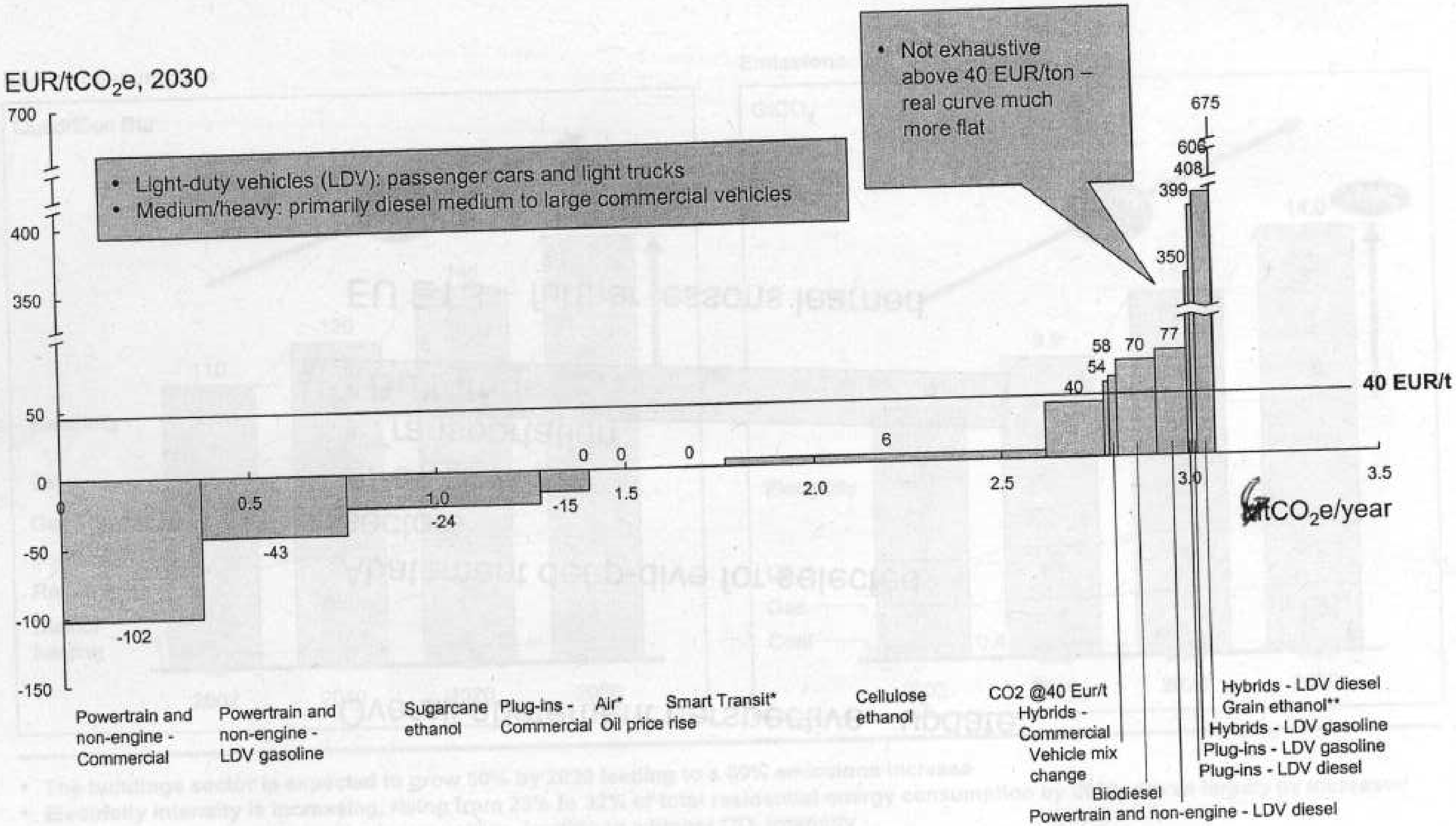
** In coal plants both with and without CCS

*** Potential represents where electricity demand is heat-peak coincident; under different circumstances, solar power is significantly more expensive

Global Transportation Sector

Exhibit 25 presents cost curves for the global transportation sector, 2030. Costs range from -102 euros (fuel economy) to 399 euros (hybrids LDV gasoline) (-144 to 561dollars) per ton CO_2e reduced. Note: The Exhibit list the tonnage as $MtCO_2$ e/year. It should be listed as $GtCO_2$ e/year.

Exhibit 25: Marginal Abatement Cost Curve for the Global Transport Sector 2030



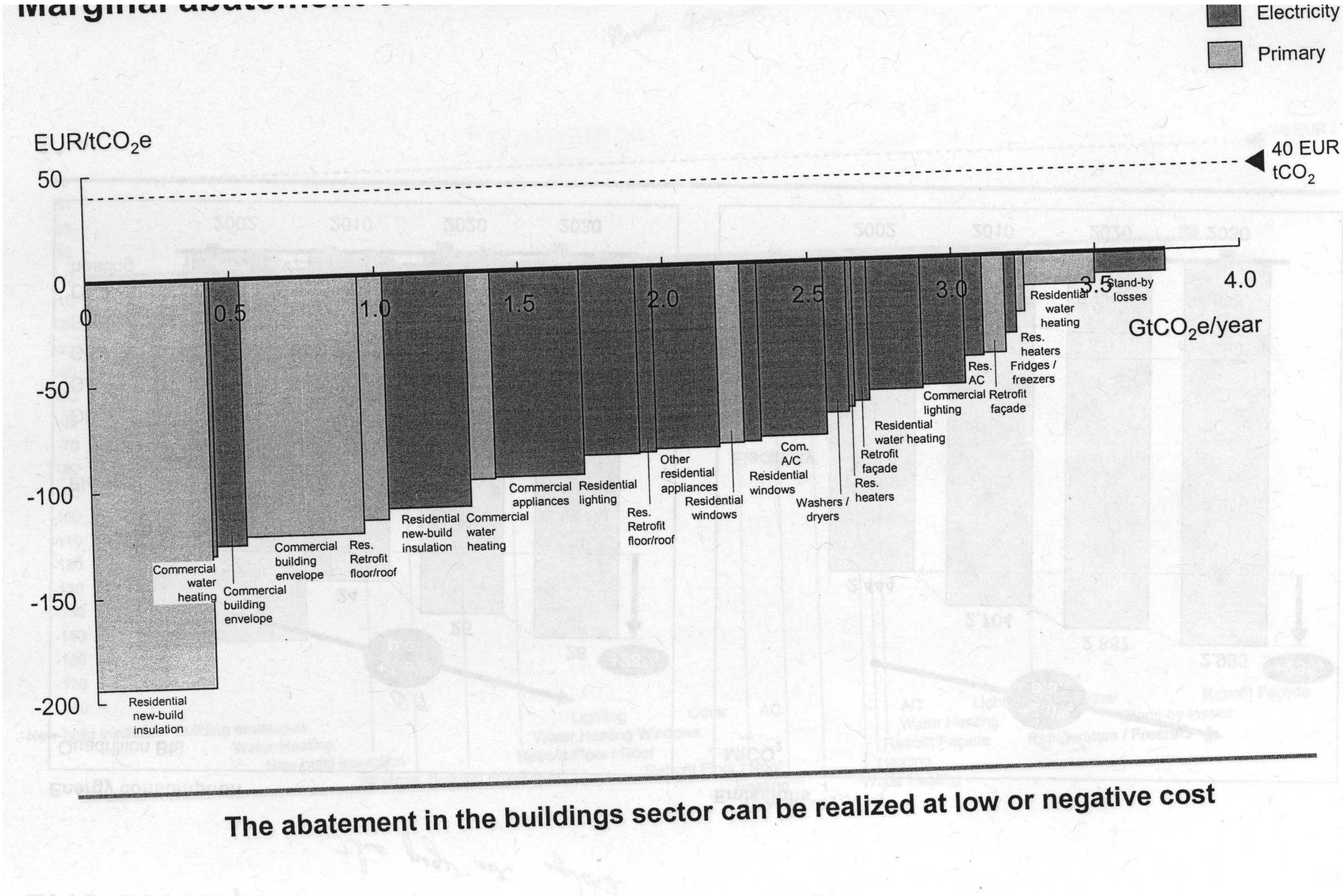
* Air efficiency and smart transit opportunities are assumed to have a zero cost, and expected to be adopted with policy support

