# Modeling of Greenhouse Gas Reduction Measures to Support the Implementation of the California Global Warming Solutions Act (AB32)



## ENERGY 2020 Model Inputs and Assumptions

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**Prepared By:**
ICF Consulting Canada, Inc.
277 Wellington St. W.
Suite 808
Toronto, ON M5V 3E4

Systematic Solutions, Inc.
1519 Heatherwood Trail
Xenia, OH 45385

**Contact:**
R. Levesque
Systematic Solutions, Inc.
T: (937) 429-4010

***PLEASE NOTE:***

***This report outlines the assumptions and data inputs used in developing a Reference Case and Policy Analysis for the California Air Resources Board.***

***The development of the Reference Case is on-going and as such this should be viewed as a living document that will evolve as the model is reviewed and refined.***

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# Acronyms & Definitions

| | |
|---|---|
| AEO | Annual Energy Outlook (published by EIA) |
| ARB | California Air Resources Board |
| BPA | Bonneville Power Administration |
| Btu | British Thermal Units |
| CAC | Criteria Air Contaminants (SOx, NOx, PM, etc.) |
| CEC | California Energy Commission |
| CFL | Compact Fluorescent Light bulb |
| CHP | Combined Heat and Power |
| CPUC | California Public Utilities Commission |
| $CO_2e$ | Carbon Dioxide equivalent |
| GDP | Gross Domestic Product |
| GO | Gross Output |
| GWP | Global Warming Potential |
| DG | Distributed Generation |
| EDRAM | Environmental Dynamic Revenue Analysis Model |
| EIA | Energy Information Administration |
| EISA | Energy Independence and Security Act |
| EPACT | Energy Policy Act of 2005 |
| ESCO | Energy Service Company |
| GHG | Greenhouse Gas |
| IECC | International Energy Conservation Code |
| IGCC | Integrated Gasification Combined Cycle |
| kW | Kilowatt |
| kWh | Kilowatt-hour |
| Mt | Mega ton |
| MW | Megawatt |
| MWe | Megawatt electric |
| MTCE | Megatons Carbon Equivalent (also as Mt $CO_2e$) |
| NOx | Nitrogen Oxides |
| OGCC | Oil/Gas Combined Cycle Turbine |
| OGCT | Oil/Gas Combustion Turbine |
| OGST | Oil/Gas Steam Turbine |
| PC | Pulverized Coal |
| REMI | Regional Economic Models, Inc. |
| RECS | Renewable Energy Certificates |
| Rest of US | Balance of systems in US |
| SOx | Sulphur Oxides (including sulphur dioxide) |
| USEPA | United States Environmental Protection Agency |
| W | Watt |

# 1 Background and Project Scope

California has for many years led the nation in combating climate change. In 2006, the most ambitious element of the State's policy was enacted: *The California Global Warming Solutions Act of 2006*, known as AB32. AB32 requires the California Air Resources Board (ARB) to implement a program that reduces the State's GHG emissions to 1990 levels by 2020. The California Air Resources Board estimated that the State would need to reduce GHGs by approximately 174 million tons from baseline levels to achieve this target in 2020.[1]

ICF International (ICF) in partnership with Systematic Solutions Inc. (SSI) was engaged by the California Air Resources Board to provide a version of ENERGY 2020 to be used to assist the Board in modeling GHG reductions under AB32. Under this contract ICF and SSI agreed to develop and deliver a version of ENERGY 2020 tailored to the ARB's requirements and reflecting California-specific data wherever appropriate. The model has been used to develop a Reference Case of expected GHG emissions under a business-as-usual scenario over the period to 2020. ICF and SSI have also assisted the ARB in modeling proposed policies for comparison with this Reference Case in order to determine the extent to which such policies could reduce future emissions and the effects of such policies.

This report outlines the assumptions and data inputs used in developing the Reference Case and policies modeled. The report describes the initial data and assumptions used, the sources of this data, and the processes used in developing the Reference Case as well as assumptions used in modeling the policies considered.

# 2 Organization of the Report

The report is organized into five main sections. Section 1 provides background information regarding the purpose and scope of the project. Section 2 describes how the report is organized. Section 3 describes the analytic approach used by ENERGY 2020 and the characteristics of the model. Section 4 describes the model inputs and assumptions used in modeling the Reference Case while section 5 describes the policies modeled and the assumptions made in representing these policies in the model. A more detailed explanation of the ENERGY 2020 model is included as Appendix A. Additional appendices describe some of the data or relationships used in the model.

[1] California Greenhouse Gas Emissions Inventory http://www.arb.ca.gov/cc/inventory/inventory.htm

# 3 Analytic Approach

This project uses ENERGY 2020 to model the likely business-as-usual outlook for California and neighboring jurisdictions in the WECC region, and the impact of potential GHG reduction policies.

ENERGY 2020 is an integrated multi-region multi-fuel energy and emissions model that provides complete and detailed, demand and supply sector simulations. These simulations can additionally include macroeconomic interactions to determine the benefits or costs to the local economy of new facilities or changing energy prices. The model can be used in regulated as well as deregulated and transitioning environments. Greenhouse Gas and Criteria Air Contaminant pollution emissions and costs, including allowances and trading, are endogenously determined, thereby allowing assessment of environmental risk and co-benefit impacts.

The basic implementation of ENERGY 2020 for North America now contains a user-defined level of aggregation down to the 10 provincial and 50 state (and sub-state) level. ENERGY 2020 contains historical information on all generating units in the US and Canada. Data for Mexico can be incorporated as needed. ENERGY 2020 is parameterized with local data for each region/state/province as well as all the associated energy suppliers it simulates. Thus, it captures the unique characteristics (physical, institutional and cultural) that affect how people make choices and use energy. Collections of state and provincial models are currently validated from 1986 to the most recent historic year available.[2]

ENERGY 2020 can be linked to a detailed macroeconomic model to determine the economic impacts of energy/environmental policy and the energy and environmental impacts of national economic policy. For US regional and state level analyses, the REMI macroeconomic model is regularly linked to ENERGY 2020.[3] The Informetrica macroeconomic model is linked to ENERGY 2020 for Canadian national and provincial efforts.[4] The REMI and Informetrica macroeconomic models include inter-state/provincial, US and world trade flows, price and investment dynamics, and simulate the real-time impact of energy and environmental concerns on the economy and vice versa.

[2] Energy supplier data comes from FERC and US DOE for the US and Statistics Canada. US and Canadian fuel and demand data come from the US Department of Energy and Natural Resources Canada, respectively. US and Canadian pollution data come from US EPA and Environment Canada, respectively.
[3] Regional Economic Models, Inc. www.remi.com
[4] Informetrica Limited www.informetrica.ca

The structure of the model is well tested and has been used to simulate not only US and Canadian energy and environmental dynamics, but also those of several countries in South America, Western, Central, and Eastern Europe. These efforts include strategic and tactical analyses for both planning and energy industry restructuring/deregulation. In the 1990's, the US EPA made ENERGY 2020 available to interested states to analyze emissions, energy, and economic impacts of state-level climate change initiatives Further, the model has been used successfully for deregulation analyses in all the US states and Canadian provinces. Many US and Canadian energy suppliers use the model for the analysis of combined electricity and gas deregulation dynamics.[5]

The default model simulates demand by three residential categories (single family, multi-family, and agriculture/rural), over 40 NAICS commercial and industrial categories, and three transportation services (passenger, freight, and off-road). There are approximately six end-uses per category and six technology/mode families per end-use.[6] Currently the technology families correspond to six fuels groups (oil, gas, coal, electric, solar and biomass) and 30 detailed fuel products. The transportation sector contain 45 modes including various type of automobile, truck, off-road, bus, train, plane, marine and alternative-fuel vehicles. More end-uses, technologies, and modes can be added as data allow. For all end-uses and fuels, the model is parameterized based on historical, locale-specific data. The load duration curves are dynamically built up from the individual end-uses to capture changing conditions under consumer choice and combined gas/electric programs.

Each energy demand sector includes cogeneration, self-generation, and distributed generation simulation, including mobile-generation, micro-turbines, and fuel-cells. Fuel-switching responses are rigorously determined. The technology families (which can be split, as an option, to portray specific technology dynamics) are aggregates that, within the model, change building shell, economic-process and device efficiency and capital costs as price or other information that the decision makers see, change. ENERGY 2020 utilizes the historical and forecast data developed for each technology family to parameterize and disaggregate the model.

The supply portion of the model includes endogenous detailed electric supply simulation of capacity expansion/construction, rates/prices, load shape variation

[5] ENERGY 2020 is the only model known to have simulated and predicted the dynamics that occurred in the UK electric deregulation. These include gaming, market consolidation and re-regulation dynamics.
[6] End-uses include Process Heat, Space Heating, Water Heating, Other Substitutable, Refrigeration, Lighting, Air Conditioning, Motors, and Other Non-Substitutable (Miscellaneous). Detailed modes include: small auto, large auto, light truck, medium-weight truck, heavy-weight truck, bus, freight train, commuter train, airplane, and marine. Each mode type can be characterized by gasoline, diesel, electric, ethanol, NG, propane, fuel-cell, or hybrid vehicles.

due to weather, and changes in regulation.[7] The model dispatches plants according to the specified rules whether they are optimal or heuristic and simulates transmission constraints when determining dispatch.[8] A sophisticated dispatch routine selects critical hours along seasonal load duration curves as a way to provide a quick but accurate determination of system generation. Peak and base hydro usage is explicitly modeled to capture hydro-plant impacts on the electric system.

ENERGY 2020 supply sectors include electricity, oil, natural gas, refined petroleum products, ethanol, land-fill gas, and coal supply. Energy used in primary production and emissions associated with primary production and its distribution is included in the model. The supply sectors included in a particular implementation of ENERGY 2020 will depend on the characteristics of the area being simulated and the problem being addressed. If the full supply sector is not needed, then a simplified simulation determines delivered-product prices.

The ENERGY 2020 model includes pollution accounting for both combustion (by fuel, end-use, and sector) and non-combustion, and non-energy (by economic activity) for SO2, NO2, N2O, CO, CO2, CH4, PMT, PM2.5, PM5, PM10, VOC, CF4, C2F6, SF6, and HFC at the state and provincial level by economic sector. Other (gaseous, liquid, and solid) pollutants can be added as desired. Pollution does not need to be determined directly by coefficients but can recognize the accumulation of capital investments that result in pollution emission with usage. National and international allowance trading is also included. Plant dispatch can consider emission restrictions.

The model captures the feedback among energy consumers, energy suppliers, and the economy using Qualitative Choice Theory and co-integration.[9] For example, a change in price affects demand which then affects future supply and price. Increased economic activity increases demand which increases the investment in new capital stock. The new investment affects the economy and energy prices. The energy prices also affect the economy.

[7] ENERGY 2020 does include a complete, but aggregate representation of the electric transmission system. Electric transmission data is provided by FERC, the Department of Energy, and the National Electric Reliability Council. The dispatch technologies in the basic model include: Oil/Gas Combustion turbine, Oil/Gas Combined Cycle, Oil/Gas Combined Cycle with CCS, Oil/Gas Steam Turbine, Coal Steam Turbine, Advanced Coal, Coal with CCS, Nuclear, Baseload Hydro, Peaking Hydro, Small Hydro, Wind, Solar, Wave, Geothermal, Fuel-cells, Flow-Battery Storage, Pumped Hydro, Biomass, Landfill Gas, Trash, and Biogas.

[8] A 110 node transmission system is used in the default model, but a full AC load-flow bus representation model has also been interfaced with ENERGY 2020.

[9] The model has used the work of Daniel McFadden and Clive Granger since its inception in the late 1970’s.

Finally, the system includes confidence and validity testing software that places uncertainty bounds on simulation results, quantifies confidence intervals, and ranks the contributions to uncertainty in future conditions. This feature can be used to limit data efforts to information most important to the analysis.

In order to assess the potential impacts of proposed policy options, a b*usiness-as-usual* scenario is developed as a point of reference. This "Reference Case" represents a scenario that is viewed as a reasonable expectation of how the economy, energy use and emissions might develop over time.

Part of the nature of developing a Reference Case is the need to address inherently uncertain issues that can have significant impacts on future energy use and emissions. No forecast is going to be "right" or "accurate" in that no one can tell today how some of the key underlying issues may develop. Given the level of uncertainty involved in any projection of a possible future, caution should be used in applying a high level of precision to the modeling results. Understanding the Reference Case, however, can be extremely useful in providing an underlying structure against which to model proposed policies, and in determining directionality and cause and effect.

Numerous assumptions are required to perform an analysis of this type across a range of topic areas, including economic developments, fuel and electric markets, and regulatory structures. Projected outcomes are only as good as the input assumptions upon which they are based, with more rigorous assumptions leading to a more rigorous analysis. The inputs and assumptions described in this document were developed to provide as accurate a representation as possible of the activities and structures underlying energy use and greenhouse gas emissions in California.

# 4 Reference Case Inputs

ENERGY 2020 derives energy demands, such as the demand for electricity, based on economic activity and device efficiency. The following sections provide a brief overview of the data inputs and assumptions as well as the sources of data used in the Reference Case. Actual data inputs for specific elements such as generating units, emission factors, etc., can be provided separately in Excel spreadsheets as required.

As a multi-sector analytical tool, ENERGY 2020 requires data and assumptions covering a broad range of economic sectors and their interactions. In most cases, the necessary data – both historical and projected – is available from the federal government (EIA, EPA, etc.). In past analyses, ENERGY 2020 has relied heavily on these federal sources to populate and calibrate the model. In developing the model for California, a considerable amount of state-specific information was available and has been used. And wherever possible, inputs and assumptions consistent with those from the California Energy Commission's *2009 Integrated Policy Report* were used in this analysis.

The following sections provide an overview of the data and assumptions required to perform the multi-sector analysis and list the data sources that have been used to populate ENERGY 2020 to this point.

Data[10] inputs for ENERGY 2020 are required in five areas:

1. Population and economic
2. Fuel prices
3. Energy use and consumption
4. Emissions and air regulations
5. Electricity generation capacity and operation

The sections below list the key data elements required in each of these areas, along with the sources that have been used to supply this data for other analyses. For each data element the default data used in the model is described. This data is generally used in modeling the jurisdictions around California. In most instances, state-specific data (consistent with the data used in the CEC's *2009 Integrated Energy Report*) has been used in place of national sources for modeling energy use and emissions in California.

[10] "Data" here refers to both historical data and assumptions and projections of future inputs.

ENERGY2020 requires both historical data and projections to calibrate and generate forward-looking projections. Projections for the period to be modeled (e.g. through 2020) will be gathered where possible to provide points of comparison and check the reasonableness of the projection.

