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EPA U.S. National MARKAL Database: Database Documentation

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Abstract

This document describes the database used in EPA's National Model, which is a MARKAL model developed to aid in technology assessment as part of a larger Air Quality Assessment being performed by EPA's Office of Research and Development. The MARKAL (MARket ALlocation) model was developed in the late 1970s at Brookhaven National Laboratory. In 1978, the International Energy Agency adopted MARKAL and created the Energy Technology and Systems Analysis Program (ETSAP), which is a group of modelers and developers that meet every six months to discuss model developments, extensions, and applications. MARKAL is a dynamic, data-driven energy/economic model of a region over a time span of several decades. The economy is modeled as a system of processes that have material, energy, and monetary flows between them and that represent all activities necessary to provide products and services for that region. Each process can choose from among a set of alternate technologies to complete the process, and each technology is characterized quantitatively by energy, emission, and monetary characteristics. Both the supply and demand sides are integrated, so that one side responds automatically to changes in the other. The model selects that combination of technologies that minimizes total energy system cost.

The characteristics and constraints associated with the alternate technologies for each process are put into the model as a database, which is defined by the user. This document describes that database for the U.S. EPA MARKAL model. Constraints are determined by the demand for products and services, the maximum introduction rate of new technologies, the availability of resources, environmental policy goals for energy use and emissions, and so forth. Processes are characterized by their physical inputs and outputs of energy and material, by their costs, and by their environmental impacts such as emissions of carbon dioxide and oxides of nitrogen and sulfur.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

EPA Review Notice

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Acronyms and Abbreviations

Acronym	Definition
AEO	U.S. Department of Energy's Annual Energy Outlook report
APB	Atmospheric Protection Branch
APPCD	Air Pollution Prevention and Control Division
Btu	British thermal unit
CAIR	Clean Air Interstate Rule
CCAR	Climate Change Action Report
CCS	carbon capture and sequestration
CNG	compressed natural gas
DOE	U.S. Department of Energy
EE/RE	DOE's Energy Energy Efficiency and Renewable Energy programs
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPANMD	EPA National MARKAL database
EPRI	Electric Power Research Institute
ETSAP	Energy Technology and Systems Analysis Program
FGD	flue gas desulfurization
GHG	green house gas
GW	gigawatts
IEA	International Energy Agency
ICE	internal combustion engine
IGCC	integrated gasification combined cycle
IHM	initial heavy metal (enriched uranium)
IPM	EPA's Integrated Planning Model
ISA-W	Integrated Strategic Assessment Workgroup
LBL	Lawrence Berkley Laboratories
LDC	local distribution center
LDV	light duty vehicles
LEV	low emissions vehicles
LNB	low-NO_x burners
LPG	liquid propane gas
LWR	light water reactor
MARKAL	MARKet ALlocation model
mpg	miles per gallon
NANGAS	North American Natural Gas Analysis System
NEI	Nuclear Energy Institute
NEMS	U.S. EIA's National Energy Modeling System
NESCAUM	Northeast States for Coordinated Air Use Management
NMOCs	non-methane organic compounds
NO_x	oxides of nitrogen
NREL	National Renewable Energy Laboratory
NRMRL	ORD's National Risk Management Research Laboratory
OECD	Organization for Economic Co-operation and Development

Acronyms and Abbreviations (concluded)

Acronym	Definition
ORD	U.S. EPA's Office of Research and Development
ORNL	Oak Ridge National Laboratories
OTT	DOE's Office of Transportation Technologies
PJ	petajoules
PJ/a	petajoules per annum
PM_{10}	fine particulate matter
QM	quality metrics
RES	reference energy system
SAGE	System for Analysis of Global Energy
SAIC	Science Applications International Corporation
SCR	selective catalytic reduction
SMR	steam methane reforming
SO_X	oxides of sulfur
SULEV	super ultra low emissions vehicles
SUV	sports utility vehicle
TAG	EPRI's Technological Assessment Guide
ULEV	ultra low emissions vehicles
USGCRP	U.S. Global Change Research Act
VMT	vehicle miles traveled
VOC	volatile organic compounds

EPA U.S. National MARKAL Database

1. Introduction

The purpose of this document is to describe in detail the U.S. Energy System database developed by the EPA's Integrated Strategic Assessment Workgroup (ISA-W) for use with the MARKAL model. The ISA-W is part of the Office of Research and Development (ORD), located in the National Risk Management Research Laboratory (NRMRL), Air Pollution Prevention and Control Division's (APPCD) Atmospheric Protection Branch (APB). The documentation is designed to help users of the database, hereafter referred to as the EPA National MARKAL Database (EPANMD). The EPANMD was developed to aid in technology assessment as part of a larger Air Quality Assessment being performed by EPA ORD. For a complete understanding of the Air Quality Assessment approach see, "Demonstration of a Scenario Approach for Technology Assessment: Transportation Sector" (EPA-600/R-04/135, January 2004).

2. MARKAL

2.1 Description of MARKAL

The MARKAL (MARket ALlocation) model was developed in the late 1970s at Brookhaven National Laboratory. In 1978, the International Energy Agency adopted MARKAL and created the Energy Technology and Systems Analysis Program (ETSAP), which is a group of modelers and developers that meet every 6 months to discuss model developments, extensions, and applications. MARKAL therefore benefits from an unusually active and interactive group of users and developers. MARKAL is currently in use by more than 40 countries for research and energy planning. For a detailed description of MARKAL, see the ETSAP MARKAL users manual at http://www.etsap.org/documentation.asp .

MARKAL is a data-driven, energy systems economic-optimization model. The user inputs the structure of the energy system to be modeled, including resource supplies, energy conversion technologies, end use demands, and the technologies used to satisfy these demands. The user must also provide data to characterize each of the technologies and resources used, including fixed and variable costs, technology availability and performance, and pollutant emissions. MARKAL then calculates, using straightforward linear programming techniques, the least cost way to satisfy the specified demands, subject to any constraints the user wishes to impose. Outputs of the model include a determination of the technological mix at intervals into the future, estimates of total system cost, energy services (by type and quantity), estimates of criteria and greenhouse gas (GHG) emissions, and estimates of energy commodity prices.

The basis of the MARKAL model framework is a network diagram called a Reference Energy System (RES), which depicts an energy system from resource to end-use demand (Figure 1). The RES divides an energy system up into stages. The four technology stages represented are resource, process, conversion, and demand technologies. These technologies feed into a final stage consisting of end-use demands for useful energy services. End-use demands include items such as residential lighting, commercial space conditioning, and automobile passenger miles traveled. Energy carriers interconnect the stages.

The first technology stage, resource technologies, represents all flows of energy carriers into and out of the energy system. These include imports and exports, mining and extraction, and renewable energy resources. The second technology stage, transformation technologies, is subdivided into two classes: conversion technologies, which model electricity generation, and process technologies, which change the form, characteristics, or location of energy carriers. Process technologies include oil refineries, hydrogen production technologies, and pipelines. Process technologies are also used in the model as "dummy" technologies, where emissions are tracked or resources of varying qualities are collected. They are referred to as "dummy"

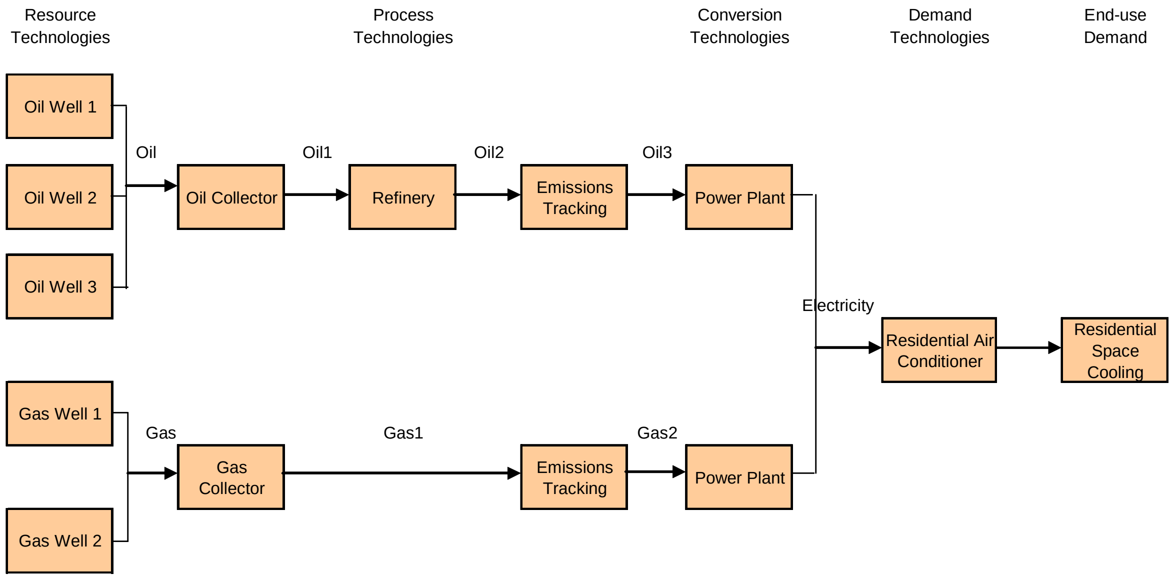


Figure 1. Example of a Simple Reference Energy System.

technologies because they are not an actual process with costs associated with them. The final technology stage, demand technologies, are those devices that are used to directly satisfy the final RES stage, end-use service demands. Demand technologies include vehicles, furnaces, and electrical devices.

Energy carriers are the various forms of energy consumed and produced in the RES. These can include coal variants (e.g., with different sulfur contents), crude oil, refined petroleum products, electricity to different grids, and renewable energy (e.g., biomass, solar, geothermal, hydro). The model requires that the total amount of energy produced be at least as much as that consumed. The inter-connections between the various technologies in a MARKAL model are accomplished by energy carriers flowing out of one or more technologies and into others.

The MARKAL RES concept offers a significant enhancement over single sector energy technology models because it allows technologies and sectors to interact through the interconnections in the RES. For example, the residential air conditioner in the RES above can use either oil or gas. If it were to switch its fuel usage from heavily oil to heavily gas, it may shift the relative prices of gas to the industrial, and transportation sectors, potentially leading to a shift away from gas for some end uses.

2.2 Data Needs

A MARKAL database uses a variety of data parameters to describe each element of the Reference Energy System. The general categories of data required for a MARKAL model are:

- System-wide global parameters,
- Energy service demands,
- Energy carriers,
- Resource technologies,
- Process and demand technology profiles, and
- Environmental emission factors.

2.2.1 System-Wide Parameters

System-wide, otherwise known as global, parameters are assumptions that apply to the entire model. Two important system-wide aspects of the model are:

- Cost discounting - All costs must be entered in the same monetary unit and discounted to a common year; U.S. $1995 for the EPANMD, and
- Subdivision of the year into load fractions - MARKAL subdivides the year into three seasons Z (Z = Summer, Winter, Intermediate) and two times of day Y (Y = Day, Night).

2.2.2 Energy Service Demands

Energy service demands describe the requirement for specific end-use energy services to be delivered to individuals and the economy. Examples of energy services include residential lighting, personal automotive transport, and industrial process heat. The demand for an energy service does not refer to the consumption of a particular energy commodity, but rather to the provision of services such as manufacturing steel, transportation, lighting offices, and heating homes. These energy services are measured in units of useful energy, which may vary with sector. For example, in the U.S. model, demand for the majority of transport services is specified in miles traveled, while the demand for industrial process energy is specified in petajoules (PJ).

Key demand related data include:

- Projections for useful energy demand services by sector, and
- The load shape of the demand pattern by season/day-night (for end use demands that use electricity or low-temperature heat).

2.2.3 Energy Carriers

Energy carriers are the various forms of energy produced and consumed in the Reference Energy System depicted in a MARKAL model. Energy carriers can include fossil fuels, such as coal with different sulfur content, crude oil and oil products, electricity to different grids, synthetic fuels produced by model processes, and renewable energy (e.g., biomass, solar, geothermal, hydro). Energy carriers provide the interconnections between the various technologies in a MARKAL model by flowing out of one or more technologies and into others. The model requires that the total amount of each energy carrier produced is greater than or equal to the total amount consumed.

Key energy carrier related data include:

- Overall transmission efficiency for all energy carriers,
- For electricity and low-temperature heat -
  - Investment and operation and maintenance cost for transmission and distribution systems, and
  - Reserve margin, or amount of installed capacity above the highest average annual demand.

2.2.4 Resource Technologies

Resource technologies are the entry points for raw fuels into and out of the energy system and include imports and exports, mining and extraction, and renewable energy. These technologies are generally characterized using stepwise supply curves that indicate how much of a resource can be obtained at a given price during each model period. In the EPANMD, imported electricity is modeled using a three-step curve, while the mining of various grades of coal is represented using eight-step curves.

Key resource technology data include:

- Bounds indicating the size of each step on each resource supply curve. (These bounds might arise for technical reasons, such as a limitation on the amount of oil that can be produced from a particular reservoir in a given year, or for economic reasons),
- A corresponding resource supply cost for each supply step, and
- Cumulative resources limits indicating the total amount of a resource at a particular supply step that can be delivered over the entire modeling horizon (e.g., total proven size of a petroleum reservoir).

2.2.5 Process and Demand Technologies

Process technologies are those that change the form, characteristics, or location of energy carriers. Examples of process technologies in the U.S. model include oil refineries and hydrogen production technologies. A sub-category of the process technologies is the conversion technologies, which model electricity and low-temperature heat production. Demand technologies are those devices that are used to directly satisfy end-use service demands, including vehicles, furnaces, and electrical devices. These technologies are characterized using parameters that describe technology costs, fuel consumption and efficiency, and availability.

Key process and demand technology data include:

- Technology costs-
  - The cost of investing in new capacity,
  - Fixed operating and maintenance (O&M) costs for installed capacity,
  - Variable O&M costs according to the operation of installed capacity, and
  - Fuel delivery costs corresponding to any sectoral difference in the price of an energy carrier;
- Energy carriers into and out of each technology;
- The technical efficiency (usually defined as the ratio between the sum of energy carrier or useful energy service outputs to the sum of energy carrier inputs);
- The model year in which the technology first becomes available for investment;
- Availability factors (for process technologies) and capacity utilization factors (for demand technologies) that describe the maximum percent annual (or season/day-night) availability for operation or a fixed percent annual (or season/day-night) capacity utilization per unit of installed capacity;
- The current existing installed capacity;
- Limits on capacity in the form of incremental new investment (absolute or growth rate) or total installed capacity. Such bounds may be set for economic, technical, behavioral, or other reasons; and
- "Hurdle" rates, or technology specific discount rates, that can be used to represent non-economic, behavioral aspects of investment choices (e.g., consumer preferences, expectation of very rapid rates of return, or information gaps). Often the "real world" does not

make decisions based strictly upon the least-cost perspective that MARKAL uses. These impediments to the market can be represented to MARKAL as technology-specific discount rates, higher than the systemwide discount rate, for such technologies.

2.2.6 Environmental Emissions

MARKAL has the capacity to track the production of emissions according to the activity, installed capacity, or new investment in capacity of a resource or technology. In the EPANMD this capacity is used to track emissions such as carbon, NO_X, sulfur, VOCs, and particulates. The EPANMD tracks these emissions by sector.

Key environmental variable related data (expressed in terms of pollutant emissions) include:

- Emissions per unit of technology activity, installed capacity, or new investment.
- Emission constraints, which can take the form of a cap on total emissions in a year, or a cumulative cap on emissions over the entire modeling horizon.

3. The MARKAL EPANMD

3.1 The ANSWER Framework and Corresponding Excel Spreadsheets

The EPANMD was developed using the ANSWER framework. ANSWER is a Windows interface to MARKAL developed using MS Visual Basic, MS Access, MS Excel, and requiring the GAMS mathematical modeling language software. For a complete description of ANSWER see, "ANSWER MARKAL, An Energy Optimization Tool version 5" (available from Ken Noble of Nobel-Soft noblesoft@netspeed.com.au). All data for the EPANMD was organized and transformed from raw data to MARKAL-ready data in Excel spreadsheets that are available along with the database.

3.2 Software

All results referenced in this document were based on:

- ANSWER version 5.5.3
- GAMS version 21.3, and
- EPANMD version 1.0

3.3 Developing the EPA's National MARKAL Database

The goal for the development of the national model was to focus on five key sectors: transportation, commercial, residential, industrial, and electricity generation.

The database was initially based on a MARKAL database produced in 1997 by Brookhaven National Laboratory for the U.S. Department of Energy (hereafter referred to as the "1997 DOE MARKAL database"). Over time, all sectors have been thoroughly revised and updated, although the original values were maintained for several technologies that were outside this study's focus areas. Wherever possible, the data for updating the database was drawn from DOE's Annual Energy Outlook (AEO) and the input data to the National Energy Modeling System (NEMS), which is used to produce the AEO.

AEO data were selected for the RES because it is a nationally recognized source of technology data and widely used where reference or default data are required. It presents mid-term forecasts of energy prices, supply, and demand. The projections are based on results from NEMS and take into account federal, state, and local laws and regulations in effect at the time of the model run.

Where AEO data were not available in a form appropriate to the MARKAL needs, data were derived from other widely recognized authoritative sources:

- In the transportation sector, personal vehicle technology data were drawn from the U.S. Department of Energy (DOE) Office of Transportation Technologies (OTT) Quality Metrics assessment. Quality Metrics (QM) describes the analytical process used in estimating future energy, environmental, and economic benefits of U.S. DOE Energy Efficiency and Renewable Energy (EE/RE) programs. Two additional vehicle technology characterizations were derived from the report by DeCicco et al., 2001;
- Data for the electricity sector were drawn from NEMS with supplemental data pulled from the Electric Power Research Institute (EPRI) Technical Assessment Guide (TAG). The TAG is a standard reference work for the energy industry that characterizes key electric generation technologies and their operation, costs, environmental impacts, and so forth.

The database is divided into five year time periods. The current database runs from 1995 to 2035. Subsequent updates will drop historical time periods such as 1995 and 2000, and extend the time horizon out to 2055.

As each sector of the model was completed, data characterizing the associated technologies was peer-reviewed by sector experts for appropriateness of the data source, completeness of the technology options, and correctness of the methodology in converting the data from the original source to MARKAL inputs.

After assembling a complete representation of the energy system, the model was calibrated against the AEO 2002 report and peer reviewed by US Energy System experts with MARKAL experience. The goals of the calibration and peer review were to: (i) ensure that the model was producing reasonable results, given its input assumptions, (ii) determine whether the model was providing a plausible, consistent representation of the key features of the U.S. energy system, (iii) be able to identify why differences exist in cases where our results differ from AEO results, and (iv) identify any significant errors in the construction or characterization of the RES. It should be noted that an exact calibration of MARKAL to the AEO is not practical or desirable since the models are very different in structure and purpose.

3.4 Future Technologies for Scenario Analysis

In order to evaluate various technological pathways to 2050, future technologies for the transportation and energy production sectors will be added to the EPANMD database over time. Specific technologies in the transportation sector include biofuels and hydrogen fuel. Specific technologies in the electricity production sector are still being developed. Technology characterizations will be added or updated as deemed necessary.

3.5 Detailed Model Descriptions

The remaining pages of this document give a detailed description of the data in the EPANMD and the calibration steps the model went through to verify its accuracy. It is divided into twelve sections: naming conventions (section 4), system-wide parameters (section 5), energy carriers (section 6), resource supply technologies (section 7), process technologies (section 8), conversion technologies (section 9), demand technologies and end-use demands (section 10), emissions accounting (section 11), the hydrogen sector (section 12), model quality control processes (section 13), model calibration (section 14), and preliminary model results (section 15).

Appendix B at the end of the report is detailed data for each sector.

4. MARKAL Naming Conventions

4.1 Introduction

Naming conventions help the user to organize the information and to have some idea where in the RES a particular component belongs.

4.2 Naming Convention Guidelines

The naming convention guidelines are laid out below by sector.

4.2.1 Energy Carrier and Material Commodity Names

Energy carriers are named with up to 10 characters such that:

- The first one to five characters signifying the energy type,
- The remaining characters added on to specify the process it is coming from or going to,
- Energy carriers used in the Industrial Sector are an exception to these guidelines, starting with ‘I’ for Industrial and followed by letters that specify the process type and the industrial sub-sector.

The list of energy carriers in the EPANMD is provided in Table 1.

Table 1. Energy Carriers in the EPANMD.

Item	Description
BIOHC-0	Herbaceous crops from all sources to all end uses
BIOWD-0	Wood to all purposes
BMSWX-0	Municipal solid waste (X added for MTH[a])
CABHS	High sulfur bituminous coal from App.[b], surface
CABHU	High sulfur bituminous coal from App., undergrd.
CABLS	Low sulfur bituminous coal from App.,, surface
CABLU	Low sulfur bituminous coal from App., undergrd.
CABMS	Med. sulfur bituminous coal from App., surface
CABMU	Med. sulfur bituminous coal from App., undergrd.
CAGHS	High sulfur gob pile coal from App.
CALMS	Med. sulfur, lignite coal from App., surface
CAMLU	Low sulfur, metallurgical coal from App., underrd.
CAMMU	Med.sulfur, metallurgical coal from App., underrd.
CCFP	All coal to coal-fired power
CDLMS	Med.sulfur, lignite coal, from Dakota surface
CGLHS	High sulfur, lignite coal from Gulf Coast, surface
CGLMS	Med. sulfur, lignite coal from Gulf Coast, surface
CIBHS	High sulfur, bit. coal from Interior, surface
CIBHU	High sulfur, bit. coal from Interior, undergrd.
CIBMS	Med. sulfur, bit. coal from Interior, surface
CIBMU	Med. sulfur, bit. coal from Interior, undergrd.
CMET	Metallurgical coal to coking
CMETIMP-0	Imported Metallurgical coal to coking
CNG	Compressed natural gas
CNGTH	CNG to trucks
CNGTL	CNG to light duty vehicles
CNGX	Fuel for CNG-gasoline bifuel vehicles
CNSMS	Med. sulfur, sub-bit. coal from NW, surface
COACFP	Coal to coal-fired power
COACFPR	Coal to coal-fired power - repowered
COAEAFB	Coal to atmospheric fluidized bed
COAEIGC	Coal directly to IGCC[c]
COAEMCFC	Coal to molten carbide fuel cells
COAEPFB	Coal to pressurized fluidized bed

continued

Table 1 (continued). Energy Carriers in the EPANMD.

Item	Description
COAGASH	Coal to high Btu gasification
COAGASIS	Coal to in-stu coal gasification
COAGASM	Coal (med Btu) to coal gasification
COAI	Coal to industry prior to emissions accounting
COAIEA	Coal to entire industrial sector after emis. acctng.
COALBH-0	Coal: bit. high sulfur (>1.67 lb mmBtu[d])
COALBL-0	Coal: bit. low sulfur (0.4 - 0.8 lb mmBtu)
COALBM-0	Coal: bit. medium sulfur (0.8 - 1.67 lb mmBtu)
COALEX	All types of coal to export
COALLH-0	Coal: lignite high sulfur (>1.67 lb mmBtu)
COALLL-0	Coal: lignite low sulfur (0.6 - 0.8 lb mmBtu)
COALLM-0	Coal: lignite medium sulfur (0.8 - 1.67 lb mmBtu)
COALML-0	Coal: metallurgical low sulfur (<0.6 lb mmBtu)
COALMM-0	Coal: metallurgical med sulfur (>0.6 lbs mmBtu)
COALSL-0	Coal: sub bit. low sulfur (<0.4 lbs mmBtu)
COALSM-0	Coal: sub bit. med sulfur (>0.4 lbs mmBtu)
COKE	Coke input into industrial applications
COKEIMP-0	Coke input into industrial applications
CPBLU	Low sulfur, bit. coal from PRB[e], undergrd.
CPSLS	Low sulfur, sub-bit. coal from PRB, surface
CPSMS	Med. sulfur, sub-bit. coal from PRB, surface
CRBLU	Low sulfur, bit. coal, Rocky Mtns., undergrd.
CRSLS	Low sulfur, sub-bit. coal, Rocky Mtns., surface
CSBLS	Low sulfur, bit. coal from Southwest, surface
CSSMS	Med. sulfur, sub-bit. coal from Southwest, surface
CSTMBHE1	HS[f] bit. coal to stm. elec. prior to SOx[g] controls
CSTMBITE	Bit coal to existing steam electric
CSTMBITE2	Bit. coal to stm elec. prior to NOx[h] control options
CSTMBITE3	Bit. coal between LNB[i] and SCR/SNCR[j] retrofits for NOx control
CSTMBLE1	LS[k] bit coal to stm. elec. prior to SOx controls
CSTMBME1	MS[l] bit coal to stm. elec. prior to SOx controls
CSTMLHE1	HS lignite to stm. elec. prior to SOx controls
CSTMLIGE	Lignite to existing steam electric
CSTMLIGE2	Lignite to stm. elec prior to NOx control options
CSTMLIGE3	Lignite to stm. elec. between LNB and SCR/SCNR for NOx control
CSTMLLE1	LS lignite to stm. elec. prior to SOx controls
CSTMLME1	MS lignite to stm. elec prior to SOx controls
CSTMSLE1	LS sub-bit. to stm. elec. prior to SOx controls
CSTMSME1	MS sub-bit. to stm. elec. prior to SOx controls
CSTMSUBE	Sub-bit. coal to existing steam electric
CSTMSUBE2	Sub-bit. to stm. elec. prior to NOx control options
CSTMSUBE3	Sub-bit. to stm. elec. between LNB and SCR/SNCR for NOx control
DHO-0	Diesel, heating oil
DLG	DUMMY LIQUID FUEL-HIGH
DSH	All sources of heavy distillate
DSHCEA	Fuel oil to commercial sector after emis. acctg.
DSHEEA	Emissions: fuel oil to electricity generation
DSHEEAN	Fuel oil to steam electric after NOx emissions
DSHEEAS	Fuel oil to steam electric after SOx emissions
DSHH-0	Imported high sulfur fuel oil
DSHIEA	Emissions: fuel oil to the industrial sector
DSHL-0	Imported low sulfur fuel oil
DSHT	Fuel oil (bunker fuel) for shipping
DSL	All sources of diesel fuel and heating oil
DSLCEA	Diesel after emissions acctg. for commercial uses
DSLEEA	Diesel to the electricity generation

continued

Table 1 (continued). Energy Carriers in the EPANMD.