** Grain ethanol is not cost competitive even by 2030, however it is assumed to be adopted due to government subsidies

Global Building Sector

Exhibit 26 presents cost curves for the global building sector for 2030. Costs range from about -200 euros (building insulation) to about -10 euros (residential water heating) (-281 to -14 dollars) per ton CO2e reduced. Abatement cost in the building sector can be realized at low or negative cost.

Exhibit 26: Marginal Abatement Cost Curve for the Global Building Sector 2030



6. Intergovernmental Panel on Climate Change, Working Group III, Fourth Assessment Report, Industry [11]

Industry, is the 7th chapter of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and provides an in-depth analysis of the costs and benefits of different approaches to mitigating and avoiding climate change. In the first two volumes of "Climate Change 2007" Assessment Report, the IPCC analyzed the physical science basis of climate change and the expected consequences for natural and human systems. The third volume of the report presents an analysis of costs, policies and technologies that could be used to limit and/or prevent emissions of greenhouse gases, along with a range of activities to remove these gases from the atmosphere. It recognizes that a portfolio of adaptation and mitigation actions is required to reduce the risks of climate change. It also has broadened the assessment to include the relationship between sustainable development and climate change mitigation.

The IPCC developed cost of CO2 abatement estimates for selected industries. Costs are presented for Global, Organization for Economic Co-operation and Development (OECD), Economies-in-Transition (EIT), and Developing Nations (Dev.Nat.)

Exhibits 27 and 28 present summary information taken from IPCC (Exhibit 29 is taken directly from IPCC).

Exhibit 27: Cost-effectiveness by Product (Global Analysis) CO2 Emissions from Processes & Energy Use -2030

Product	Cost Range $/ton	Tons Reduced MTCO2eq/yr
Steel	20 - 50	420 -1,500
Primary Aluminum	<100	53 - 82
Cement	<50	480 – 2,100
Ethylene	<20	58
Ammonia	<20	110
Petroleum Refining	<20	140 - 300
Pulp and paper	<20	37- 420

[11] *Industry*, Intergovernmental Panel on Climate Change, Working Group III, Fourth Assessment Report, October 2007.
http://www.mnp.nl/ipcc/pages_media/FAR4docs/final%20pdfs%20of%20chapters%20WGIII/IPCC%20WGIII_chapter%207_final.pdf
http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html
http://www.mnp.nl/ipcc/pages_media/ar4.html

Exhibit 28: Cost-effectiveness for Carbon Capture and Storage (Global Analysis) - 2030

Product	Cost Range $/ton	Tons Reduced MTCO2eq/yr
Ammonia	<50	140 – 150
Petroleum Refining	<50	72 - 150
Cement	<100	200 – 350
Iron and Steel	<50	70 - 180

From Chapter 7, page 472:
http://www.mnp.nl/ipcc/pages_media/FAR4docs/final%20pdfs%20of%20chapters%20WGIII/IPCC%20WGIII_chapter%207_final.pdf

Exhibit 29 should be interpreted with care. It is based on a limited number of studies – sometimes only one study per industry – and implicitly assumes that current trends will continue until 2030. Key uncertainties in the projections include: the rate of technology development and diffusion, the cost of future technology, future energy and carbon prices, the level of industrial activity in 2030, and policy driver, both climate and non-climate. The use of two scenarios, A1B and B2, is an attempt to bracket the range of these uncertainties. The A1 family of scenarios describes a future with very rapid economic growth, low population growth and rapid introduction of new and more efficient technologies. B2 describes a world 'in which emphasis is on local solutions to economic, social, and environmental sustainability'. It features moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than the A1B scenario.

Exhibit 29 shows 2030 mitigation potential for the industrial sector at a cost of <100 US$/tCO2-eq (<370 US$/tC-eq) of 3.0 to 6.3 GtCO2-eq/yr (0.8 to 1.7 GtC-eq/yr) under the A1B scenario*, and 2.0 to 5.1 GtCO2-eq/yr (0.6 to 1.4 GtC-eq/yr) under the B2 scenario*. The largest mitigation potentials are found in the steel, cement, and pulp and paper industries and in the control of non-CO2 gases. Much of that potential is available at <50 US$/tCO2-eq (<180 US$/tC-eq). Application of carbon capture and storage (CCS) technology offers a large additional potential, albeit at higher cost *(low agreement, little evidence).*

* A1B and B2 refer to scenarios described in the IPCC Special Report on Emission Scenarios (IPCC, 2000b). The A1 family of scenarios describe a future with very rapid economic growth, low population growth, and rapid introduction of new and more efficient technologies. B2 describes a world 'in which emphasis is on local solutions to economic, social, and environmental sustainability'. It features moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than the A1B scenario.