The ARB implementation of ENERGY 2020 includes the geographic areas of California, Oregon, Washington, Idaho, Arizona, New Mexico, Nevada, Colorado, Utah, Montana and Wyoming, Alberta, British Columbia and the northern state of Baja California. Interactions between these states and provinces are modeled, particularly with respect to electricity generation. To ensure consistency the assumptions used in California are applied to other states to the extent possible. In determining which data sources to use for California, consideration has been given to the potential impacts of using different sources of data for different states (or in-state vs. out-of-state).

## 4.1 *Population and Economic Data*

Demographic and economic data are required to generate demands for services. For California, economic data and forecasts including gross output, personal income and inflation, used in the model were compiled by the ARB from several California sources. The historic data for the US states is from the BEA, for the Canadian provinces data is from CANSIM.

The table below describes the sources that have been used in the California model.

| Description of Data/Input | Sources Used/Available |
|---|---|
| Total population, historical and growth over time | - “Chap1Stateforms-RF2-09.xls”, from *California Energy Demand 2010-2020 Staff Revised Forecast*, November 2009.<br>- US Census Bureau<br>- Statistics Canada/Informetrica |
| Population by housing type (single-family, multi-family, etc.) | - US Census Bureau<br>- Statistics Canada/Informetrica |
| Households by housing type (single-family, multi-family, etc.) | - US Census Bureau<br>- Statistics Canada/Informetrica |
| Personal income | - “Chap1Stateforms-RF2-09.xls”, from *California Energy Demand 2010-2020 Staff Revised Forecast*, November 2009.<br>- US Bureau of Economic Analysis<br>- Statistics Canada/Informetrica |
| Employment by sector | - US Bureau of Economic Analysis<br>- Statistics Canada/Informetrica |

The model covers the surrounding states and provinces that are part of the WECC region.  In the table above, the state-specific data sources used for California are shown first, followed by the sources of US information used for surrounding states and the sources of data for the Canadian provinces.

The population forecast used in the model assumes population growth of just over one percent across the forecast period.

| California Population | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Population (thousands) | 36,895 | 39,266 | 41,701 | 44,136 |
| Average Annual Growth Rate | | 1.19% | | |

Personal income is projected to grow just over two percent over the forecast period.

| California Personal Income | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|
| Per Capita Income (2007$) | 38,374 | 39,438 | 43,010 | 46,023 |
| Average Annual Growth Rate | | 2.09% | | |

## 4.2 *Price data*

Energy prices can play a significant role in end user decisions on equipment, capital and operating decisions. Fuel costs can be critical in determining the costs of electric dispatch, as well as input costs of some industrial processes and home heating. ENERGY2020 calculates future electric prices based in part on these fuel costs.

Energy prices are largely determined by international markets, although domestic demand, such as electric sector demand for natural gas can influence prices. As a result, fuel prices are treated by the model as an exogenous input.

Historic energy prices for all states are obtained from the State Energy Consumption, Price and Expenditure Estimates in the State Energy Data System (SEDS) for the U.S. and from Statistics Canada for Canada. Price data for California was obtained from the California Energy Commission website and directly from the ARB.

The default energy price forecast for the US is based on the Energy Information Administration's Annual Energy Outlook Reference Case forecast for 2009 to 2030. For Canada, the National Energy Board's price forecast has been used. Where inconsistencies exist between these two forecasts, the US AEO projection was used with appropriate currency conversion.

Biomass prices in the model are based on research completed for a previous project, shown in the table below. Unlike other fuels, biomass prices are significantly influenced by local cost and supply issues. As a result, the ARB may wish to adjust these values to reflect regional variations.

| **Biomass Cost** *(per mBtu in 2006$)* | |
|---|---|
| Residential | $11.53 |
| Commercial | $10.09 |
| Industrial | $10.06 |

Power prices are calculated endogenously by the model based on generation costs and dispatch. While the model calculates retail electricity prices, actual consumer prices may differ as a result of political, regulatory or market influences. The model can be calibrated to actual prices, within reasonable parameters for the historic period if desired. A forecast of electricity prices for comparison purposes was obtained from the California Energy Commission (CEC).

## 4.3 *Historic Energy Consumption Data*

ENERGY 2020 models energy use at the end-use level within each economic sector based on the existing physical stock and the efficiency of that stock. The database of device efficiencies reflects both the average efficiency of energy use for current stocks and the efficiency/energy alternatives available to consumers at the margin. Technology and efficiency choices are modeled based on past experience with consumer choice rather than on pure economic evaluation.

The default historic energy use and consumption data used in the model is derived from the federal Energy Information Administration (EIA) State Energy Data (SEDS) database. For California, historic energy consumption was derived from both the *2009 Integrated Energy Policy Report* (California Energy Commission, December 2009) and the California Greenhouse Gas Emissions

Inventory. Future consumption was calibrated to the energy forecast reported in the *2009 Integrated Energy Policy Report.*

Default sectoral and end-use data as well as energy intensities are based on the Residential Energy Consumption Survey (RECS), Commercial Energy Consumption Survey (CECS) and Manufacturers Consumption Energy Survey (MECS).

The table below describes sources that have been used in the California model.

| Description of Data/Input | Sources Used/Available |
|---|---|
| **Residential Data**<br>- Household income by housing type<br>- No. of people per household<br>- End-use consumption data, including fuels used for space and water heating, air conditioning, etc. | California Statewide Residential Appliance Saturation Study: Final Report (400-04-009), California Energy Commission, June 2004.<br><br>2001 EIA Residential Energy Consumption Survey (RECS), by Census Region and Division (2005 RECS in process)<br>http://www.eia.doe.gov/emeu/recs/contents.html |
| **Commercial Data**<br>- Floor area by sub-sector<br>- End-use consumption data, including fuels used for space and water heating and energy intensities | California Commercial End-Use Survey, (CEC-400-2006-005), California Energy Commission, March 2006.<br><br>2003 EIA Commercial Buildings Energy Consumption Survey (CBECS), by Census Region and Division (2007 CBECS underway)<br>http://www.eia.doe.gov/emeu/cbecs/contents.html |
| **Industrial/Manufacturing Data**<br>- Energy use by fuel for each sub-sector and end-use | Non-Residential Market Share Tracking Study, Final Report on Phases 1 & 2 CEC, April 2005.<br><br>2002 EIA Manufacturing Energy Consumption Survey (MECS), by Census Region (2006 MECS underway)<br>http://www.eia.doe.gov/emeu/mecs/contents.html |
| **State Energy Data:**<br>- Energy consumption and expenditures by sector and energy source | *2009 Integrated Energy Policy Report;* California Energy Commission, Dec. 2009 (CEC-100-2009-0003-CMF);www.energy.ca.gov<br><br>California Greenhouse Gas Emissions Inventory<br>http://www.arb.ca.gov/cc/inventory/inventory.htm<br><br>California Public Utilities Commission<br>http://www.cpuc.ca.gov/PUC/energy/<br><br>2004 EIA State Energy Data System (SEDS)<br>http://www.eia.doe.gov/emeu/states/_seds.html |

Household data for California was gathered from the US Census Bureau supplemented by data from the EIA's State data on Prices and Expenditures.

Information regarding past electricity consumption for the state was provided by the ARB and obtained from the California Energy Commission website.

## 4.4 *Historic Emission Data*

### 4.4.1 Emissions and Air Regulations

Historic GHG emissions are based on the inventory of California GHG emissions and sinks[11] and the US GHG emissions inventory as published by the EPA[12]. ENERGY 2020 is calibrated using historic information on all of the major greenhouse gas emissions including:

- Carbon dioxide ($CO_2$),
- Nitrous oxide ($N_2O$),
- Methane ($CH_4$),
- Sulphur hexafluoride ($SF_6$),
- Hydrofluorocarbons (HFCs) and
- Perfluorocarbons (PFCs).

GHG emissions are presented in $CO_2$ equivalent ($CO_2e$) terms. The global warming potentials used to convert the different greenhouse gas emissions into $CO_2e$ terms are provided in Appendix F.

**Sources of Emissions Data**

| Input | Sources Used/Available |
|---|---|
| Emissions by sector, end-use, fuel and GHG | California Greenhouse Gas Emissions Inventory http://www.arb.ca.gov/cc/inventory/inventory.htm<br><br>US EPA http://www.epa.gov/climatechange/emissions/usinventoryreport.html<br><br>Environment Canada http://www.ec.gc.ca/pdb/ghg/inventory_e.cfm |

[11] California Greenhouse Gas Emissions Inventory http://www.arb.ca.gov/cc/inventory/inventory.htm
[12] EPA website: http://www.epa.gov/climatechange/emissions/usinventoryreport.html

### 4.4.2 Emission Factors

Emission factors for most fuels are based on values used by ICF in developing national and state inventories. For the transportation sector however, the emission factors for $CH_4$ and $N_20$ pollutants were adapted from the Canadian National Inventory Report[13]. ENERGY 2020 calculates GHG emissions at the point of combustion for most fuels. Upstream emissions from extraction and processing are captured as part of those respective economic sectors.

Emissions associated with the use of biomass as a fuel are deemed to be biogenic and therefore not contribute to global warming. As a result, the model assumes no GHG emissions are created from the use of biomass.

Emissions from ethanol and other bio-fuels represent an exception from a modeling perspective. In order to capture the emissions associated with their production and distribution, the model applies full cycle emission factors for these fuels. While the combustion of ethanol and biodiesel are not deemed to result in any anthropogenic emissions, the model uses an emission factor to recognize upstream emissions.

Past research has resulted in a range of estimates of full cycle emissions for biofuels; particularly for ethanol production. The range of estimates found for emission coefficients for corn and cellulosic ethanol as well as biodiesel are provided below. The emissions estimates vary depending on assumptions regarding the type of farming practices, technology and processes assumed. In general, the energy balance for the production of corn ethanol has improved over time and is expected to improve further in future.

The full-cycle emission factor used in the model for each biofuels type is shown in the right hand column in the table below.

| Fuel | Emission Coefficients (lbs of $CO_2$ per mmBtu) | | |
|---|---|---|---|
| | Low | High | Proposed Value |
| Corn Ethanol | 136 | 276 | 154 |
| Cellulosic Ethanol | 10 | 36 | 20 |
| Bio-diesel | 68 | 102 | 90 |

When these fuels are used in combination with other fuels, for example in a mix of gasoline and ethanol, the emissions associated with gasoline combustion are reported as part of total gasoline-related emissions. Therefore, *for each gallon of*

[13] Environment Canada. National Inventory Report 1990-2005, Greenhouse Gas Sources and Sinks in Canada, April 2007. (Annex 12 Emission Factors)

*unblended, neat corn ethanol, the model uses an emission coefficient set at 154 lbs of $CO_2$ per mmBtu, or roughly 21% below that for a gallon of unblended motor gasoline.*

## 4.5 *Electricity Sector Data*

### 4.5.1 Generation Data

The electricity sector differs from other sectors in the extent to which emissions associated with power use within the state may result from emissions outside the state as power is imported from other areas. In California, 14% of total state gross GHG emissions in 2004 were due to in-state generation and a further 14% of total state gross GHG emissions that year were attributable to imported electricity.[14]

ENERGY 2020 contains information on every generating unit in the state, as well as in neighboring jurisdictions which may supply power to the state. The model tracks and uses the following information for each generating unit:

- Historic Peak Capacity (MW);
- Historic generation levels (GWh);
- Type of fuel used;
- Heat rate;
- Historic annual fuel use (PJ);
- Emissions by pollutant type;
- O&M costs;
- Capacity factors;
- Emission rates;
- Outage rates;
- State or Province;
- Physical location (latitude and longitude);
- Ownership information;
- Plant type (Hydraulic, Coal, Combined Cycle Turbine, etc.)

The data used on existing and committed generating units was obtained from the National Electric Energy Data System (NEEDS) 2006 database and reconciled with a list of plants from Bonneville Power Administration (BPA) and data from FERC.

[14] California Greenhouse Gas Emissions Inventory http://www.arb.ca.gov/cc/inventory/inventory.htm

### 4.5.2 Electricity Generation Capacity and Operation Data

ENERGY 2020 has been populated with data describing the type, operation and performance of every generating unit in the western US. In addition to plant-level data, the table below includes sources for other inputs necessary to describe the electric system, including transmission capability.

| Input | Sources Used/Available |
|---|---|
| Plant type | FERC reports for US<br>Statistics Canada for Canada |
| Plant capacity | FERC reports for US<br>Statistics Canada for Canada |
| Plant historical generation | FERC reports for US<br>Statistics Canada for Canada<br>Total generation output by plant type for California from CEC |
| Plant fuel type | FERC reports for US<br>Statistics Canada for Canada |
| Plant Heat Rate | FERC reports for US<br>Statistics Canada for Canada |
| Plant fuel consumption | FERC reports for US<br>Statistics Canada for Canada |
| Plant emissions by pollutant | EPA or Environment Canada |
| Plant costs (operation and maintenance, variable and fixed) | FERC reports for US<br>Statistics Canada for Canada |
| Plant historical capacity factor | FERC reports for US<br>Statistics Canada for Canada |
| Plant availability (outages) | FERC reports for US<br>Statistics Canada for Canada |
| Plant owner and location | FERC reports for US<br>Statistics Canada for Canada |
| Planned capacity additions and retirements | California Public Utility Commission<br>GHG Modeling process (E3) |
| Transmission Capability | NERC |

This data was compared to generation data provided by Energy and Environmental Economics, Inc. (E3) as part of its modeling for the California Public Utilities Commission[15] (CPUC) to ensure consistency between the models.

Modeling results were compared to statistics published by the California Energy Commission. Information was also obtained from the Bonneville Power Administration[16] and from the Federal Electricity Commission for Mexico[17].

15 www.ethree.com/cpuc_ghg_model.html

The resulting list of generating units was matched to emission data from the EPA and Environment Canada in order to calculate emission rates. Emission rates for the targeted GHG emissions were then reviewed for reasonableness based on plant type and capacity factors, etc.

Historic generation by plant type was calibrated with historic generation data available from the CEC and the EIA.

### 4.5.3 Transmission Structure and Dispatch / Natural Gas Pipeline System

Power flows between neighboring US states are modeled within ENERGY 2020 based on existing transmission capabilities and interconnections as obtained from NERC reports. Appendix B describes the inter-regional transmission capabilities between model regions (or nodes) as well as the maximum capacity limit of each transmission path used in the model. Interconnection capacities used in the model were based on the IPM Model 2006[18] updated to reflect changes in the region based on past work for past clients such as the Bonneville Power Administration.

Generation is dispatched at the node level for a set of sample hours in each season. Each node is economically dispatched, selecting lowest cost generation first with the resulting clearing price determining the generation price for that node as described in Appendix A. As part of the calculation the model can utilize resources from a neighboring node within the constraints of the transfer capacity between nodes. The transfer of energy between nodes is subject to a 1% loss to represent additional transmission losses.