Item	Description
DSLEPN	Diesel to the electricity generation before EA[m]
DSLIEA	Diesel after NOx emis. contrls. for industrial use
DSLL-0	Imported low sulfur highway diesel
DSLREA	Diesel to residential after emissions
DSLT	Transportation diesel
DSLTH2	Transportation diesel for H2 transport
DSLU-0	Imported ultralow sulfur highway diesel
E85	E85 fuel
ELC	Electricity to all purposes
ELCPVH2	Electricity from PV[n] to H2 production
ELCWTH2	Electricity from wind to H2 production
ETH	Ethanol for all purposes
ETHTL	Ethanol to transport
ETHX	Fuel for E85-gasoline flex vehicles
FEQ	Fossil equivalent
GEOTHM-0	Geothermal energy to all end uses
GSL	Gasoline to all end uses
GSLIEA	Gasoline to industrial sector
GSLIMP-0	Imported gasoline
GSLRNGL	Gasoline from refineries and NG[o] liquids
GSLT	Gasoline to all transport
HYDRO-0	Hydroelectric for electricity generation
HYDROGEN 02	Hydrogen to the transportation sector
IECH	Industrial electro-chemical process chemicals
IEIS	Industrial electro-chemical process iron and steel
IELP	Industrial electro-chemical process pulp and paper
IENF	Industrial electro-chemical process non-ferrous metal
IENM	Industrial electro-chemical process non-metals
IEOI	Industrial electro-chemical process other industry
IFCH	IFCH[p]
IFIS	Industrial iron and steel feedstock
IMCH	Industrial machine drive chemicals
IMIS	Industrial machine drive iron and steel
IMLP	Industrial machine drive pulp and paper
IMNF	Industrial machine drive non-ferrous metals
IMNM	Industrial machine drive non-metals
IMOI	Industrial machine drive other industry
INDBFG	Blast Furnace Gas (IND[q])
INDBIO	Biofuels (IND)
INDCOA	Coal (IND)
INDCOK	Ovencoke (IND)
INDELC	Electricity (IND)
INDETH	Ethane (IND)
INDHET	Heat (IND)
INDHFO	Heavy fuel oil (IND)
INDHYD	Hydro (IND)
INDLPG	Liquified petroleum gases (IND)
INDNAP	Naphtha (IND)
INDNGA	Natural gas mix (IND)
INDNUC	Nuclear (IND)
INDOIL	Refined petroleum products (IND)
INDPTC	Petroleum coke (IND)
INDSOL	Solar (IND)
INDWIN	Wind (IND)
IOCH	Industrial other chemicals
IOIS	Industrial Other Iron and Steel
IOLP	Industrial other pulp and paper
IONF	Industrial other non-ferrous metals

continued

Table 1 (continued). Energy Carriers in the EPANMD.

Item	Description
IONM	Industrial other non-metals
IOOI	Industrial other all other industry
IPCH	Industrial process heat chemicals
IPIS	Industrial process heat iron and steel
IPLP	Industrial process heat pulp and paper
IPNF	Industrial process heat non-ferrous metals
IPNM	Industrial process heat non-metals
IPOI	Industrial process heat other industry
ISCH	Industrial steam chemicals
ISIS	Industrial steam iron and steel
ISLP	Industrial steam pulp and paper
ISNF	Industrial steam non-ferrous metals
ISNM	Industrial steam non-metals
ISOI	Industrial steam other industry
JTF	Jet fuel from all sources to all end uses
JTFIMP-0	Imported jet fuel
KER	Kerosene from all sources to all end uses
KERIMP-0	Imported kerosene
KERREA	Kerosene to residential after emissions
LPG	Liquid petroleum gas from all sources
LPGCEA	LPG[r] to commercial sector after emissions acctng.
LPGIEA	LPG to industrial sector after emissions acctng.
LPGIMP-0	Imported LPG
LPGREA	LPG to residential after emissions
LPGT	LPG to transportation
LPGX	Fuel for LPG-gasoline bifuel vehicles
LTH	Low-temperature heat
M95	M95 fuel
MTH	Methanol for all purposes
MTHE	Methanol to electricity generation
MTHIMP-0	Imported methanol
MTHT	Methanol to transportation
MTHX	Fuel for M95-gasoline flex vehicles
NEMISC	Miscellaneous petroleum products
NGA	Natural gas from all sources
NGACEA	Pipeline gas to commercial sec. after acctng. for emis.
NGACLDC	Pipeline gas to commercial sector through LDC[s]
NGAEEA	Nat. gas to electricity generation after emis. actng.
NGAENSTM	Nat gas to non-steam electricity generation
NGAESTM	Nat gas to electricity sector
NGAIEA	Nat. gas to industrial sector after emissions actg.
NGAIEA_N	Nat. gas to industrial sector no emissions actg.
NGAIEAZ	NGA to industrial after emissions actg. - surrogate
NGAILDC	Natural gas to industry sector through LDCs
NGAIMP-0	Imported NGA
NGAMIN-0	Mined NGA
NGAREA	NGA to residential after emissions
NGARLDC	NGA to residential through LDC
NGL	Natural Gas Liquids from all sources
NGLIMP-0	Imported NGL
NGLMIN-0	Mined NGL
NGPQ	Pipeline quality gas
NUCFUEL	Dummy nuclear fuel technology
OIL	Crude oil from all sources
OILHH	Imported crude oil high sulfur, heavy gravity
OILHL	Imported crude oil, high sulfur, low gravity
OILHV	Imp. crude oil, high sulfur, very high gravity
OILIMP-0	Imported crude oil
OILLL	Imported crude oil, low sulfur, low gravity

continued

Table 1 (concluded). Energy Carriers in the EPANMD.

Item	Description
OILMH	Imported crude oil, medium sulfur, heavy gravity
OILMIN-0	Crude oil from domestic sources
PFDST	Hydrocarbon petrochemical feedstocks
PFDSTIMP-0	Imported PFDST
RCC	Residential conservation, cooling
RCH	Residential conservation, heating
SOLAR-0	Solar energy to all sources
WIN-0	Wind to all end uses

[a] MTH = methanol
[b] App. = Appalachia
[c] IGCC = integrated gasification combined cycle
[d] mmBtu = M Btu
[e] PRB = Powder River Basin
[f] HS = high sulfur
[g] SOx = oxides of sulfur
[h] NOx = oxides of nitrogen
[i] LNB = low NOx burners
[j] SCR/SNCR = selective catalytic reduction/selective noncatalytic reduction
[k] LS = low sulfur
[l] MS = medium sulfur
[m] EA = emissions accounting
[n] PV = photovoltaic
[o] NG = natural gas
[p] IFCH = industrial chemical feedstock
[q] IND = industrial
[r] LPG = liquid petroleum gas
[s] LDC = local distribution center

4.2.2 Resource Technologies

Resource technologies are given an up to 10 character name such that:

- The 1st three characters of the name should use the pre-defined prefixes of—
  - MIN – domestic extraction of conventional resources (e.g., coal mining, oil/gas wells),
  - IMP – imports of energy and materials,
  - EXP – exports of energy and materials,
  - RNW – renewable energy carriers with physical limits (e.g., municipal solid waste, biomass), and
  - STK – stockpiling of energy and materials between periods (e.g., nuclear fuel);
- The next up to six (6) characters should specify the name of the commodity produced and correspond to the name of the energy carrier output by the resource;
- The final character should correspond to a price step.

Examples of Resource Technologies are in Table 2.

Table 2. Resource Technologies in the EPANMD - Examples.

Item	Description
MINCABHS1	Coal—App.[a], bit., high sulfur, surface, Stp 1
MINCABLS8	Coal—App., bitum., low sulfur, surface, Stp 8
MINCABMU5	Coal—App., bit., med. sulfur, undergrnd, Stp 5
MINCIBHU1	Coal—Interior, bit., high sul., undergrd, Stp 1

continued

Table 2 (concluded). Resource Technologies in the EPANMD - Examples.

Item	Description
MINNGA1	Domestic dry natural gas- Step 1
MINNGA2	Domestic dry natural gas- Step 2
MINNGA3	Domestic dry natural gas- Step 3
MINOIL1	Domestic crude oil -Lower 48-Step1
MINOIL2	Domestic crude oil -Lower 48-Step2
MINOIL3	Domestic crude oil -Lower 48-Step3
IMPCOKE1	IMPORT COKE
IMPDSHH1	Imported high sulfur fuel oil—Step 1
IMPDSHL3	Imported low sulfur fuel oil—Step 3
IMPDSLL1	Imported low sulfur diesel—Step 1
IMPDSLU3	Imported ultra-low sulfur diesel—Step 3
IMPELC1	IMPORT ELECTRICITY 1
IMPGSL2	Imported reform. and conventional gasoline—Step 2
IMPKER1	Imported kerosene and other refined prod.—Step 1
IMPNGA1	Imported natural gas- Step1
IMPOILHH2	Imported oil—high sulfur, heavy gravity—Step 2
IMPOILHH3	Imported oil—high sulfur, heavy gravity—Step 3
IMPOILHL3	Imported oil—high sulfur, low gravity—Step 3
IMPOILHV1	Imported oil—high sulfur, very high grav—Step 1
IMPPFDST1	Imported petroleum feedstocks—Step 1
RNWBIOHC1	HERBACEOUS ENERGY CROPS
RNWBIOWDA	AEO95 BIOMASS SUPPLY CURVE 1
RNWBIOWDF	AEO95 BIOMASS SUPPLY CURVE 6
RNWGEOTHM	Geothermal renewable resources
RNWHYDRO	Hydro renewable resources
RNWSOLAR	SOLAR renewable resources
RNWWIN	WIND renewable resources

[a] App. = Appalachia

4.2.3 Process, Conversion, and Demand Technology Names

The following naming conventions are defined to help further organize the RES and to allow the user to quickly determine the general function of a process from the technology name:

- P (transformation) = Processes that transform an energy or material through a physical, chemical or other type operation,
- SC (collector) = Processes that collect energy carriers or materials from multiple sources to provide a single supply to downstream technologies. Such processes are called "dummy" processes, and their main purpose is to change the names of like commodities. Therefore, they usually have no associated price or technical implications,
- SE (emission accounting) = Processes that are used to characterize the emissions from a particular energy carrier stream,
- E (electricity and coupled production) = Conversion plants that produce electricity, and possibly heat, and
- H (heat production) = Conversion plants that produce only heat.

The naming convention for process, conversion, and demand technologies is summarized in Table 3.

Table 3. Example Naming Convention for Process, Conversion, and Demand Technologies.

Technologies		Designators for Character Sectors			
		1st Character	2nd to 4th Characters	Next 2–4 Characters	Last 2–4 Characters
Process Technologies	Transformation	P for processes that transform energy or material	3 character name for input energy carrier	2 or 3 character abbreviation for output energy carrier or next process	2 character vintage corresponds to the year in which the technology is first available (e.g., 00 for 2000)
	Collection	S for other supply step processes	C for collector	3 character name for input energy carrier	2 or 3 character descriptor for the output energy type
	Emissions Accounting	S for other supply step processes	E for emission accounting	3 character name for energy carrier	2 or 3 character descriptor for the output energy use/sector
Conversion Technologies		E for electric power plants (including CHP) and H for district heating plants (no electric output)	1 to 3 character designator taken from the primary energy carrier name	1 to 4 character user-chosen descriptor (e.g., IGC for Integrated Gasification Combined cycle power plants, AFB for Atmospheric Fluidized Bed power plants) or 2 character designator used to order the list of conversion technologies that use the particular commodity	2 character vintage corresponding to the year in which the technology is first available (e.g., 00 for 2000, 05 for 2005, etc.)
Demand Technologies		C, I, R, T (The 1st character of the 3 character designator for the MARKAL demand sector)	1 character sub-sector descriptor (e.g., space cooling, C; or water heating, W)	2 or 3 character descriptor for the demand technology or 2 character designator used to order the list of demand technologies that service the particular demand	2 character vintage corresponding to the year in which the technology is first available (00 for 2000, 05 for 2005, etc.)

4.2.4 Emission Names

The names for emission commodities in a MARKAL model generally consist of one to three characters describing the emissions type, with additional characters added for sectoral breakdowns, as listed in Table 4.

Table 4. Emissions Commodities in the EPANMD.

Item	Description
CARBON	System-wide carbon emissions
C_RES	Carbon emissions : Resource Technologies
COC	Carbon emissions : Commercial Sector
COE	Carbon emissions : Electric Sector
COO	Carbon emissions : Other
COR	Carbon emissions : Residential Sector
COT	Carbon emissions : Transportation Sector
INDCH4N	Industrial methane emissions
INDCO2N	Industrial CO2 emissions
INDN2ON	Industrial N2O emissions
NOE	NOx emissions: Electric Sector
NOI	NOx emissions: Industrial Sector
NOR	NOx emissions: Residential Sector
NOT	NOx emissions: Transportation Sector
SULFUR	System-wide sulfur emissions
SOE	Sulfur emissions: Electric Sector
SOI	Sulfur emissions: Industrial Sector
SOR	Sulfur emissions: Residential Sector
SOT	Sulfur emissions: Transportation Sector
P10	System-wide PM10 emissions
VOC	System-wide VOC emissions

4.2.5 User-Defined Constraints

User-defined constraints are usually introduced to reflect considerations beyond the scope of the model and to avoid abrupt, unrealistic changes over time. Such constraints may be defined to control the investment, capacity or operation of a set of processes in absolute (noted A_*) terms (e.g., capacity of all nuclear plants) or as a share (noted S_*) of a larger set (e.g., percent of total electricity that must come from renewable sources). Table 5 describes the naming convention typically used in the EPANMD for user defined constraints.

5. System-Wide Variables

As previously stated, system-wide parameters are assumptions that apply to the entire model.

5.1 System-Wide Variable Data Sources

Data were taken from the 1997 DOE MARKAL database.

5.2 System-Wide Parameters

DISCOUNT: Specifies the long-term annual discount rate for the economy as a whole. For the EPANMD the discount rate is 5%.

QHR(Z)(Y): Specifies the fraction of the year by season (Z) and time-of-day (Y) that best describes the electrical load through the typical year.

Table 6. QHR(Z)(Y) Values in the EPANMD.

Item	Description	Value
ID	Intermediated day	0.25
IN	Intermediate night	0.25
SD	Summer day	0.125
SN`	Summer night	0.125
WD	Winter day	0.125
WN	Winter night	0.125

6. Energy Carriers

As previously stated, energy carriers provide the interconnections between the various technologies in a MARKAL model by flowing out of one or more technologies and into others. For a complete list of energy carriers in the EPANMD, see Table 1.

6.1 Energy Carrier Data Sources

Data were taken from the 1997 DOE MARKAL database.

6.2 Energy Carrier Parameters

TE(ENT): Specifies the average transmission and distribution efficiency of each energy carrier in each specified period. With the exception of electricity, the transmission efficiencies of all energy carriers in the model is 100%. Due to losses during transmission, the transmission efficiency of electricity in the model is 93.5%.

6.2.1 Electricity Only Parameters

There are a series of parameters that apply only to electricity, covering the cost of distribution and transmission of

Table 5. Naming Convention for User-Defined Constraints.

User-Defined Constraint	Designators for Character Sectors			
	1st and 2nd Character	3rd to 5th Characters	6th up to 8th Characters	Last 2 Characters
Absolute	A_	1 to 3 character descriptor corresponding to the energy carrier involved, or the demand sub-sector(s)	2 to 5 character descriptor for the constraint or commodity/technology involved	2 character vintage corresponding to the year in which the constraint is applied (if applicable) (e.g., 00 for 2000, 05 for 2005, etc.)
Share	S_			

electricity as well as the base load and reserve capacity. The parameters and their values in the EPANMD are listed in Table 7.

Table 7. Electricity Specific Energy Carrier Parameters Values in the EPANMD.

Item	Value
(E)DISTINV	$ 496 million per GW
(E)DISTOM	$ 0.736 per PJ
(E)LCFEQ	3.125
(E)RESERVE	0.2
(E)TRANINV	$ 228.75 million per GW
(E)TRANOM	$ 0.1 million per PJ
BAS(E)LOAD	0.95

(E)DISTINV: Specifies the investment cost for the distribution systems constructed for all electricity conversion technologies, including labor costs, material costs, and equipment costs. It is measured as the average annual investment cost per unit of additional conversion capacity.

(E)DISTOM: Specifies the distribution system operating and maintenance costs for all electricity conversion technologies. It is measured as the average annual O&M cost per unit of conversion production.

(E)LCFEQ: Specifies the fossil fuel equivalent of any imported or exported electricity and is measured from the conversion efficiency of a standard fossil fueled power plant.

(E)RESERVE: Specifies the Reserve Capacity Fraction, which is equal to the reserve capacity (the amount by which the installed electricity generation capacity exceeds the average load of the season and time-of-day division of peak demand) divided by the capacity required to meet the average load of the season/time-of-day of peak load.

(E)TRANINV: Specifies the investment cost for the transmission systems for centralized electricity conversion technologies, including labor costs, material costs, and equipment costs. It is measured as the average annual investment cost per unit of additional conversion capacity.

(E)TRANOM: Specifies the transmission system operating and maintenance costs for centralized electricity conversion technologies. It is measured as the average annual O&M cost per unit of conversion production.

BAS(E)LOAD: Specifies the baseload capacity of the electricity generation system as a fraction of the total night production of electricity.

6.2.2 Low-Temperature Heat Only Parameters

There are a series of parameters that cover the cost of distribution and the distribution efficiency that apply only to the low-temperature heat produced by electricity co-generation technologies. The parameters and their values in the EPANMD are listed in Table 8.

Table 8. Low-Temperature Heat Specific Energy Carrier Parameters Values in the EPANMD.

Item	Value
HRESERVE	0.5
DTRANINV	$ 228.75 million per GW
DTRANOM	$ 0.736 million per PJ
DHDE(Z)	92% for each of the seasons

HRESERVE: Specifies the reserve capacity fraction, which is equal to the reserve capacity (the amount by which the installed low-temperature heat production capacity exceeds the average load of the season and time-of-day division of peak demand) divided by the capacity required to meet the average load of the season/time-of-day of peak load.

DTRANINV: Specifies the investment cost for the transmission systems for centralized low-temperature heat conversion technologies, including labor costs, material costs, and equipment costs. It is measured as the average annual investment cost per unit of additional conversion capacity.

DTRANOM: Specifies the transmission system operating and maintenance costs for centralized low-temperature heat conversion technologies. It is measured as the average annual O&M cost per unit of conversion production.

DHDE(Z): Specifies the distribution efficiency for low-temperature heat in each season: intermediate, summer, and winter.

7. Resource Supply

There are six major energy resource categories represented in the model: Crude Oil, Imported Refined Products, Natural Gas, Coal, Nuclear Power, and Renewables. MARKAL characterizes the resource supplies for each of these using a series of stepped supply curves.

7.1 Parameters Definitions

BOUND(BD)Or: Specifies the maximum additional annual production or availability of a resource at each step cost and is expressed in units of the energy carrier.

COST: Specifies the cost at which each step's quantity is available to the model.

CUM: Specifies a limit on the total availability of a resource from its source to the energy system over the entire model time horizon.

START: Specifies the first time period of availability.

7.2 Crude Oil

Both imported and domestic crude oil are represented in the model. For imported oil, there are five crude grades, each of which have three steps characterized in each model year by a cost and the amount that is available to the model at that cost. The domestic oil is characterized by two domestic oil supply curves: one for the lower 48 states and one for Alaska. Again, each have three steps characterized in each model year by a cost and the additional amount that is available to the model at that cost. All oil feeds directly into the three refineries characterized in MARKAL. A detailed description of refineries is given in Section 8.2.

7.2.1 Crude Oil Data Sources

Original data for imported crude oil was taken from the AEO2002 Reference Supply Curves for Imported Crude Oil provided by Han-Lin Lee of EIA. These curves supply data for MARKAL years 1995 through 2020. For the years after 2020, the values were linearly extrapolated.

Original data for domestic oil were obtained from the 1996, 1999, and 2002 Annual Energy Outlooks. The specific AEO tables from which the data was gathered is outlined in Table 9.

Table 9. Data Sources for Domestic Oil in the EPANMD.

1995	2000, 2005	2010, 2015, 2020	2025, 2030, 2035
AEO1996 and AEO1999 Reference Case Forecast Table A11: Petroleum Supply and Disposition Balance	AEO2002 Reference Case Forecast Table A11: Petroleum Supply and Disposition Balance	AEO2002 Oil Price Comparison Cases Table C11: Petroleum Supply and Disposition Balance	Incresae incrementally by percentage based on the growth change from 2015 to 2020.

7.2.2 Crude Oil RES

The naming conventions used for crude oil are described in Tables 10 – 13. The RES diagram is shown in Figure 2. It starts with imported and domestic oil resource technologies, which output oil energy carriers into collectors, which then deliver oil to the refineries. (For a specific description of the refinery types, see Section 8.2.)

7.2.3 Crude Oil Parameters

All costs are expressed in millions of 1995 dollars (95m$). All energy quantities are expressed in petajoules (PJ).

Table 10. Naming Convention for Crude Oil Resource Technologies.

Character number							
1	2	3	4	5	6	7	
Technology type			Resource type			step	Description
I	M	P	O	I	L	1	Imported, step 1 (S1)
						2	Imported, step 2 (S2)
						3	Imported, step 3 (S3)
M	I	N				1	mined, lower 48, S1
						2	mined, lower 48, S2
						3	mined, lower 48, S3
						A	mined, Alaska, S1
						B	mined, Alaska, S2
						C	mined, Alaska, S3

Table 11. Naming Convention for Crude Oil Energy Carriers.

Character number						
1	2	3	4	5	6	
Resource type			Crude grade			Description
O	I	L	H	H		HS[a], heavy gravity
			H	L		HS, low gravity
			L	L		LS[b], low gravity
			M	H		MS[c], heavy gravity
			H	V		HS, very heavy gravity
			Technology type			
			M	I	N	mined domestically
			I	M	P	imported

[a] HS = high sulfur
[b] LS = low sulfur
[c] MS = medium sulfur
Note: Some resource energy carriers have a '-0' at the end of the name. This is done for fuel accounting purposes in the model.

Table 12. Naming Convention for Crude Oil "Dummy" Collector Process Technologies.