Exhibit 29: Industry Mitigation Potential and Costs in 2030

Product	Area[b]	2030 production (Mt)[a]		GHG intensity (tCO_2-eq/t prod.)	Mitigation potential (%)	Cost range (US$)	Mitigation potential ($MtCO_2$-eq/yr)	
		A1	B2				A1	B2
CO_2 emissions from processes and energy use								
Steel[c,d]	Global	1,163	1,121	1.6-3.8	15-40	20-50	430-1,500	420-1,500
	OECD	370	326	1.6-2.0	15-40	20-50	90-300	80-260
	EIT	162	173	20.-3.8	25-40	20-50	80-240	85-260
	Dev. Nat.	639	623	1.6-3.8	25-40	20-50	260-970	250-940
Primary aluminium[e,f]	Global	39	37	8.4	15-25	<100	53-82	49-75
	OECD	12	11	8.5	15-25	<100	16-25	15-22
	EIT	9	6	8.6	15-25	<100	12-19	8-13
	Dev. Nat.	19	20	8.3	15-25	<100	25-38	26-40
Cement[g,h,i]	Global	6,517	5,251	0.73-0.99	11-40	<50	720-2,100	480-1,700
	OECD	600	555	0.73-0.99	11-40	<50	65-180	50-160
	EIT	362	181	0.81-0.89	11-40	<50	40-120	20-60
	Dev. Nat.	5,555	4,515	0.82-0.93	11-40	<50	610-1,800	410-1,500
Ethylene[j]	Global	329	218	1.33	20	<20	85	58
	OECD	139	148	1.33	20	<20	35	40
	EIT	19	11	1.33	20	<20	5	3
	Dev. Nat.	170	59	1.33	20	<20	45	15
Ammonia[k,l]	Global	218	202	1.6-2.7	25	<20	110	100
	OECD	23	20	1.6-2.7	25	<20	11	10
	EIT	21	23	1.6-2.7	25	<20	10	12
	Dev. Nat.	175	159	1.6-2.7	25	<20	87	80
Petroleum refining[m]	Global	4,691	4,508	0.32-0.64	10-20	Half <20	150-300	140-280
	OECD	2,198	2,095	0.32-0.64	10-20	Half <50	70-140	67-130
	EIT	384	381	0.32-0.64	10-20	"	12-24	12-24
	Dev. Nat.	2,108	2,031	0.32-0.64	10-20	"	68-140	65-130
Pulp and paper[n]	Global	1,321	920	0.22-1.40	5-40	<20	49-420	37-300
	OECD	695	551	0.22-1.40	5-40	<20	28-220	22-180
	EIT	65	39	0.22-1.40	5-40	<20	3-21	2-13
	Dev. Nat.	561	330	0.22-1.40	5-40	<20	18-180	13-110

Exhibit 29 (con't): Costs of Carbon Capture and Storage by Selected Industry in 2030

Product	Area[b]	2030 production (Mt)[a]		CCS Potential (tCO_2/t)	Mitigation potential (%)	Cost range (US$)	Mitigation potential ($MtCO_2$-eq)	
		A1	B2				A1	B2
Carbon Capture and Storage								
Ammonia[o,p]	Global	218	202	0.5	about 100	<50	150	140
	OECD	23	20	0.5	about 100	<50	15	13
	EIT	21	23	0.5	about 100	<50	14	16
	Dev. Nat.	175	159	0.5	about 100	<50	120	110
Petroleum Refining[m,p,q]	Global	4,691	4,508	0.032-0.064	about 50	<50	75-150	72-150
	OECD	2,198	2,095	0.032-0.064	about 50	<50	35-70	34-70
	EIT	384	381	0.032-0.064	about 50	<50	6-12	6-12
	Dev. Nat.	2,108	2,031	0.032-0.064	about 50	<50	34-70	32-65
Cement[r]	Global	6,517	5,251	0.65-0.89	about 6	<100	250-350	200-280
	OECD	600	555	0.65-0.80	about 6	<100	23-32	22-27
	EIT	362	181	0.73-0.80	about 6	<100	16-17	8-9
	Dev. Nat.	5,555	4,515	0.74-0.84	about 6	<100	210-300	170-240
Iron and Steel	Global	1,163	1,121	0.32-0.76	about 20	<50	70-180	70-170
	OECD	370	326	0.32-0.40	about 20	<50	24-30	21-26
	EIT	162	173	0.40-0.76	about 20	<50	13-25	14-26
	Dev. Nat.	639	623	0.32-0.76	about 20	<50	33-120	35-120

Notes and sources:

[a] Price *et al.*, 2006.
[b] Global total may not equal sum of regions due to independent rounding.
[c] Kim and Worrell, 2002a.
[d] Expert judgement.
[e] Emission intensity based on IAI Life-Cycle Analysis (IAI, 2003), excluding alumina production and aluminium shaping and rolling. Emissions include anode manufacture, anode oxidation and power and fuel used in the primary smelter. PFC emission included under non-CO_2 gases.
[f] Assumes upgrade to current state-of-the art smelter electricity use and 50% penetration of zero emission inert electrode technology by 2030.
[g] Humphreys and Mahasenan, 2002.
[h] Hendriks *et al.*, 1999.
[i] Worrell *et al.*, 1995.
[j] Ren *et al.*, 2005.
[k] Basis for estimate: 10 GJ/t NH_3 difference between the average plant and the best available technology (Figure 7.2) and operation on natural gas (Section 7.4.3.2).
[l] Rafiqul *et al.*, 2005.
[m] Worrell and Galitsky, 2005.
[n] Farahani *et al.*, 2004.
[o] The process emissions from ammonia manufacturing (based on natural gas) are about 1.35 tCO_2/t NH_3 (De Beer, 1998). However, as noted in Section 7.4.3.2, the fertilizer industry uses nearly half of the CO_2 it generates for the production of urea and nitrophosphates. The remaining CO_2 is suitable for storage. IPCC (2005a) indicates that it should be possible to store essentially all of this remaining CO_2 at a cost of <20 US$/t.
[p] IPCC, 2005a.
[q] US refineries use about 4% of their energy input to manufacture hydrogen (Worrell and Galitsky, 2005). Refinery hydrogen production is expected to increase as crude slates become heavier and the demand for clean products increases. We assume that in 2030, 5% of refinery energy use worldwide will be used for hydrogen production, and that the byproduct CO_2 will be suitable for carbon storage.
[r] Total potential and application potential derived from IEA, 2006a. Subdivision into regions based in production volumes and carbon intensities. IEA, 2006a does not provide a regional breakdown.
[s] Extrapolated from US EPA, 2006b. This publication does not use the SRES scenarios as baselines.
[t] See Section 7.5.1 for details of the estimation procedure.
[u] Due to gaps in quantitative information (see the text) the column sums in this table do not represent total industry emissions or mitigation potential. Global total may not equal sum of regions due to independent rounding.
[v] The mitigation potential of the main industries include electricity savings. To prevent double counting with the energy supply sector, these are shown separately in Chapter 11.
[w] Mitigation potential for other industries includes only reductions for reduced electricity use for motors. Limited data in the literature did not allow estimation of the potential for other mitigation options in these industries.