### 4.5.4 Planned Capacity Changes

As part of the modeling process, ENERGY 2020 builds new capacity endogenously as needed to meet capacity and reserve requirements. At any

[16] BPA, 2007 Pacific Northwest Loads and Resource Study, Operating Years 2008 through 2017, March 2007.

[17] http://aplicaciones.cfe.gob.mx/aplicaciones/QCFE/EstVenta/Historico.aspx?Estado=M%C3%A9xico&Idioma=I&YearMin=2000&YearMax=2006&imp=1

[18] Table 3.5 of section 3 of the documentation for the EPA Base Case 2006 (v3.0) posted on the EPA website: http://epa.gov/airmarkets/progsregs/epa-ipm/index.html#docs

given time, however, plans may already be in place to build, re-furbish, upgrade or retire generation facilities. These plans must be incorporated into the model in order to reflect decisions and commitments that have already been made. In the interests of maintaining consistency with modeling completed for the CPUC, committed and planned generation was based on the results of the CPUC's GHG modeling process.

The mix of renewable resources to be used in meeting the State RPS in the Reference Case and complementary policies case has been based on the CPUC's "33% RPS Implementation Analysis".[19]

ENERGY 2020 can determine the need for new generation based on a pre-determined reserve requirement. Normally, this determination is based on the highest level of demand for power and the available capacity at the time of that peak. Some types of generation, such as wind or some types of hydro-electric generation however, may not be available at the time of the peak. For modeling purposes the model assumes that only 15% of installed wind capacity is available at the time of the peak.

### 4.5.5 New Generation Characteristics

The costs and characteristics of new generation are adapted from information developed by Energy and Environmental Economics, Inc. as part of their modeling process for the California Public Utility Commission[20]. For those plant types not reported by E3, default characteristics were used. Appendix E contains the specific costs and characteristics used in the model for California and the rest of the WECC.

### 4.5.6 Industrial Generation and Co-generation

ENERGY 2020 models both utility generation, which supplies the power grid, and industrial generation which supplies a particular end user. Industrial generation is defined as power generation that is within the industrial end user's facility and is not used to supply power to the grid. Industrial generation, as defined in ENERGY 2020, could also be referred to as self-generation or load displacement generation. Industrial generation may be supplied by any of the fuels listed below:

- Biomass

[19] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33implementation.htm
[20] www.ethree.com/cpuc_ghg_model.html

- Coal
- LPG
- Oil
- Solar
- Steam

Co-generation, or combined heat and power facilities, simultaneously generate electricity and supply a heat load. ENERGY 2020 recognizes that co-generation may occur either as industrial generation or as utility generation and may use any of a number of fuels.

- Within the power sector, these plants are treated as 'must run' units, meaning that they will always operate when available. Power from these units contributes to overall electricity supply. Heat from these units may be captured as part of a separate steam supply system. However, limited data is available regarding overall US steam demand.
- Within the industrial sector, co-generation capacity will run based on heating requirements. Heat produced from co-generation is used to meet industrial heat requirements based on a co-generation heat rate. Co-generated electricity is used to meet industrial power requirements, reducing net demand from the grid.

Where the heat contribution of co-generation is significant, the preferred modeling approach is to include these units in the industrial sector.

The databases used to represent electricity generation often include all significant generators, including both utility and industrial boilers and generators. By contrast, reported electricity consumption information tends to be based on metered electricity sales, and as such are net of self generation. Total electricity consumption and generation will generally be slightly higher than reported electricity sales. It is therefore important in calibrating the model with historic electricity consumption that existing generation used as industrial or self-generation be appropriately identified.

## 4.6 *Transportation*

ENERGY 2020 models passenger, freight, and off road transportation separately, based on different underlying drivers. Passenger and freight transportation are modeled by mode and vehicle type. Changes in transportation demand, in terms of passenger miles traveled and ton-miles of freight, are calibrated for the historic period.

The bulk of existing and forecast passenger transportation is used in personal vehicles. Off road transportation energy use is modeled in ENERGY 2020 based on drivers including Agriculture, Forestry and Construction activity.

## 4.7 *Built Environment*

The State of California has a long history of promoting energy efficiency and demand side management for electricity and natural gas energy use. As a result, average appliance and equipment efficiencies are expected to be higher than for the US as a whole. Information on current levels of equipment efficiency and the state of the market for efficiency technologies was used to adjust end-use data within the model to reflect current levels of efficiency of market saturations.

The Reference Case does not assume any increase in equipment or appliance efficiency other than the improvements due to the *Energy Independence and Security Act of 2007*, as noted in section 4.8 and existing California appliance standards[21].

## 4.8 *Programs/Policies Incorporated in Reference0 and Reference Cases*

### 4.8.1 Reference0 Case

The Reference 0 case is designed to approximate the CEC energy forecast. It contains the Pavley I vehicle standards for California. The marginal vehicle efficiency for passenger cars and light trucks is incrementally increased by a fixed percentage each year starting in 2011 to reach the mandated new vehicle fleet efficiency of 35.5 mpg; consistent with Pavley I Vehicle Standards (per above).

### 4.8.2 Reference Case

- **EISA (Energy Independence and Security Act 2007):** Specific laws and regulations may be incorporated in the model to reflect policies which have been approved but have not yet come into effect. The federal Energy Independence and Security Act of 2007, which was passed into law in early January 2008, has been included in the model.

[21] *2007 Appliance Efficiency Regulations, California Energy Commission, December 2007.*

The following assumptions will be used to model the Act in the Reference Case:

- **Transportation**: In the rest of the West, the current marginal vehicle efficiency for passenger cars and light trucks will be incrementally increased by a fixed percentage each year starting in 2011 to reach the mandated new vehicle fleet efficiency of 35.5 mpg; consistent with Pavley I Vehicle Standards.
- **Renewable Fuels**: In the rest of West, the EISA specifies required levels of biofuel production for the US. The values used are the ones developed for the WCI study (EA08_Biofuels.txp)
- **Residential Boilers and Furnace Fans**: Savings estimates developed by the ACEEE for each state will be used to model this portion of the Act, using only the benefits realized by upgrades to the residential energy boilers, leaving out any energy benefits associated with reduced electricity consumption by furnace fans.
- **Walk-In Coolers and Walk-In Freezers:** Savings estimates developed by the ACEEE for each state will be used to model this portion of the Act.
- **Electric Motor Efficiency Standards**: The model will utilize the ACEEE savings projections, pro-rated to California's relative industrial electricity sales.
- **External Power Supply Efficiency Standard**: Savings estimates developed by the ACEEE for each state will be used to model this portion of the Act.
- **Energy Efficient Light Bulbs:** Information will be collected on existing market shares for efficient lighting in California in order to estimate the impact of this aspect of the Act. The base assumptions are that general service lighting accounts for about 90% of residential lighting, 10% of commercial lighting and 5% of industrial lighting.
- **Metal Halide Lamp Fixtures**: The model assumes that 15% of commercial lighting and 60% of industrial lighting now use metal halide fixtures. For new installations the model assumes that 80% of this market would use pulse start ballasts.

- **Renewable Portfolio Standard**: The reference case includes Renewable Portfolio Standards (RPS) for each US state as well as renewable energy targets established by Canadian provinces. For California, the RPS implemented in the Reference Case requires that 20% of electricity sales be supplied by renewable sources by 2020.

# 5 Policy Case Inputs and Assumptions

## 5.1 *Programs/Policies Incorporated in Complementary Case*

The following policies were implemented as "complementary policies" in the model:

- **Vehicle Efficiency:** For California, in the Reference0 case average new vehicle efficiency will be increased starting in 2010 to reach the standard of 35.5 mpg by 2016. Under the complementary policies scenario average new vehicle efficiency for cars and light trucks will be further increased to reach a target of 42.5mpg by 2020. The change in vehicle costs required to meet these standards are based on estimates by the California Air Resources Board[22].
- **California - Low Carbon Fuel Standard (LCFS):**
  - This standard calls for a 10% reduction in the carbon intensity of fuels by 2020 in California. This is modeled by increasing the ethanol share of passenger ground transportation fuels to approximately 18% for electric and ethanol vehicles and by increasing the biodiesel share of freight ground transportation to approximately 15%.
  - The EISA sets out targets for increasing the percentage of biofuels derived from cellulosic and advanced biofuels. These targets have been reflected in the model by adjusting the full-cycle emission factors associated with ethanol between 2010 and 2020. The effect of this adjustment is to reduce the full cycle emission factor for ethanol by about 40% from the initial level (the level for corn-based ethanol) by 2020.

[22] California Environmental Protection Agency, Air Resources Board, Regulations to Control Greenhouse Gas Emissions from Motor Vehicles, Final Statement of Reasons, August 4, 2005.

- **Renewable Portfolio Standard**: In the complementary policies case, the RPS for California is increased to require that 33% of electricity sales be supplied by renewable sources. The type of renewable generation built to meet the RPS requirement was based on the resource mix projections by the California Public Utilities commission.[23] As the level of electricity demand varied between cases, it was assumed that the renewable content of imports would match the required RPS percentage (renewables as a percentage of sales) for that year. In-state renewable generation as projected by the CPUC was then adjusted to meet the total level of renewables required.
- **Energy Efficiency:** The modeling assumes that programs are introduced to achieve a State target of reducing electricity sales by 24,000 GWh and natural gas sales by 800 million therms reduction by 2020. This reduction is modeled through increases in process and device efficiencies distributed across the residential, commercial and industrial sectors. The costs of actual equipment upgrades associated with these efficiency gains are captured in the model; however, program and administration costs are not modeled. The following assumptions were made with respect to the energy efficiency policies.
    - <u>Efficiency Improvement</u> - In order to translate this policy into modeling terms, ICF/SSI assume that the increase in efficiency would be implemented across all sectors (residential, commercial and industrial) and all end uses. Through an iterative process, operating this policy on a stand-alone basis, we will determine a level of efficiency gain for marginal devices for each year that would achieve the targeted reduction in electricity and natural gas use. The increase in efficiency will be introduced into the model through a multiplier applied evenly across processes and devices.
    - <u>Economies of Scale</u> - An assumption was made that as more efficient devices are required, the cost of devices would not benefit from economies of scale.
    - <u>Retrofits</u> - No retrofits, or premature retirements of existing equipment, were assumed in the modeling. The efficiency improvements required to meet the policy target were assumed to take place at the margin. In ENERGY 2020 devices and processes are each continually replaced with

[23] http://www.cpuc.ca.gov/PUC/energy/Renewables/hot/33implementation.htm

assumed lifetimes of less than 20 years so at least 5% of the devices and processes are replaced each year.

- Process Efficiency Impacts on Device Investments – Changes in process efficiency generally reflect changes in the level of energy service required (e.g. the amount of lighting reduced due to day-lighting or improved design or water heating needs reduced due to more efficient end-use devices). To the extent the process efficiency increases, this tends to lower the level of device investment required in these end-uses; as lower lighting requirements are reflected in fewer new fixtures being required. For modeling purposes, we have assumed that 30% of the efficiency gains attained under the complementary policy will come from process efficiency gains, while 70% come from device efficiency gains.

- **Combined Heat and Power**: Electricity output from CHP facilities in California was assumed to increase by 30,000 GWh by 2020. For modeling purposes it was assumed that the heat output of these facilities is used to serve existing or new heating loads. This means that the addition of these facilities results in some increase in overall fuel requirements based on the heat rate assumed for the co-generation unit but contributes additional electricity supply.
- **VMT Reduction**: Vehicle miles travelled per year in California were assumed to be reduced by 5% by 2020. No assumptions were made with regards to how this reduction would be achieved. For example, an increase in public transit use was not assumed in the modeling.
- **Heavy Duty Vehicle Efficiency**: This policy simulates an increase in freight end use efficiency to reflect Smart Way Truck Efficiency (saving approximately 1.4 MMT of GHG emissions with the establishment of medium and heavy duty vehicle hybrids as a viable technology saving an additional 0.5 MMT of GHG emissions).
- **Ship Electrification at Ports**: This policy reflects the provision of on-shore electricity to ships in port to reduce the use of on-board engines and associated emissions (saving approximately 0.2 MMT of GHG emissions).

## 5.2 *Cap and Trade Scenarios*

The following describes the cap-and-trade scenarios modeled.

- **Region:** California only
- **GHG Pollutants:** CO2, CH4, N2O, SF6, PFC, and HFC
- **Emissions Goal:** State-wide target of 427 MMT in 2020
- **Covered Sectors**
    - **Narrow Scope (2012-2014):** Electricity Production and Industrial facilities emitting >25,000 metric tonnes CO2e per year
        - In order to approximate the 25kt CO2e cut off, it is assumed that only emission intensive industrial sectors are included in this initial phase
        - Emission intensive industries defined as chemicals, paper, petroleum products, primary metals, mining, and oil & gas extraction. In the case of petroleum products sector only emissions associated with operations are included in this phase.
    - **Broad Scope (2015-2020):** Narrow Scope plus transportation fuels, commercial and residential fuels and small industrial.
- **Banking:** Banking is allowed without limitation.
- **Allowance Allocation:** All of the allowances are auctioned; there are no gratis allocations.
- **Offsets:** Offsets are limited to 49% of the required reduction.
- **Sensitivities (Modeling Scenarios)**
    - **S0** – contains all the complementary polices
    - **S1** – reduces the effectiveness of the transportation policies. The VMT reduction is eliminated while the LCFS and the Pavley II vehicle standard increase is reduced by 50%
    - **S2** – reduces the effectiveness of energy efficiency, CHP, and RPS policies. The energy efficiency and CHP programs are cut in half while the RPS is set to just 20%.
    - **S3** - reduces the effectiveness of transportation, energy efficiency, CHP, and RPS policies. The VMT reduction is eliminated while the LCFS and the Pavley II vehicle standard increase is reduce by

50%. The energy efficiency and CHP programs are cut in half while the RPS is set to just 20%.

**Summary of Modeling Scenarios**

| Scenario | Policies | LCFS | VMT | Pavley II | CHP | EE | RPS |
|---|---|---|---|---|---|---|---|
| S0 | Complementary | Y | -4% | Y | Y | Y | 33% |
| S1 | Transportation Reduced | 50% | 0% | 50% | Y | Y | 33% |
| S2 | Other Policies Reduced | Y | -4% | Y | 50% | 50% | 20% |
| S3 | All Policies Reduced | 50% | 0% | 50% | 50% | 50% | 20% |

# Appendix A: The ENERGY 2020 Model

## The Model – ENERGY 2020

ENERGY 2020 is an integrated multi-region, multi-sector energy analysis system that simulates the supply, price and demand for all fuels. It is a causal and descriptive model, which dynamically describes the behavior of both energy suppliers and consumers for all fuels and for all end-uses. It simulates the physical and economic flows of energy users and suppliers. It simulates how they make decisions and how those decisions causally translate to energy-use and emissions.