Character number								
1	2	3	4	5	6	7	8	
Collector		Resource type			Crude grade			Description
S	C	O	I	L	H	H		HS[a], heavy gravity
					H	L		HS, low gravity
					L	L		LS[b], low gravity
					M	H		MS[c], heavy gravity
					H	V		HS, very heavy gravity
					Technology			
					M	I	N	mined domestically
					I	M	P	imported

[a] HS = high sulfur
[b] LS = low sulfur
[c] MS = medium sulfur

BOUND(BD)Or:
For Imported crude oil - The upper bound on available imported crude oil has been calculated from the AEO 2002 Supply Curves for Imported Crude Oil by summing the quantities by step in each of five regions: East Coast, Mid-

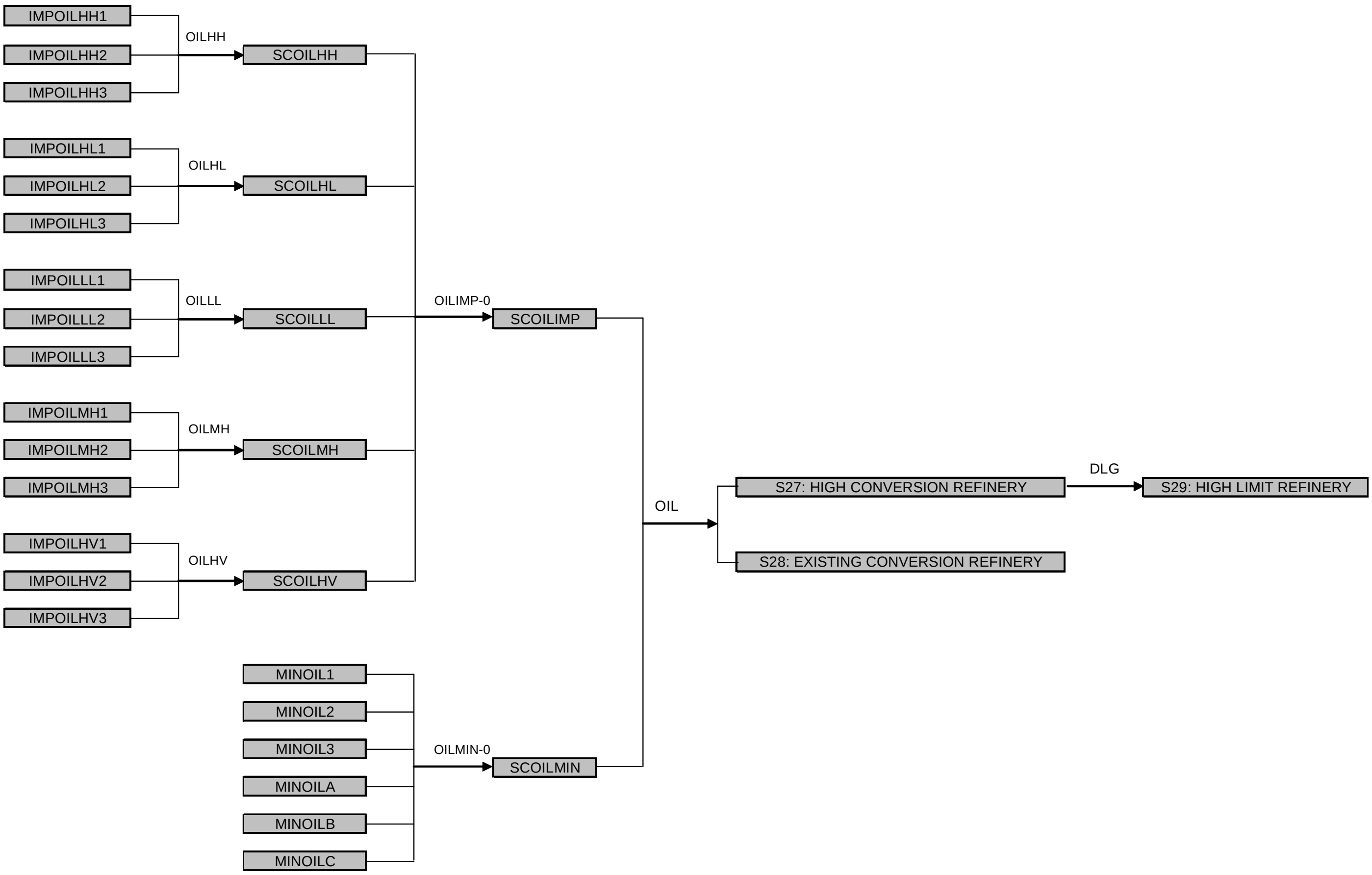


Figure 2. Crude Oil RES in the EPANMD.

west, Gulf Coast, Rocky Mountains, and West Coast; taking a 5-year average centered on the MARKAL model year and converting to petajoules. BOUND(BD)Or for 2020 uses the 2020 source data only and is not a five-year average. For the years after 2020, it has been extrapolated using the percentage change from 2015 to 2020.

For domestic crude oil - The year 1995 was calculated by averaging the quantities for the years 1993 through 1997. The values for 1993, 1994, and 1995 came from the 1996 AEO Reference Case Forecast Table A11: Petroleum Supply and Disposition Balance. The values for 1996 and 1997 came from the 1999 AEO version of the same table. For the years 2000 through 2020 the quantity came directly from the 2002 AEO, Tables A11 and C11 (see table 9). For the years 2025 through 2035 the quantity and price were obtained by using the percent change from 2015 through 2020 on the 2002 AEO.

COST:

For imported crude oil - Calculated by taking a quantity-weighted average of AEO step prices across the five AEO regions, then taking a quantity weighted five-year average centered on the MARKAL model year, and converting to millions of 1995 dollars per petajoule. (COST for 2020 uses the 2020 source data only and is not a five-year average.) For the years after 2020, it was extrapolated using the percentage change from 2015 to 2020.

For domestic crude oil - The year 1995 was calculated by averaging the costs for the years 1993 through 1997. The values for 1993, 1994, and 1995 came from the 1996 AEO Reference Case Forecast Table A11: Petroleum Supply and Disposition Balance. The values for 1996 and 1997 came from the 1999 AEO version of the same table. For the years 2000 through 2020 the costs came directly from the 2002 AEO, tables A11 and C11 (see Table 9). For the years 2025 through 2035 the costs were obtained by applying the percent change from 2015 through 2020 to each subsequent time period.

START:

The start year specifies the first time period of availability. All crude oil grades, both imported and domestic, are assumed to be available at the beginning of the model time horizon, 1995.

7.3 Imported Refined Products

There are 10 imported refined products represented in the EPANMD. These are imports of the same products produced by the oil refineries. For each product, three steps are characterized in each model year by a cost and the additional amount that is available to the model at that cost. Table 13 lists the sub-categories of petroleum and how they are represented in the model.

Table 13. Petroleum Products in the EPANMD.

Product	Condition
Diesel	Imported and refined
Fuel oil	Imported and refined
Gasoline	Imported and refined
Natural gas liquids (NGL)	Imported and refined
Jet fuel	Imported and refined
Kerosene	Imported and refined
Liquid petroleum gas	Imported and refined
Petroleum feedstocks	Imported
Methanol	Imported and refined
Miscellaneous petroleum	Refined

7.3.1 Imported Refined Products Data Sources

Original data for imported refined products were taken from the AEO2002 Supply Curves for Imported Refined Products provided by Han-Lin Lee of EIA.

7.3.2 Imported Refined Products RES

The naming conventions used for imported refined products are described in Tables 14 – 16. The RES diagrams are shown in Figures 3 – 9.

Table 14. Naming Convention for Imported Refined Products Resource Technologies.

Character number									
1	2	3	4	5	6	7	8		Final
Technology type			Oil type					Description	Step
I	M	P	D	S	H	H		high sulfur fuel oil	1
			D	S	H	L		low sulfur fuel oil	2
			D	S	L	L		low sulfur diesel	3
			D	S	L	U		ultra low sulfur diesel	
			D	H	O			diesel heating oil	
			G	S	L			gasoline	
			N	G	L			natural gas liquids	
			L	P	G			liquid petroleum gas	
			J	T	F			jet fuel	
			K	E	R			kerosene	
			P	F	D	S	T	petroleum feedstocks	
			M	E	T	H		methanol	

Table 15. Naming Convention for Imported Refined Products Energy Carriers.

Character number								
1	2	3	4	5	4/5/6	5/6/7	6/7/8	
Oil type					Technology type			Description
(see Table 14)					I	M	P	imported

Note: Some resource energy carriers have a '-0' at the end of the name. This is done for fuel accounting purposes in the model.

Table 16. Naming Convention for Imported Refined Products "Dummy" Collector Process Technologies.

Character number								
1	2	3	4	5	6	7	8	Final 3
Collector		Oil type						Technology type
S	C	(see Table 14)						IMP

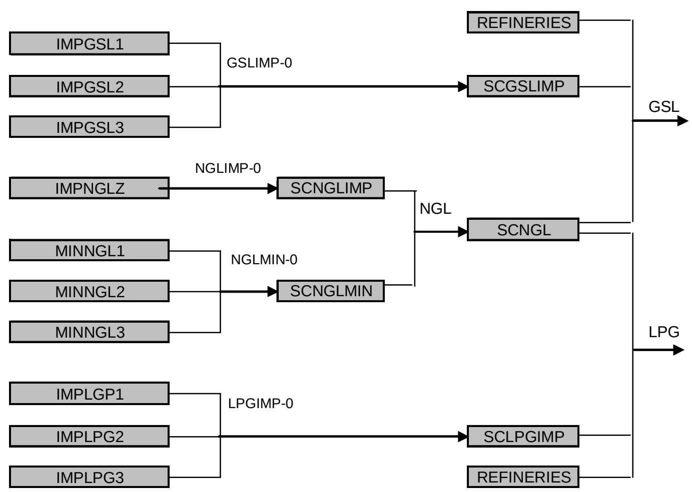


Figure 3. Imported GSL, NGL, and LPG RES in the EPANMD.

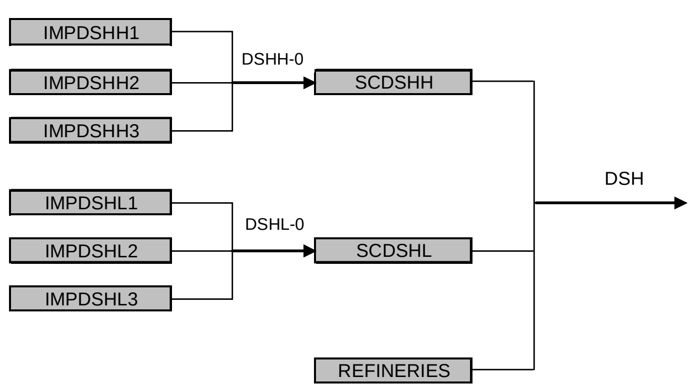


Figure 4. Imported Fuel Oil (DSH) RES in the EPANMD.

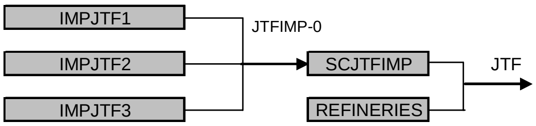


Figure 5. Imported Jet Fuel RES in the EPANMD.

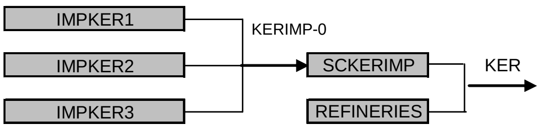


Figure 6. Imported Kerosene RES in the EPANMD.

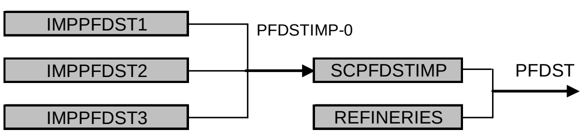


Figure 7. Imported Petroleum Feedstocks RES in the EPANMD.

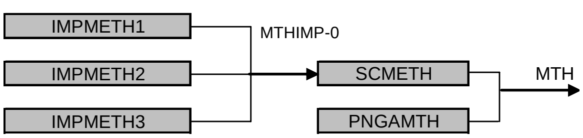


Figure 8. Imported Methanol RES in the EPANMD.

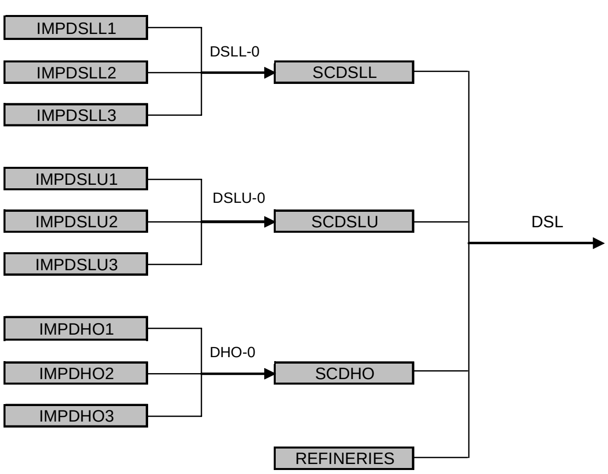


Figure 9. Imported Diesel RES in the EPANMD.

7.3.3 Imported Refined Products Parameters.

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules.

BOUND(BD)Or: For all imported refined products, the upper quantity bound has been calculated from the AEO2002 Supply Curves for Imported Refined Products by summing the imported quantities by step across the five AEO regions: East Coast, Midwest, Gulf Coast, Rocky Mountains, and West Coast; taking a five-year average centered on the MARKAL model year, and converting to petajoules. For the years 2021–2035, yearly bounds were generated by extrapolation using the average percentage change from 2016–2020, and then five-year averages were calculated.

COST: For all imported refined products, the cost has been calculated from the AEO2002 Supply Curves for Imported Refined Products by taking a quantity-weighted average of AEO step prices across the five AEO regions, taking a quantity weighted five-year average centered on the MARKAL model year, and converting to millions of 1995 dollars per petajoule. For years 2021–2035, yearly COSTs were generated by extrapolation using the average percentage change from 2016–2020, and then five-year averages were calculated.

START: For imported refined products and natural gas, all resources are assumed to be available at the beginning of the model time horizon, 1995.

7.4 Natural Gas

The natural gas supply curves were developed to estimate the future prices of natural gas corresponding to the projected future supply and demand levels. The natural gas resource supplies are characterized using a series of five stepped curves representing the incremental cost increases associated with increased demands in different time periods.

7.4.1 Natural Gas Data Sources

Data for the natural gas price/supply curves primarily comes from the North American Natural Gas Analysis System (NANGAS) Model used by the EPA's Integrated Planning Model (IPM). The resources in NANGAS model include over 20,000 individual reservoirs and undiscovered accumulations, frontier resources (which include Alaska North Slope, Mackenzie Delta, Sable Island, and LNG), and oil sands recovery in Western Canada. The resulting price/supply curves from the NANGAS model are plotted in Figure 10.

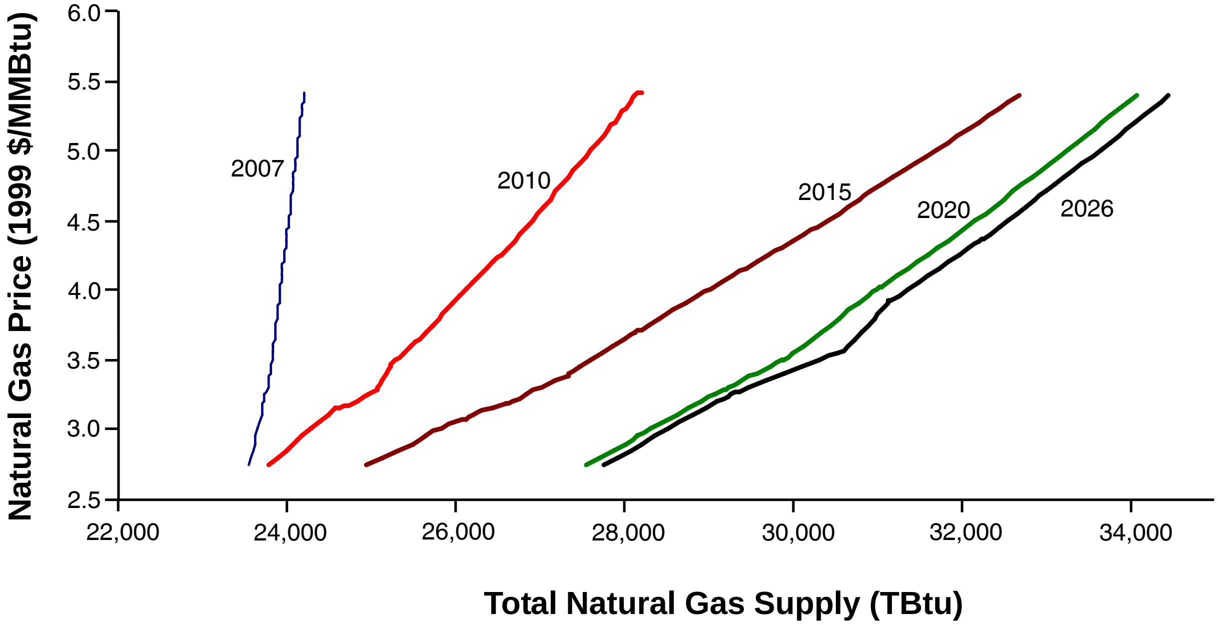


Figure 10. Price/Supply Curves for Years 2007, 2010, 2015, 2020, and 2026 from the NANGAS Model.

Note that the supply curves in NANGAS for the early years are steeper compared to later year supply curves. This is due to the fact that a substantial increase in gas demand and gas price for early modeling years will not easily result in any substantial increase in production and imports, etc, as substantial supply increases need lead times (U.S. EPA 2005). For example, according to EPA (2005), a new LNG terminal takes over 4 years to get certificated and built.

The price/supply curves from the NANGAS model are translated to a series of time dependent five step cost/supply curves and extrapolated to 2035. This cost/supply curve is different from the price/supply curve in that other factors, such as transportation, distribution, and sector-specific mark-ups will be added later to the system on top of the cost/supply curves. The final "price" will be the total cost that consumers paid at the system equilibrium.

The cost/supply curves for 2030 and 2035 are extrapolated based on the 2025 curve, assuming the same cost/supply curve will be applied for 2025, 2030, and 2035 except the curves for 2030 and 2035 reach much farther out to have more resources available at higher prices. The 2000 and 2005 points were based on the reported natural gas total consumption and well-head price from the Annual Energy Outlook 2006 (Energy Information Administration 2006).

The same cost/supply curves are applied for both domestic natural gas production and imports based on the rationale that, at market equilibrium, natural gas should have the same unit price regardless of its origin. Therefore, an ADRATIO is added to the database to constrain the ratio of domestic production and imports of natural gas based on EIA's AEO projections. The ratios used are listed in Table 17.

Table 17. Natural Gas Supply Domestic Production/Imports Ratios Used in the EPANMD.

Gas Source	ADRATIO in %						
	2005	2010	2015	2020	2025	2030	2035
Domestic prod.	81.1	79.3	78.3	79.1	77.4	76.1	76.1
Imports	18.9	20.7	21.7	20.9	22.6	23.9	23.9

7.4.2 Natural Gas RES

The naming conventions used for natural gas are described in Tables 18 – 20. The RES diagram is shown in Figure 12.

Table 18. Naming Convention for Natural Gas Resource Technologies.

Character number							
1	2	3	4	5	6	7	
Technology type			Resource type			step	Description
I	M	P	N	G	A	1	Imported, step 1
↓	↓	↓	↓	↓	↓	2	Imported, step 2
↓	↓	↓	↓	↓	↓	3	Imported, step 3
↓	↓	↓	↓	↓	↓	4	Imported, step 4
↓	↓	↓	↓	↓	↓	5	Imported, step 5
M	I	N	↓	↓	↓	1	mined, step 1
↓	↓	↓	↓	↓	↓	2	mined, step 2
↓	↓	↓	↓	↓	↓	3	mined, step 3
↓	↓	↓	↓	↓	↓	4	mined, step 4
↓	↓	↓	↓	↓	↓	5	mined, step 5

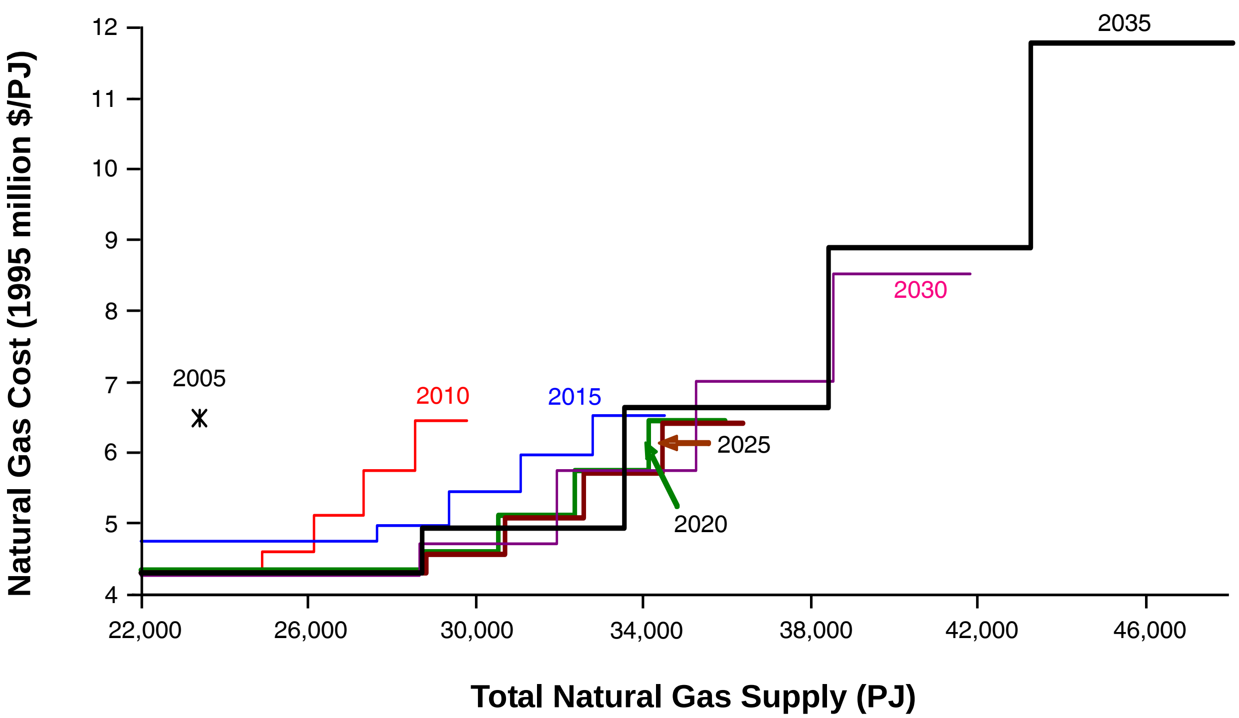


Figure 11. Cost/Supply Curves Used in the EPANMD.

Table 19. Naming Convention for Natural Gas Energy Carriers.

Character number						
1	2	3	4	5	6	
Resource type			Technology type			Description
O	I	L	M	I	N	mined NGA
			I	M	P	imported NGA

Note: Some resource energy carriers have a '-0' at the end of the name. This is done for fuel accounting purposes in the model.

Table 20. Naming Convention for Natural Gas "Dummy" Collector Process Technologies.

Character number								
1	2	3	4	5	6	7	8	
Collector		Resource type			Technology			Description
S	C	N	G	A	M	I	N	mined NGA
					I	M	P	impoerted NGA

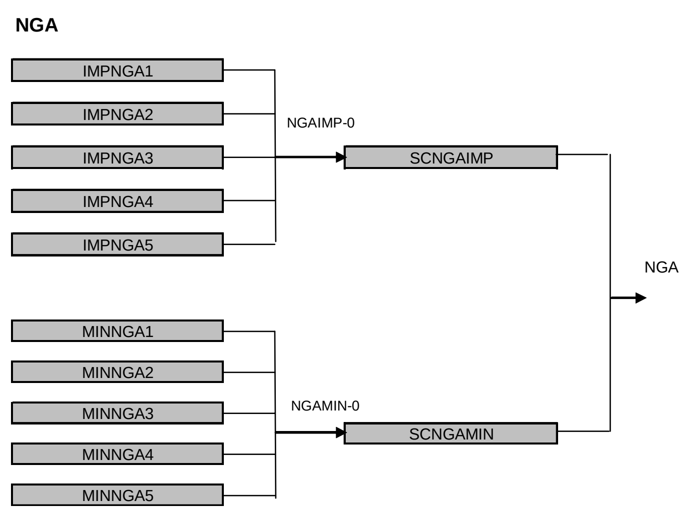


Figure 12. Natural Gas RES in the EPANMD.

7.4.3 Natural Gas Parameters

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules.

BOUND(BD)Or: The bounds for natural gas supply are derived from the five step cost/supply curves illustrated above. The 2000 and 2005 data are one-step upper bounds based on the reported natural gas supply from the AEO 2003 and 2006 (EIA 2003, EIA 2006). The cost/supply curves are further broken down to domestic production/imports based on the domestic production/import ratio projected by the AEO 2006. The resulting bounds for the domestic and import supply curves are listed in Table 21.

COST: Similar to BOUND(BD)Or, the costs for natural gas supply are derived from the five step cost/supply curves. The 2000 and 2005 data are based on the reported natural gas well-head price from the reference case Table 1 (Total Energy Supply and Disposition Summary) of AEO 2003 and 2006. The resulting costs for the domestic and import supply curves are listed in Table 22.

Table 21. BOUND(BD)Or for Domestic and Import NGA Supply Curves.

Technology	Bound	Value of BOUND(BD)Or Parameter for Years							
		2000	2005	2010	2015	2020	2025	2030	2035
MINNGA1	UP	20,427	19,568	20,190	22,123	23,293	22,989	22,627	22,411
MINNGA2	UP	0	0	988	1,370	1,467	1,512	2,599	3,778
MINNGA3	UP	0	0	988	1,370	1,467	1,512	2,599	3,778
MINNGA4	UP	0	0	988	1,370	1,467	1,512	2,599	3,778
MINNGA5	UP	0	0	988	1,370	1,467	1,512	2,599	3,778
IMPNGA1	UP	4,043	4,546	4,705	5,523	5,435	5,810	6,035	6,321
IMPNGA2	UP	0	0	230	342	342	382	693	1,066
IMPNGA3	UP	0	0	230	342	342	382	693	1,066
IMPNGA4	UP	0	0	230	342	342	382	693	1,066
IMPNGA5	UP	0	0	230	342	342	382	693	1,066

Table 22. Domestic and Import NGA Supply Costs.