474

Appendix B

Appendix B presents additional cost studies that were reviewed, but not included in the summary Exhibits. These studies were considered dated, not representative of California, or to broad in scope.

1. Intergovernmental Panel on Climate Change Costs to Industry[12]

In 2001 the IPCC published a review of CO2 abatement cost US$/tC) for selected industries.

From the IPCC report:
3.5.3.1 Energy Efficiency Improvement
Energy efficiency improvement can be considered as the major option for emission reduction by the manufacturing industry. A wide range of technologies is available to improve energy efficiency in this industry. An overview is given in Exhibit 1**.** Note that the total technical potential consists of a larger set of options and differs from country to country (see Section 3.5.5). Especially options for light industry are not worked out in detail. An important reason is that these sectors are very diverse, and so are the emission reduction options. Nevertheless, there are in relative terms probably more substantial savings possible than in heavy industry (see, e.g., De Beer *et al.*, 1996). Examples of technologies for the light industries are efficient lighting, more efficient motors and drive systems, process controls, and energy saving in space heating. An extended study towards the potential of energy efficiency improvement was undertaken by the World Energy Council (WEC, 1995a). Based on a sector-by-sector analysis (supported by a number of country case studies) a set of scenarios is developed. In a baseline scenario industrial energy consumption grows from 136EJ in 1990 to 205EJ in 2020. In a state-of the- art scenario the assumption is that replacement of equipment takes place with the current (1995 in this case) most efficient technologies available; in that case industrial primary energy requirement is limited to 173EJ in 2020. Finally, the *ecologically driven/advanced technology* scenario assumes an international commitment to energy efficiency, as well as rapid technological progress and widespread application of policies and programmes to speed up the adoption of energy efficient technologies in all major regions of the world. In that case energy consumption may stabilize at 1990 levels.

The difference between baseline and ecologically driven/advanced technology is approx. 70EJ, which is roughly equivalent to 1100 MtC. Of this reduction approx. 30% could be realized in OECD countries; approx. 20% in economies-in-transition, and approximately 50% in developing countries. The high share for developing countries can be explained by the high production growth assumed for these countries and the currently somewhat higher specific energy use in these countries. Apart from these existing technologies, a range of new technologies is under development. Important examples are found in the iron and steel industry. Smelt reduction processes can replace pelletizing and sinter plants, coke ovens, and blast furnaces, and lead to substantial savings. Near net shape casting techniques for steel avoids much of the energy required for rolling (De Beer *et al*., 1998). Other examples are black liquor gasification in the pulp industry, improved water removal processes for paper making, e.g., impulse drying and air impingement drying, and the use of membrane reactors in the chemical industry. A further overview is given in Blok *et al*. (1995). Although some of these options already can play a role in

[12] *Mitigation, Chapter 3*, Intergovernmental Panel on Climate Change, Third Assessment Report pg. 209, 2001. **http://www.grida.no/climate/ipcc_tar/wg3/pdf/3.pdf**
http://www.grida.no/climate/ipcc_tar/wg3/index.htm
http://www.grida.no/climate/ipcc_tar/

the year 2010 (see Exhibit 1), their full implementation may take some decades. De Beer (1998) carried out an in-depth analysis for three sectors (paper, steel and ammonia). He concludes that new industrial processes hold the promise to reduce the current gap between industrial best practice and theoretical minimum required energy use by 50%.

Exhibit 1: Industrial Energy Efficiency Improvement Technologies, Emission Reduction Potentials and Costs

Sources: Kashiwagi et al. (1996), De Beer et al. (1994), ETSU (1994), WEC (1995a or b), IEA Greenhouse Gas R&D Programme (2000a), Martin et al. (2000). For complete reference information see page 266 at http://www.grida.no/climate/ipcc_tar/wg3/pdf/3.pdf

Sector	Technology	Potential in 2010	Emission reduction costs	Remarks
All industry	Implementation of process control and energy management systems	■■■■	-	Estimate: 5% saving on primary energy demand worldwide
	Electronic adjustable speed drives	■■	++	In industrial countries ~30% of industrial
	High-efficiency electric motors	■■	+ *	electricity demand is for electric drive systems
	Optimized design of electric drive systems, including low-resistance piping and ducting	■■	+++	Not known for developing countries.
	Process integration, e.g., by applying pinch technology	■■■■	+	Savings vary per plant from 0%-40% of fuel demand; costs depend on required retrofit activity.
	Cogeneration of heat and power	■■■■	-	
Food, beverages and tobacco	Application of efficient evaporation processes (dairy, sugar)	■	+	
	Membrane separation	■	++	
Textiles	Improved drying systems (e.g., heat recovery)	■	++	
Pulp and paper	Application of continuous digesters (pulping)	■	+	Applicable to chemical pulping only; energy generally supplied as biofuels
	Heat recovery in thermal mechanical pulping	■	+++	Energy generally supplied as biofuels
	Incineration of residues (bark, black liquor) for power generation	■	+	
	Pressing to higher consistency, e.g., by extended nip press (paper making)	■	-	Not applicable to all paper grades
	Improved drying, e.g., impulse drying or condensing belt drying	■■	-	Pre-industrial stage; results in a smaller paper machine (all paper grades)
	Reduced air requirements, e.g., by humidity control in paper machine drying hoods	■	+	
	Gas turbine cogeneration (paper making)	■■	-	
Refineries	Reflux overhead vapour recompression (distillation)	■	+	
	Staged crude preheat (distillation)	■	+	
	Application of mechanical vacuum pumps (distillation and cracking)	■■	+	
	Gas turbine crude preheating (distillation)	■■	-	Applicable to 30% of the heat demand of refineries
	Replacement of fluid coking by gasification (cracking)	■	+	
	Power recovery (e.g., at hydrocracker)	■	-	
	Improved catalysts (catalytic reforming)	■■	+	

(continued)

Exhibit 1 (con't): Industrial Energy Efficiency Improvement Technologies, Emission Reduction Potentials and Costs