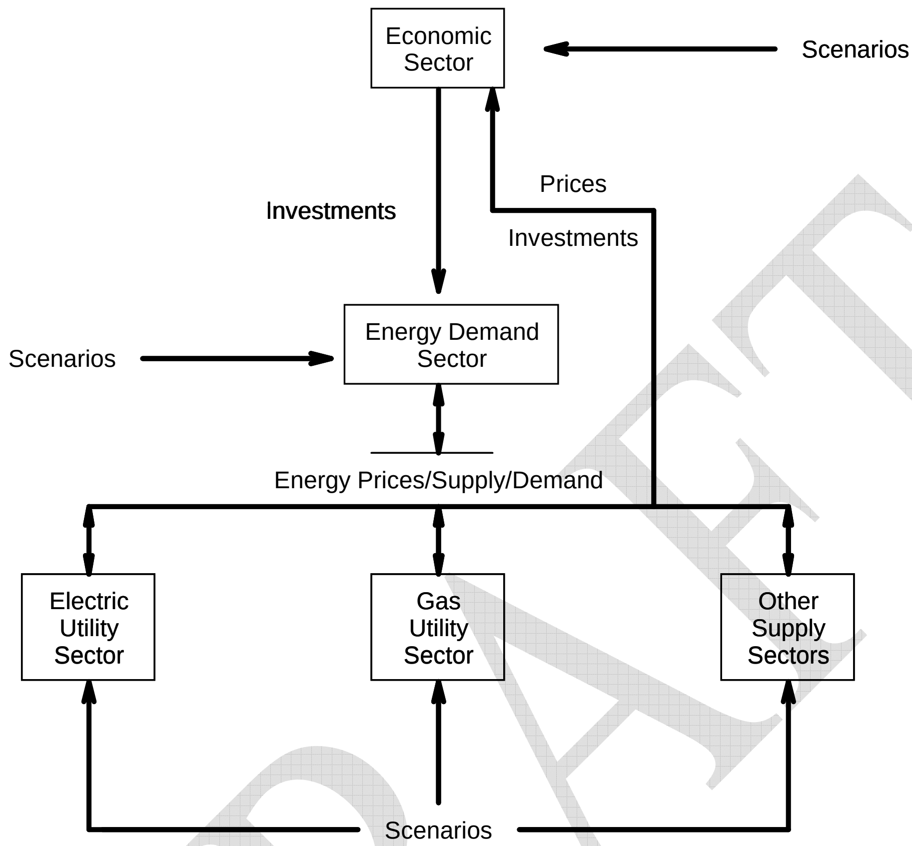
ENERGY 2020 is an outgrowth of the FOSSIL2/IDEAS model developed for the US Department of Energy (DOE) and used for all national energy policy since the Carter administration.[24] This early version of ENERGY 2020 was developed in 1978 at Dartmouth College for the DOE's Office of Policy Planning and Analysis.

## Model Overview:

The basic structure of ENERGY 2020 is provided in Figure 1-1. Energy Demand sector interacts with the Energy Supply sector to determine equilibrium levels of demand and energy prices. Energy Demand is driven by the Economy sector, which in turn provides inputs to the Economy sector in terms of investments in energy using equipment and processes and energy prices. The model has a simplified Economy sector to capture the linkages between the energy system and the macro-economy. However, the model is best run with full integration with a macroeconomic model such as REMI. Given the modular nature of ENERGY 2020, additional sectors or modules from other, non-ENERGY 2020 related, models (macroeconomic, supply such as oil, gas, renewables etc.) can be incorporated directly into the ENERGY 2020 framework.

[24] FOSSIL2 was the original version but was renamed to IDEAS a few years ago to reflect its evolutionary development since its original construction.

**Figure 1.1: ENERGY 2020 Overview**




## Energy Demand:

The demand sector of the model represents the geographic area by disaggregating the four economic sectors into subsectors based on energy services. As many or as few subsectors can be incorporated as required. Multiple technologies, multiple end-uses and multiple fuels are detailed. The level of detail that can be incorporated is of course subject to the data availability. The four economic sectors are:

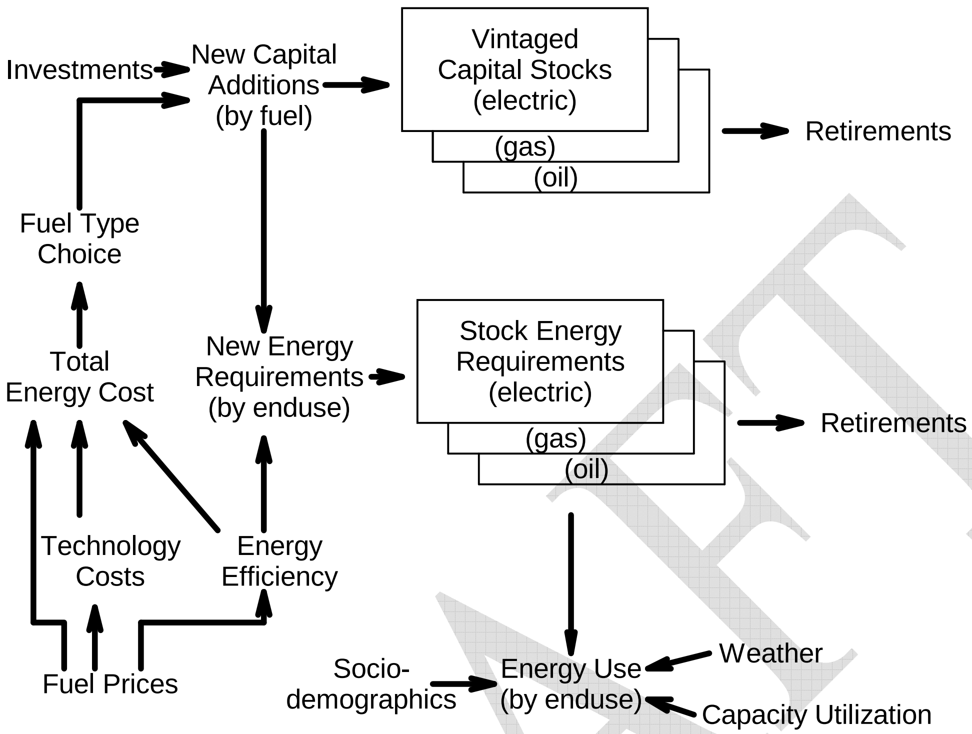
- Residential sector which includes three classes, single family, multifamily and rural/agricultural with 8 end-uses including space heating, water heating, lighting, cooling, refrigeration, other substitutable, and other non-substitutable.
- Commercial sector which is aggregated into one class and end-uses including space heating, water heating, cooling, lighting, other substitutable, other non-substitutable.

- Industrial sector which includes 10 (23 for US) 2-digit SIC categories and is further broken down into process heat, motors, lighting, miscellaneous as the end uses.
- Transportation sector which includes several modes of transportation including automobile, truck, bus, train, plane, marine and electric vehicles. Also, each of the residential, commercial and industrial sectors has separate transportation demands.

For each of the end-uses, up to six fuels are modeled, for example, the residential space heating has the choice of a gas, oil, coal, electric, solar and biomass space heating technologies. Added end-uses, technologies and modes can be added as data allow. For all end-uses and fuels, the model is parameterized based on historical locale-specific data. The load duration curves are dynamically built up from the individual end-uses to capture changing condition under consumer choice and combined gas/electric programs.

A few basic concepts are crucial to an understanding of how the model simulates the energy system. These concepts including, the capital stock driver, the modeling of energy efficiency through trade-off curves, the fuel market share calculation, utilization multipliers and the cogeneration module are discussed below in abbreviated form. Figure 3-1 (Demand Overview) illustrates the demand sector interactions.

**Figure 3.2: Demand Overview**




**Energy Demand as a Function of Capital Stock:**

The model assumes that energy demand is a consequence of using capital stock in the production of output. For example, the industrial sector produces goods in factories, which require energy for production; the commercial sector requires buildings to provide services; and the residential sector needs housing to provide sustained labor services. The occupants of these buildings require energy for heating, cooling, and electromechanical (appliance) uses.

The amount of energy used in any end-use is based on the concept of energy efficiencies. For example, the energy efficiency of a house along with the conversion efficiency of the furnace determines how much energy the house uses to provide the desired warmth. The energy efficiency of the house is called the capital stock energy or process efficiency. This efficiency is primarily technological (e.g. insulation levels) but can also be associated with control or life-style changes (e.g. less household energy use because both spouses work outside the home.) The furnace efficiency is called the device or thermal efficiency. Thermal efficiency is associated with air conditioning, electromotive devices, furnaces and appliances.

The model simulates investment in energy using capital (buildings and equipment) from installation to retirement through three age classes or vintages. This capital represents embodied energy requirements that will result in a specified energy demand as the capital is utilized, until it is retired or modified.

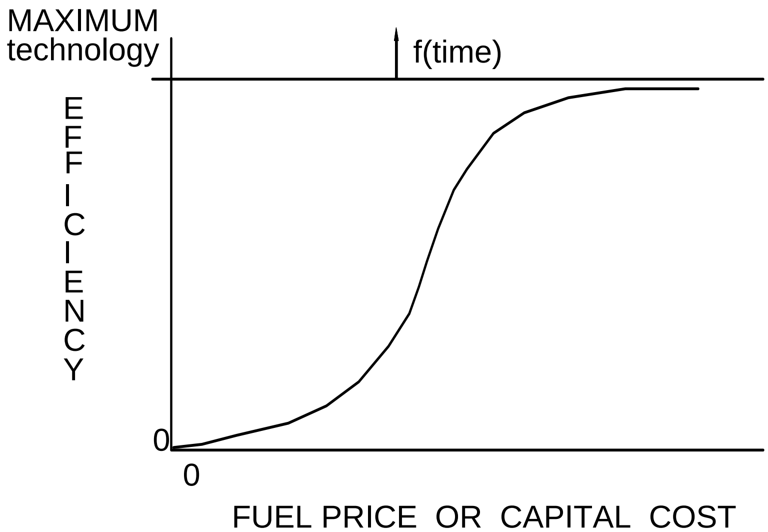
The size and efficiency of the capital stock, and hence energy demands, change over time as consumers make new investments and retire old equipment. Consumers determine which fuel and technology to use for new investments based on perceptions of cost and utility. Marginal trade-offs between changing fuel costs and efficiency determine the capital cost of the chosen technology. These trade-offs are dependent on perceived energy prices, capital costs, operating costs, risk, access to capital, regulations, and other imperfect information.

The model formulates the energy demand equation causally. Rather than using price elasticities to determine how demand reacts to changes in price, the model explicitly identifies the multiple ways price changes influence the relative economics of alternative technologies and behaviors, which in turn determine consumers' demand. In this sense, price elasticities are outputs, not inputs, of the model. The model accurately recognizes that price responses vary over time, and depend upon factors such as the rate of investment, age and efficiency of the capital stock, and the relative prices of alternative technologies.

**Device and Process Energy Efficiency:**

The energy requirement embodied in the capital stock can be changed only by new investments, retirements, or by retrofitting. The efficiency with which the capital uses energy has a limit determined by technological or physical constraints. The trade-off between efficiency and other factors (such as capital costs) is depicted in Figure 3.3 (Efficiency/Capital Cost Trade-Off). The efficiency of the new capital purchased depends on the consumer's perception of this trade-off. For example, as fuel prices increase, the efficiency consumers choose for a new furnace is increased despite higher capital costs. The amount of the increase in efficiency depends on the perceived price increase and its relevance to the consumer's cash flow.

**Figure 3.3: Efficiency/Capital Cost Trade-Off**




The standard model efficiency trade-off curves are called consumer-preference curves because they are estimated using cross-sectional (historical) data showing the decisions consumers made based on their perception of a choice's value. Many planners are now interested in measure-by-measure or least-cost curves which use engineering calculations and discount rates to show how consumers should respond to changing energy prices. Another analysis focuses on the technical/price differences in alternative technologies and the incentives needed to increase the market-share or market penetration of a specific technology. This perspective on the choice process uses market share curves. The model allows the user to select any of these three types of curves to represent the way consumers make their choices. Shared savings, rebate, subsidy programs, etc. can be tested using any of the curves.

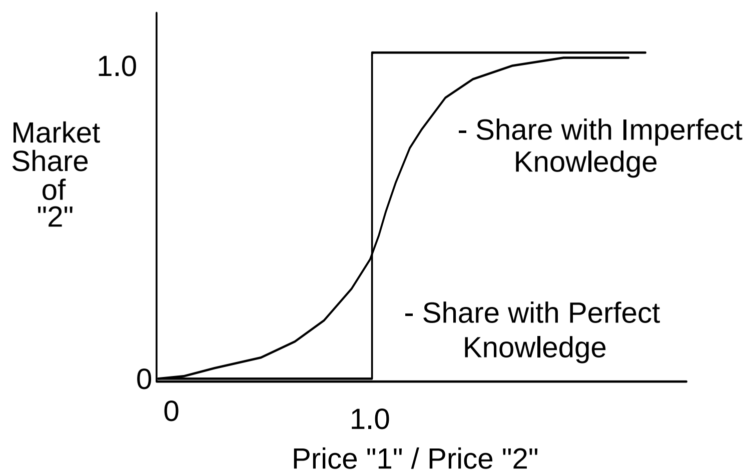
Cumulative investments determine the average "embodied" efficiency. The efficiency of new investments versus the average efficiency of existing equipment is one measure of the gap between realized and potential conservation savings.

The model uses saturation rates for devices to represent the amount of energy services necessary to produce a given level of output. Saturation rates may change over time to reflect changes in standard of living or technological improvements. For example, air conditioning has historically increased with rising disposable incomes. These rates can be specified exogenously or can be defined in relation to other variables within the model (such as disposable income).

**The Market Share Calculation:**

Not all investment funds are allocated to the least expensive energy option. Uncertainty, regional variations, and limited knowledge make the perceived price a distribution. The investments allocated to any technology are then proportional to the fraction of times one technology is perceived as less expensive (has a higher perceived value) than all others. This process is shown graphically in Figure 3.4 (Market Share Dynamics).

**Figure 3.4: Market Share Dynamics**




**Short Term Budget Responses:**

A short-term, temporary response to budget constraints is included in the model. Customers reduce usage of energy if they notice a significant increase in their energy bills. The customers' budgets are limited and energy use must be reduced to keep expenditures within those limits. These cutbacks are temporary behavioral reactions to changes in price, and will phase out as budgets adjust and efficiency improvements (true conservation) are implemented. This causes the initial response to changing prices to be more exaggerated than the long-term response, a phenomenon called "take-back" in studies of consumer behavior.