Technology	Value of COST Parameter for Years							
	2000	2005	2010	2015	2020	2025	2030	2035
MINNGA1	3.19	6.05	4.35	4.75	4.34	4.30	4.26	4.28
MINNGA2	0	0	4.59	4.97	4.59	4.54	4.70	4.94
MINNGA3	0	0	5.13	5.44	5.13	5.09	5.73	6.63
MINNGA4	0	0	5.75	5.95	5.74	5.71	7.00	8.87
MINNGA5	0	0	6.45	6.51	6.43	6.40	8.53	11.77
IMPNGA1	3.19	6.05	4.35	4.75	4.34	4.30	4.26	4.28
IMPNGA2	0	0	4.59	4.97	4.59	4.54	4.70	4.94
IMPNGA3	0	0	5.13	5.44	5.13	5.09	5.73	6.63
IMPNGA4	0	0	5.75	5.95	5.74	5.71	7.00	8.87
IMPNGA5	0	0	6.45	6.51	6.43	6.40	8.53	11.77

Table 23. Domestic and Import NGA Supply Constraints.

Parameter	Technology	Constraint	Bound	Value of BOUND(BD)Or Parameter for Years							
				2000	2005	2010	2015	2020	2025	2030	2035
RAT__RHS	---	A_NGAIMP	FX			0	0	0	0	0	0
RAT_ACT	SCNGAIMP	A_NGAIMP	---			-0.811	-0.8002	-0.8108	-0.7983	-0.7894	-0.78
RAT_ACT	SCNGAMIN	A_NGAIMP	---			0.189	0.1998	0.1892	0.2017	0.2106	0.22

START: For natural gas, all resources are assumed to be available at the beginning of the model time horizon, 1995.

ADRATIO: As shown in Table 16, constraints are added to constrain the ratio of domestic production and imports of natural gas. The constraint values listed in Table 23 are in line with EIA's AEO projections.

7.5 Coal

There are 25 coal types represented in the EPANMD. For each of the 25 types, eight steps are characterized in each model year by a cost and the amount that can be produced at that cost. A cumulative amount that can be extracted from each type over the entire model horizon has also been assigned.

7.5.1 Coal Data Sources

Data for supply curves was taken from the coal supply curves underlying the AEO 2002 reference case, supplied by Mike Mellish of EIA. The reserves data were taken from EIA, 1999.

7.5.2 Coal Assumptions

Some AEO regions have been added together to produce MARKAL regions as illustrated in Table 24.

7.5.3 Coal RES

There are 25 supply curves for coal and, therefore, 25 energy carriers that the supply curve steps feed into. There are 10 coal collector process technologies and, therefore, 10 energy carriers that come from them. The naming con-

Table 24. MARKAL Coal Regions.

MARKAL Region	AEO Region
Appalachia	Northern Appalachia
	Central Appalachia
	Southern Appalachia
Interior	Eastern Interior
	Western Interior

ventions used for coal are described in Tables 25–29. Figure 13 shows an example RES flow chart for one of the coal resources: high sulfur surface bituminous coal from the Appalachian region.

7.5.4 Coal Parameters

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules.

BOUND(BD)Or: Bounds are calculated by multiplying the period averaged quantity by step from the AEO 2002 Coal Supply Curves by the average BTU content and converting to petajoules. This procedure produces the bounds for the years covered by the AEO source data, 2000–2020. The value for 1995 has been set equal to that for 2000, and the values for 2025–2035 have been set equal to that for 2020.

COST: Costs are calculated by dividing the period averaged AEO Step Price by the average BTU content. This procedure produces the costs for the years covered by the

Table 25. Examples of Coal Resource Technologies.

Name	Description
MINCABHS1	coal - Appalachia, bit., high sulfur, surface, step1
MINCALMS3	coal - Appalachia, lignite, med. sulfur, surface, step 3
MINCIBHS5	coal - interior, bit., high sulfur, surface, step 5
MINCPSMS8	coal - Powder R., subbit., med. sulfur, surface, step 8
MINCSSMS5	coal - Southwest, subbit, med. sulfur, surface, step 5
MINCSSMS6	coal - Southwest, subbit., med. sulfur, surface, step 6
MINCSSMS7	coal - Southwest, subbit., med. sulfur, surface, step 7
MINCSSMS8	coal - Southwest, subbit., med. sulfur, surface, step 8

Table 27. Naming Convention for Coal Energy Carriers.

Energy Carriers before Collector Technologies

Character Number				
1	2	3	4	5
coal	region	coal type	S content	mine type

Energy Carriers after Collector Technologies

1	2	3	4	5	6
C	O	A	L	coal type	S content

Table 28. Examples of Coal Energy Carriers.

Name	Description
CABMU	Appalachian bituminous medium sulfur underground coal
CGLMS	Gulf lignite medium sulfur surface coal
CIBHS	interior bituminous high sulfur surface coal
CNSMS	Northwest subbituminous medium surfur surface coal
CPSLS	Powder River subbituminous low sulfur surface coal

Table 29. Naming Convention for Coal “Dummy” Collector Process Technologies.

Character Number						
1	2	3	4	5	6	7
S	C	C	region	coal type	S content	mine type

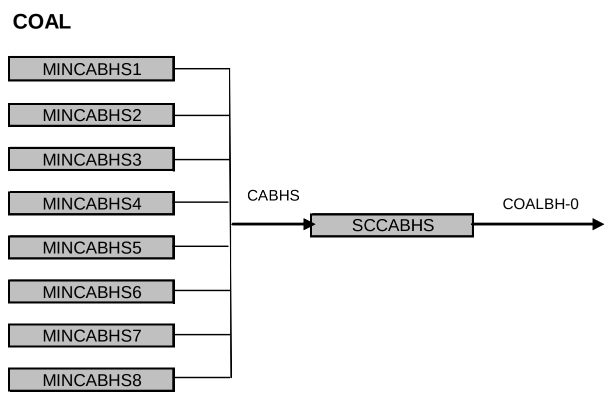


Figure 13. High Sulfur Bituminous Coal RES in the EPANMD.

Table 26. Naming Convention for Coal Resource Technologies.

Character Number											
1	2	3	4	5		6		7		8	
Technology		Type	Coal	Region	Description	Coal Type	Description	S Content	Description	Mine Type	Description
M	I	N	C	A	Appalachia	B	bituminous	H	high	S	surface
				D	Dakota	G	GOB	M	medium	U	underground
				G	Gulf	L	lignite	L	low		
				I	interior	M	metallurgical				
				N	Northwest	S	subbituminous				
				P	Powder River						
				R	Rocky Mountain						
				S	Southwest						

AEO source data, 2000–2020. The value for 1995 has been set equal to that for 2000, and the values for 2025–2035 have been set equal to that for 2020.

CUM: Total recoverable reserves by state, by grade and source, from the EIA report on the update of U.S. Coal Reserves for 1997 (EIA,1999) are summed into MARKAL regions and converted into petajoules. Reserve percentages by sulfur content derived from the EIA report are used to apportion reserves by sulfur content and by step. For each step in each resource curve, the fraction of the total resource belonging to that step is calculated by dividing the sum of its 2000–2020 quantity bounds by the sum of the bounds for all eight steps. This fraction is then multiplied by the total reserves for the appropriate coal type to get to the CUM for that step.

START: For coal, all resources are assumed to become available in the first model year, 1995.

7.6 Renewables

7.6.1 Biomass

Biomass resources are utilized in MARKAL for fuel and heat production as well as electricity generation. Biomass resources are organized in three separate categories: woody, herbaceous, and landfill gas from municipal solid waste.

Data Sources

Data on biomass resources were taken from the 1997 DOE MARKAL database.

RES

With respect to biomass, MARKAL includes renewable resources, energy carriers, processes, and conversion technologies. The sector uses the following naming conventions: RNW denotes renewable, BIOHC denotes herbaceous crop biomass, BMSWX denotes municipal solid waste, and BIOWD denotes woody biomass. Processes that convert biomass resources to other fuels are named starting with a P, followed by the type of biomass resource, and ending with the three letter description of the energy carrier the biomass is converted into. Figure 14 is the RES flowchart.

Parameters

Costs for biomass resources are expressed in millions of 1995 dollars per petajoule. Investment costs for biomass-related process technologies are expressed in million dollars per petajoule per year, the exception being biomass combined cycle electricity generation technologies, which

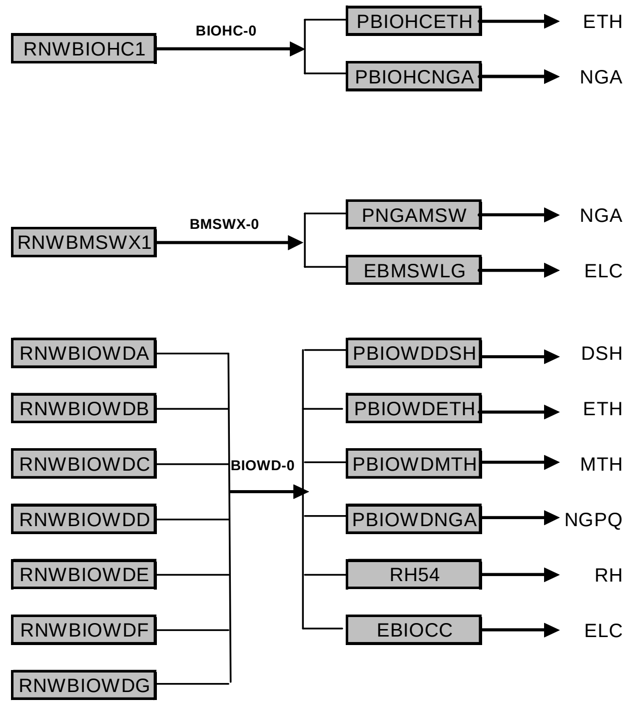


Figure 14. Biomass Resource RES.

are expressed in million dollars per gigawatt. Resource supply is defined in units of petajoule.

BOUND(BD)Or: With respect to woody biomass, this parameter specifies the maximum annual production available at each step cost. Annual limits were derived from the 1997 DOE MARKAL database.

COST: For woody biomass, costs were defined at each step according to data drawn from the 1997 DOE MARKAL database.

7.6.2 Wind, Solar, Hydro, and Geothermal

Wind, hydro, and geothermal resources are utilized in MARKAL for electricity production. Solar resources are utilized in MARKAL for both residential water heating and electricity production.

Data Sources

There are no costs associated with these resources. Geothermal has an upper bound in activity of 2500 PJ, which is based on the AEO2002 projection of geothermal use.

RES

Figure 15 shows the reference energy system for wind, hydro, and geothermal resources.

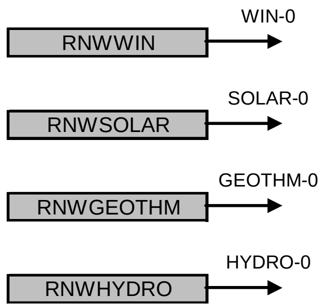


Figure 15. Wind, Solar, Hydro, and Geothermal Resource RES.

7.7 Export Technologies

7.7.1 Oil and Natural Gas Exports

MARKAL uses resource technologies to allow the export of some of the resource supplies. In the EPANMD, there are export technologies for coal, diesel, gasoline, and natural gas. Each technology has an input energy carrier, a cost equal to zero, and a fixed bound, listed in Table 30. These values are fixed to the export values found in the AEO2002. There is no fixed bound for diesel because there are no diesel exports in the AEO2002. The RES for oil and natural gas exports is shown in Figure 16.

Table 30. BOUND(BD)Or on Gasoline and NGA Exports.

Technology	1995	2000	2005	2010	2015	2020	2025	2030	2035
EXPGSL1	2268	2268	1797	2012	2129	2223	2223	2223	2223
EXPNGA	261	261	428	666	693	595	595	595	595

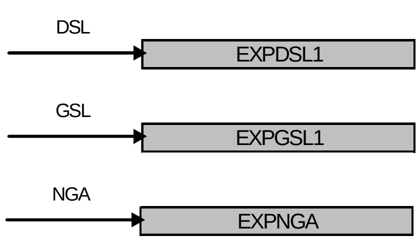


Figure 16. Oil and NGA Exports in the RES.

7.7.2 Coal Exports

There are 10 “dummy” collector process technologies used to collect coal for exporting. The collectors are used to collect export coal based on the distinctions by coal type (bituminous, sub-bituminous, metallurgical, and lignite) and sulfur content (low, medium, and high). Figure 17 shows one example of how the RES represents coal being collected and transported for export. The bounds for coal export, listed in Table 31, are set to the values in the AEO2002.

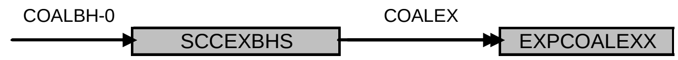


Figure 17. Coal Export RES Example.

Table 31. Coal Export BOUND(BD)Or.

Technology	1995	2000	2005	2010	2015	2020	2025	2030	2035
EXPCOALEXX	1612	1612	1492	1436	1414	1456	1498	1540	1582

8 Process Technologies

General process technologies are discussed below. Sector specific process technologies are discussed in the demand sector sections.

8.1 Process Technology Parameters

AF: Specifies the total annual availability of a technology. It is equal to the annual hours of actual availability divided by the total hours in a year.

INVCOST: Specifies the cost of investment in one incremental unit of new capacity.

INP(ENT)p: Specifies the amount of an energy carrier that is input to a process technology.

OUT(ENC)p: Specifies the amount of an energy carrier that is output from a process technology.

VAROM: Specifies the annual variable operating and maintenance costs associated with the installed capacity of a technology expressed as base year monetary units per unit of activity.

FIXOM: Specifies the annual fixed operating and maintenance costs associated with the installed capacity of a technology expressed as base year monetary units per unit of capacity.

LIFE: Specifies the lifetime of a technology in years.

START: Specifies the first time period of availability.

RESID: Specifies the residual capacity in each model year for technology stock already existing at the beginning of the modeling horizon (1995). Since the technology stock has been installed before the model start year, the investment cost is assumed to have already been expended and is therefore not included in the model.

BOUND(BD): Specifies a lower, upper, or fixed limit on a process technology's installed capacity in a specified period.

8.2 Refineries

The EPANMD representation of the refinery sector has three refinery types. S28 represents existing refinery conversion practices. S27 represents a high conversion refinery that can produce up to 50% of a dummy liquid intermediate that feeds S29, the high limit refinery, which can produce very high proportions of diesel and gasoline. This cascaded implementation of the refinery processes permits more flexibility within the sector.

8.2.1 Refinery RES

The reference energy system for refineries is illustrated in Figure 18.

8.2.2 Refinery Parameters

All costs are expressed in millions of 1995 dollars. Energy quantities are expressed in petajoules.

Cost and availability parameters

Table 32 lists the availability and cost parameters for the three refinery types. Data come from the 97 DOE MARKAL database.

Input and output parameters

INP(ENC)p: Refinery Energy consumption factors are calculated based on output of the reference case from EIA's AEO2002 by dividing the total refinery energy consumption (NEMS Table 35, Refining Industry Energy Consumption) by the sum of the total refinery production (Table 69, Domestic Refinery Production). The unit is in petajoules input per petajoules output. This simple approach assumes the same mix of energy input for all types of final product mix. Table 33 lists the energy demand for each of the refineries. The energy demands of the refineries increase slightly over time. This is due to the fact that more energy will be needed at the refinery in order to fuel emissions reduction retrofits to comply with more stringent environmental regulations.

Table 32. Cost and Availability Parameters for Refinery Types.

Parameter	S27 High Conversion Refinery	S28 Existing Conversion Refinery	S29 High Limit Refinery
AF	1.00	1.00	1.00
INVCOST	5.334	3.035	1.00
VAROM	0.239	0.216	0.1
FIXOM	0	0.071	0
LIFE	25	25	25
START	1995	1995	1995

OUT(ENC)p: The energy output (production per unit crude oil) is also modified from the AEO 2002. NEMS Table 31. Refinery Production, MBCD, PADD6 is divided by the total annual crude oil production of the AEO 2002 Table 1. Total Energy Supply and Disposition Summary.

The sum of energy carrier output, OUT(ENC)p, for each refinery is greater than one, and therefore, LIMIT=1 is imposed as the maximum sum of all output carrier units per unit of activity. When LIMIT is used, OUT(ENC)p then represents the maximum production of each carrier instead of the fixed proportional production of each carrier. This allows MARKAL (and thus, the refineries) to vary that output of the facility to meet demands. In this way, the blend and output of the refinery can be chosen by the MARKAL optimization procedure. Table 34 lists the

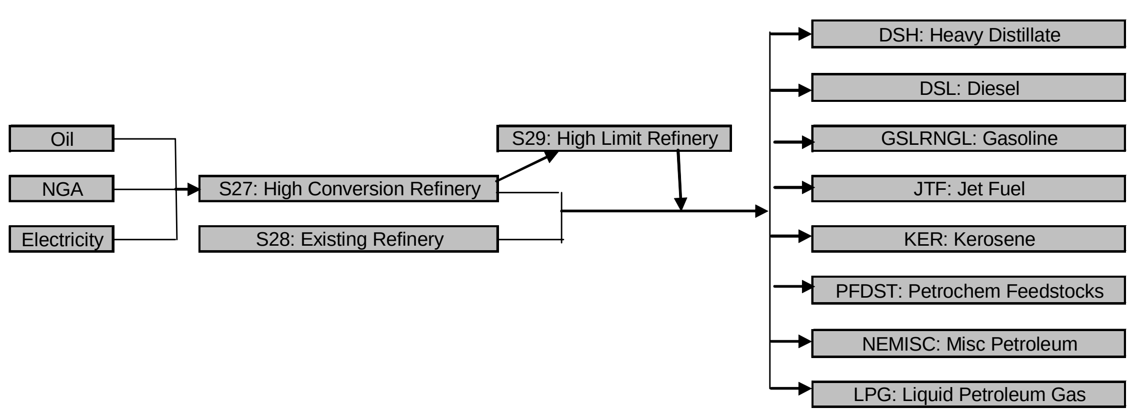


Figure 18. Refinery RES.

Table 33. Input Energy Carrier INP(ENC)p Values (units are in PJ/PJ).

Refinery	Parameter	1995	2000	2005	2010	2015	2020	2025	2030	2035
S27	OIL	1	1	1	1	1	1	1	1	1
S27	INDELC	0.0034	0.0034	0.0038	0.0048	0.0051	0.0051	0.0051	0.0051	0.0051
S27	NGAIEA	0.0254	0.0254	0.0271	0.0272	0.0247	0.0238	0.0256	0.0257	0.0257
S28	OIL	1	1	1	1	1	1	1	1	1
S28	INDELC	0.0034	0.0034	0.0038	0.0048	0.0051	0.0051	0.0051	0.0051	0.0051
S28	NGAIEA	0.0254	0.0254	0.0271	0.0272	0.0247	0.0238	0.0256	0.0257	0.0257
S29	DLG	1	1	1	1	1	1	1	1	1

product mixes and maximum production for each of the refineries.

Table 34. Output Energy Carrier OUT(ENC)p Values (units are in PJ/PJ).

Parameter	S27 High Conversion Refinery	S28 Existing Conversion Refinery	S29 High Limit Refinery
DLG	0.5	—	—
DSH	0.0552	0.06	0.6
DSL	0.312	0.23	0.3
GSLRNGL	0.864	0.51	0.3
JTF	0.216	0.1	1
KER	0.0072	0.01	0.04
LPG	0.0552	0.05	0.05
NEMISC	0.24	0.12	0.2
PFDST	0.048	0.03	0.1

Other parameters

RESID: The Existing Conversion refinery has residual capacity starting in 1995 that is set equal to its bound on capacity. In other words, the stated RESID, is the only capacity that will be available for Existing Conversion refineries. No new capacity will be installed. The RESID data for the Existing Conversion refinery, S28, comes from two sources: EIA AEO (2004) Figure 100 (Domestic refining capacity in three cases) and Table 68 (Domestic Refinery Distillation Base Capacity, Expansion, and Utilization). The RESID equals the existing capacity minus the expected retirement by year.

BOUND(BD): The High Conversion refinery has a capacity bound starting in the year 2010. Therefore, there will always be a limit to the amount of refinery capacity available to the model.

According to the EIA, new refinery construction is three to four times more expensive than capacity expansion at an existing site. However, there is no easy way in MARKAL to allow capacity expansion at the same facility. Therefore, the only expansion allowed in MARKAL is new capacity at an existing refinery plant (i.e., S27 and its extension S29). Bound on domestic capacity of S27 is calculated based on the extrapolation of the Figure 100 high growth scenario. The relevant capacity upper bound and residual capacity for existing and high conversion refineries are listed in Table 35. All values are expressed in petajoules per year.

8.2.3 Refinery Emissions

The refinery process emission factor calculations are based on a model for refinery emissions developed by Delucchi (2003). The emission factor change over time is based on assumptions about the fraction of equipment that includes emission controls. The assumptions used for this analysis are defaults from Delucchi 2003, reflecting his judgement on best values for reproducing EPA estimates. These emissions are all process emissions (i.e., emissions NOT due to combustion of fuels). However, they do include combustion of some by-products—e.g., CO and non-methane organic compounds (NMOCs). Process emissions tend to decrease over time due to increased use of control technologies. CO and NMOCs emissions are controlled by burning the CO or NMOC, which produces CO_2. Therefore, increased controls of CO and NMOC will lead to increased CO_2 emissions. The unit of emission factors listed in Table 36 is thousand tones per petajoule, excepting CO_2 emission factors, which is in million tones per petajoule.

8.3 Coal Gasification

The EPANMD has three process technologies for coal gasification: high BTU coal gasification, medium BTU coal gasification, and in-situ gasification.

8.3.1 Gasification RES

Each coal type passes through a “dummy” process technology which tracks the emissions and then through the gasification process. Each process produces pipeline quality natural gas (NGPQ). The reference energy system for coal gasification is shown in Figure 19.

Table 35. Existing Refinery Residual Capacity and Bound on Capacity, High Conversion Bound on Capacity.

Refinery	Parameter		1995	2000	2005	2010	2015	2020	2025	2030	2035
S27	BOUND(BD)	UP	0	185	3,323	9,330	13,262	17,106	19,354	21,602	23,850
S28	BOUND(BD)	UP	34,240	36,880	35,367	34,010	34,010	33,429	32,849	32,268	31,687
S28	RESID	—	34,240	36,880	35,367	34,010	34,010	33,429	32,849	32,268	31,687

Table 36. Emission factors of Existing Refinery (S28) and High Conversion Refinery (S27).

Refinery	Parameter	1995	2000	2005	2010	2015	2020	2025	2030	2035
S27	CO2[a,b]	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
S27	COI	0.1996	0.2029	0.2048	0.2059	0.2065	0.2069	0.2084	0.2099	0.2113
S27	NOI	0.0020	0.0021	0.0021	0.0021	0.0022	0.0022	0.0022	0.0022	0.0022
S27	P10	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
S27	SO2[c]	0.0047	0.0041	0.0037	0.0034	0.0032	0.0031	0.0028	0.0025	0.0023
S27	SOI	0.0047	0.0041	0.0037	0.0034	0.0032	0.0031	0.0028	0.0025	0.0023
S27	VOC	0.0112	0.0075	0.0053	0.0041	0.0034	0.0031	0.0022	0.0015	0.0010
S28	CO2	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
S28	COI	0.1996	0.2029	0.2048	0.2059	0.2065	0.2069	0.2084	0.2099	0.2113
S28	NOI	0.0020	0.0021	0.0021	0.0021	0.0022	0.0022	0.0022	0.0022	0.0022
S28	P10	0.0007	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0005	0.0005
S28	SO2	0.0047	0.0041	0.0037	0.0034	0.0032	0.0031	0.0028	0.0025	0.0023
S28	SOI	0.0047	0.0041	0.0037	0.0034	0.0032	0.0031	0.0028	0.0025	0.0023
S28	VOC	0.0112	0.0075	0.0053	0.0041	0.0034	0.0031	0.0022	0.0015	0.0010

[a] All emission factors are in thousand tonnes per petajoule excepting CO2, which is in million tonnes per petajoule.
[b] CO_2 emission factors are in million tonnes carbon rather than CO_2.
[c] SO_2 emission factors are in thousand tonnes sulfur rather than SO_2.