Sector	Technology	Potential in 2010	Emission reduction costs	Remarks
Fertilizers	Autothermal reforming	■	- *	
	Efficient CO_2 separation (e.g., by using membranes)	■	+ *	Saving depends strongly on opportunities for process integration of old and new techniques.
	Low pressure ammonia synthesis	■	+ *	Site-specific: an optimum has to be found between synthesis pressure, gas volumes to be handled, and reaction speed
Petrochemicals	Mechanical vapour recompression (e.g., for propane/propene splitting)	■	+	
	Gas turbine cogeneration	■	-	Not yet demonstrated for furnace heating
	De-bottlenecking	■■	-	Estimate: 5% saving on fuel demand
	Improved reactors design, e.g., by applying ceramics or membranes	■	+	Not yet commercial
	Low pressure synthesis for methanol	■	+ *	Site-specific: an optimum has to be found between synthesis pressure, gas volumes to be handled, and reaction speed
Other chemicals	Replacement of mercury and diaphragm processes by membrane electrolysis (chlorine)	■	+ *	In some countries, e.g., Japan, membrane electrolysis is already the prevailing technology
	Gas turbine cogeneration	■■	-	
Iron and steel	Pulverized coal injection up to 40% in the blast furnace (primary steel)	■■	-	Maximum injection rate is still topic of research
	Heat recovery from sinter plants and coke ovens (primary steel)	■■	+	
	Recovery of process gas from coke ovens, blast furnaces and basic oxygen furnaces (primary steel)	■■■	-	
	Power recovery from blast furnace off-gases (primary steel)	■	+	
	Replacement of open-hearth furnaces by basic oxygen furnaces (primary steel)	■■■	- *	Mainly former Soviet Union and China
	Application of continuous casting and thin slab casting	■■■	- *	Replacement of ingot casting
	Efficient production of low-temperature heat (heat recovery from high-temperature processes and cogeneration)	■	++	Heat recovery from high temperature processes is technically difficult
	Scrap preheating in electric arc furnaces (secondary steel)	■	+	
	Oxygen and fuel injection in electric arc furnaces (secondary steel)	■	-	
	Efficient ladle preheating	■		
	Second-generation smelt reduction processes (primary steel)	■■■	-	First commercial units expected after 2005
	Near-net-shape casting techniques	■■	-	Not yet commercial
Aluminium	Retrofit existing Hall-Héroult process (e.g., alumina point-feeding, computer control)	■	-/+	
	Conversion to state-of-the-art PFBF technology	■	+	
	Wettable cathode	■	+++	Not yet commercial
	Fluidized bed kilns in Bayer process	■	++	
	Cogeneration integrated in Bayer process			

(continued)

Exhibit 1 (con't): Industrial Energy Efficiency Improvement Technologies, Emission Reduction Potentials and Costs

Sector	Technology	Potential in 2010	Emission reduction costs	Remarks
Cement and other non-metallic minerals	Replacement of wet process kilns	■■	-/+ *	
	Application of multi-stage preheaters and pre-calciners	■	+	No savings expected in retrofit situations
	Utilization of clinker production waste heat or cogeneration for drying raw materials	■■	-	
	Application of high-efficiency classifiers and grinding techniques	■	+	
	Application of regenerative furnaces and improving efficiency of existing furnaces (glass)	■	+	Costs of replacing recuperative furnaces by regenerative furnaces are high (++)
	Tunnel and roller kilns for bricks and ceramic products	■	- *	
Metal processing and other light industry	Efficient design of buildings, air conditioning and air treatment systems, and heat supply systems	■	- *	
	Replacement of electric melters by gas-fired melters (foundries)	■	- *	
	Recuperative burners (foundries)	■	- *	
Cross-sectoral	Heat cascading with other industrial sectors	■■	+	
	Waste heat utilization for non-industrial sectors	■■	+	

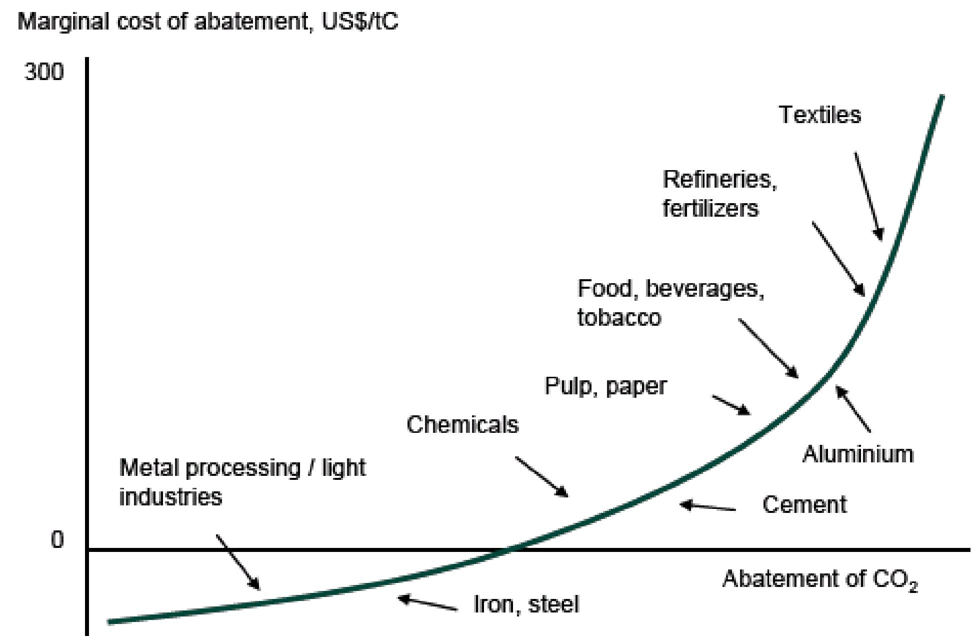
Legend
Potential: ■ = 0-10MtC; ■■ = 10-30MtC; ■■■ = 30-100MtC; ■■■■ > 100MtC.
Annualized costs at discount rate of 10%: - = benefits are larger than the costs; + = US$0-US$100/tC ; ++ = US$100-US$300/tC; +++ > US$300/tC
An asterisk (*) indicates that cost data are only valid in case of regular replacement or expansion.

2. Lehman Brothers[13]

Lehman Brothers decided to take a hard look at global warming, starting with the scientific and climatological evidence, then proceeding to the economic consequences and implications for policy; and finally – with significant help from the Firm's equity analysts – considering potential impacts on major business sectors. Exhibit 2 presents cost of abatement (tons carbon) for various industrial sectors (global analysis). Exhibit 2 is based on the IPCC Third Assessment Report, Table 3.19 found in Chapter 3, Mitigation, pg. 209, which is presented as Exhibit 1 above. **http://www.grida.no/climate/ipcc_tar/wg3/pdf/3.pdf**

[13] *The Business of Climate Change*, Lehman Brothers, Feb. 2007, pg. 28. http://www.cs.bc.edu/~muller/teaching/cs021/lib/ClimateChange.pdf
Exhibit 2 is based on Table 3.19 found in the IPCC, the Third Assessment Report, Chapter 3, Mitigation, pg. 209.

Exhibit 2: Industrial Energy Efficiency Costs (US$/tC)



Source: Intergovernmental Panel on Climate Change (2001), vol.IV, ch.4.

3. Intergovernmental Panel on Climate Change Cost of Reducing CO2 from Transportation[14]

The IPCC also reviewed several studies that assessed the cost (US$/tC) of reducing CO2 from transport. The results of the review are presented in Exhibit 3.