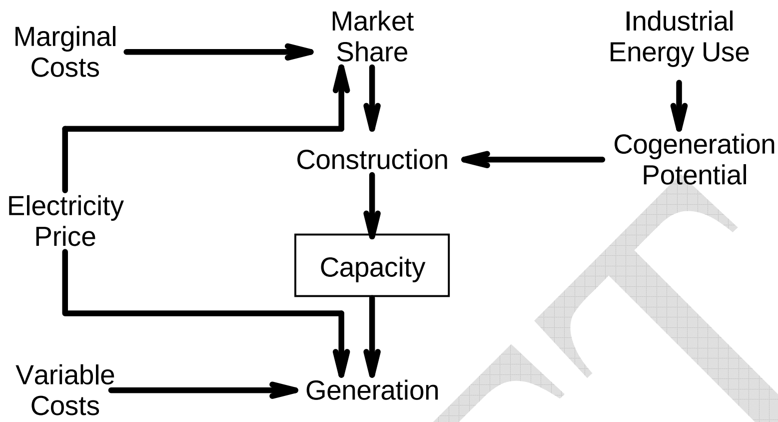
**Accounting for Fungible Demand:**

Some furnaces and processes can use multiple fuels. That is, they can switch almost instantaneously between, for example, gas and oil or coal and biomass as prices or the market dictates. Energy demand that is affected by this short-term fuel switching phenomena is called fungible demand. The model explicitly simulates this market share behavior.

**Modeling Cogeneration:**

Most energy users meet their electricity requirements through purchases from a utility. Some users (industrial and commercial) can, however, convert some of their own waste heat into usable electricity when economics warrant such action. Other users (residential and commercial) can purchase self-generation energy sources such as gas turbines, diesel-generators or fuel cells. Figure 3.5 shows a simplified overview of the cogeneration structure.

**Figure 3.5: Cogeneration Concepts**




In the model all energy used for heating is a candidate for cogeneration. The cost of cogeneration is the fixed capital cost of the investment plus the variable fuel costs (net of efficiency gains). This cogeneration cost is estimated for all technologies and compared to the price of electricity. The marginal market share for each cogeneration technology is based on this comparison.

Cogeneration is restricted to consumers who directly produce part of their own electricity requirement. Companies which generate power primarily for resale to the electric utility are considered independent power producers and are represented in the electric supply model.

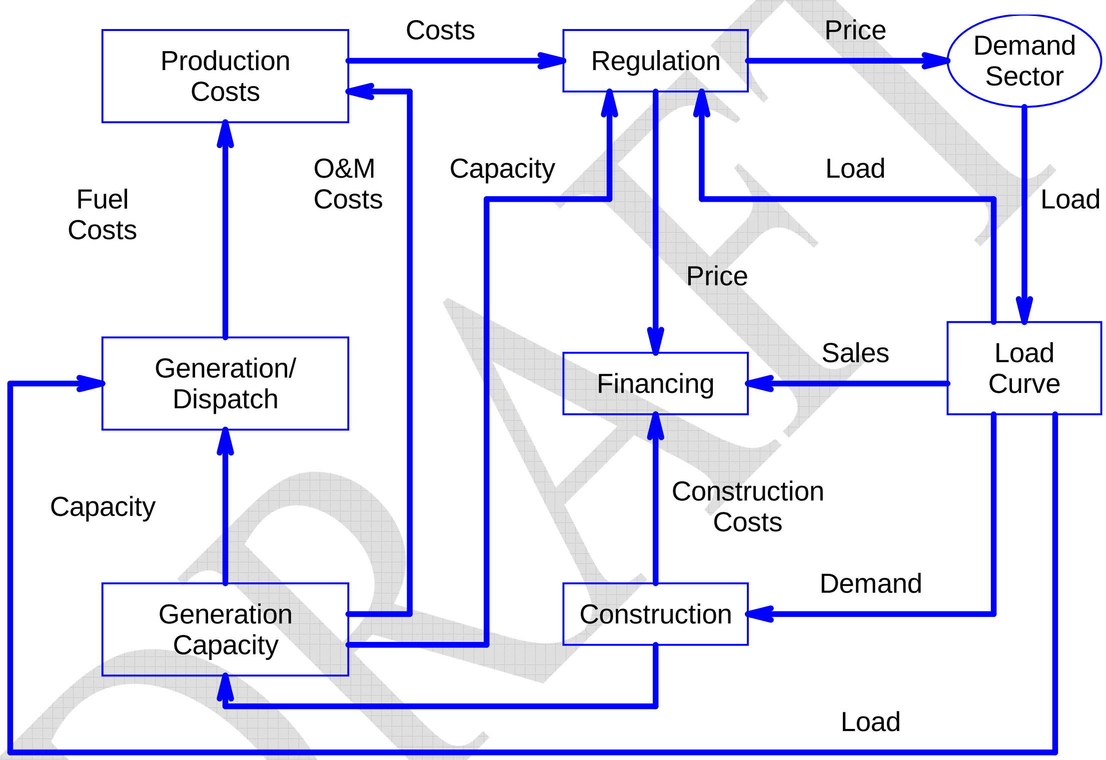
**Energy Supply:**

For electric and gas utilities (separate or combined), ENERGY 2020 internally and self-consistently simulates sales, load (by end-use, time-of-use, and class), production (across thirty-six dispatch types), demand-side management (by technology), forecasting, capacity expansion (new generation, independent power producers, purchases, and DSM), all important financial variables, and rates (by class, end-use, and time-of-use.)

The version used in this analysis has only the electricity utility sector. With the inclusion of the electric utility sector, the generic supply model turns over the calculation of electricity prices to that sector. The model endogenously simulates the forecasting of capacity needs, as well as the planning, construction, operation and retirement of generating plants and transmission facilities. Each step is financed in the model by revenues, debt, and the sale of stock. The simulated utility, like its real world counterpart, pays taxes and generates a complete set of accounting books. In ENERGY 2020, the regulatory function is modeled as a part of the utility sector. The regulator sets the allowed rate of return, divides revenue responsibility among customer classes, approves rate base, revenues and expenses, and sets fuel adjustment charges.

The interactions in the electric utility sector are summarized in Figure 3.6

**Figure 3.6: Electric Utility Structure Overview**




**Expansion Planning:**

The utility sector endogenously forecasts future demand for electricity. From the forecast it projects the future capacity required meeting future demand by taking into account retirements and plants already under construction. If future electricity requirements, including reserves, are forecast to exceed available capacity (using seasonal ratings), then construction of additional capacity is initiated.

If additional capacity is needed to meet forecast needs, the basic capacity expansion module in ENERGY 2020 determines whether base or peaking capacity is required. The model determines the maximum number of hours that new peaking capacity can be economically operated, before it would be less expensive to construct and operate base load capacity instead. If the forecast peaking capacity would operate more than that economic maximum, base loads units are initiated, otherwise peaking units are initiated. Any plant type including geothermal, wind, biomass and storage can be considered.

New plants, of a pre-specified minimum size, are initiated when the reserve margin would be violated if the plants were not built or if base load capacity is inadequate to serve base load energy needs at the end of the forecast period. The model does allow the minimum reserve margin to be temporarily violated at the peak if new base load capacity is scheduled to be available within the year. Peaking units are allowed to serve more than the "maximum economical" number of hours until base load capacity comes on-line.

Minimum plant size is exogenous. The mix of new base load plants (i.e. alternative coal technologies, hydro, or nuclear) is user-specified in the standard ENERGY 2020 configuration. The model also evaluates the financial implications of new construction, including total construction costs, cost schedules, and AFUDC/CWIP (Accumulated Funds Used During Construction/Construction Work in Progress). The gross rate on AFUDC equals the weighted average cost of capital. The actual construction progress and financial impacts are simulated on a year by year basis.

ENERGY 2020 can also be configured to consider intermediate load units, firm purchases contracts, external sales, independent power producers, and demand-side options. These options can be activated based on endogenous least-cost analysis or can be chosen by user-specified criteria. A detailed automatic Integrated Resource Planning module that would endogenously choose (with user control) from DSM measures utility and non-utility generation and purchase alternatives using linear programming techniques is now being offered as an enhancement.

**Financing:**

The ENERGY 2020 utility finance subsector simulates the activities of a utility's finance department. It forecasts funding requirements and follows corporate policies for obtaining new funds. The model simulates borrowing and issuing of stock, and can repurchase stock or make investments if it has excess cash. Cash flows are explicitly modeled, as are any decision that affects them. Coverage ratios, intermediate- and long-term debt limits, capitalization, rates of return, new stock issues, bond financing, and short-term investments are endogenously calculated. The model keeps track of gross, net, and tax assets. It also calculates the depreciation values used for the income statement and tax obligations.

**Regulation:**

The utility sector sets electricity prices according to regulatory requirements. The regulatory procedures use allowed rate-of-return and test year cost and demands to determine allowed revenues. Electricity prices are calculated from peak-demand fractions by allocation of costs. Any other allocation scheme can also be considered. The regulatory subsector of ENERGY 2020 automatically factors in a wide variety of regulatory policies and options. More importantly, the model can be readily modified to consider a wide spectrum of scenarios.

The regulatory process revolves around a test year, usually one year forward, when proposed rates will go into effect. The utility sector forecasts test year sales and peak demands by season and customer class, just as it does to determine capacity needs. These test year demand estimates are used to allocate responsibility for system peak, and therefore, generation capacity costs.

Fuel costs for the test year are estimated by dispatching the plants that will be available in the test year, using the dispatching routine explained below. Fuel costs and operating and maintenance costs are adjusted for expected inflation, and these costs are factored into the electricity rates using forecasted sales.

ENERGY 2020 calculates the utility rate-base according to a detailed conventional rate making formula. The model allows the user to adjust allowable costs, and has been used extensively to evaluate alternative rate-base scenarios for individual plants, including allowing return of, but no return on investment, and partial disallowment of construction and interest costs.

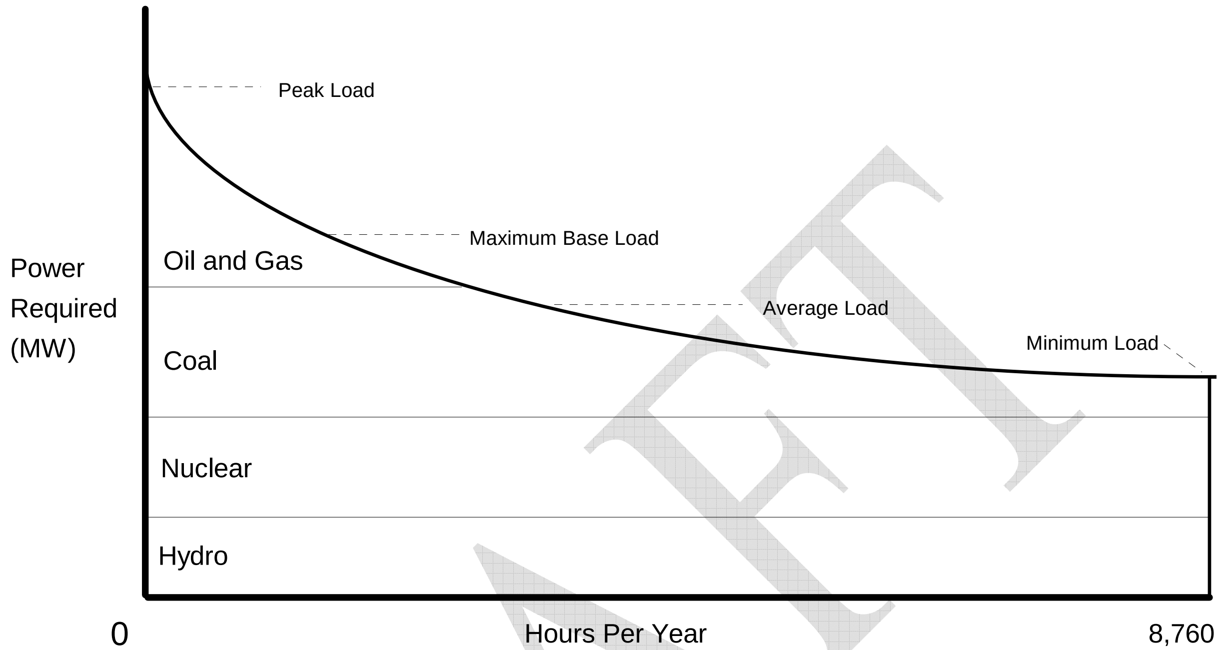
The ENERGY 2020 system also includes estimation of avoided costs, which determines when the utility may be required to purchase third party power. Environmental constraints, such as air pollution restrictions, can also be included in the model. If ENERGY 2020 is configured as a regional or state-wide system, municipal utilities, with their unique tax and rate structures, are incorporated. Similarly, regional or power pool interchange is also recognized by ENERGY 2020. As with the other sectors of ENERGY 2020, the regulatory subsector is flexible enough to accommodate any existing or hypothetical circumstance.

**Operations:**

Each end-use in ENERGY 2020 has a related set of load shape factors. Typically, these factors define the relationship between peak, minimum, and average load for each season. These factors, when combined with the weather-adjusted energy demand by end-use and corrected for cogeneration, resale, and load management programs, form the basis of the approximated system load duration curve. Alternatively, unit hourly loads for each end-use for three days per month (average weekday, weekend, and peak weekday) are used.

The standard ENERGY 2020 production subsector uses an advanced de-rating or chronological method to estimate the seasonal or hourly dispatch of plants. It purchases power externally when economic or necessary. Plant availability and generation for coal, nuclear, hydroelectric, oil and gas are currently considered, as well as pumped storage, firm purchases, interruptible load, and fuel switching and qualified facilities. Figure 3.7 also shows a typical plant dispatch schedule.

**Figure 3.7: Generation from the Load Curve**




The ENERGY 2020 system estimates conventional fuel costs based on the unit dispatch, heat rates, and fuel prices (from the supply sector.) Nuclear fuel costs are capitalized and depreciated throughout the re-fuelling cycle. Nuclear fuel expenses also include fuel disposal costs.

ENERGY 2020 explicitly models the costs of maintaining the transmission and distribution (T&D) system. New facility investments are scheduled and incurred endogenously. In addition, the user can specify the decision rules that dictate T&D expenditures. ENERGY 2020 also explicitly models both fixed and variable operation and maintenance costs, power pool interchanges, nuclear decommissioning costs, plant capital additions, plant cancellations, and general administration costs.