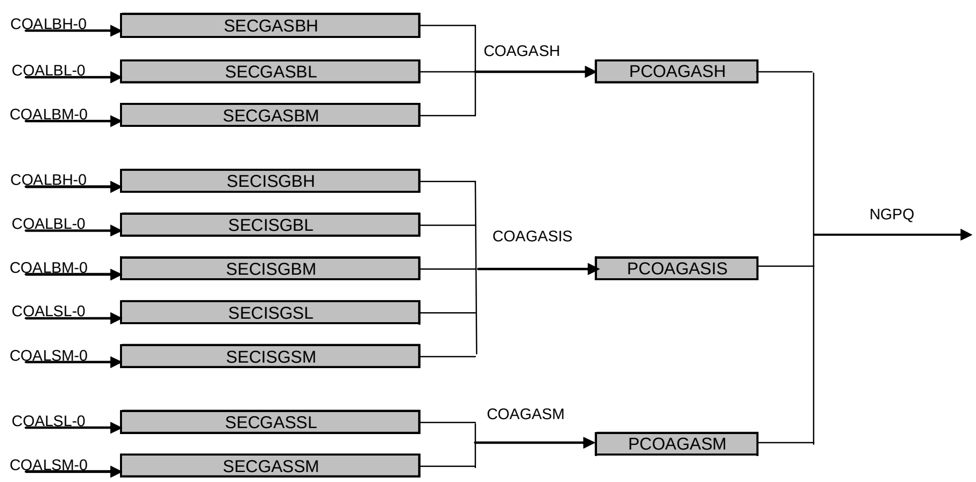


Figure 19. Coal Gasification RES.

8.3.2 Gasification Parameters

All data came from the 1997 DOE MARKAL database. All costs, listed in Table 37, are expressed in millions of 1995 dollars, and energy quantities, listed in Table 38, are in petajoules.

Table 37. Cost and Availability Parameters for Gasification.

Parameter	PCOAGAASH High Btu Coal Gasification	PCOAGASM Medium Btu Coal Gasification	PCOAGASIS In-situ Gasification
AF	0.90	0.90	0.90
INVCOST	40.003	48.049	36.669
VAROM	7.506	7.472	7.506
LIFE	30	30	20
START	2000	2000	2005

8.4 Other Natural Gas Process Technologies

There are three additional process technologies that transform in some way the natural gas energy carrier (NGA).

Table 38. Bounds on Gasification Capacity in PJ per Year.

Technology	1995	2000	2005	2010	2015	2020	2025	2030	2035
High Btu Gasification	—	128	128	253	378	563	565	565	565
Medium Btu Gasification	—	505	1000	1800	2600	3400	4200	4600	5000
In-situ Gasification	—	—	62.5	100	325	550	775	887.5	1000

The cost values all come from the 1997 DOE MARKAL database. All costs are expressed in millions of 1995 dollars, and energy quantities are expressed in petajoules.

8.4.1 Pipeline Quality NGA

Before going to the demand sectors, NGA passes through a process, shown in Figure 20, to transform it into pipeline quality Natural Gas (NGPQ), and there are some costs associated with this. The parameters associated with pipeline quality natural gas are

- INVCOST: 14.369
- RESID: 21000
- LIFE: 45
- INP(ENT)p: 1.0417 (it is assumed that there is some gas loss in the pipeline)

Figure 20. Pipeline Quality NGA RES.

8.4.2 Natural Gas Compression

Pipeline quality natural gas is compressed (CNG), Figure 21, for use in CNG fueled vehicles. The parameters associated with compressing natural gas are

- INP(ENT)p: 1.0753
- AF: 0.75

Figure 21. CNG RES.

8.4.3 Methanol from Natural Gas

Pipeline quality natural gas is processed into methanol, Figure 22, for the transportation and electric generation sectors. The parameters associated with processing methanol from natural gas are

- INVCOST: 36.681
- VAROM: 4.713
- BOUND(BD): 325
- AF: 0.9
- LIFE: 30
- INP(ENT)p: 1.0

Figure 22. Methanol from NGA RES.

8.5 Coke

Coke is fuel produced by partially burning coal in a reduced oxygen atmosphere. This removes most of the gasses, leaving a solid that burns at a higher temperature than coal. There are two grades of coke in the EPANMD. Chemical grade coke is a lower grade and is used for reducing phosphate rock in electric furnaces and in the production of calcium carbide. In the EPANMD this is referred to as COKE. Metallurgical grade coke produces a much higher temperature and is used as the heat source in blast furnaces primarily for making iron and steel. In the EPANMD this is referred to as COMET.

8.5.1 Coke RES

Imported COMET is put into a "dummy" collector process, SCCMETIMP. Metallurgical low- and medium- sulfur coal pass through a "dummy" emissions accounting process. All three resources are then fed into a coking furnace process, PCOKE, which produces the energy carrier COKE. Imported coke is put into a "dummy" collector process, SCCOKEIMP, which can then become the emissions carrier COKE. The reference energy system for coke is shown in Figure 23.

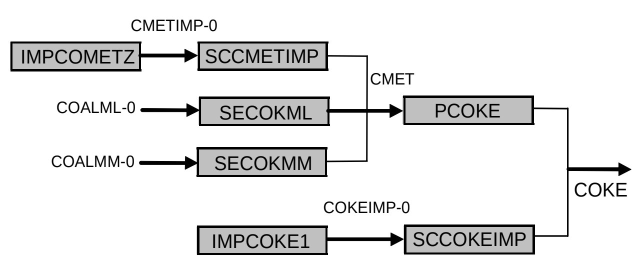


Figure 23. Coke RES.

8.5.2 Coke Parameters

The emissions and collector "dummy" process technologies have no costs associated with them. The only process parameters are for the coking process, PCOKE. The cost values all come from the 1997 DOE MARKAL database and are expressed in millions of 1995 dollars. Energy quantities are expressed in petajoules.

- INP(ENT)p: 1.4286
- INVCOST: 16.208
- FIXOM: 2.586
- LIFE: 30
- RESID: The RESID is 2200 in 1995 and is linearly decreased by 367 each time period until all the RESID is gone.

9 Conversion Technologies

9.1 Electricity Generation

This section describes the parameters and sources of data used to characterize electricity generation technologies in the EPANMD. Cogeneration, a specific type of electric generation process, is discussed in the Industrial Sector description.

9.1.1 Electricity Data Sources

Original data for this sector was taken from the six sources that are listed below in order of the priority they were used:

- EIA Annual Energy Outlook (AEO) 2002 Tables 38, 45, and 69;
- EIA Annual Energy Outlook 2002 Reference Case Performance Characteristics;
- National Energy Technology Laboratory;
- "Supporting Analysis for the Comprehensive Electricity Competition Act", DOE/PO-0059;
- 1993 EPRI TAG guide; and
- 1997 DOE MARKAL database.

These data sources are applied in MARKAL as listed in Table 39.

9.1.2 Electricity RES

The Electric Generation RES, shown in Figure 24, consists of conversion technologies and import electricity resource technologies that all output electricity to the system. At the front end of the conversion technologies, emissions are tracked through "dummy" emissions tracking process technologies.

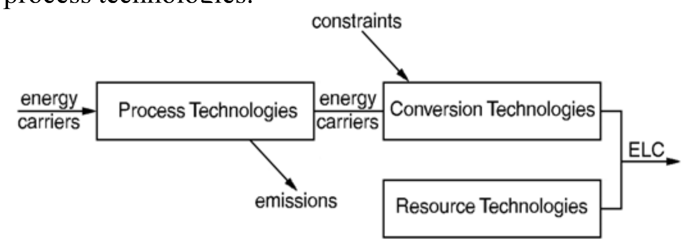


Figure 24. Electrical Generation Sector RES.

9.1.3 Electricity Resource Technologies

The EPANMD has three resource steps for import electricity as shown in Figure 25. Each step has an upper bound and a cost for each unit of available electricity (similar to the step curves for other resource technologies). The values for cost and upper bound were taken from the 1997 DOE MARKAL database.

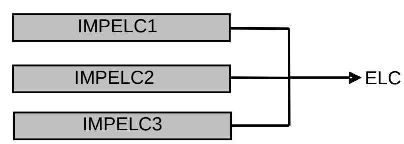


Figure 25. Imported Electricity Resource Technologies.

9.1.4 Electricity Conversion Technologies

The first letter in the name reflects the technology sector. In this case 'E' is used for 'Electricity'. The next three or four characters represent the fuel type and the remaining

Table 39. Data Sources for Electric Sector Technologies.

MARKAL	Technology Name	Cap. Cost Source	O&M Source	Heat Rate Source
EWINLWT	Local wind turbine	1997 MARKAL	1997 MARKAL	1997 MARKAL
ECOAMCFC	Coal gasification molten carb. fuel cell	1997 MARKAL	1997 MARKAL	1997 MARKAL
EMTHFC	Methanol fuel cell	1997 MARKAL	1997 MARKAL	1997 MARKAL
EDSLICE	Diesel internal combustion engine	1997 MARKAL	1997 MARKAL	1997 MARKAL
ENGAGCE	Existing natural gas combined cycle	AEO 2002	AEO 2002	AEO 2002
ENGASTM	Natural gas steam	AEO 2002	AEO 2002	AEO 2002
ENGACTE	Existing natural gas combustion turbine	AEO 2002	AEO 2002	AEO 2002
ENUCCONV	Conventional nuclear	AEO 2002	AEO 2002	AEO 2002
EDSHSTM	Residual fuel oil steam	AEO 2002	AEO 2002	AEO 2002
EDSLCT	Distillate oil combustion turbine	AEO 2002	AEO 2002	AEO 2002
EHYDROPS	Hydroelectric pumped storage	AEO 2002	AEO 2002	AEO 2002
EHYDRO	Hydroelectric	AEO 2002	AEO 2002	AEO 2002
ESOLPVR	Photovolataic—residential	AEO 2002, Table 12	1997 MARKAL	AEO 2002, Table 38
ENGADGB05	Distributed generation—base—2005	AEO 2002, Table 38	AEO 2002, Table 38	AEO 2002, Table 38
ENGADGB10	Distributed generation—base—2010	AEO 2002, Table 38	AEO 2002, Table 38	AEO 2002, Table 38

continued

Table 39 (concluded). Data Sources for Electric Sector Technologies.

MARKAL	Technology Name	Cap. Cost Source	O&M Source	Heat Rate Source
ENGADGP	Distributed generation—peak	AEO 2002, Table 38	AEO 2002, Table 38	AEO 2002, Table 38
ENGAFC	Gas fuel cell	AEO 2002, Table 38	AEO 2002, Table 38	AEO 2002, Table 38
ENUCADV	Advanced nuclear	AEO 2002, Table 38	AEO 2002, Table 38	AEO 2002, Table 38
ECOAIGC00	Integrated coal gasif. combined cycle—2000	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ECOAIGC05	Integrated coal gasif. combined cycle—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ECOAIGC10	Integrated coal gasif. combined cycle—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ECOANSE00	Pulverized coal—2000	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ECOANSE05	Pulverized coal—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ECOANSE10	Pulverized coal—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAGC00	Natural gas combined cycle—2000	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAGC05	Natural gas combined cycle—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAGC10	Natural gas combined cycle—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAAGC05	Natural gas advanced combined cycle—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAAGC10	Natural gas advanced combined cycle—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGACT00	Natural gas combustion turbine—2000	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGACT05	Natural gas combustion turbine—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGACT10	Natural gas combustion turbine—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAACT05	Natural gas advanced combustion turbine—2005	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
ENGAACT10	Natural gas advanced combustion turbine—2010	AEO 2002, Table 45	AEO 2002, Table 38	AEO 2002, Table 45
EBIOCC	Biomass gasification combined cycle	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
EGEOBCFS	Geothermal binary cycle and flashed steam	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
EBMSWLG	Municipal solid waste-landfill gas	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
ESOLCT	Solar central thermal	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
ESOLCPV	Central photovoltaic	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
EWINCELC	Wind central electric	AEO 2002, Table 69	AEO 2002, Table 38	AEO 2002, Table 38
ECOAPFB	Pressurized fluidized bed	NETL	NETL	NETL
ECOASTMB	Existing bituminous coal steam	TAG	AEO 2002	AEO 2002
ECOASTMS	Existing sub-bituminous coal steam	TAG	AEO 2002	AEO 2002
ECOASTML	Existing lignite steam	TAG	AEO 2002	AEO 2002
ECOANSER	Repowered existing coal powered facilities	TAG	AEO 2002	AEO 2002

characters are used to represent the technology type. Numbers are then used to refer to the vintage, the first year of availability. Table 40 lists the electricity conversion technologies.

Table 40. Electricity Conversion Technologies.

Name	Electricity Conversion Technology
ECOAIGC00	integrated coal gasif. combined cycle—2000
ECOAIGC05	integrated coal gasif. combined cycle—2005
ECOAIGC10	integrated coal gasif. combined cycle—2010
ECOAPFB	pressurized fluidized bed
ECOASTMB	existing bituminous coal steam
ECOASTMS	existing sub-bituminous coal steam
ECOASTML	existing lignite steam
ECOACFP00	pulverized coal—2000
ECOACFP05	pulverized coal—2005
ECOACFP10	pulverized coal—2010
ECOACFPR	repowered existing coal powered facilities
ENGADGB05	distributed generation—base—2005
ENGADGB10	distributed generation—base—2010
ENGADGP	distributed generation—peak
ESOLPVR	photovolataic—residential
EWINLWT	local wind turbine
ECOAMCFC	coal gasification molten carb fuel cell
ENGAFC	gasoline fuel cell
EMTHFC	methanol fuel cell
ENGAGCE	existing natural gas combined cycle

continued

Table 40 (concluded). Electricity Conversion Technologies.

Name	Electricity Conversion Technology
ENGAGCE	existing natural gas combined cycle
ENGAGC00	natural gas combined cycle—2000
ENGAGC05	natural gas combined cycle—2005
ENGAGC10	natural gas combined cycle—2010
ENGAAGC05	natural gas advanced combined cycle—2005
ENGAAGC10	natural gas advanced combined cycle—2010
ENGASTM	natural gas steam
ENGACTE	existing natural gas combustion turbine
ENGACT00	natural gas combustion turbine—2000
ENGACT05	natural gas combustion turbine—2005
ENGACT10	natural gas combustion turbine—2010
ENGAACT05	natural gas advanced combustion turbine—2005
ENGAACT10	natural gas advanced combustion turbine—2010
ENUCCONV	conventional nuclear
ENUCADV	advanced nuclear
EDSLICE	diesel internal combustion engine
EDSHSTM	residual fuel oil steam
EDSLCT	distillate oil combustion turbine
EHYDROPS	hydroelectric pumped storage
EBIOCC	biomass gasification combined cycle
EGEOBCFS	geothermal binary cycle and flashed steam
EHYDRO	hydroelectric
EBMSWLG	municipal solid waste-landfill gas
ESOLCT	solar central thermal
ESOLCPV	central photovoltaic
EWINCELC	wind central electric

9.1.5 Electricity Process Technologies

The only process technologies used in the electricity generation sector are "dummy" technologies for tracking emissions. Those processes are described in Section 9.1.8, Electricity Emissions Accounting.

9.1.6 Electricity Parameters

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules. Capacities are expressed in gigawatts, while activities (production of electricity) are expressed in petajoules.

Availability parameters

START: The start year specifies the first time period of availability of a technology within the model time horizon.

LIFE: Specifies the number of years for which a technology's capacity may be utilized. The data for this parameter comes from the 1997 DOE MARKAL database, and its value is listed in Table 41.

AF: Specifies the total annual availability of a technology in each period. The data for this parameter comes from "Supporting Analysis for the Comprehensive Electricity Competition Act", Table C4 and the 1997 DOE MARKAL database, and its value is listed in Table 41.

AF_TID: Specifies the fraction of the total unavailability of a technology that is forced outage. The remaining unavailability is assumed to be scheduled outage. The data for this parameter comes from "Supporting Analysis for the Comprehensive Electricity Competition Act", Table C4 and the 1997 DOE MARKAL database, and its value is listed in Table 41.

AF(Z)(Y): Specifies the availability for technologies whose availabilities vary by season (Z) and time-of-day (Y). The availability accounts for both forced and scheduled outages in each time division. In MARKAL, Z refers to season, S = summer, I = intermediate (spring and autumn), and W = winter. Y refers to time-of-day, D = day, and N = night. AF(Z)(Y) is a fraction calculated as the hours of availability in the specified season and time-of-day divided by the total hours in the specified season and time-of-day. The data for this parameter comes from the 1997 DOE MARKAL database.

CF(Z)(Y): Specifies the capacity utilization rate of a fixed capacity utilization technology in each season (Z) and time-of-day (Y). The utilization rate applies to fixed capacity utilization technologies that can have seasonal or diurnal variations in capacity utilization. It is generally measured as the average of the utilization for each season and time-of-day division in each year over the period. The data for this parameter comes from the 1997 DOE MARKAL database.

PEAK(CON): Specifies the fraction of a generation technology's capacity that can be counted on to be available to meet peak demand and reserve margin requirements based on its availability, reliability, and other considerations. The data for this parameter come from the 1997 DOE MARKAL database, and its value is listed in Table 41.

IBOND(BD): This parameter can be used to place an upper (UP), lower (LO), or fixed (FX) bound on investment in new capacity. In this sector, it has primarily been used to prevent investment in an older vintage technology once a newer vintage has become available (upper bound of zero).

Table 41. Availability Values for Electric Sector Technologies.

MARKAL	Technology	LIFE Technical Lifetime	AF Availability Fraction	AF_TID Fraction of Unavailability that is Forced	PEAK(CON) Fraction of Capacity for Peak and Reserve
ECOAIGC00	Integrated coal gasif. combined cycle—2000	30	0.846	0.3727	0.899
ECOAIGC05	Integrated coal gasif. combined cycle—2005	30	0.846	0.3727	0.899
ECOAIGC10	Integrated coal gasif. combined cycle—2010	30	0.846	0.3727	0.899
ECOAPFB	Pressurized fluidized bed	40	0.85	0.5	0.8
ECOASTMB	Existing bituminous coal steam	40	0.846	0.3727	0.96
ECOASTMS	Existing sub-bituminous coal steam	40	0.846	0.3727	0.96
ECOASTML	Existing lignite steam	40	0.846	0.3727	0.96
ECOACFP00	Pulverized coal—2000	40	0.85	0.3727	0.96
ECOACFP05	Pulverized coal—2005	40	0.85	0.3727	0.96
ECOACFP10	Pulverized coal—2010	40	0.85	0.3727	0.96
ECOACFPR	Repowered existing coal powered facilities	30	0.846	0.3727	0.865

continued

Table 41 (concluded). Availability Values for Electric Sector Technologies.

MARKAL	Technology	LIFE Technical Lifetime	AF Availability Fraction	AF_TID Fraction of Unavailability that is Forced	PEAK(CON) Fraction of Capacity for Peak and Reserve
ENGADGB05	Distributed generation—base—2005	30	0.835	0.63	0.96
ENGADGB10	Distributed generation—base—2010	30	0.835	0.63	0.96
ENGADGP	Distributed generation—peak	30	0.835	0.63	0.96
ESOLPVR	Photovolataic—residential	20	—[a]	—	0.3
EWINLWT	Local wind turbine	20	—	—	0.3
ECOAMCFC	Coal gasification molten carb. fuel cell	30	0.87	0.7957	0.6
ENGAFC	Gasoline fuel cell	30	0.87	0.7957	0.6
EMTHFC	Methanol fuel cell	30	0.87	0.7957	0.6
ENGAGCE	Existing natural gas combined cycle	30	0.906	0.5729	1
ENGAGC00	Natural gas combined cycle—2000	30	0.906	0.5729	0.94
ENGAGC05	Natural gas combined cycle—2005	30	0.906	0.5729	0.94
ENGAGC10	Natural gas combined cycle—2010	30	0.906	0.5729	0.94
ENGAAGC05	Natural gas advanced combined cycle—2005	30	0.906	0.5729	0.862
ENGAAGC10	Natural gas advanced combined cycle—2010	30	0.906	0.5729	0.862
ENGASTM	Natural gas steam	40	0.846	0.3727	0.96
ENGACTE	Existing natural gas combustion turbine	30	0.924	0.4675	0.96
ENGACT00	Natural gas combustion turbine—2000	30	0.924	0.4675	0.96
ENGACT05	Natural gas combustion turbine—2005	30	0.924	0.4675	0.96
ENGACT10	Natural gas combustion turbine—2010	30	0.924	0.4675	0.96
ENGAACT05	Natural gas advanced combustion turbine—2005	30	0.924	0.4675	0.944
ENGAACT10	Natural gas advanced combustion turbine—2010	30	0.924	0.4675	0.944
ENUCCONV	Conventional nuclear	40	0.8	0.4162	0.85
ENUCADV	Advanced nuclear	40	0.85	0.3838	0.85
EDSLICE	Diesel internal combustion engine	20	0.835	0.63	0.96
EDSHSTM	Residual fuel oil steam	40	0.846	0.3727	0.9825
EDSLCT	Distillate oil combustion turbine	30	0.924	0.4675	0.96
EHYDROPS	Hydroelectric pumped storage	50	—	1	0.95
EBIOCC	Biomass gasification combined cycle	30	0.8	0.8	0.84
EGEOBCFS	Geothermal binary cycle and flashed steam	30	0.635	1	0.63
EHYDRO	Hydroelectric	60	0.44	0.1	0.944
EBMSWLG	Municipal solid waste-landfill gas	30	—	—	0.9
ESOLCT	Solar central thermal	30	—	—	0.3
ESOLCPV	Central photovoltaic	30	—	—	0.5
EWINCELC	Wind central electric	30	—	—	0.3

[a] Dashed entries represent technologies whose output varies by time of day and/or season and is specified by the parameter AF(Z)(Y) instead.

Cost parameters

AEO2002: Cost and performance characteristics from EIA's AEO2002 Reference Case. These inputs represent EIA's assumptions about costs and heat rates.

Assumptions to the AEO 2002 Table 38: AEO 2002 Cost and Performance Characteristics of New Electricity Generating Technologies

Assumptions to the AEO 2002 Table 45: Cost and Performance Characteristics for Fossil-Fueled Generating Technologies: Three Cases

Assumptions to the AEO 2002 Table 69: Cost and Performance Characteristics for Renewable Energy Generating Technologies: Two Cases

INVCOST: Specifies the cost of investment in one incremental unit of new capacity. Values were taken directly from these sources and converted from their original units to the MARKAL units of millions of 1995 dollars per gigawatt.

VAROM: Specifies the annual variable operating and maintenance coasts. Values were taken directly from these sources and converted from their original units to the MARKAL units of millions of 1995 dollars per petajoule.

FIXOM: Specifies the fixed operating and maintenance costs for a technology. Values were taken directly from these sources and converted from their original units to the MARKAL units of millions of 1995 dollars per gigawatt.

Input and output parameters

INP(ENT)c: The Heat rate. Specifies the amount of energy input needed to produce one unit of electricity output. Values were taken directly from these sources and converted from their original units of British thermal units per kilowatt and converted to the MARKAL units of petajoules per petajoule.

OUT(ELC)_TID: Specifies that electricity is produced by the technology. The value of 1 indicates that each technology only produces electricity.

Other MARKAL parameters
CAPUNIT: This parameter is used to provide MARKAL with the conversion factor for converting from a technology's capacity unit (gigawatts) to its activity unit (petajoules). The value is 31.536 PJ/GW for all technologies in this sector.

RESID: Specifies the residual installed technology stock in place at the beginning of the model horizon and its projection over time. 1995 data for this parameter comes from 1995 EIA Form 860 utility data (net summer capability) and the 1995 Electric Power Annual Volume II, Table 52, Summary Statistics for U.S. Nonutility Power Producers. Residual stocks are then assumed to depreciate according to their technical lifetimes (LIFE parameter).

9.1.7 Electricity Energy Carriers

Twenty energy carriers go to the electricity conversion technologies. Two of them are universal and go to all sectors: woody biomass (BIOWD-0) and municipal solid waste (BSMWX-0). Table 42. lists the other energy carriers.

Table 42. Electric Sector Energy Carriers.

MARKAL	Electricity Generation Energy Carriers
COAEAFB	Coal to atmospheric fluidized bed
COAEIGC	Coal to integrated gasification combined cycle
COAEMCFC	Coal to molten carbide fuel cells
COAECFG	Coal to new and repowered coal-fired generation
COAEPFB	Coal to pressurized fluidized bed
CSTMBITE	Bituminous coal to existing steam electric
CSTMLIGE	Lignite to existing steam electric
CSTMSUBE	Subbituminous coal to existing steam electric
DSHSTMN	Fuel oil to steam electric
DSLEEA	Diesel to electricity generation
GEOTHM-0	Geothermal
HYDRO-0	Hydroelectric
METHE	Methanol to electricity generation
NGAENSTM	NGA[a] to non-steam electricity generation
NGACLDC	Pipeline gas to commercial through LDCs[b]
NGAEEA	NGA to electricity generation after emissions acctng.
NGAESTM	NGA to electricity generation

[a] NGA = natural gas
[b] LDC = local distribution center

9.1.8 Electricity Emission Accounting

There are 90 "dummy" process technologies used to track emissions in the electric generation sector. All emissions tracking process technology names begin with the letters 'SE' followed by a three letter description of the energy carrier and a several character description of the process step.