From the IPCC report, page 204:
Over the past 25 years, transport activity has grown at approximately twice the rate of energy efficiency improvements. Because the world's transportation system continued to rely overwhelmingly on petroleum as an energy source, transport energy use and GHG emissions grew in excess of 2% per year. Projections to 2010 and beyond reviewed above reflect the belief that transport growth will continue to outpace efficiency improvements and that without significant policy interventions, global transport GHG emissions will be 50%–100% greater in 2020 than in 1995. Largely as a result of this anticipated growth, studies of the technical and economic potential for reducing GHG emissions from transport generally conclude that while significant reductions from business-as-usual projections are attainable, it is probably not practical to reduce transport emissions below 1990 levels by the 2010–2015 time period. On the other hand, the studies reviewed generally indicate that cost-effective reductions on the order of 10%–20% versus baseline appear to be achievable. In addition, more rapid than expected advances in key technologies such as hybrid and fuel cell vehicles, should they continue, hold out the prospect of dramatic reductions in GHG emission from road passenger vehicles beyond 2020. Most analyses project slower rates of GHG reductions for freight and air passenger modes, to a large extent reflecting expectations of faster rates of growth in activity. Assessing the total global potential for

[14] *Mitigation, Chapter 3*, Intergovernmental Panel on Climate Change, Third Assessment Report, pg. 204. 2001. **http://www.grida.no/climate/ipcc_tar/wg3/pdf/3.pdf**
http://www.grida.no/climate/ipcc_tar/wg3/index.htm
http://www.grida.no/climate/ipcc_tar/

reducing GHG emissions from transportation is hindered by the relatively small number of studies (especially for non-OECD countries) and by the lack of consistency in methods and conventions across studies. Not all studies shown in Exhibit 3 cover the entire transportation sector, even of the countries included in the study. Most consider a limited set of policy options, (e.g., only motor vehicle fuel economy improvement). In general, the studies do not report marginal costs of GHG mitigation, but rather average costs versus a base case. Keeping all of these limitations in mind, *Exhibit 12* summarizes the findings of several major studies. For 2010, the average low GHG reduction estimate is just under 7% of baseline total transport sector emissions in 2010, with the higher estimates averaging a 17% reduction. There is, however, considerable dispersion around both numbers, indicative both of uncertainty and differences in methodology and assumptions. For studies looking ahead to 2020, the average low estimate is 15% and the average high estimate is 34% of baseline 2020 transport sector emissions. Estimated (average rather than marginal) costs are generally negative (as much as -US$200/tC), indicating that fuel savings are expected to outweigh incremental costs. There are some positive cost estimates as high as US$200/tC, however. The majority of the studies cited in *Exhibit 12* are based on engineering-economic analyses. Some argue that this method tends to underestimate welfare costs because trade-offs between CO_2 mitigation and non-price attributes (e.g., performance, comfort, reliability) are rarely explicitly considered (Sierra Research, Inc., 1999).

Exhibit 3: Estimates of the Costs of Reducing Carbon Emissions from Transport 2010-2030

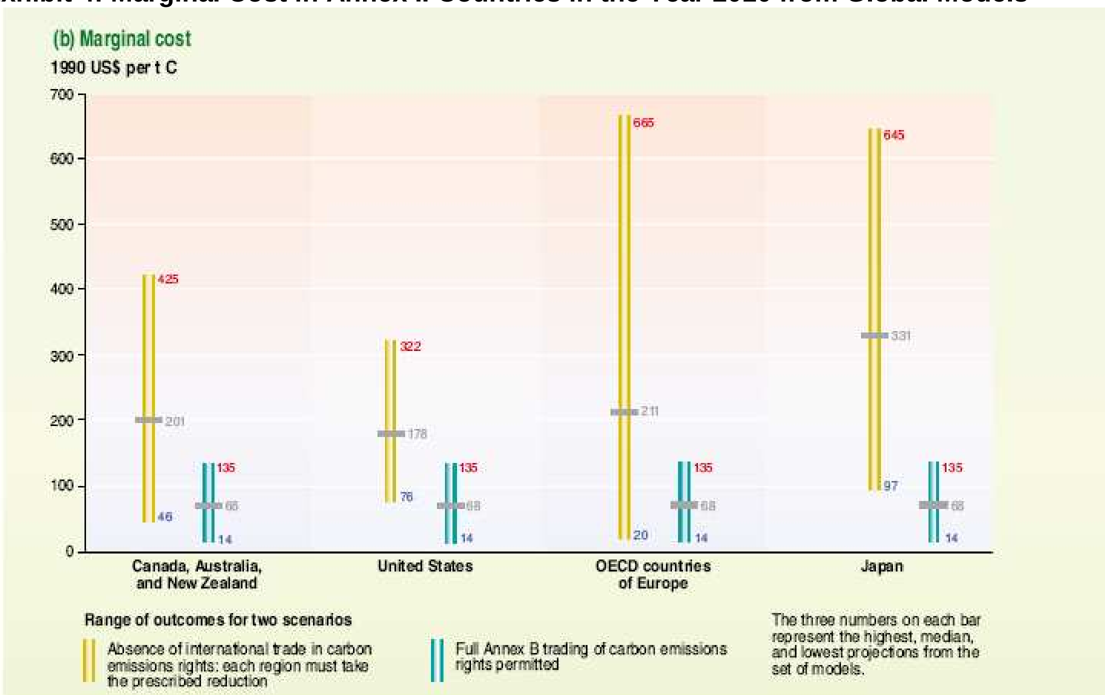
Source: Brown *et al*., 1998; ECMT, 1997; US DOE/EIA, 1998; DeCicco and Mark, 1998; Worrell *et al*., 1997b; Michaelis, 1997; Denis and Koopman, 1998*.* For complete reference information see page 266 in http://www.grida.no/climate/ipcc_tar/wg3/pdf/3.pdf