**Model Applications**:

The structure of the model is well tested and has been used to simulate not only US and the Canada energy and environmental dynamics but also those of several countries in Western, Central and Eastern Europe. Current efforts include strategic and tactical analyses for South America deregulation. The US EPA uses ENERGY 2020 to perform the regional (energy, environmental and macroeconomic) impacts of proposed Kyoto initiatives at the 50-state level.

Further, the model has been used successfully for deregulation analyses in over 50 energy suppliers and in all the US states and Canadian provinces. Several US and Canadian energy suppliers currently use the model for the analysis of combined electricity and gas deregulation dynamics.[25] The model contains confidence and validity packages that allow it to determine how to take maximal advantage of RTO rules. The ISO NE used the model to find “gaps” in its rules and to develop more efficient market conditions. The model was used for the CAPX/ISO to show, before the fact, many of the “games” played in the California market.



[25] ENERGY 2020 is the only model known to have simulated and predicted the dynamics that occurred in the UK electric deregulation. These include gaming, market consolidation and re-regulation dynamics.

# Appendix B: Inter-Regional Transmission Capacity in ENERGY 2020

## Transmission Capabilities between Model Regions

| Region From | Region To | Capacity Limit (MW) |
|---|---|---|
| Alberta | British Columbia | 1,000 |
| British Columbia | Alberta | 1,200 |
| Allston, OR | Olympia, WA | 4,200 |
| Olympia, WA | Allston, OR | 4,200 |
| Allston, OR | Williamet, OR | 4,120 |
| Williamet, OR | Allston, OR | 4,120 |
| Arizona | LADWP, CA | 1,229 |
| LADWP, CA | Arizona | 1,229 |
| Arizona | New Mexico | 2,500 |
| New Mexico | Arizona | 2,500 |
| Arizona | Pace, UT | 600 |
| Pace, UT | Arizona | 600 |
| Arizona | San Diego & Imperial Valley, CA | 1,133 |
| San Diego & Imperial Valley, CA | Arizona | 1,133 |
| Arizona | Southern California | 2,150 |
| Southern California | Arizona | 2,150 |
| Arizona | WAPA L.C. (AZ,NM) | 9,999 |
| WAPA L.C. (AZ,NM) | Arizona | 9,999 |
| British Columbia | North Puget, WA | 2,850 |
| North Puget, WA | British Columbia | 2,000 |
| British Columbia | Spokane, WA | 200 |
| Spokane, WA | British Columbia | 200 |
| British Columbia | West Kootenay, BC | 9,999 |
| West Kootenay, BC | British Columbia | 9,999 |
| Bonanza, UT | Bridger, WY | 300 |
| Bridger, WY | Bonanza, UT | 300 |
| Bonanza, UT | Pace, UT | 785 |
| Pace, UT | Bonanza, UT | 400 |
| Bonanza, UT | WAPA R.M., CO | 650 |
| WAPA R.M., CO | Bonanza, UT | 650 |
| Bridger, WY | Eastern Idaho | 2,200 |
| Eastern Idaho | Bridger, WY | 600 |
| Bridger, WY | WAPA R.M., CO | 1,450 |
| WAPA R.M., CO | Bridger, WY | 1,450 |
| Bridger, WY | Wyoming R.M. | 400 |
| Wyoming R.M. | Bridger, WY | 400 |
| Bridger, WY | Yellowtail, MT | 625 |
| Yellowtail, MT | Bridger, WY | 400 |
| Brownlee, ID | Lower Columbia (WA,OR) | 50 |
| Lower Columbia (WA,OR) | Brownlee, ID | 50 |

| Region From | Region To | Capacity Limit (MW) |
|---|---|---|
| Brownlee, ID | McNary, WA | 300 |
| McNary, WA | Brownlee, ID | 300 |
| Brownlee, ID | Oxbow, OR | 1,700 |
| Oxbow, OR | Brownlee, ID | 1,700 |
| Brownlee, ID | Southern Idaho | 1,850 |
| Southern Idaho | Brownlee, ID | 1,850 |
| Coulee, WA | Grant County, WA | 2,396 |
| Grant County, WA | Coulee, WA | 2,396 |
| Coulee, WA | Mid Columbia (WA,OR) | 1,844 |
| Mid Columbia (WA,OR) | Coulee, WA | 1,844 |
| Coulee, WA | North Puget, WA | 1,451 |
| North Puget, WA | Coulee, WA | 1,451 |
| Coulee, WA | Olympia, WA | 126 |
| Olympia, WA | Coulee, WA | 126 |
| Coulee, WA | Seattle South, WA | 5,275 |
| Seattle South, WA | Coulee, WA | 5,275 |
| Coulee, WA | Spokane, WA | 1,140 |
| Spokane, WA | Coulee, WA | 1,140 |
| Eastern Idaho | Garrison, MT | 224 |
| Garrison, MT | Eastern Idaho | 337 |
| Eastern Idaho | Idaho | 400 |
| Idaho | Eastern Idaho | 270 |
| Eastern Idaho | Pace, UT | 400 |
| Pace, UT | Eastern Idaho | 630 |
| Eastern Idaho | Southern Idaho | 2,557 |
| Southern Idaho | Eastern Idaho | 2,557 |
| Garrison, MT | WAPA U.M., MT | 200 |
| WAPA U.M., MT | Garrison, MT | 200 |
| Garrison, MT | Western, MT | 2,200 |
| Western, MT | Garrison, MT | 2,200 |
| Garrison, MT | Yellowtail, MT | 2,573 |
| Yellowtail, MT | Garrison, MT | 2,573 |
| Idaho | Ogden, UT | 9,999 |
| Ogden, UT | Idaho | 9,999 |
| Idaho | Pace, UT | 9,999 |
| Pace, UT | Idaho | 9,999 |
| Idaho | Wyoming R.M. | 9,999 |
| Wyoming R.M. | Idaho | 9,999 |
| LADWP, CA | Lower Columbia (WA,OR) | 3,100 |
| Lower Columbia (WA,OR) | LADWP, CA | 3,100 |
| LADWP, CA | Pace, UT | 1,400 |
| Pace, UT | LADWP, CA | 1,200 |
| LADWP, CA | Sierra, NV | 235 |

| Region From | Region To | Capacity Limit (MW) |
|---|---|---|
| Sierra, NV | LADWP, CA | 235 |
| LADWP, CA | Southern Nevada | 1,841 |
| Southern Nevada | LADWP, CA | 1,841 |
| LADWP, CA | Southern California | 9,999 |
| Southern California | LADWP, CA | 9,999 |
| LADWP, CA | WAPA L.C. (AZ,NM) | 1,231 |
| WAPA L.C. (AZ,NM) | LADWP, CA | 1,231 |
| Lower Columbia (WA,OR) | Malin, OR | 1,708 |
| Malin, OR | Lower Columbia (WA,OR) | 1,708 |
| Lower Columbia (WA,OR) | McNary, WA | 1,948 |
| McNary, WA | Lower Columbia (WA,OR) | 1,948 |
| Lower Columbia (WA,OR) | Mid Columbia (WA,OR) | 5,277 |
| Mid Columbia (WA,OR) | Lower Columbia (WA,OR) | 5,277 |
| Lower Columbia (WA,OR) | Slatt, OR | 3,031 |
| Slatt, OR | Lower Columbia (WA,OR) | 3,031 |
| Lower Columbia (WA,OR) | Williamet, OR | 3,334 |
| Williamet, OR | Lower Columbia (WA,OR) | 3,334 |
| Lower Granite Dam, WA | Mid Columbia (WA,OR) | 5,560 |
| Mid Columbia (WA,OR) | Lower Granite Dam, WA | 5,560 |
| Lower Granite Dam, WA | Spokane, WA | 1,155 |
| Spokane, WA | Lower Granite Dam, WA | 1,155 |
| Malin, OR | PG and E, CA | 4,800 |
| PG and E, CA | Malin, OR | 4,800 |
| Malin, OR | Sierra, NV | 300 |
| Sierra, NV | Malin, OR | 300 |
| Malin, OR | Southern Idaho | 1,500 |
| Southern Idaho | Malin, OR | 1,500 |
| Malin, OR | Southern Oregon | 4,782 |
| Southern Oregon | Malin, OR | 4,782 |
| McNary, WA | Mid Columbia (WA,OR) | 2,000 |
| Mid Columbia (WA,OR) | McNary, WA | 2,000 |
| McNary, WA | Slatt, OR | 2,854 |
| Slatt, OR | McNary, WA | 2,854 |
| McNary, WA | Williamet, OR | 227 |
| Williamet, OR | McNary, WA | 227 |
| Baja, Mexico | San Diego & Imperial Valley, CA | 800 |
| San Diego & Imperial Valley, CA | Baja, Mexico | 800 |
| Mid Columbia (WA,OR) | Oxbow, OR | 400 |
| Oxbow, OR | Mid Columbia (WA,OR) | 400 |
| Mid Columbia (WA,OR) | Seattle South, WA | 3,700 |
| Seattle South, WA | Mid Columbia (WA,OR) | 3,700 |
| Mid Columbia (WA,OR) | Slatt, OR | 4,100 |
| Slatt, OR | Mid Columbia (WA,OR) | 4,100 |

| Region From | Region To | Capacity Limit (MW) |
|---|---|---|
| Mid Columbia (WA,OR) | Spokane, WA | 273 |
| Spokane, WA | Mid Columbia (WA,OR) | 273 |
| Mid Columbia (WA,OR) | Williamet, OR | 2,600 |
| Williamet, OR | Mid Columbia (WA,OR) | 2,600 |
| N. King, WA | Seattle South, WA | 526 |
| Seattle South, WA | N. King, WA | 526 |
| New Mexico | PS Colorado | 558 |
| PS Colorado | New Mexico | 558 |
| New Mexico | WAPA L.C. (AZ,NM) | 817 |
| WAPA L.C. (AZ,NM) | New Mexico | 817 |
| New Mexico | WAPA R.M., CO | 690 |
| WAPA R.M., CO | New Mexico | 690 |
| North Puget, WA | Seattle North, WA | 3,000 |
| Seattle North, WA | North Puget, WA | 3,000 |
| North Puget, WA | Seattle South, WA | 3,000 |
| Seattle South, WA | North Puget, WA | 3,000 |
| Ogden, UT | Pace, UT | 9,999 |
| Pace, UT | Ogden, UT | 9,999 |
| Olympia, WA | Seattle South, WA | 4,500 |
| Seattle South, WA | Olympia, WA | 4,500 |
| OVERTHRS, WY | Wyoming R.M. | 9,999 |
| Wyoming R.M. | OVERTHRS, WY | 9,999 |
| Oxbow, OR | Southern Idaho | 90 |
| Southern Idaho | Oxbow, OR | 50 |
| Oxbow, OR | Spokane, WA | 450 |
| Spokane, WA | Oxbow, OR | 300 |
| Pace, UT | Scenic SW, UT | 300 |
| Scenic SW, UT | Pace, UT | 300 |
| Pace, UT | Sierra, NV | 205 |
| Sierra, NV | Pace, UT | 205 |
| Pace, UT | Station Load, WY | 9,999 |
| Station Load, WY | Pace, UT | 9,999 |
| Pace, UT | WAPA L.C. (AZ,NM) | 265 |
| WAPA L.C. (AZ,NM) | Pace, UT | 265 |
| Pace, UT | Wyoming R.M. | 9,999 |
| Wyoming R.M. | Pace, UT | 9,999 |
| PG and E, CA | Sierra, NV | 160 |
| Sierra, NV | PG and E, CA | 150 |
| PG and E, CA | Southern Oregon | 30 |
| Southern Oregon | PG and E, CA | 80 |
| PG and E, CA | Southern California | 3,400 |
| Southern California | PG and E, CA | 3,000 |
| PS Colorado | WAPA R.M., CO | 9,999 |

| Region From | Region To | Capacity Limit (MW) |
|---|---|---|
| WAPA R.M., CO | PS Colorado | 9,999 |
| Southern California Edison | Southern California | 200 |
| Southern California | Southern California Edison | 200 |
| Scenic SW, UT | Southern Nevada | 300 |
| Southern Nevada | Scenic SW, UT | 300 |
| Scenic SW, UT | St. George, UT | 9,999 |
| St. George, UT | Scenic SW, UT | 9,999 |
| Scenic SW, UT | Station Load, WY | 26 |
| Station Load, WY | Scenic SW, UT | 26 |
| San Diego & Imperial Valley, CA | Southern California | 5,000 |
| Southern California | San Diego & Imperial Valley, CA | 5,000 |
| Seattle North, WA | Seattle South, WA | 1,690 |
| Seattle South, WA | Seattle North, WA | 1,690 |
| Sierra, NV | Southern Idaho | 262 |
| Southern Idaho | Sierra, NV | 500 |
| Sierra, NV | Southern California | 17 |
| Southern California | Sierra, NV | 17 |
| Southern Oregon | Williamet, OR | 4,495 |
| Williamet, OR | Southern Oregon | 4,495 |
| Southern Nevada | Southern California | 2,754 |
| Southern California | Southern Nevada | 2,754 |
| Southern Nevada | WAPA L.C. (AZ,NM) | 4,554 |
| WAPA L.C. (AZ,NM) | Southern Nevada | 4,554 |
| Southern California | WAPA L.C. (AZ,NM) | 1,140 |
| WAPA L.C. (AZ,NM) | Southern California | 1,140 |
| Spokane, WA | West Kootenay, BC | 200 |
| West Kootenay, BC | Spokane, WA | 200 |
| Spokane, WA | Western, MT | 6,500 |
| Western, MT | Spokane, WA | 6,500 |
| Station Load, WY | Wyoming R.M. | 9,999 |
| Wyoming R.M. | Station Load, WY | 9,999 |
| WAPA L.C. (AZ,NM) | WAPA R.M., CO | 485 |
| WAPA R.M., CO | WAPA L.C. (AZ,NM) | 485 |
| WAPA U.M., MT | Yellowtail, MT | 390 |
| Yellowtail, MT | WAPA U.M., MT | 390 |

# Appendix C: Data Sets Used in ENERGY 2020

This Appendix describes the initial "set" definitions for ENERGY 2020 used for this project. The "sets" are the dimensions of the variables (sometimes called indexes) which delineate the scope and detail of the model. For example, the time frame set could be defined as a base year 1990 and every 5 years.

### Time Frame

- The initial historical year for calibration is 1985.
- The end year of the analysis is 2030.
- All data sets include annual data for each year of history and the forecast.

For some data sets, the period covered by actual data will depend on available data (e.g., emissions).

### Geographical Areas

Each area in the model will represent a state or a province (no sub-state break-outs). The model will provide separate results for the state of California, the surrounding Region, the rest of the U.S., and for Canada.