DSL
Diesel going to the electricity generation sector passes through an initial process technology that tracks CO_2, SO_X, PM_{10}, and VOCs. After that it passes through one of two options for NO_X, either an existing NO_X emissions or improved NO_X control. There is an investment cost associated with the improved NO_X process.

For the diesel naming convention, the 'SE' is followed by DSL and then 'ELC' for diesel going to the electrical sector. As shown in Figure 26, there are an additional two letters for the second pass: 'EN' for existing NO_X controls and 'IN' for improved NO_X controls.

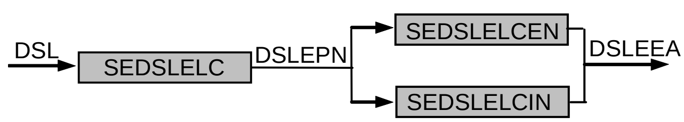


Figure 26. Diesel (DSL) to Electric Sector Emissions Accounting RES.

NGA
Similar to diesel, natural gas goes through two processes to track emissions. The first dummy process tracks CO_2, SO_X, PM_{10}, and VOCs. The second dummy process tracks NO_X.

In the naming convention for NGA, the 'SE' is followed by NGA and then three letters representing the type of technology: NST for non steam electric and STM for steam electric. For the second pass there are an additional two letters: 'EN' for existing NO_X controls and 'IN' for improved NO_X controls. The RES representations for each of these fuels are given in Figure 27.

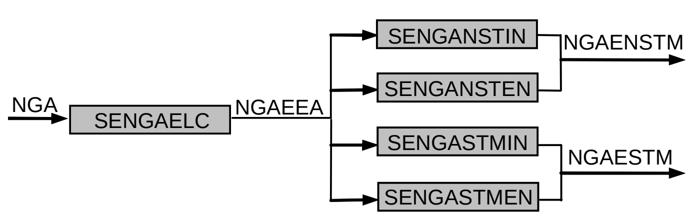


Figure 27. Natural gas (NGA) to Electric Sector Emissions Accounting RES.

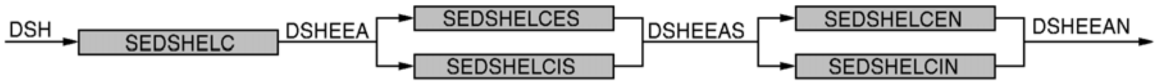


Figure 28. Fuel Oil (DSH) to Electric Sector Emissions Accounting RES.

DSH

Fuel oil goes through three dummy processes to track emissions. The first pass tracks CO_2, PM_{10}, and VOCs. The second process tracks SO_X and the third process tracks NO_X.

In the naming convention for fuel oil, the 'SE' is followed by DSH and then ELC representing fuel oil going to electric. For the second pass, there are two letters: 'ES' for existing SO_X controls and 'IS' for improved SO_X controls. For the third pass, there are an additional two letters: 'EN' for existing NO_X controls and 'IN' for improved NO_X controls. The RES representations for each of these fuels are given in Figure 28.

MTH

As illustrated in Figure 29, methanol passes through one process technology that tracks all emissions.

Figure 29. Methanol (MTH) to Electric Sector Emissions Accounting RES.

Coal

The naming convention for electrical generation from coal combustion is outlined in Table 43. For example, SECIGCBL identifies emissions from low sulfur bituminous coal going through IGCC, and SECPFBLM identifies emissions from medium sulfur lignite coal going through a pressurized fluid bed.

New Steam Electric Technologies

New steam electric technologies pass through two stages for emissions tracking. The first stage tracks CO_2, SO_X, NO_X, and PM_{10}. The second stage tracks VOCs. All new plants are assumed to be built with the best emissions reductions processes available.

The first seven characters of the new steam electric technologies follow the naming convention in Table 43. The second stage tracks the VOCs by sulfur type, dropping the sulfur content. Figure 30 represents the RES diagram.

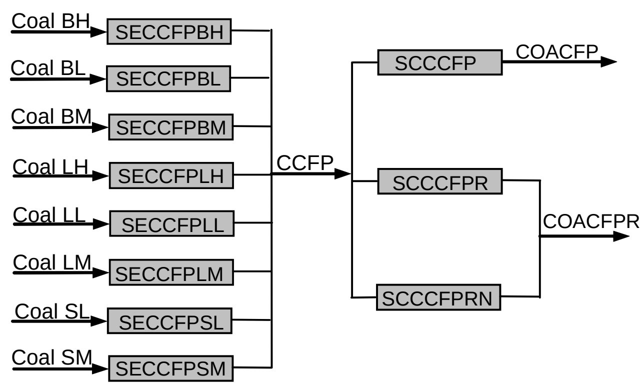


Figure 30. New Steam Electric Emissions Accounting RES.

9.1.9 Constraints

1. Hydro and pumped hydro capacity constrained to approximate AEO2002 values.
2. Constrained investment in distributed wind, central solar thermal, and photovoltaic to low levels, based on analysis by in-house researchers and AEO 2002 estimates.
3. Set RESID for existing NUC to AEO 2002 capacity .
4. Growth constraints placed on landfill gas based on AEO growth rate.

Table 43. Naming Convention for Electric Sector Emissions Tracking.

Name Character Number and Description											
1	2	3	4	5	6	7		7/8		8/9	
Emissions			Process Type				Description	Coal Type	Description	Sulfur Content	Description
S	E	C	A	F	B		atmospheric fluidized bed	B	bituminous	H	high
			I	G	C		integrated gasification combined cycle	L	lignite	M	medium
			M	C	F	C	molten carbon fuel cell	S	subbituminous	L	low
			P	F	B		pressurized fluidized bed				
			S	T	M		existing steam electric				
			C	F	P		coal-fired power				

5 No investment in EDSLCT (DSL combustion turbine) in 1995.
6 Limited investment in IGCC to AEO2002 levels.

9.2 Conventional LWR Nuclear Technology

9.2.1 Nuclear Data Sources

- OECD, 2002.
- Ansolabehere, S. et al., 2003.
- Nuclear Energy Institute: http://www.nei.org/documents/OM_Costs_1981_2003.pdf
- EIA, 1998, Table 10.
- DOE, 2001.

9.2.2 Nuclear RES

The nuclear conversion technology RES, shown in Figure 31, consists of mined uranium, stockpiled spent and depleted uranium, and stockpiled plutonium resource technologies which feed materials (instead of energy carriers) into two process technologies—one that enriches the uranium and one for plutonium uranium recovery extraction. These processes create the materials needed for the reactors. The reactors then output either electricity or spent materials to be stockpiled.

9.2.3 Nuclear Materials

Mined raw uranium does not have an implicit energy content (like coal) because it depends on the ultimate level of enrichment. Different nuclear technologies required uranium enriched to different levels but draw on the same supply of global raw uranium. As a result, mined uranium, and the other nuclear resources, must be defined as a material with a cost per unit mass rather than per unit energy. The materials used are:

- MOX – Mixed (Uranium and Plutonium) oxide fuel,
- MOXSPT – Spent MOX fuel,
- MOXWST – Waste from MOX fabrication,
- NURN – mined natural uranium,
- PU – Plutonium,
- U45 – Uranium enriched to 4.5% U-235 for light water reactors (LWR),
- URD – Depleted uranium generated during enrichment,
- USPT – Spent fuel from LWRs, and
- UWST – Waste from PUREX process.

9.2.4 Nuclear Parameters

Resource technologies

- MINNURN1 – Extraction of uranium, Step 1.
- MINNURN2 – Extraction of uranium, Step 2.
- MINNURN3 – Extraction of uranium, Step 3.

COST and CUM data taken from OECD, 2002, Page 21, Table 1.

Stockpiles

Stockpiles are treated like mining processes in that they have no apparent input when looking at the RES diagram. The name of the input and output energy or material carriers must be the same. The naming convention for stockpiles (this *must* be followed) is:

- First three placeholders: STK,
- Fourth through nineth placeholders: name of outgoing energy/material carrier, and
- Last placeholder must be a number.

If this naming convention is followed, then the energy/material carrier with the same name as that outputted by the stockpile will find its way to the stockpile. Only the parameter OUT(MAT)r = 1 for URD (Tonne/tonne) is then

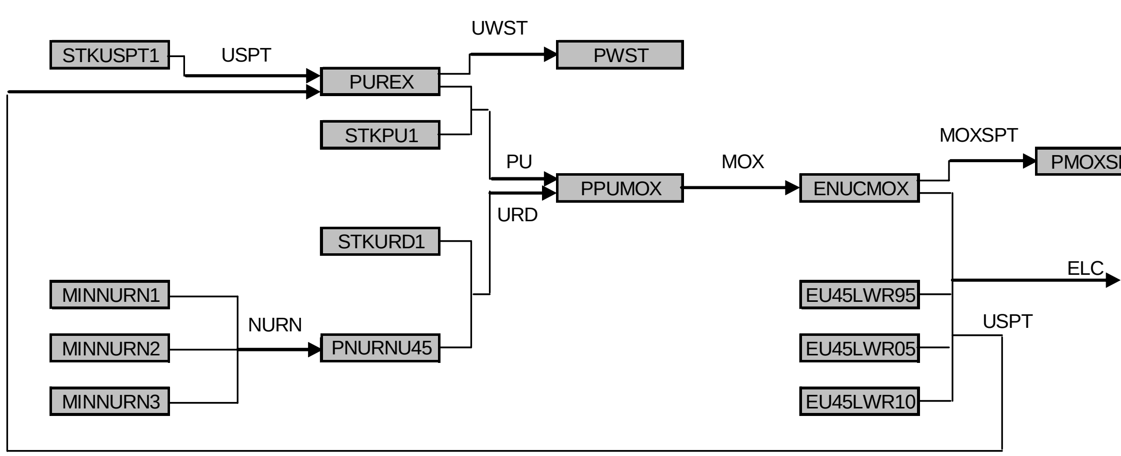


Figure 31. Nuclear RES.

defined, otherwise material balance equations will be wrong.

- STKURD1: Depleted uranium from the enrichment processes.
- STKPU1: Plutonium recovered from spent uranium.
- STKUSPT1: Spent uranium fuel from LWRs.

Spent uranium can be drawn from the stockpile for Single-Pass Plutonium Recycling. USPT from EU45LWR95, EU45LWR05, EU45LWR10 all end up in this stockpile.

Process technologies

PNURNU45: Process technology for uranium enrichment to 4.5% U235 for LWRs. (Data taken from page 146 of Ansolabehere, S. et al., 2003.) The parameters for PNURNU45 are

- INP(MAT)p: This refers to the natural uranium input, which is the only material put into this process. In the EPANMD it is equal to 1 tonne/tonne.
- VAROM: Equal to $0.158 million/tonne natural U. All costs associated with enrichment are included, except the cost of natural uranium.
  The overall cost for conversion, enrichment, and fabrication given as

  $\$2.038 \times 10^6$/tonne IHM or ($\$2.038 \times 10^6/10.2$) = 1.998×10^5 \$/tonne natural U.

  To avoid double counting, the cost of natural (raw) uranium must be factored out. The cost of raw uranium is given as:

  (\$30/kg U) × (10^3 kg/1 tonne) = \$3.0 × 104 \$/tonne natural U.

  So the cost for fabrication minus the cost of electricity and raw uranium, is:

  $\$1.998 \times 10^5 - \$3.0 \times 10^4 = 0.170$ M\$/tonne natural U.
  In \$1995: 0.158 M\$/tonne natural U.
- OUT(MAT)p of enriched uranium: 0.098 (tonne/tonne)
- OUT(MAT)p of depleted uranium: 0.902 (tonne/tonne)
  Since it takes 10.2 tonnes of natural uranium to make 1 tonne of enriched uranium (4.5% U-235 suitable for light water reactors —LWRs),

  1 tonne IHM /10.2 tonne U = 0.098 = 9.8%

  Therefore, the amount of depleted uranium is 90.2%.

PUREX: Plutonium uranium recovery by extraction. This process recovers 99.9% of the plutonium content from spent uranium, which is 1.33% by weight. (Data taken from Ansolabehere, S. et al., 2003, pages 121–122, Figure A-4.4, and text on bottom of page 122). The parameters for PUREX are

- INP(MAT)p: 1, refers to USPT (tonne/tonne).
- OUT(MAT)p: 0.0133, refers to PU (tonne/tonne). (See Deutsch et al., 2003, MOX (mixed oxide) cycle diagram, page 147.) 5.26 kg of spent OX fuel produces 0.07 kg Pu. So, normalized by input, output is 0.07/5.26 = 0.0133. (This is highly enriched weapons grade plutonium and, therefore, is regarded unfavorably, given potential security concerns.)
- OUT(MAT)p: 0.9867, refers to waste from MOX processing.

PPUMOX: Fabrication of MOX fuel for LWRs. MOX fabrication requires 0.07 kg of plutonium and 5.26 kg of depleted uranium. (Data taken from Ansolabehere, S. et al., 2003, MOX cycle diagram, page 121 and 147). The parameters for PPUMOX are

- INP(MAT)p: 0.0131 for PU [calculation: 0.07/(0.07 + 5.26) = 0.0131]
- INP(MAT)p: 0.987 for URD [calculation: 5.26/(0.07 + 5.26) = 0.987]. Depleted uranium is required to blend down the highly enriched plutonium.
- OUT(MAT)p: 1 of fresh MOX (IHM).
- VAROM: 1.266 M\$/tonne. According to Ansolabehere, S. et al., 2003, cost of MOX reprocessing is \$8,886/kg of fresh MOX fuel. In the MIT (Ansolabehere, S. et al., 2003) report, no distinction in costs made between PUREX and MOX fabrication, so all costs for MOX production included here. In MARKAL units,

  (\$8886/kg)×(1 tonne/10^3 kg)×(1 m\$/\$$10^6$) = 8.886 M\$/tonne.

  The credit for the storage and disposal fee associated with once-through spent uranium is (-0.310 M\$/tonne). The storage and disposal fee for once-through spent uranium was already assessed at PNURNU45, and so it must be subtracted here to avoid double counting.) The net cost is:

  8.886 – 0.310 = 8.576 M\$/tonne.
  In \$1995: 7.975 M\$/tonne.

PWST: Dummy process for disposal of waste from PUREX process. The parameter for PWST is

- INP(MAT)p: 1 for UWST (tonne/tonne)

PMOXSPT: Dummy process for disposal of waste from ENUCMOX. The parameter for PMOXSPT is

- INP(MAT)p: 1 for MOXSPT (tonne/tonne)

Nuclear reactors

EU45LWR95: Pre-Existing Conventional Nuclear (LWR). This technology only exists as residual capacity. Data taken from

- Nuclear Energy Institute: http://www.nei.org/documents/OM_Costs_1981_2003.pdf Average O&M from 1999–2003 is 0.0135 $/kWh,
- Ansolabehere, S. et al., 2003, Table A-5.C.2, page 44, and
- EIA (1998), Table 10, page 30.

The parameters for EU45LWR95 are

- **VAROM:** 3.48 M$/PJ: O&M costs are not broken down into fixed and variable and are given in cents / kWh (MIT, NEI, and EIA). Since NEI data were expressed as an annual average instead of by quartiles, annual averages were averaged to obtain a rough average composite over last 5 years:

  5 year average O&M for existing nuclear = ($0.0135/kWh) × (277.78 kWh/GJ) × (10^6 GJ/1 PJ) = 3.75 M$/PJ.
  In $1995: 3.48 M$/PJ.
- **IBOND(BD):** 0: This insures no new capacity will be built.
- **RESID:** It is assumed that existing nuclear capacity remains constant at ~100 GW (99 GW in 2003) over the model horizon. This is a reasonable assumption because retirements (3% by 2025) will be roughly compensated by uprating of other existing plants. See EIA, 2004, page 70, Figure 69.
- **AF:** 85%. In recent years, capacity factor at existing nuclear plants has been roughly 85–90%, and this performance is expected to continue over the next 20 years. See EIA, 2004, page 70 and EIA Annual Energy Review 2004, page 270, Figure 9.2 (bottom right).
- **INP(MAT)c:** 0.701 for U45. Tonnes of enriched uranium (MTIHM) required to produce 1 PJ of electricity. According to Ansolabehere, S. et al., 2003, page 117, the average burnup of U.S. LWRs is currently 50 GWd/MTIHM (metric tonne initial heavy metal).

  (50 GWd/1 MTIHM) × (1×10^6 kW/1 GW) × (24 hours/1 day) × (1 GJ/277.78 kWh) × (1 PJ/10^6 GJ) = 4.32 PJ/MTIHM = 0.231 MTIHM/PJ.

  But this is thermal energy, so electrical output, assuming a thermal efficiency of 33%, 0.231/0.33 = 0.7 MTIHM/PJ.
- **AF_TID:** 0.4162
- **OUT(ELC)_TID:** 1. Simply specifies that this conversion technology produces electricity.
- **OUT(MAT)c:** 0.701. Material output per unit of electricity produced (tonnes/petajoule). The fissioning of uranium produces spent uranium (URNSPT), which consists of several material byproducts. The conversion of mass into energy through fission is neglected, since the mass of the spent fuel is only 0.0047% less than the initial heavy metal.

  To determine the composition of spent fuel from LWRs, use Ansolabehere, S. et al., 2003, page 120, Table A-4.1. Spent Fuel Composition:

  U (all isotopes) 93.4%
  Fissionable products (FP)= 5.15%
  Pu = 1.33%
  Minor Actinides (MA) = 0.12%
  Since 0.7 MTIHM are required to produce 1 PJ of electricity:
  U = 0.934×0.7 = 0.6538 tonnes/PJ
  FP = 0.0515×0.7 = 0.03605 tonnes/PJ
  Pu = 0.0133×0.7 = 0.00931 tonnes/PJ
  MA = 0.0012×0.7 = 0.00084 tonnes/PJ
  LIFE = 40 years.
  Start = 1995.

EU45LWR05: New conventional nuclear (LWR) technology available in 2005. Parameters are the same as EU45LWR95, except

- **FIXOM:** 58.6 M$/GW
- **VAROM:** 0.13 M$/PJ
  ($0.00047/kWh) × (277.78 kWh/GJ) × (10^6 GJ/PJ) × (1 M$/$$10_6$) = 0.13 M$/PJ
- **INVCOST:** 1860 m$/GW; START = 2005
- **INVBLOCK:** 0.8 GW (lower bound on capacity). Costs were taken from Ansolabehere, S. et al., 2003, page 135, Table A-5.A.4. All costs discounted to 1995$.

EU45LWR10: Advanced nuclear (LWR) technology available in 2010. Costs were taken from DOE (2001), pages 71-75. Parameters are the same as EU45LWR95, except

- **AF:** 90%
- **VAROM:** 1.29 M$/PJ (includes all O&M)
  ($0.005/kWh) × (277.78 kWh/GJ) × (10^6 GJ/PJ) × (1 m$/$$10^6$) = 1.39 M$/PJ
  In $1995: 1.29 M$/PJ

- **INVCOST:** 1340 M$/GW
  According to DOE (2001), 1440 M$/GW.
  In $1995: 1340 M$/GW.
- **INVBLOCK:** 0.8 GW (lower bound on capacity)
- **START:** 2005
- **INP(MAT)c:** 0.651. Tons of enriched uranium (MTIHM) required to produce 1 PJ of electricity. According to Ansolabehere, S. et al., 2003, page 117, the average burnup of U.S. LWRs is currently 50 GWd/MTIHM (metric tonne initial heavy metal).

  (50 GWd/1 MTIHM) × (1×10^6 kW/1 GW) × (24 hours/1 day) × (1 GJ/277.78 kWh) × (1 PJ/10^6 GJ) = 4.32 PJ/MTIHM = 0.231 MTIHM/PJ.

  But this is thermal energy, so electrical output, assuming a thermal efficiency of 35%, 0.231 / 0.355 = 0.651 MTIHM/PJ.
- **OUT(MAT)c:** 0.651 tonne/PJ.

ENUCMOX: New MOX nuclear technology. Identical to EU45LWR05, but accepts MOX as input fuel and output is MOXSPT rather than USPT. There appears to be no appreciable difference in cost or performance between LWRs operating on UOX or MOX.

Note that the separated uranium could theoretically be reprocessed for plutonium extraction also. As of 2002, nowhere in the world is MOX fuel reprocessed, in part due to the isotopic composition of plutonium in spent MOX. It is possible that MOX recycling could take place in the future, but very little cost data exist with any operational experience. See Ansolabehere, S. et al., 2003, page 129.

10 Demand Technologies and End-Use Demands

There are four major demand sectors represented in the model: Residential, Commercial, Transportation, and Industrial. The end-use demands along with the technologies to meet these demands are described in each sector.

10.1 Demand Sector Parameters

10.1.1 Availability and Utilization Parameters

- **CF:** Specifies the maximum capacity utilization of a technology (i.e., the maximum fraction of the year in which the technology may operate).
- **IBOND(BD):** Specifies a user imposed bound on investment in new capacity.
- **LIFE:** Specifies the lifetime of a technology in years.
- **START:** The start year specifies the first time period of availability of a technology within the model time horizon.

10.1.2 Efficiency and Cost Parameters

- **EFF:** Specifies the efficiency of a technology where efficiency is measured as units of end-use demand satisfied per unit of input energy carrier consumed.
- **INVCOST:** Specifies the cost of investment in one incremental unit of new capacity.
- **FIXOM:** Specifies the fixed operating and maintenance (O&M) costs for a technology.
- **VAROM:** Specifies the annual variable (or running) operating and maintenance costs such as technology repairs.

10.1.3 Input and Output Parameters

- **MA(ENT):** Specifies the amount of each energy carrier that is input to a demand technology.

- **OUT(DM):** Specifies the end-use demand (DM) serviced by the technology and is expressed as units of end-use demand satisfied per unit of demand technology activity.

10.1.4 Other MARKAL Parameters

- **CAPUNIT:** Specifies the conversion factor between units of activity and units of capacity. The value for all Demand technologies is 1.0.
- **RESID:** Specifies the residual capacity in each model year for technology stock already existing at the beginning of the modeling horizon (1995). Having been installed before the model start year, the investment cost is assumed to have already been expended on this pre-existing capacity.
- **DISCRATE:** Specifies user defined technology-specific discount rates (hurdle rates) to represent a reluctance to invest.

10.1.5 Constraints

- **RAT_RHS:** Specifies the right hand side (RHS) coefficient of a constraint equation and the relationship type (i.e., >, =, or <).
- **RAT_ACT:** Specifies the left hand side coefficient for the specified process technology's activity variable.
- **RAT_CAP:** Specifies the left hand side coefficient for the specified conversion, process, or demand technology's capacity variable.

10.1.6 Electricity Generation "Only" Technology Parameters

- **AF:** Specifies the total annual availability of a technology in each period.
- **AF_TID:** Specifies the fraction of the total unavailability of a technology that is forced outage.
- **AF(Z)(Y):** Specifies the availability for technologies whose availabilities vary by season (Z) and time-of-day (Y). The availability accounts for both forced and scheduled outages in each time division. In MARKAL, Z refers to season, S = summer, I = intermediate (spring and autumn), and W = winter, and Y refers to time-of-day, D = day, and N = night. AF(Z)(Y) is a fraction calculated as the hours of availability in the specified season and time-of-day divided by the total hours in the specified season and time-of-day.
- **CF(Z)(Y):** Specifies the capacity utilization rate of a fixed capacity utilization technology in each season (Z) and time-of-day (Y). The utilization rate applies to fixed capacity utilization technologies that can have seasonal or diurnal variations in capacity utilization such as cogeneration plants. It is generally measured as the average of the utilization for each season and time-of-day division in each year over the period.
- **PEAK(CON):** Specifies the fraction of a generation technology's capacity that can be counted on to be available to meet peak demand and reserve margin requirements, based on its availability, reliability, and other considerations.
- **INP(ENT)c:** The heat rate. Specifies the amount of energy input needed to produce one unit of electricity output.
- **INP(ENC)_TID:** Specifies the initial fuel core requirements for nuclear power plants expressed as units of the energy carrier per unit of the technology capacity.
- **OUT(ELC)_TID:** Specifies that electricity is produced by the technology. The value of 1 indicates that each technology only produces electricity.

10.2 Residential Sector

The residential sector consists of demands technologies needed to meet residential demands for space heating and cooling, cooking, refrigeration, water heating, lighting, and various other energy use technologies.

10.2.1 Residential Data Sources

Data for most residential sector technologies was taken from EIA, 2002e. Data for existing capital stocks of these technologies was taken from NEMS Vintage Program data for the AEO 2002 Reference Case Tables and Technology Files for the Building Sector, also provided by John Cymbalsky. Data for lighting technologies was retained from the 1997 DOE MARKAL database.

Additional data sources include:

- EIA 2002e Table 4: Residential Sector Key Indicators and Consumption,
- EIA 2002e Table 21: Residential Sector Equipment Stock and Efficiency, and
- EIA 2002c: Residential Sector Key Indicators and Assumptions.