						Quantity		Reduction		Cost in US$/MtC	
Study	Year of publication	Application	Year of scenario	Years in future	Country	Low (MtC)	High (MtC)	Low (%)	High (%)	Low	High
OECD Working Paper 1	1997	Light-duty road vehicle efficiency	2010	13	OECD	50	150	2.5	7.5	US$0	US$0
US National Academy of Sciences	1992	Vehicle efficiency	2010	18	USA	20	79	3.2	12.7	-US$275	-US$77
	1992	System efficiency	2010	18	USA	3	13	0.5	2.1	-US$183	US$18
US DOE 5-Lab Study	1997	Transport sector	2010	13	USA	82	103	13.2	16.6	-US$157	US$6
US Energy Information Administration	1998	Transportation sector	2010	12	USA	41	55	6.6	8.9	-US$121	US$163
Tellus Institute	1997	Transportation efficiency	2010	13	USA	90	90	14.5	14.5	-US$465	-US$465
	1997	Transportation demand reduction	2010	13	USA	61	61	9.8	9.8	US$0	US$0
ACEEE	1998	Transport sector	2010	12	USA		125		22.6	-US$139	
US DOE, Clean Energy Futures	2000	Transport sector	2010	10	USA	20	66	3.2	10.5	-US$280	-US$144
European Council of Ministers of Transport	1997	Transport sector	2010	13	Austria	2			8.3		
	1997	Transport sector	2010	13	Belgium	4			13.3		
	1997	Transport sector	2010	13	Czech R.	6			57.1		
	1997	Transport sector	2010	13	Netherlands	11			37.2		
	1997	Transport sector	2010	13	Poland	5			12.8		
	1997	Transport sector	2010	13	Slovak R.	1			16.3		
	1997	Transport sector	2010	13	Sweden	4			23.2		
	1997	Transport sector	2010	13	UK	22			14.3		
Summary for 2010					**Minimum/maximum**			**0.5**	**57.1**	**-US$465**	**US$163**
					average			**6.7**	**16.9**	**-US$153**	**-US$62**
Denis and Koopman	1998	Road pricing	2015	17	EU				25.0		
	1998	CO_2 tax	2015	17	EU				13.0		
	1998	Purchase subsidy + CO_2 tax	2015	17	EU				14.0	US$0	US$0
US Congress OTA	1991	Transportation efficiency	2015	24	USA		195		29.2	-US$180	US$195
Summary for 2015					**Minimum/maximum**			**13.0**	**29.2**	**-US$180**	**US$195**
					average				**20.3**		
US DOE, Clean Energy Futures	2000	Transport sector	2020	20	USA	58	163	8.3	23.4	-US$234	-US$153
ACEEE	1998	Transport sector	2020	22	USA		260		42.4	-US$164	
United Nations	1997	Transport sector	2020	23	Industrialized	153	423	14.9	41.2		
	1997	Transport sector	2020	23	Transitional	72	126	18.2	31.8		
	1997	Transport sector	2020	23	Developing	297	450	28.4	43.1		
OECD Working Paper 1	1997	Light-duty road vehicle efficiency	2020	23	OECD	100	500	4.3	21.7	US$0	US$0
Summary for 2020					**Minimum/maximum**			**4.3**	**43.1**	**-US$234**	
					average			**14.8**	**34.0**		
ACEEE	1998		2030	32	USA		401		58.8	-US$192	

4. Intergovernmental Panel on Climate Change Cost to Countries[15]

The IPCC estimated the marginal abatement costs (1990 US$ per tC) for Annex B[16] countries to implement the Kyoto Protocol with and without carbon trading. These estimates are presented in Exhibit 4.

Exhibit 4: Marginal Cost in Annex II Countries in the Year 2010 from Global Models



The cost estimates for Annex B countries to implement the Kyoto Protocol vary between studies and regions, and depend strongly, among others, upon the assumptions regarding the use of the Kyoto mechanisms, and their interactions with domestic measures. The great majority of global studies reporting and comparing these costs use international energy-economic models. Nine of these studies suggest the following GDP impacts. In the absence of emissions trade between Annex B countries (see next page for definition of Annex B countries), these studies show reductions in projected GDP (10**)** of about 0.2 to 2% in the year 2010 for different Annex II regions (see next page for definition for Annex regions). With full emissions trading between Annex B countries, the estimated reductions in the year 2010 are between 0.1 and 1.1% of projected GDP.

The global modeling studies reported above show national marginal costs to meet the Kyoto targets from about US$20 up to US$600 per t C without trading, and a range from about US$15 up to US$150 per t C with Annex B trading. For most economies-in-transition countries, GDP

15 *Synthesis Report, Summary for Policy Makers***,** IPCC Third Assessment Report**,** Climate Change 2001, pg. 25 http://www.ipcc.ch/pub/un/syreng/spm.pdf
http://www.grida.no/climate/ipcc_tar/vol4/english/051.htm
http://www.grida.no/climate/ipcc_tar/vol4/english/index.htm

16 See next page for definition of Annex B and Annex II countries.

effects range from negligible to a several percent increase. However, for some economies-in-transition countries, implementing the Kyoto Protocol will have similar impact on GDP as for Annex II countries. At the time of these studies, most models did not include sinks, non-CO2 greenhouse gases, the Clean Development Mechanism (CDM), negative cost options, ancillary benefits, or targeted revenue recycling, the inclusion of which will reduce estimated costs. On the other hand, these models make assumptions which underestimate costs because they assume full use of emissions trading without transaction costs, both within and among Annex B countries, that mitigation responses would be perfectly efficient and that economies begin to adjust to the need to meet Kyoto targets between 1990 and 2000. The cost reductions from Kyoto mechanisms may depend on the details of implementation, including the compatibility of domestic and international mechanisms, constraints, and transaction costs.

(10) The calculated GDP reductions are relative to each model's projected GDP baseline. The models evaluated only reductions in CO2. In contrast, the estimates cited from the bottom-up analyses above included all greenhouse gases. Many metrics can be used to present costs. For example, if the annual costs to developed countries associated with meeting Kyoto targets with full Annex B trading are in the order of 0.5% of GDP, this represents US$125 billion (1,000 million) per year, or US$125 per person per year by 2010 in Annex II (SRES assumptions). This corresponds to an impact on economic growth *rates* over 10 years of less than 0.1 percentage point.

Annex B countries
Group of countries included in Annex B in the *Kyoto Protocol* that have agreed to a target for their *greenhouse gas emissions*, including all the *Annex I countries* (as amended in 1998) but Turkey and Belarus. See also *Annex II, non- Annex I*, and *non-Annex B countries/Parties*.