The States and Provinces included in the "Region" for modeling purposes include:

- California
- Oregon
- Washington
- Idaho
- Arizona
- New Mexico
- Nevada
- Colorado
- Utah
- Montana
- Wyoming
- Alberta
- British Columbia
- Manitoba
- Saskatchewan
- Baja, Mexico

### Generating Units

The list of units is based on the NEEDS database for the US plus a similar database for the units in Canada. Within the Region and the rest of the US, some of the smaller plants may be aggregated by plant type in order to allow the expedite model operation. With the aggregation of smaller plants, the model will likely end up with approximately 2000 units/plants.

**Electric Companies**

California electric utilities will be simulated in a manner similar to the E3 representation of seven total including: PG&E, SCE, SDG&E, LADWP, SMUD, Other North and Other South. Outside California in the broader western region, we will assume that each state has a single aggregate electric company. The exception to this is BPA.

**Sectors and Classes**

The energy demand portion of the model will simulate residential, commercial, industrial, and transportation demands. There will be an electric sales class for each sector.

**Emission Only Sectors**

Several sectors generate emissions, but do not have full energy demand simulations in the model. These include solid waste, waste water, incineration, and land use. It may be possible to develop a full energy demand simulation for one or more of these.

**Offsets**

Possible offset categories, if broken out as a set, could include:

- Sequestration
- Landfill Gas Capture
- Agricultural Methane
- Energy Efficiency (for each sector)

**Pollutants**

The model currently has the capability to cover 15 pollutants, although the final set will depend on the ARB's requirements and available data. The GHG pollutants include Carbon Dioxide, Methane, Nitrous Oxide, Sulfur-Hexafluoride, Perfluorocarbon, and Hydrofluorocarbon. The criteria air pollutants include Sulfur Dioxide, Nitrogen Oxides, Total Particulate Matter, Volatile Organic Compounds, Carbon Monoxide, Particulate Matter 2.5, Particulate Matter 10, Mercury, and Ozone.

**Fuels**

There are currently three sets of fuels in the model. The largest category contains 34 fuels (shown below). The second category includes the fuels that emit pollution and contains 15 fuels. The third category is the list of technologies which the energy demand sectors choose from. This smaller set contains only the basic types of fuels (Electricity, Natural Gas, Oil, LPG, Biomass, and Solar). The aggregate category oil is later broken out into the different types of oil (LFO, HFO, petroleum coke, etc.).

*Entire List of Fuels*

- Asphalt
- Aviation Fuel
- Biomass
- Coal
- Coke
- Coke Oven Gas
- Diesel
- Electric
- Ethanol
- Geothermal
- Heavy Fuel Oil
- Hydro
- Hydrogen
- Kerosene
- Landfill Gases
- Light Fuel Oil
- LPG
- Lubricants
- Motor Gasoline
- Naphtha Specialties
- Natural Gas
- Nuclear
- Oil, Unspecified
- Other Non-Energy Products
- Petrochemical Feedstocks
- Petroleum Coke
- Solar
- Steam
- Still Gas
- Wave
- Wind
- Unknown 1
- Unknown 2

**Electric Generation Plants Types**

The electric generation plant types are used to hold the data for future generic plants which the model will construct endogenously. The list currently includes:

- Gas/Oil Peaking
- Gas/Oil Combined Cycle

- Gas/Oil Steam
- Coal
- Coal Advanced
- Coal with CCS
- Gas CC with CCS
- Nuclear
- Base Hydro
- Peak Hydro
- Other Generation
- Biomass
- Landfill Gas
- Wind
- Solar
- Fuel Cells
- Pumped Hydro
- Small Hydro
- Wave
- Geothermal
- Other Storage
- Biogas
- Trash

**Residential Sectors**

The residential sector is split into housing types:

- Single Family
- Multi-Family
- Other Residential

**Commercial Sectors**

- Transportation Services
- Pipelines
- Communication
- Electric Utilities
- Gas Utilities
- Water & Other Utilities
- Wholesale
- Retail
- FIRE
- Offices - Business Services
- Education
- Health & Social
- Food, Lodging, Recreation
- Government



**Industrial Sectors**

- Food & Tobacco
- Textiles
- Apparel
- Lumber
- Furniture
- Pulp & Paper Mills
- Converted Paper
- Printing
- Petrochemicals
- Industrial Gas
- Other Chemicals
- Fertilizers

- Petroleum Products
- Rubber
- Leather
- Cement
- Glass
- Lime & Gypsum
- Other Non-Metallic
- Iron & Steel
- Aluminum
- Other Nonferrous
- Fabricated Metals
- Machines
- Computers
- Electric Equipment
- Transport Equipment
- Other Manufacturing
- Iron Ore Mining
- Other Metal Mining
- Non-metal Mining
- Light Oil Mining
- Heavy Oil Mining
- Frontier Oil Mining
- Oil Sands In-Situ
- Oil Sands Mining
- Oil Sands Upgraders
- Gas Mining
- Coal Mining
- Construction
- Forestry
- Agriculture

**Transportation Sectors**

- Passenger
- Freight
- Off Road

**Miscellaneous Sectors**

- Misc. & Street Lighting
- Electric Resale
- Utility Electric Generation
- Industry Electric Generation
- Steam Generation
- Solid Waste
- Waste Water
- Incineration
- Land Use

**Residential End-Uses**

- Space Heating
- Water Heating
- Other Substitutable
- Refrigeration
- Lighting
- Air Conditioning
- Other Non-Substitutable

**Commercial End-Uses**

- Space Heating
- Water Heating

- Other Substitutable
- Refrigeration
- Lighting
- Air Conditioning
- Other Non-Substitutable

### Industrial End-uses

- Process Heat
- Electric Motors
- Other Substitutable
- Miscellaneous

### Transportation End-Uses

- Ground
- Air/Water

### Residential, Commercial, and Industrial Technology Types

Each technology type has its own trade-off curve which determines the efficiency and the capital cost of the technology type. These curves allow the model to contain many different technologies within these broad types.

- Electric
- Gas
- Coal
- Oil
- Biomass
- Solar
- LPG
- Steam

### Transportation Technology Types

Several technology types are provided for transportation, and each of these contains a trade-off curve which allows the model to simulate even more individual technologies.

- Plug-in Hybrids
- Light Gasoline
- Light Diesel
- Light Propane
- Light CNG
- Light Electric (Plug-in)
- Light Ethanol
- Light Hybrid Gasoline
- Light Hybrid Diesel
- Light Fuel Cell Gasoline
- Light Fuel Cell CNG
- Light Fuel Cell Hydrogen
- Medium Gasoline
- Medium Diesel

- Medium Propane
- Medium CNG
- Medium Ethanol
- Medium Hybrid Gasoline
- Medium Hybrid Diesel
- Medium Fuel Cell Gasoline
- Medium Fuel Cell CNG
- Medium Fuel Cell Hydrogen
- Heavy Gasoline
- Heavy Diesel
- Heavy Propane
- Heavy CNG
- Heavy Ethanol
- Heavy Hybrid Gasoline
- Heavy Hybrid Diesel
- Heavy Fuel Cell Gasoline
- Heavy Fuel Cell CNG
- Heavy Fuel Cell Hydrogen
- Motorcycle
- Bus Gasoline
- Bus Diesel
- Bus Propane
- Bus CNG
- Bus Fuel Cell Gasoline
- Bus Fuel Cell Hydrogen
- Bus Fuel Cell Ethanol
- Train
- Plane
- Marine
- Off Road

**Prices**

Delivered energy prices are presented for the following fuels:

- Residential Electricity
- Residential Natural Gas
- Residential Coal
- Residential Oil
- Residential Biomass
- Residential LPG
- Residential Steam
- Commercial Electricity
- Commercial Natural Gas
- Commercial Coal
- Commercial Oil
- Commercial Biomass
- Commercial LPG
- Commercial Steam
- Industrial Electricity
- Industrial Natural Gas
- Industrial Coal
- Industrial Oil
- Industrial Biomass
- Industrial LPG
- Industrial Steam
- Gasoline
- Diesel
- Aviation Fuel
- Transportation HFO
- Transportation Natural Gas
- Transportation LPG
- Electric Utility Residual Oil
- Electric Utility Distillate Oil
- Electric Utility Natural Gas
- Electric Utility Coal
- Electric Utility Nuclear
- Electric Utility Biomass
- Ethanol
- Hydrogen

**Electric Load Segments**

The model dispatches for 6 different hour types (high peak, low peak, high intermediate, low intermediate, high base load, low base load) for each of the four seasons.

# Appendix D: Mapping of EDRAM and REMI Macro-Economic Categories to ENERGY 2020 Sectors/Sub-Sectors

| Map Between EDRAM and ENERGY 2020 | | |
|---|---|---|
| **EDRAM Sectors** | **Description** | **ENERGY 2020 Sector/ Sub-Sector** |
| AGRIC | Agriculture | Agriculture |
| CATTLE | Cattle | Agriculture |
| DAIRY | Dairy | Agriculture |
| FOREST | Forestry | Forestry |
| OILGAS | Petroleum and Natural Gas Extraction | Gas Mining |
| OTHPRI | Mining | Other Metal Mining |
| DISTEL | Electrical Power Generation and Distribution | Electric Utilities |
| DSTGAS | Natural Gas Distribution | Gas Utilities |
| DSTOTH | Water Distribution and Sewage Treatment | Water & Other Utilities |
| CONRES | Residential Construction | Construction |
| CONNON | Nonresidential Construction | Construction |
| CONSTR | Street and Bridge Construction | Construction |
| CONUTL | Utility Infrastructure Construction | Construction |
| CONOTH | Other Construction-related Industry | Construction |
| FDMFG | Food Manufacturing | Food & Tobacco |
| FDPROC | Food Processing | Food & Tobacco |
| FDOTH | Other Food Related Industry | Food & Tobacco |
| BEVTOB | Beverage and Tobacco Products | Food & Tobacco |
| TEXLTH | Textile and Leather Manufacturing | Textiles |
| APPREL | Apparel Manufacturing | Apparel |
| WOOD | Wood Products Manufacturing | Lumber |
| PLPMLL | Pulp and Paper Mills | Pulp and Paper Mills |
| PAPER | Paper Products Manufacturing | Pulp and Paper Mills |
| PRINT | Printing | Printing |
| OILREF | Oil Refineries | Petroleum Products |
| INDGAS | Industrial Gas | Petrochemicals |
| CHMDRG | Chemical and Drugs Manufacture | Petrochemicals |
| CHMBAS | Basic Chemical Manufacture | Petrochemicals |
| CHMSPS | Soaps and Detergents Manufacture | Petrochemicals |
| CHMOTH | Other Chemical Products Manufacture | Petrochemicals |
| PLASTC | Plastics Manufacture | Petrochemicals |
| GLASS | Glass Products Manufacture | Glass |
| CEMENT | Cement | Cement |
| CONCRT | Concrete | Lime & Gypsum |
| SCAOTH | China and Clay Products | Lime & Gypsum |
| PRIMTL | Primary Metals | Iron & Steel |
| ALUM | Aluminum | Aluminum |

| Map Between EDRAM and ENERGY 2020 | | |
|---|---|---|
| **EDRAM Sectors** | **Description** | **ENERGY 2020 Sector/ Sub-Sector** |
| MTLFAB | Metal Fabrication | Fabricated Metals |
| MACHIN | Machinery Manufacture | Machines |
| RFARCN | Refrigeration and Air Conditioning | Machines |
| CMPMFG | Computer Manufacture | Computers |
| CMPCMM | Communications Equipment Manufacture | Electric Equipment |
| CMPRTS | Electronic Components Manufacture | Electric Equipment |
| CMPINS | Electronic Instruments Manufacture | Electric Equipment |
| CMPMED | Electronic Recording Media Manufacture | Electric Equipment |
| ELCTRC | Electrical Equipment Manufacture | Electric Equipment |
| AUTOMF | Automobile Manufacturing | Transport Equipment |
| VEHMFG | Other Vehicle Manufacture | Transport Equipment |
| VEHBDY | Motor Vehicle Body Manufacture | Transport Equipment |
| VEHPRT | Motor Vehicle Parts Manufacture | Transport Equipment |
| VEHSHP | Ship Building and Repair | Transport Equipment |
| VEHOTH | Other Vehicle Manufacture | Transport Equipment |
| VEHAER | Aerospace Manufacture | Transport Equipment |
| FURN | Furniture | Furniture |
| LABDNT | Laboratory and Dental Equipment | Other Manufacturing |
| MSCMFG | Miscellaneous Manufacturing | Other Manufacturing |
| VEHSRV | Vehicle Services | Transportation Services |
| WHLDUR | Wholesale Durable Goods | Wholesale |
| WHLNON | Wholesale Non Durable Goods | Wholesale |
| WHLGAS | Wholesale Gas | Wholesale |
| WHLAGN | Wholesale Trade | Wholesale |
| TRANSP | Transportation | Transportation Services |
| AIRTNS | Air Transportation | Transportation Services |
| RRTNS | Railroad Transportation | Transportation Services |
| WATTNS | Waterway Transportation | Transportation Services |
| TRKTNS | Truck Transportation | Transportation Services |
| PUBTNS | Public Transportation | Transportation Services |
| OTHTNS | Other Transportation | Transportation Services |
| VEHTNS | Vehicle Transportation | Transportation Services |
| RETVEH | Retail Vehicles and Parts | Retail |
| RETFRN | Retail Furniture | Retail |
| RETELC | Retail Electronics and Appliances | Retail |
| RETBLD | Retail Building Materials | Retail |
| RETFD | Retail Food and Beverage | Retail |
| RETDRG | Retail Health and Personal Care | Retail |
| RETGAS | Retail Gasoline Stations | Retail |
| RETAPP | Retail Clothing and Accessories | Retail |
| RETSPT | Retail Sporting Goods, Books, Music | Retail |
| RETGEN | Retail General Merchandise | Retail |

| Map Between EDRAM and ENERGY 2020 | | |
|---|---|---|
| **EDRAM Sectors** | **Description** | **ENERGY 2020 Sector/ Sub-Sector** |
| RETMSC | Retail Miscellaneous | Retail |
| RETNON | Retail Nonstore | Retail |
| INFOPC | Motion Picture Industry | Communication |
| INFOTH | Other Broadcasting and Recording Industry | Communication |
| INFOTL | Telecommunications | Communication |
| INFCOM | Internet and Information Services | Communication |
| FINSEC | Financial Securities | FIRE |
| FINSUR | Insurance | FIRE |
| FIBNKS | Banking | FIRE |
| FIREAL | Real Estate | FIRE |
| FINOTH | Other Financial | FIRE |
| PROLEG | Legal Services | Offices - Business Services |
| PROACC | Accounting | Offices - Business Services |
| PROARC | Architecture | Offices - Business Services |
| PRODES | Design | Offices - Business Services |
| PROCOM | Computer Related Services | Offices - Business Services |
| PROCNS | Consulting | Offices - Business Services |
| PRORES | Research | Offices - Business Services |
| PROADV | Advertising | Offices - Business Services |
| PROOTH | Other Professional Services | Offices - Business Services |
| BUSSRV | Business Services | Offices - Business Services |
| ADMTMP | Temporary Administrative Services | Offices - Business Services |
| ADMSEC | Security Services | Offices - Business Services |
| ADMBLD | Building Maintenance | Offices - Business Services |
| ADMOTH | Other Administrative Services | Offices - Business Services |
| WSTSRV | Waste Management | Waste Water |
| LNDFIL | Landfills | Solid Waste |
| EDUC | Education | Education |
| MEDAMB | Medical Services | Health & Social |
| MEDHSP | Hospitals | Health & Social |
| MEDNRS | Nursing | Health & Social |
| MEDSA | Day Care | Health & Social |
| RECENT | Recreation and Entertainment | Food, Lodging, Recreation |
| RECAMS | Amusement Parks | Food, Lodging, Recreation |
| ACCHOT | Hotels | Food, Lodging, Recreation |
| ACCRST | Full Service Restaurants | Food, Lodging, Recreation |
| ACCFST | Fast Food | Food, Lodging, Recreation |
| ACCSPC | Caters and Mobile Food Services | Food, Lodging, Recreation |
| ACCBRS | Drinking Establishments | Food, Lodging, Recreation |
| PERSRV | Personal Services | Offices - Business Services |