10.2.2 Residential Assumptions

1. Technology specific hurdle rates (DISCRATE parameter) have been applied differentially to base and advanced technologies to simulate the consumer's reluctance to purchase newer technology.
2. Heating technologies (space heating and water heating) fuel use splits have been implemented to be equivalent in 2000 to the AEO 2002, with a 3% relaxation rate each subsequent time period.
3. A growth rate constraint (GROWTH parameter) of 10% has been applied to gas heat pumps to limit the rate of penetration (based on AEO 2000 Table 4 2000-2020 growth rate).
4. The capacity of various heating and cooling technologies is assumed to be the following (based on input from Jim Cymbalsky of EIA):
   - Radiators and furnaces 50000 btu/hr
   - Heat pumps 36000 btu/hr
   - Room air conditioners 10000 btu/hr
   - Central air 36000 btu/hr
5. The model assumes that for solar water heaters solar energy provides 55% of the energy needed to satisfy hot water demand, and the remaining 45% is satisfied by an electric back-up unit.

10.2.3 Residential RES

The Residential Sector RES, Figure 32, consists of demand technologies that are capable of meeting end-use demands. All energy carriers going to the Residential Sector pass through an emissions tracking "dummy" process technology on the front end of the demand technology.

10.2.4 Residential End-Use Demands

The residential sector's eight end-use demands, listed in Table 44, are derived from Table A4 of EIA, 2002d, and Table 21 of EIA, 2002e. Demand values are listed in Table 45. Overall, residential heating (RH) constitutes the largest demand, followed by residential cooling (RC), miscel-

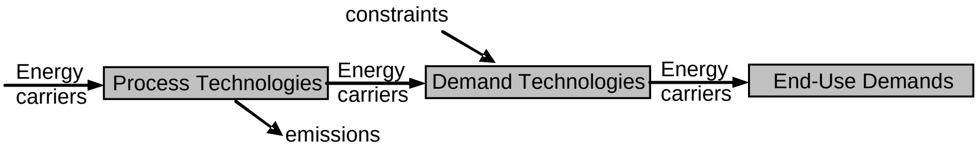


Figure 32. Residential Sector RES.

laneous electric (RME), and residential water heating (RW). RC and RME have the largest growth rates (177% and 194%, respectively) within the modeling period, while RF has the smallest increase (15%) among all residential demands.

Table 44. Residential Sector End-Use Demands.

Name	Definition
RC	Residential cooling
RF	Residential freezers
RH	Residential heating
RL	Residential lighting
RME	Residential miscellaneous electric
RMG	Residential miscellaneous gas
RR	Residential refrigeration
RW	Residential water heating

Table 46. shows the calculation of residential demands according to various AEO tables. These calculations yield (except for lighting) service demands matching the AEO 2002 time horizon: every year from 2000–2020. Values for 2000 and 2020 were each used for the corresponding MARKAL model years. Values for MARKAL model years 2005, 2010, and 2015 are five-year averages of the AEO calculated demands, centered on the corresponding model years. For example, for the year 2005, the average of 2003 through 2007 was taken. Values for 1995 and years beyond 2020 were extrapolated. For 1995, the percent change for years 2000 through 2005 was calculated and used to adjust 1995 down from 2000. For 2025–2035, the percent change was calculated for 2015-2020 and adjusted by time

Table 45. Residential Sector Demand Values in the EPANMD.

Demand	Units	1995	2000	2005	2010	2015	2020	2025	2030	2035
RC	PJ	1586	1792	2024	2285	2604	2969	3384	3858	4398
RF	million units/yr	34	34	34	34	34	35	37	38	39
RH	PJ	4325	4699	5106	5314	5536	5823	6126	6443	6778
RL	PJ	473	503	602	638	672	694	716	740	764
RME	PJ	1498	1879	2358	2656	2969	3275	3613	3985	4396
RMG	PJ	375	404	435	449	467	486	505	524	545
RR	million units/yr	114	119	124	130	136	142	148	155	162
RW	PJ	1182	1242	1305	1371	1436	1504	1574	1648	1725

Table 46. Residential Demand Calculations.

Demand	Source	Units	Comments
RC	EIA, 2002d, Table A4 EIA, 2002e, Table 21	PJ	∑ (delivered energy consumption for fuel *i* and technology *i j* × stock average equipment efficiency *i j*) × PJ/10^{15} Btu
RF	EIA, 2002e, Table 21: Total Technology Stock	million units/yr	
RH	EIA, 2002d, Table A4 EIA, 2002e, Table 21	PJ	∑ (delivered energy consumption for fuel *i* and technology *i j* × stock average equipment efficiency *i j*) × PJ/10^{15} Btu
RL	1998 DOE MARKAL EIA, 1998, Table A4 EIA, 2002d, Table A4	PJ	This demand has been updated from the 1998 DOE MARKAL database by applying the ratio of electricity consumption for lighting from EIA, 2002d, Table 4 to that from EIA, 1998, Table 4 as a multiplier.
RME	EIA, 2002d, Table A4 Delivered Energy Consumption	PJ	Includes cooking, clothes washing and drying, dishwashing, television, computers, fans, and other
RMG	EIA, 2002d, Table A4 Delivered Energy Consumption	PJ	Includes cooking, clothes drying, and other
RR	EIA, 2002e, Table 21: Total Technology Stock	million units/yr	
RW	EIA, 2002d, Table A4 EIA, 2002e, Table 21	PJ	Water heater stock (million units) × average end-use energy service provision per water heater (11.87 PJ)

period. The 1995 value for lighting was taken directly from the 1997 DOE MARKAL database.

10.2.5 Residential Demand Technologies

Demand technologies consume fuels (energy carriers) to meet the end-use demands. Examples of end-use technologies in the residential sector include air conditioners, freezers, clothes washers, and water heaters.

There are 155 demand technologies in the residential sector, broken down into 8 sub-categories. Within each subcategory are different technologies powered by a variety of energy carriers with different efficiency levels. The subcategories are:

Space Heating	63
Space Cooling	35
Water Heating	35
Refrigeration	10
Freezers	7
Lighting	3
Miscellaneous - Gas	1
Miscellaneous - Electric	1

Table 47. Residential End-Use Technology Naming Convention.

Category			Description
1	2/2&3	3&4/4&5	
Sector	Category	Numbered listing	
R	H	01	heating
	C		cooling
	W		water heating
	L		lighting
	R		refrigeration
	F		freezing
	ME		miscellaneous - electric
	MG		miscellaneous - gas

The naming convention for residential end-use technologies is outlined in Table 47, and examples are:

RH01	space heating, electric furnace, existing
RH27	space heating, gas radiator #2 – 2010
RC05	space cooling, room a/c #2 – 2020
RW23	water heating, distillate #2 – 1995
RR03	refrigeration #1 – 2005
RF01	freezing, existing
RL01	Incandescent lighting
RME01	Miscellaneous electric

Heat pumps service two kinds of demands—heating and cooling—and have different efficiencies and capacity factors for each of those demands. Therefore, two technologies were created to model each heat pump. For example, RH04 is the 1995 typical electric heat pump for heating, and RC19 is the 1995 typical electric heat pump for cooling. The technologies are linked by constraints that force the model to invest in the appropriate amount of one when it buys the other. Capital costs for all heat pumps for cooling have been set to zero to avoid double counting.

10.2.6 Residential Process Technologies

There are five process technologies in the residential sector. Four of them are used for emissions accounting and will be explained later. The other one is used to represent the distribution of natural gas through a local distribution company.

PNGALDCR = NGA to residential through LDCs

A natural gas local distribution company does not earn a profit on the buying and reselling of the natural gas itself. An LDC is allowed to earn a fair return on the money that the LDC has invested in the system that delivers the gas to customers. Therefore, PNGALDCR has an investment cost (INVCOST) associated with it as well as variable operating and maintenance costs (VAROM).

10.2.7 Residential Parameters

This section describes the parameters used to characterize residential demand and process technologies in MARKAL and the calculations required to transform source data into MARKAL form. This is a summary of all parameters used and not meant to indicate that all technologies have each of these parameters in their description.

Units

As detailed in Table 48, all costs are expressed in millions of 1995 dollars. Energy quantities are expressed in petajoules, with the exception of refrigerators and freezers, which are expressed in terms of million units.

AEO 2002 Residential Technology Equipment Type Description file (Res Tech File)

Table 48. Residential Sector Cost and Efficiency Units.

MARKAL Category	Technology	Units
INVCOST	Refrigerators	95million$/million units
	Freezers	95million$/million units
	All others	95million$/PJ/annum
EFF	Refrigerators	million units × yr/PJ
	Freezers	million units × yr/PJ
	All others	PJ/PJ

This AEO Residential Demand Module file (EIA, 2002e) represents a “menu” of efficiency levels and installed cost combinations by technology type projected by year available. Installed costs given represent the capital cost of the equipment plus the cost to install it, excluding any finance costs. The efficiency measurements vary by equipment type. Electric heat pumps and central air conditioners are rated for cooling performance using the Seasonal Energy Efficiency Ratio (SEER); natural gas furnaces are based on Annual Fuel Utilization Efficiency; room air conditioners are based on Energy Efficiency Ratio (EER); refrigerators are based on kilowatt-hours per year; and water heaters are based on energy factor (delivered Btu divided by input Btu).

Availability and utilization parameters

CF: These values were retained from the 1997 DOE MARKAL database. The values are as follows:

Heating	= 0.16
Cooling	= 0.15
Water Heating	= 0.10
Refrigeration	= 1.00
Freezing	= 1.00
Lighting	= 1.00

Most lights are not used 100% of the time, but the costs for lighting in MARKAL are based on the life of a light bulb which is directly related to when the light bulb is on.

IBOND(BD): Specifies a user imposed bound on investment in new capacity. This parameter has been used to place an upper bound of zero, preventing investment in new capacity, for all technologies past the “Last year” value specified in the Res Tech File. This “Last year” is the year beyond which the technology in question becomes obsolete. For example, when the efficiency of a particular heat pump is improved and introduced to the market, the less efficient version is no longer available. It has also been used to prevent investment in new capacity for all “existing” technologies which represent residual installed capacity at the beginning of the model horizon. An example of how this parameter is used is given in Table 49.

LIFE: Specifies the lifetime of a technology in years. The values for this parameter, listed in Table 50. were retained from the 1997 DOE MARKAL database.

Table 50. Residential Sector LIFE Values.

MARKAL Demand	Technology	Life (yr)
RC	all	15
RF	all	15
RH	heat pumps	15
RH	all others	30
RL	all	15
RR	all	15
RW	all	10

START: For all technologies except lighting technologies, data for this parameter came from the Res. Tech. File (EIA, 2002e). Lighting data was taken directly from the 1997 DOE MARKAL database.

Efficiency and cost parameters

EFF: For all technologies except lighting, data for this parameter came from the Res. Tech. File (EIA, 2002e).

For RC, RH, and RW: The AEO efficiency data are provided in units of British thermal units output per British thermal units input. These values are converted MARKAL units of petajoules out per petajoules in.

For RR and RF: The efficiency is given in units of kilowatt-hour per year per unit, which are converted to million units per year per petajoule.

For RL: Data were taken directly from the 1997 DOE MARKAL database.

INVCOST: For all technologies except lighting, data for this parameter came directly from the Res. Tech. File (EIA, 2002e).

Table 49. Residential Sector IBOND Example.

MARKAL	MARKAL Description	Last Year	1995	2000	2005	2010	2015	2020	2025	2030	2035
RH03	space heating, electric heat pump, existing	1995	0	0	0	0	0	0	0	0	0
RH04	space heating, electric heat pump #1, 1995	2005				0	0	0	0	0	0
RH06	space heating, electric heat pump #2, 1995	2005				0	0	0	0	0	0
RH07	space heating, electric heat pump #2, 2010	2019						0	0	0	0

For RC and RH: The Res. Tech. File lists capital costs in 2001 dollars per unit and capacity per unit in British thermal units per hour. The capital costs were divided by the capacities and the results converted to millions of 1995 dollars per petajoule.

INVCOST = Capital Cost/Capacity

For RW: For each of the water heater fuel types (electric, NGA, diesel, and LPG), the energy output (in petajoules) per million units was calculated using the fuel specific energy consumption found in EIA, 2002d, Table A-4, Residential Sector Key Indicators and Consumption, and the fuel specific stock average efficiency and total stock units found in EIA, 2002e, Table 21. Those values were used to calculate a stock-weighted average annual useful energy service output in petajoules. The investment cost was then calculated by dividing the capital costs in 2001 dollars per unit found in the Res. Tech. File (EIA, 2002e) by the weighted average annual useful energy service and then multiplying by a water heater Capacity Factor of 0.1.

INVCOST = Capital Cost ÷ Average Annual Useful Energy Service × Capacity Factor

For RR and RF: The Res. Tech. File (EIA, 2002e) lists capital costs in 2001 dollars per unit, which were converted to millions of 1995 dollars per unit.

For RL: Lighting data were taken directly from the 1997 DOE MARKAL database.

VAROM: In the residential sector, VAROM is only specified for lighting technologies, and the values used were taken directly from the 1997 DOE MARKAL database.

Input and output parameters

MA(ENT): In the residential sector, most technologies only use one energy carrier, and therefore MA(ENT) is equal to 1.0. Solar water heaters, the exception, have a solar energy input and an electricity backup. For those technologies, MA(ENT) for solar energy is 0.55 (55% of total energy input) and MA(ENT) for electricity is 0.45 (45% of total energy input).

OUT(DM): For the residential sector, these units are petajoules per petajoule. For all residential demand technologies, all of the energy activity of the technology contributes to a single end-use demand, and therefore OUT(DM) equals 1.0.

Other MARKAL parameters

CAPUNIT: The value for all residential technologies is 1.0.

RESID: Specifies the residual capacity in each model year for technology stock already existing at the beginning of the modeling horizon (1995). Having been installed before the model start year, the investment cost is assumed to have already been expended and is therefore not included in the model.

For RC, RH, RR, RF, and RW: Data for residual capacity and average efficiency of residual capacity were taken from the Vintage Program data for the AEO 2002 Reference Case Tables and Technology Files for Building Sector. These give surviving capacities from historical model years and the average efficiency of shipments in each model year. Five-year averages were taken around each MARKAL model year for years 1995 through 2025. (For distillate heaters, the Vintage Program data are inconsistent with EIA 2002e, Table 21 data. Vintage Program data show 4.4 million distillate furnaces and 21 million distillate radiators in 1995, while Table 21 shows 9.04 million combined distillate units in 2000. The Vintage Program stocks for distillate radiators have been reduced by 75 percent to account for this discrepancy.)

For RL: RESID values were retained from the 1997 DOE MARKAL database.

10.2.8 Residential Energy Carriers

Eight fuels go directly to the residential sector end-use technologies as indicated in Table 51. Three of the fuels—electricity (ELC), solar (SOLAR), and biomass (BIOWD-0)—are universal and go to all sectors. For the other five, the first three letters of the name refer to the fuel type, the fourth letter is an 'R' for Residential, and the final letters indicate the path: EA is after Emissions Accounting and LDC is after passing through LDC (NGA only).

Table 51. Residential Sector Energy Carriers.

Name	Definition
ELC	Electricity
BIOWD-0	Biomass
SOLAR-0	Solar
DSLREA	Diesel to residential after emissions accounting
KERREA	Kerosene to residential after emissions accountin
LPGREA	LPG to residential after emissions accountin
NGAREA	NGA to residential after emissions accountin
NGARLDC	NGA to residential through LDCs

10.2.9 Residential Emissions Accounting

All fuels with residential-specific emission factors pass through a "dummy" process technology which tracks emissions from a particular fuel type going to residential demand technologies. There are no costs associated with these "technologies". They simply have an incoming energy carrier and an outgoing energy carrier. There are four of these for the residential sector. As delineated in Table 52, the first two letters in the names of these process technologies are 'SE' for Emissions. The last three letters are 'RES' for residential. The letters in-between represent the fuel type. The emissions data assumptions and calculations are explained in Section 11.

Table 52. Residential Emissions "Dummy" Process Technologies.

Name	Definition
SEDSLRES	Emissions: Diesel to residential
SEKERRES	Emissions: kerosene to residential
SELPGRES	Emissions: LPG to residential
SENGARES	Emissions: NGA to residential

10.2.3 Residential Constraints

There are twenty-one constraints in the residential sector that are used to tie together the two separate technologies that were created to describe each heat pump, one technology for space heating and one technology for space cooling. The cooling capacity of specific heat pump technology is subtracted from the heating capacity of the same heat pump with the fixed result of zero. This ensures that if a technology is invested in for cooling, it will also be used for heating. These constraints are absolute constraints and are named A_RHP1 through A_RHP21.

Table 53. Residential Space and Water Heating Fuel Splits.

AEO 2002 Table A4 Residential Sector Key Indicators and Consumption

Delivered Energy Consumption by Fuel	**2000**	**2000**
Space Heating	(Quads)	(%)
Electricity	0.42	0.0771
Natural Gas	3.44	0.6312
Distillate	0.7	0.1284
Liquid Petroleum Gas	0.33	0.0606
Biomass	0.43	0.0789
Other	0.13	0.0239
Total	**5.45**	
Water Heating		
Electricity	0.41	0.2103
Natural Gas	1.32	0.6769
Distillate	0.12	0.0615
Liquid Petroleum Gas	0.1	0.0513
Total	**1.95**	

There are twelve constraints in the residential sector used to apply specific fuel use splits to heating and water heating technologies. The initial fuel use splits were taken from the EIA, 2002d, Table A4: Delivered Energy Consumption by Fuel and are listed in Table 53. Splits are relaxed over time to allow the model more variation in technologies to choose from.

These constraints are share splits so the name begins with S_. The second letter in the constraint name reflects the technology sector, which in this case is 'R' for 'Residential'. The third letter represents the technology type, and the 4th—7th letters represent the energy carrier. The fuel split constraints are listed in Table 54.

Table 54. Residential Space and Water Heating Constraints.

Name	Definition
S_RHBIT	Biomass fuel split - heating
S_RHELC	Electricity fuel split - heating
S_RHGAS	Gas fuel split - heating
S_RHLPG	LPG fuel split - heating
S_RHOIL	Oil fuel split - heating
S_RHOTH	Other fuel split - heating
S_RWBIT	Biomass fuel split - water heating
S_RWELC	Electricity fuel split - water heating
S_RWGAS	Gas fuel split - water heating
S_RWLPG	LPG fuel split - water heating
S_RWOIL	Oil fuel split - water heating
S_RHOTH	Other fuel split - water heating

10.3 Commercial Sector

The commercial sector includes businesses not engaged in manufacturing, transportation, agriculture, mining, construction, or other industrial activity.

10.3.1 Commercial Data Sources

Data for commercial sector technologies was taken from the AEO 2002 Commercial Technology Cost and Performance File (EIA, 2002f) for the Commercial Model, provided by Erin Boedecker of the Energy Information Administration. AEO 2002 commercial sector service demand reports were also used to characterize 1995 residual technology stocks.

10.3.2 Commercial Assumptions

1. Technology-specific discount rates, or hurdle rates, (DISCRATE parameter) have been applied differentially to base and advanced technologies.
2. All installed technologies are BOUND to force RESID to be used.
3. Heating technologies (space heating and water heating) fuel splits have been implemented to be equiva-

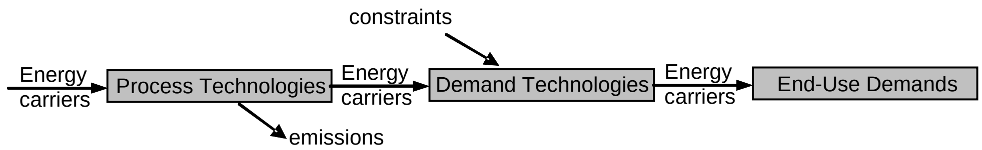


Figure 33. Commercial Sector RES.

lent in 2000 to the AEO 2002, with a 3% relaxation rate each subsequent time period.

10.3.3 Commercial RES

The Commercial Sector RES, illustrated in Figure 33, consists of demand technologies that are capable of meeting end-use demands. All energy carriers going to the Commercial Sector pass through an emissions tracking "dummy" process technology on the front end of the demand technology.

10.3.4 Commercial End-Use Demands

The commercial sector is characterized by thirteen end-use demand technologies. Table 55 lists the end-use demands in the EPANMD.

Table 55. Commercial Sector End-Use Demands.

Name	Definition
CC	Commercial space cooling
CE	Commercial computer and office equipment
CH	Commercial space heating
CK	Commercial cooking
CL	Commercial lighting
CMD	Commercial miscellaneous - Diesel
SME	Commercial miscellaneous - electric
CMG	Commercial miscellaneous - gas
CML	Commercial miscellaneous - LPG
CMR	Commercial miscellaneous - residual fuel
CR	Commercial refrigeration
CV	Commercial ventilation
CW	Commercial water heating

The commercial demands are derived from the AEO 2002 NEMS Commercial Sector Demand module output file 'KSDOUT'. Demand values are listed in Table 56. Overall, commercial lighting (CL) constitutes the largest demand, followed by miscellaneous electric (CME) and commercial cooling (CC).

Demand calculations

Each row of the KSDOUT file contains the forecast of service demand for each year of the NEMS forecast period (1996-2020) that is satisfied by a particular type of equipment, for a particular service, in a particular area. The area data covers the 9 census divisions and data for national totals (Area 11). For our demands, we used the national data. Table 57 shows a small portion of the output file.

To calculate the demand, service demand data by service type and energy carrier was summed up by year. The demands for each year (2005–2020) were then converted to MARKAL units using the conversion factors listed in Table 58.

Demands by MARKAL model time horizon

The above calculations yield service demands matching the AEO 2002 time horizon for every year from 2000–2020. Values for 2000, 2005, 2010, 2015, and 2020 were each used for the corresponding MARKAL model years. For 1995, the percent change for years 2000 through 2005 was calculated and used to adjust 1995 down from 2000.

Table 56. Commercial Sector Demand Values.

Demands	Units	1995	2000	2005	2010	2015	2020	2025	2030	2035
CC	PJ	1246	1383	1535	1665	1799	1927	2065	2213	2371
CE	PJ	358	499	702	885	1056	1196	1363	1561	1799
CH	PJ	1189	1248	1329	1390	1450	1506	1564	1624	1686
CK	PJ	125	138	151	162	174	185	197	210	224
CL	PJ	1799	1977	2187	2362	2546	2719	2905	3103	3314
CMD	PJ	57	73	93	95	96	98	100	102	104
CME	PJ	938	1105	1302	1572	1885	2215	2603	3058	3594
CMG	PJ	896	1049	1228	1324	1450	1625	1821	2041	2287
CML	PJ	89	88	87	93	99	105	111	118	125
CMR	PJ	172	145	122	129	137	141	145	149	154
CR	PJ	235	258	282	301	319	335	352	370	389
CV	PJ	63	70	77	84	91	98	106	114	123
CW	PJ	544	602	667	724	783	840	901	967	1037

Table 57. Sample portion of KSDOUT.

Area	Service	Energy	Type	t	v	1996	1997	1998	1999	2000
11[a]	Heating	Electric	New	Heat Pump	Current	0.586	0.616	0.605	0.634	0.632
11	Heating	Electric	Replacement	Heat Pump	Current	1.8	1.831	1.654	1.731	1.751
11	Heating	Electric	Retrofit	Heat Pump	Current	0.83	3.707	6.077	8.094	9.977
11	Heating	Electric	New	Heat Pump	Typical	0	0	0	0	0
11	Heating	Electric	Replacement	Heat Pump	Typical	0	0	0	0	0
11	Heating	Electric	Retrofit	Heat Pump	Typical	0	0	0	0	0
11	Heating	Electric	New	Heat Pump	High Eff.	0	0	0.032	0.034	0.033
11	Heating	Electric	Replacement	Heat Pump	High Eff.	0	0	0.221	0.147	0.176
11	Heating	Electric	Retrofit	Heat Pump	High Eff.	0	0	0.291	0.683	0.985

[a] Area 11 is the National totals in KSDOUT.

Table 58. Commercial Sector Conversion Factors.

Conversion	Multiply Demand by
PJ per QBTU	1055.056
Normalization of Btu per ft^3/min	1.87530075
Normalization of watts per lumin	0.01726873
PJ per billion watt hours	31.536

For 2025-2035, the percent change was calculated for 2015-2020 and adjusted by time period.

10.3.5 Commercial Demand Technologies

There are 328 end-use technologies in the commercial sector, broken down into 12 sub-categories. Within each subcategory are different technologies powered by a variety of energy carriers at different efficiency levels. The subcategories are:

Space Heating	50
Space Cooling	80
Cooking	4
Water Heating	22
Refrigeration	79
Ventilation	53
Lighting	35
Office and Computer Equip.	1
Miscellaneous - Diesel	1
Miscellaneous - Electric	1
Miscellaneous - LPG	1
Miscellaneous - Residual Fuel	1

The naming convention for the commercial sector end-use technologies is outlined in Table 59. The following are examples of commercial end-use technology names:

CC01	Air Source heat pump for cooling – Installed base
CC08	Air Source heat pump for cooling – 2010 high
CK02	Range, Electric-induction, 4 burner, oven
CH10	Air source heat pump for heating – 2020 high
CW21	Oil water heater – Installed base
CL01	Incandescent 1150 lumens, 75 watts
CR04	Central Rfg. Sys. w/ Ambient Subcooling
CV25	VAV 30,000 ft^3/min Systme – 1995 High

Table 59. Commercial Sector End-Use Technology Naming Convention.