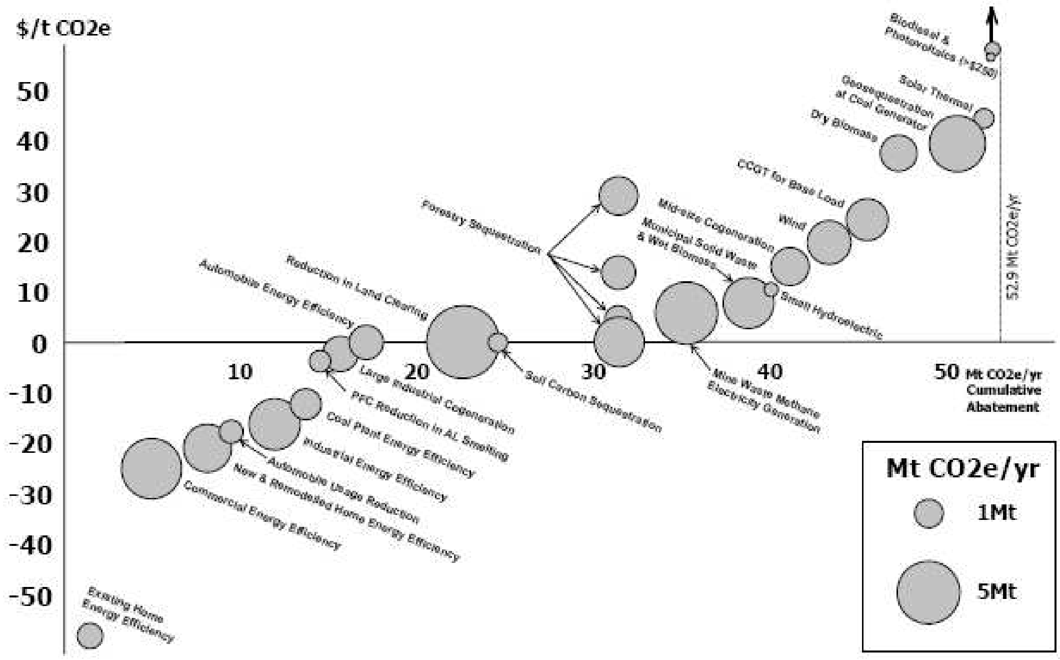
Annex I countries/Parties
Group of countries included in Annex I (as amended in 1998) to the *United Nations Framework Convention on Climate Change*, including all the developed countries in the Organisation for Economic Cooperation and Development, and *economies in transition*. By default, the other countries are referred to as *non-Annex I countries*. Under Articles 4.2(a) and 4.2(b) of the Convention, Annex I countries commit themselves specifically to the aim of returning individually or jointly to their 1990 levels of *greenhouse gas emissions* by the year 2000. See also *Annex II, Annex B*, and *non-Annex B countries*.

Annex II countries
Group of countries included in Annex II to the *United Nations Framework Convention on Climate Change*, including all developed countries in the Organisation for Economic Cooperation and Development. Under Article 4.2(g) of the Convention, these countries are expected to provide financial resources to assist developing countries to comply with their obligations, such as preparing national reports. Annex II countries are also expected to promote the transfer of *environmentally sound technologies* to developing countries. See also *Annex I, Annex B, non-Annex I*, and *non-Annex B countries/Parties*.

5. New South Wales (NSW) GHG Abatement Costs[17]

The study was commissioned by the NSW Cabinet Office to help better understand the options for abating greenhouse gas (GHG) emissions within NSW. The intention is to identify areas where additional policy attention might best be brought to bear by providing an indication of both the magnitude and the likely total costs of these opportunities. The abatement costs are presented in Exhibit 5.

Exhibit 5: New South Wales GHG Abatement Cost Curve to 2014



The key assumptions, mitigation potential, and costs are provided in Exhibit 6.

---

[17] *Cost Curve for New South Wales Greenhouse Gas Abatement*, Prepared for the NSW Green House Office, November 2004, pg 1. http://www.greenhouse.nsw.gov.au/__data/assets/pdf_file/0017/4544/cost_curve.pdf

Exhibit 6: New South Wales GHG Abatement Measures

Abatement Type	NSW Potential MtCO2e pa	Cost, $/tCO2e	Key Assumptions
Energy Efficiency			
Commercial energy efficiency	4.6	-$25	All measures with cumulative payback of 4 years or less at time of major refurbishment are implemented.
Industrial energy efficiency	3.4	-$16	All measures with cumulative payback of 4 years or less at time of major refurbishment are implemented.
New and remodeled home energy efficiency	2.9	-$20	40% reduction in GHG emissions achieved for new and remodeled homes
Existing home energy efficiency	0.80	-$58	High efficiency appliances (e.g., refrigerators, dishwashers, lights) with less than 6.5 year simple payback at time of purchase are used. Does not include heating, cooling or water heating opportunities.
Automobile energy efficiency	1.5	$0	10% improvement in average fuel economy of automobile fleet at no net cost
Automobile usage reduction	0.7	-$18	25% of NSW households participate in a program similar to the National Travel Behaviour Change program
Renewable electricity generation			
Wind	2.4	$20	Suitable sites found for 1000 MW of wind; cost based on 4% pa declines thru 2009; no RECs value; NEM pays $40/MWh
Small hydroelectric	0.2	$11	50 MW developed at existing dams without generation currently; NEM pays $40/MWh
Photovoltaics	0.3	$273	200 MW installed; 6% pa cost drop thru 2009; NEM pays $40/MWh
Solar thermal	0.5	$43	36MW solar preheat units are installed at 8 existing NSW coal units.
MSW and wet biomass	3.3	$8	113 MW of generation developed; avaoids fugitive methane emissions from landfill; NEM pays $40/MWh
Dry biomass	1.7	$38	200 MW of mainly bagasse with supplemental dry waste fuel; cost stable; NEM pays $40/MWh
Biofuels - biodiesel and ethanol	0.1	$265	350 million litres pa of biofuels substitute for diesel and petrol; current technology only.
Lower emission fossil-fuel electricity generation			
Large industrial cogeneration	1.6	-$2	350 MW steam-matched industrial host, eg former ALISE proposal; $4.50/GJ gas; $400 /Kva network benefit; NEM pays $40/MWh
Mid size cogeneration	1.8	$16	13x30MW units, steam matched, $4.50/GJ gas; $400/kVA network benefit; NEM pays $80/MWh incl. dist'n benefit
Combined cycle gas turbine for base load	2.2	$25	500 MW CCGT operates as base load unit, avoids high efficiency new coal unit; $4.50/GJ gas price
Mine waste methane electricity generation	4.9	$6	120 MW of new capacity using mine vent air and methane drainage; 50 MW of cofiring at coal power stations
Efficiency upgrade for existing coal plant	1.2	-$12	2% gains at major NSW coal generators at average cost of $2m/MW; NEM pays $40/MWh
Geosequestration at coal generator	4	$40	Suitable depository available in/near NSW; major technology cost/performance gains by 2010.
Industrial process	0.6	-$3	Intensive PFC management implemented at time of major aluminium smelter upgrade.
Land use change and management			
Reduction in land clearing	6.6	$0	75% reduction from last 5 year averages reported in the 20002 National Carbon Accounting
Soil carbon sequestration	0.5	$0	0.6 million hectares adopt practices increasing carbon uptake by 2 t per hectare, building up over 10 years
Seq – forestry	3.1	$0	Plantations established where value exceeds the agricultural value of the land. ABARE's alternate evaluation based on a lower economic hurdle (i.e., exceeding farm profitability) produces higher potential. Potential average annual sequestration during 30 year establishment of sustainably harvested plantations.
	0.9	$5	Incremental plantations over above estimate, established with an assumed $5 / t CO2e revenue stream
	1.4	$15	Incremental plantations over above estimate, established with an assumed $15 / t CO2e revenue stream
	1.9	$30	Incremental plantations over above estimate, established with an assumed $30 / t CO2e revenue stream
TOTAL	52.9		