# Appendix E:  New Generation Performance and Cost Assumptions

Table 1A.  Input Values to Busbar Energy Costs - California Resources (2008 $)

| Resource Technology | 2020 Overnight Capital Cost ($/kW) | Fixed O&M Cost ($/kW-year) | Variable O&M Cost ($/MWh) | Capacity Factor | Nominal Heat Rate (Btu/kWh) |
|---|---|---|---|---|---|
| Biogas | $3,065 | $139 | 1.20 | 80% | 13,648 |
| Biomass | $4,484 | $65 | 1.20 | 80% | 9,874 |
| Geothermal | $3,339 | $157 | 1.20 | 90% | n/a |
| Hydro - Small, Peak, Pumped | $2,539 | $14 | 0.94 | 80% | n/a |
| Solar - Thermal | $3,235 | $64 | 1.20 | 27% | n/a |
| Wind | $1,962 | $37 | 1.20 | 35% | n/a |
| Coal ST | $2,479 | $33 | 1.20 | 85% | 8,844 |
| Coal IGCC (Adv Coal) | $2,866 | $47 | 1.20 | 85% | 8,309 |
| Coal IGCC with CCS | $4,101 | $55 | 1.20 | 85% | 9,713 |
| Gas CCCT (OGCC) | $1,054 | $14 | 1.20 | 90% | 6,917 |
| Gas CT | $807 | $15 | 1.20 | 93% | 10,807 |
| Base Hydro | $1,486 | $9 | 0.63 | 60% | n/a |
| Nuclear | $3,999 | $83 | 1.20 | 85% | 10,400 |
| OGSteam | $927 | $15 | 1.20 | 65% | 10,807 |
| Trash | $1,900 | $22 | 0.03 | 70% | 16,500 |
| OtherGeneration | $5,000 | $2 | 3.82 | 95% | 10,450 |
| FuelCell | $5,000 | $2 | 3.82 | 95% | n/a |
| OtherStorage | $5,000 | $2 | 3.82 | 95% | n/a |
| LandfillGas | $1,900 | $22 | 0.03 | 70% | 16,500 |
| Wave | $3,270 | $20 | 1.20 | 80% | n/a |

**Table 1B. Input Values to Busbar Energy Costs - Rest of WECC Resources (2008 $)**

| Resource Technology | 2020 Overnight Capital Cost ($/kW) | Fixed O&M Cost ($/kW-year) | Variable O&M Cost ($/MWh) | Capacity Factor | Nominal Heat Rate (Btu/kWh) |
|---|---|---|---|---|---|
| Biogas | $2,350 | $118 | 1.02 | 80% | 13,648 |
| Biomass | $3,438 | $55 | 1.02 | 80% | 8,911 |
| Geothermal | $1,582 | $192 | 1.04 | 90% | n/a |
| Hydro - Small, Peak, Pumped | $1,758 | $20 | 1.20 | 78% | n/a |
| Solar - Thermal | $2,588 | $55 | 1.03 | 36% | n/a |
| Wind | $1,504 | $31 | 1.02 | 69% | n/a |
| Coal ST | $1,901 | $29 | 1.02 | 85% | 8,844 |
| Coal IGCC (Adv Coal) | $2,197 | $40 | 1.02 | 85% | 8,309 |
| Coal IGCC with CCS | $3,144 | $47 | 1.02 | 85% | 9,713 |
| Gas CCCT (OGCC) | $808 | $12 | 1.02 | 90% | 6,917 |
| Gas CT | $619 | $13 | 1.02 | 5% | 10,807 |
| Base Hydro | $1,122 | $8 | 0.60 | 60% | n/a |
| Nuclear | $3,066 | $70 | 1.02 | 85% | 10,400 |
| OGSteam | $927 | $15 | 1.20 | 65% | 10,807 |
| Trash | $1,900 | $22 | 0.03 | 70% | 16,500 |
| OtherGeneration | $5,000 | $2 | 3.82 | 95% | 10,450 |
| FuelCell | $5,000 | $2 | 3.82 | 95% | n/a |
| OtherStorage | $5,000 | $2 | 3.82 | 95% | n/a |
| LandfillGas | $1,900 | $22 | 0.03 | 70% | 16,500 |
| Wave | $3,270 | $20 | 1.20 | 80% | n/a |

*Source: Energy and Environmental Economics, Inc., CPUC GHG Modeling - Generation Costs,* www.ethree.com/cpuc_ghg_model.html

## Appendix F:   Global Warming Potential

ENERGY 2020 models emissions of each of the six greenhouse gases reported under the Kyoto protocol. These emissions are then translated into equivalent quantities of CO2 emissions (CO2e) based on the global warming potential of each of the gases.

The Global Warming Potential (GWP) values used in ENERGY2020 are shown in the table below.

| Greenhouse Gas | Global Warming Potential |
|---|---|
| Carbon Dioxide (CO2) | 1 |
| Methane (CH4) | 21 |
| Nitrous Oxide (N2O) | 310 |
| Sulphur Hexafluoride (SF6) | 23,900 |
| Perfluorocarbons (PFC) | 7,000 |
| Hydrofluorocarbons (HFC) | 1,300 |

These values are consistent with the Global Warming Potential values used in the 1996 Second Assessment Report based on 100-year warming potential for the individual gases. In the case of HFCs and PFCs the GWP values used in the model are based on an estimated average GWP for these gases.

# Appendix G: Efficiency & Cost Data – Built Environment

**Residential:**

| Residential Device Standards | |
|---|---|
| **Equipment** | **Effective Efficiency Standard** |
| Gas hot water from 1990 to the final year | 59% |
| Oil hot water from 1990 to the final year | 51% |
| Electric hot water from 1990 to the final year (inc.tank losses) | 92% |
| LPG hot water from 1990 to the final year | 59% |
| Electric air conditioning for 1990 | 260%<br>COP = 2.6 |
| Electric air conditioning for 1991 | 261%<br>COP = 2.61 |
| Electric air conditioning for 1992 to 2006 | 265%<br>COP = 2.65 |
| Electric air conditioning for 2007 to the final year | 344%<br>COP = 3.44 |
| Electric Refrigeration for 1990 to 1992 | 34.5% |
| Electric Refrigeration for 1993 | 40.0% |
| Electric Refrigeration for 1994 to 2000. | 42.0% |
| Electric Refrigeration from 2001 to the final year | 54.7% |
| Biomass space Heating from 1993 to the final year (wood burning equipment) | 63.0% |
| Gas space Heating from 1993 to the final year | 80.0% |
| Oil space Heating from 1993 to the final year | 80.0% |
| LPG space Heating from 1993 to the final year | 80.0% |

**Residential (cont'd.)**

| Maximum Device Efficiency | | | | | | | |
|---|---|---|---|---|---|---|---|
| (Btu/Btu) | Electric | N.Gas | Coal | Oil | Biomass | LPG | Steam |
| Primary Heat | 278% | 97% | 97% | 97% | 78% | 97% | 99% |
| Water Heating | 250% | 86% | 97% | 97% | 78% | 97% | 99% |
| Other Substitutable Loads | 130% | 97% | 97% | 97% | 65% | 97% | 99% |
| Refrigerators | 98% | 0% | 0% | 0% | 0% | 0% | 0% |
| Lighting | 95% | 0% | 0% | 0% | 0% | 0% | 0% |
| Air Conditioning | 447% | 113% | 0% | 0% | 0% | 113% | 0% |
| Other Non-Substitutable Loads | 98% | 0% | 0% | 0% | 0% | 0% | 0% |

*Note – Electric heating applications include heat pumps.*
*Non-substitutable loads are those loads which require electricity (refrigerators, electronics, etc.).*
*Substitutable loads are those loads which can use multiple fuels (i.e. Range, dryers, etc.).*

| Device Capital Cost | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1985$/mmBtu/Year | Electric | N.Gas | Coal | Oil | Biomass | Solar | LPG | Steam |
| Space Heating | 17.7 | 23.1 | 19.0 | 36.0 | 17.2 | 132.0 | 23.1 | 36.0 |
| Water Heating | 8.5 | 18.5 | 19.0 | 23.5 | 17.2 | 82.0 | 18.5 | 23.5 |
| Other Substitutable Loads | 65.0 | 85.0 | 19.0 | 85.0 | 17.2 | - | 85.0 | 85.0 |
| Refrigerators | 96.5 | - | - | - | - | - | - | - |
| Lighting | 0.23 | - | - | - | - | - | - | - |
| Air Conditioning | 4.4 | 34.1 | - | - | - | - | 34.1 | - |
| Other Non-Substitutable Loads | 19.8 | - | - | - | - | - | - | - |

| Device Operating Costs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1985 $/mmBtu | Electric | N.Gas | Coal | Oil | Biomass | Solar | LPG | Steam |
| Space Heat | 0.018 | 0.024 | 0.011 | 0.020 | 0.013 | 0.012 | 0.024 | 0.030 |
| Water Heating | - | - | - | - | - | 0.010 | - | - |
| Other Substitutable Loads | - | - | - | - | - | - | - | - |
| Refrigeration | - | - | - | - | - | - | - | - |
| Lighting | - | - | - | - | - | - | - | - |
| Air Conditioning | 0.015 | 0.017 | - | - | - | - | 0.017 | - |
| Other Non-Substitutable Loads | - | - | - | - | - | - | - | - |

### Residential (cont'd.)

| Physical Life of Equipment in Years (Residential) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Space Heat | Water Heating | Substitutable Loads | Refrigeration | Light | Air Conditioning | Non-Substitutable Loads |
| Electric | 18 | 15 | 13 | 18 | 6 | 15 | 10 |
| Natural Gas | 18 | 15 | 13 | 0 | 0 | 15 | 0 |
| Coal | 18 | 15 | 13 | 0 | 0 | 0 | 0 |
| Oil | 18 | 15 | 13 | 0 | 0 | 0 | 0 |
| Biomass | 18 | 15 | 13 | 0 | 0 | 0 | 0 |
| Solar | 18 | 15 | 13 | 0 | 0 | 0 | 0 |
| LPG | 18 | 15 | 13 | 0 | 0 | 0 | 0 |
| Steam | 18 | 15 | 13 | 0 | 0 | 0 | 0 |

### Commercial:

| Device Efficiency Standards (Commercial) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Btu/Btu | Electric | N.Gas | Coal | Oil | Biomass | Solar | LPG | Steam |
| Space Heating (primary) | 450% | 97% | 97% | 97% | 65% | 1000% | 97% | 99% |
| Water Heating | 400% | 97% | 97% | 97% | 65% | 1000% | 97% | 99% |
| Other Substitutable Loads | 130% | 97% | 97% | 97% | 65% | 1000% | 97% | 99% |
| Refrigerators | 140% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Lighting | 95% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Air Conditioning | 400% | 240% | 0% | 0% | 0% | 0% | 200% | 0% |
| Other Non-Substitutable Loads | 98% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |

| Device Capital Cost (Commercial) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $/mmBtu/Year | Electric | N.Gas | Coal | Oil | Biomass | Solar | LPG | Steam |
| Primary Heat | 9.20 | 7.5 | 42.2 | 19.0 | 25.5 | 138.9 | 22.9 | 42.2 |
| Water Heating | 5.20 | 8.9 | 42.2 | 19.0 | - | 138.9 | 22.9 | 42.2 |
| Other Substitutable Loads | 19.80 | 11.3 | 11.3 | 19.0 | - | - | 11.3 | 11.3 |
| Refrigeration | 0.21 | - | - | - | - | - | - | - |
| Lighting | 0.02 | - | - | - | - | - | - | - |
| Air Conditioning | 9.20 | 34.1 | - | - | - | - | 34.1 | - |
| Other Non Substitutable Loads | 22.00 | - | - | - | - | - | - | - |

| Device Operating Cost Fraction ($/Year/$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **1985 $/mmBtu** | **Electric** | **N.Gas** | **Coal** | **Oil** | **Biomass** | **Solar** | **LPG** | **Steam** |
| Space Heating (primary) | 0.02 | 0.03 | 0.01 | 0.03 | 0.01 | 0.01 | 0.03 | 0.04 |
| Water Heating | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| Other Substitutable Loads | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Refrigeration | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Lighting | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Air Conditioning | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 |
| Other Non-Substitutable Loads | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| Physical Life of Equipment in Years | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Space Heat** | **Water Heating** | **Substitutable Loads** | **Refrigeration** | **Light** | **Air Conditioning** | **Non-Substitutable Loads** |
| Electric | 18 | 8 | 10 | 15 | 7 | 18 | 7 |
| Natural Gas | 25 | 8 | 10 | 0 | 0 | 18 | 0 |
| Coal | 18 | 8 | 10 | 0 | 0 | 0 | 0 |
| Oil | 25 | 8 | 10 | 0 | 0 | 0 | 0 |
| Biomass | 18 | 8 | 10 | 0 | 0 | 0 | 0 |
| Solar | 18 | 8 | 10 | 0 | 0 | 0 | 0 |
| LPG | 18 | 8 | 10 | 0 | 0 | 18 | 0 |
| Steam | 18 | 8 | 10 | 0 | 0 | 0 | 0 |