Characters			Description
1	2/3	Remaining	
Sector	Category	Numbered Listing	
C	C	01	cooling
↓	K		cooking
	H		heating
	W		water heating
	L		lighting
	R		refrigeration
	V		ventilation
	MD		misc. - Diesel
	ME		misc. - electric
	MG		misc. - gas
	ML		misc. - LPG
	MR		misc. - residual fuel

Heat pumps service two kinds of demands—heating and cooling—and have different efficiencies and capacity factors for each of those demands. Therefore, two technologies were created to model each heat pump. For example, CC03 is the 2000 typical air source heat pump for cooling, and CH03 is the 2000 typical air source heat pump for heating. The technologies are linked by constraints that force the model to invest in the appropriate amount of one when it buys the other. Capital costs and fixed operating and maintenance costs for all heat pumps for cooling have been set to zero to avoid double counting.

10.3.6 Commercial Process Technologies

Process technologies convert one energy carrier into another. There are five process technologies in the commercial sector. Four of them are used for emissions accounting and will be explained in section 11.3, but the other one is

PNGALDCC = NGA to commercial through LDCs

A natural gas local distribution company does not earn a profit on the buying and reselling of the natural gas itself. An LDC is allowed to earn a fair return on the money that the LDC has invested in the system that delivers the gas to customers. Therefore, PNGALDCR has an investment cost (INVCOST) associated with it as well as variable operating and maintenance costs (VAROM). These costs came from the 1997 DOE MARKAL database.

10.3.7 Commercial Parameters

This section describes the parameters used to characterize commercial demand and process technologies in MARKAL and the calculations required to transform source data into MARKAL form. This is a summary of all parameters used and is not meant to indicate that all technologies have each of these parameters in their description.

Units

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules. End-use demands for cooling, cooking, heating, water heating, and refrigeration technologies are expressed in petajoules. Lighting services are measured in billion lumen years, and ventilation services are measured in trillion cubic foot per minute (cfm)-hours.

EIA (2002f)—Technology Cost and Performance file for the AEO2002 commercial model (KTECH File)

Each record of the KTECH file provides specifications for a specific model of a specific technology in a specific Census Division. For the EPANMD, the technology data for Region 4, West North Central, was chosen as representative of national data. Data in the file that was used for MARKAL data includes First Calendar Year of Availability, Life, Capital Costs, Efficiencies, Operating and Maintenance Costs, and Initial Market Shares.

Capacity Factor file (KCAPFAC)

This AEO file is used by the Technology Choice subroutine of the National Energy Modeling System Commercial Sector Demand Module. The file lists equipment capacity factor values for each Census Division by building end use demand type. The capacity factor is the ratio of actual annual equipment output to output if equipment were run 100% of the time at full capacity.

Availability and utilization parameters

CF: The Capacity Factor value for each Census Division by building type and end use demand was taken from the KCAPFAC file. Energy consumption data for each Census Division by building type and end use demand was taken from the 1999 Commercial Buildings Energy Consumption Survey (CBECS). A national weighted average CF for each end use demand was determined from these values.

The calculated national average CF numbers by end use are:

Heating = 0.28
Cooling = 0.17
Water Heating = 0.44
Ventilation = 0.85
Cooking = 0.35
Lighting = 0.42
Refrigeration = 1.00

IBOND(BD): Specifies a user imposed bound on investment in new capacity. As detailed in Table 60, this parameter has been used to place an upper bound of zero, preventing investment in new capacity, for any technologies once they have been replaced by a new vintage on the market. It has also been used to prevent investment in new capacity for all “existing” technologies, which represent residual installed capacity at the beginning of the model horizon.

LIFE: The data for this parameter came directly from the KTECH file.

START: The data for this parameter came directly from the KTECH file.

Table 60. Commercial Sector IBOND example.

MARKAL	MARKAL Description	Last Year	1995	2000	2005	2010	2015	2020	2025	2030	2035
CC12	Ground source heat pump for cooling - 2000 typical	2000			0	0	0	0	0	0	0
CC13	Ground source heat pump for cooling - 2000 high	2000			0	0	0	0	0	0	0
CC14	Ground source heat pump for cooling - 2005 typical	2005				0	0	0	0	0	0
CC15	Ground source heat pump for cooling - 2005 high	2005				0	0	0	0	0	0
CC16	Ground source heat pump for cooling - 2010 typical	2015						0	0	0	0
CC17	Ground source heat pump for cooling - 2010 high	2015						0	0	0	0

Efficiency and cost parameters

EFF: The data for this parameter came directly from the KTECH file.

For CC, CH, CK, CW, and CR: The AEO efficiency data are provided in units of British thermal units of output per British thermal units of input, and these values are converted to MARKAL units of petajoules output per petajoules input.

For CL: Lighting efficiency data are provided in units of lumens per watt. These values were converted to billion lumen years per petajoule

For CV: Ventilation efficiency data are provided in units of 1000 cfm-hours per 1000 Btu. These values were converted to 10^{12} cfm-hours per petajoule.

For CMD, CME, CMG, CML, CMR: Efficiencies are assumed to be 1.

INVCOST: The data for this parameter came directly from the KTECH file.

For CC, CH, CK, CW, and CR: The AEO capital cost data are provided in units of 2001 dollars per 1000 Btu/hr. These values were converted to units of millions of 1995 dollars per petajoule per year.

For CL: Lighting capital cost data are provided in units of 2001 dollars per 1000 lumens. These values were converted to millions of 1995 dollars per billion lumens.

For CV: Ventilation capital cost data are provided in units of 2001 dollars per 1000 CFM. These values were converted to millions of 1995 dollars per trillion CFM per yr.

FIXOM: The data for this parameter came directly from the KTECH file. Operation and & maintenance cost data are provided in the same units as the capital costs and requires the same conversions as the INVCOST.

Input and output parameters

MA(ENT): In the Commercial sector, each technologies use one energy carrier, and therefore MA(ENT) is equal to 1.0.

OUT(DM): For the Commerical sector, these units are petajoules per petajoules. For all Commercial demand technologies, all of the energy activity of the technology contributes to a single end-use demand, and therefore OUT(DM) equals 1.0.

Other MARKAL parameters

CAPUNIT: The value is 1 for all commercial technologies.

RESID: AEO 2002 market shares by technology type were taken directly from the KTECH file. These market shares were then applied to the 1995 service demands and divided by the CF to calculate the total residual technology stock for each technology in 1995. For all technology categories, RESID values for subsequent years were calculated using straight line projections.

DISCRATE: Specifies user defined technology-specific discount rates (hurdle rates) to represent a perceived hesitation on investment. All currently available commercial technology has a discount rate of 0.18. All new commercial technology that departs from conventional technology, for example a higher efficient heat pump that would require a greater up-front capital cost investment over traditionally used technology, carries a discount rate of 0.44.

10.3.8 Commercial Energy Carriers

Six energy carriers are used by the commercial sector end-use technologies. Electricity (ELC) is universal and goes to all sectors. For the five Commercial-specific carriers (see Table 61), the first three letters of the name refer to the fuel type, the fourth letter is a 'C' for Commercial, and the final letters indicate the path: EA = after emissions accounting and LDC = after passing through LDC (NGA only).

Table 61. Commercial Sector Energy Carriers.

Name	Definition
DSHCEA	Fuel oil to commercial after emissions
DSLCEA	Diesel to commercial after emissions
LPGCEA	LPG to commercial after emissions
NGACEA	NGA to commercial after emissions
NGACLDC	NGA to commercial through LDC

10.3.9 Commercial Emissions Accounting

All fuels with commercial specific emissions factors pass through a "dummy" process technology which tracks emissions from a particular fuel type going to commercial technologies. There are no costs associated with these "technologies". They simply have an incoming energy carrier and an outgoing energy carrier. As illustrated in Table 62, the first two letters of the names of these process technologies are 'SE' for Emissions. The last three letters are 'COM' for Commercial. The letters in-between represent the fuel type. The emissions data assumptions and calculations are explained in Section 11.

Table 62. Commercial Sector Emission "Dummy" Process Technologies.

Name	Definition
SEDSHCOM	Emissions: Diesel to commercial
SEDSLCOM	Emissions: Diesel to commercial
SELPGCOM	Emissions: LPG to commercial
SENGACOM	Emissions: NGA to commercial

10.3.10 Commercial Constraints

There are 21 constraints in the commercial sector that are used to tie together the two technologies that were created to describe each heat pump, one for space heating and one for space cooling. The cooling capacity of a specific heat pump technology is subtracted from the heating capacity of the same heat pump with the fixed result of zero. This ensures that if a technology is invested in for cooling, it will also be used for heating. These constraints are absolute constraints and are named A_CHP1 through A_CHP21.

There are eight constraints in the commercial sector used to apply specific fuel use splits to heating and water heating technologies. The initial fuel use splits were taken from the AEO 2002 Table A5: Commercial Sector Key Indicators and Consumption, which is included here as Table 63. Splits are relaxed over time to allow the model more variation in technologies to choose from.

Table 63. Commercial Space and Water Heating Fuel Splits.

AEO Table A5 Commercial Sector Key Indicators and Consumption
(QBtu per Year)

Delivered Energy Consumption by Fuel			
Year		2000	2000
Space Heating			%
	Electricity	0.15	0.0798
	Natural Gas	1.5	0.7979
	Distillate	0.23	0.1223
Total		**1.88**	
Water Heating			
	Electricity	0.15	0.1705
	Natural Gas	0.65	0.7386
	Distillate	0.08	0.0909
Total		**0.88**	

These eight constraints are percentage splits, so the name begins with S_. The second letter in the constraint name reflects the technology sector, which in this case is 'C' for 'Commercial'. The third letter represents the technology type and the fourth through seventh letters represent the energy carrier. The fuel split constraints are listed in Table 64.

Table 64. Commercial Space and Water Heating Constraints.

Name	Definition
S_CHDSH	Fuel oil fuel split - heating
S_CHELC	Electricity fuel split - heating
S_CHNGA	Natural gas fuel split - heating
S_CLINC	Incandescent lighting fuel split
S_CLMAG	Magnetic lighting fuel split
S_CWDSH	Fuel oil fuel split - water heating
S_CWELC	Electricity fuel split - water heating
S_CWNGA	Natural gas fuel split - water heating

10.4 Transportation Sector

The transportation sector has eight sub-sectors: Light Duty Vehicles (LDV), Heavy trucks, Buses, Non-Highway, Air, Passenger rail, Freight rail, and Waterborne transport.

10.4.1 Transportation Data Sources

Data for the set of light duty vehicles were extracted from the 2003 Quality Metrics Report (DOE, 2003). The Quality Metrics Report is published annually by DOE under a Congressional mandate. These data were supplemented by data from Transportation Energy Data Book: Edition 21 (Davis, 2001), prepared on an annual basis by Oak Ridge National Laboratory, and from the Annual Energy Outlook 2002 (EIA, 2002d). Data for heavy trucks and buses was derived from draft Climate Change Action Report (CCAR) data (2001). Data for other forms of transport, including air, ship, and rail, was retained from the 1997 DOE MARKAL database.

10.4.2 Transportation Assumptions

1. Five classes of personal vehicles (LDVs) are represented: compacts, full-size, minivans, pick-up trucks, and sports utility vehicles (SUV). Market shares for these classes are exogenously determined based on the projections by AEO 2002 (EIA, 2002d) and cannot be changed from scenario to scenario. They are fixed at 25%, 27%, 7%, 20%, and 21%, respectively.
2. Average vehicle miles traveled (VMT) per year per vehicle are fixed at their 1995 values of 11,203 for cars and 12,018 for trucks and SUVs. All data are from Davis (2001), Tables 7.1 and 7.2.
3. Heavy trucks are those greater than 26,000 pounds (Classes 7 and 8). Medium trucks (10,000–26,000 pounds), which consume less than five percent of total highway energy use, are omitted from this study.

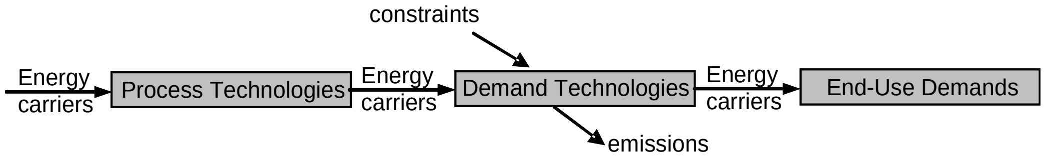


Figure 34. Transportation Sector RES.

10.4.3 Transportation RES

The Transportation Sector RES, illustrated in Figure 34, consists of demand technologies that are capable of meeting end-use demands. Prior to the demand technologies are a number of process technologies that make transportation ready fuel (i.e., the mixing of ethanol and gasoline to make E85 fuel). Emissions for transportation are tracked at the demand technology.

10.4.4 Transportation End-Use Demands

The transportation sector is characterized by seven end-use demand technologies, listed in Table 65. Demands are derived from the 1997 DOE MARKAL database with a ratio adjustment based on the changes in transportation use from 1998 to 2002 predicted by the AEO.

Table 65. Transportation Sector End-Use Demands.

Name	Definition
TA	Air transport
TB	Bus transport
TH	Heavy trucks (greater than 10,000 lb)
TL	Personal automotive - LDVs
TR1	Freight services by rail
TR2	Passenger services by rail
TS	Marine energy services
TO	Transportation other

Demand calculations

A ratio of use by transportation demand type was calculated using EIA (1998) Table 32 (Assumptions to the AEO 1998) and EIA (2002c) Table 33, Transportation Energy Use by Mode and Type. For example, Table 32 of EIA (1998) lists the use of water transport for year 2000 at 1501 trillion Btu. Table 33 of EIA (2002c) lists the year 2000 use of water transport at 1713 trillion Btu, creating a ratio of 1.14. This ratio was then applied to the 1997 DOE MARKAL database demand for water transport of 176 billion ton miles to calculate the revised demand of 200 billion ton miles shown in Table 66.

Off-highway transportation

Off-highway transportation covers a wide range of sectors, including agriculture, industrial & commercial, construction, personal & recreational, and other. According to Davis and Diegel (2004) (Table 2.8), off-highway gasoline consumption increased from 5797 million gallons in 1997 to 5870 million gallons in 2001 at a rate of 0.31% per year. On the other hand, diesel consumption increased from 9424 million gallons in 1997 to 10596 million gallons in 2001 at a rate of 2.97% per year. The projected off-highway gasoline and off-highway diesel consumption is projected to grow at 0.18% and 4.08% per year, respectively between 2000 and 2005. At these rates, off-highway gasoline and diesel consumption is projected to increase by 1.08 and 6.0 times, respectively, between 2005 and 2050. It was decided for EPANMD use that the projection for diesel consumption to 2050 should be adjusted downward. Therefore, off-highway diesel consumption was correlated with GDP projections, and the resulting diesel consumption is projected to growth by 2.5 times between 2005 and 2050.

10.4.5 Demand Technologies

There are 349 end-use technologies in the transportation sector. They are broken down into subcategories as follows:

Table 66. Transportation Sector Demands.

Demand	Units	1995	2000	2005	2010	2015	2020	2025	2030	2035
TA	billion passenger miles	348	473	539	660	793	853	985	1139	1306
TB	billion vehicle miles traveled	10	9	9	10	11	11	11	11	12
TH	billion vehicle miles traveled	220	272	317	370	421	469	521	580	644
TL	billion vehicle miles traveled	2227	2340	2659	2981	3318	3631	3970	4340	4745
TR1	billion ton miles	125	141	157	167	179	195	211	230	248
TR2	billion vehicle miles traveled	25	25	28	31	34	38	41	45	50
TS	billion ton miles	163	200	183	177	175	173	173	173	173
TO	PJ	2057	2275	2525	2849	3145	3395	3609	3847	4102

Light duty vehicles	312
Heavy trucks	15
Buses	10
Air	2
Public transport	3
Rail	3
Ship	2
Off-highway	2

The first character in the names of transportation demand technologies is a "T." The second character identifies the subcategory, which is "L" for light duty vehicles (LDVs) as shown in Table 67. The following are examples of LDV end-use technologies.

TLECGSL — Car, gasoline, existing fleet of compacts

TLCCONV15 — Car, gasoline, conventional, compacts (2015 technology)

TLCADSL25 — Car, advanced diesel, compact (2025 technology)

TLFMMPG15 — Car, gasoline, moderate miles per gallon for full size (2015 technology)

TLS2HYB30 — SUV, hybrid, twice the gas mileage of conventional SUV (2X) (2030 technology)

TLMMTHX00 — Minivan, flex methanol (2000 technology)

TLPADSL05 — Pickups and large vans, advanced diesel (2005 technology)

For heavy duty vehicles, the second letter is "H." The next three to four letters represent the fuel type and the final two letters represent the model year as illustrated in Table 68. Diesel trucks are also divided up into efficiency improvements represented as follows:

10P = 10% efficiency improvement,

Table 68. Naming Convention for Heavy Duty Vehicle Demand Technologies.

Name	Definition
THDSL00	Truck, heavy, Diesel - 2000
THDSL20P00	Truck, heavy, Diesel + 20% mpg - 2000
THDSL40P00	Truck, heavy, Diesel + 40% mpg - 2000
THEDSL	Truck, heavy, existing Diesel fleet
THGSL	Truck, heavy, gasoline
THEGSL	Truck, heavy, existing gasoline fleet
THCNG	Truck, heavy, compressed natural gas
THALC	Truck, heavy, alcohol fuel
THLPG	Truck, heavy, LPG
THDSL10	Truck, heavy, Diesel - 2010
THDSL10P10	Truck, heavy, Diesel + 10% mpg - 2010
THDSL20P10	Truck, heavy, Diesel + 20% mpg - 2010
THDSL20	Truck, heavy, Diesel - 2020
THDSL10P20	Truck, heavy, Diesel + 10% mpg - 2020
THDSL20P20	Truck, heavy, Diesel + 20% mpg - 2020

20P = 20% efficiency improvement, and

40P = 40% efficiency improvement.

The second letter in the demand technology name for buses is "B." The remaining letters and numbers follow the same convention as the heavy trucks, as illustrated in Table 69.

Table 69. Naming Convention for Bus Demand Technologies.

Name	Definition
TBGSL	Bus, gasoline
TBGSL10P	Bus, gasoline + 10% mpg
TBGSL20P	Bus, gasoline + 20% mpg
TBEGSL	Bus, existing gasoline fleet
TBDSL	Bus, Diesel
TBDSL10P	Bus, Diesel + 10% mpg
TBDSL20P	Bus, Diesel + 20% mpg
TBEDSL	Bus, existing Diesel fleet
TBCNG	Bus, compressed natural gas
TBALC	Bus, alcohol fuel

Table 67. Naming Convention for Light Duty Vehicle Demand Technologies.

Name Character Number and Description									
1	2	3		4	5	6	7		Final
Sector	Light Duty	Car Class	Description	Technology Type				Description	Model Yr
T	L	E	existing LDV	C	O	N	V	conventional	00
		C	compact LDV	M	M	P	G	moderate mpg	05
		F	full-size LDV	A	M	P	G	advanced mpg	10
		S	SUV LDV	A	D	S	L	advanced diesel	15
		M	minivan LDV	2	H	Y		2X hybrid	20
		P	pick-up LDV	3	H	Y		3X hybrid	25
				E	T	H	X	ethanol flex fuel	30
				M	T	H	X	methanol flex fuel	35
				C	N	G		CNG dedicated	
				C	N	G	X	CNG bifuel	
				E	L	C		electric	
				F	C	H		fuel cell - hydrogen	
				F	C	G		fuel cell - gasoline	
				F	C	M		fuel cell - methanol	
				L	P	G	X	LPG bifuel	

Table 70 illustrates the naming convention for air transport, Table 71 for shipping, Table 72 for public transportation, and Table 73 for Rail.

Table 70. Naming Convention for Air Transport Demand Technologies.

Name	Definition
TA01	Airplane, jet passenger
TA02	Airplane, general aviation

Table 71. Naming Convention for Shipping Demand Technologies.

Name	Definition
TSDSL	Water transport, Diesel
TSDSH	Water transport, residual oil

Table 72. Naming Convention for Public Transportation Demand Technologies.

Name	Definition
TPELCPT	Public transit powered by electricity
TPELCCR	Commuter rail, electricity
TPDSLCR	Commuter rail, Diesel

Table 73. Naming Convention for Rail Demand Technologies.

Name	Definition
TPELCPT	Public transit powered by electricity
TPELCCR	Commuter rail, electricity
TPDSLCR	Commuter rail, Diesel

10.4.6 Transportation Process Technologies

There are 19 process technologies in the transportation sector. Six of these are simply "dummy" collector process technologies used to collect fuels going to the transportation sector as illustrated in Figure 35. The other 13 process technologies are used to transform certain fuels for use in bi-fuel and flex-fuel vehicles AND are mapped out in Table 74.

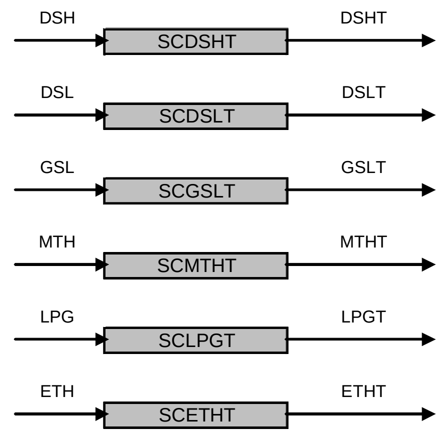


Figure 35. Transportation "Dummy" Collector Process Technologies.

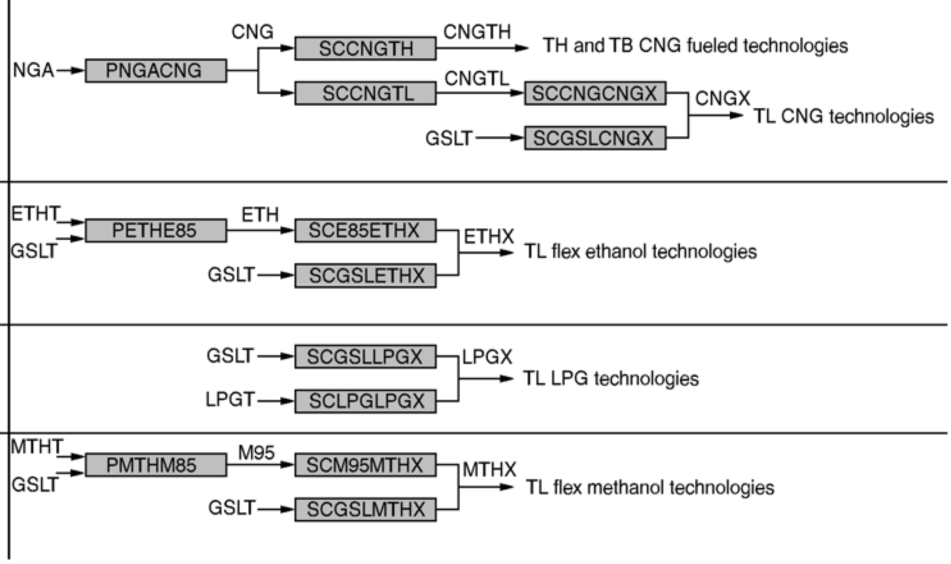
10.4.7 Transportation Parameters

This section describes the parameters used to characterize transportation demand and process technologies in MARKAL and the calculations required to transform the source data into MARKAL form. This is a summary of all parameters used and is not meant to indicate that all tech-

Table 74. Transportation Sector Process Technologies.

Name	Description
CNG	
PNGACNG	Natural gas compression
SCCNGTH	CNG to heavy truck fuel
SCCNGTL	CNG to automobile fuel
SCCNGCNGX	CNG to CNG-gasoline bifuel
SCGSLCNGX	GSL to CNG-gasoline bifuel
Flex Ethanol	
PETHE85	Ethanol and gasoline to E85
SCE85ETHX	E85 to E85-gasoline flex fuel
SCGSLETHX	Gasoline to E85-gasoline flex fuel
LPG	
SCGSLLPGX	Gasoline to LPG-gasoline bifuel
SCLPGLPGX	LPG to light duty vehicle fuel
Flex Methanol	
PMTHM85	Methanol and gasoline to M95
SCGSLMTHX	Gasoline to M95-gasoline flex fuel
SCM95MTHX	Methanol to M95-gasoline flex fuel

RES Diagram



nologies have each of these parameters in their description.

Units
Demand for light duty transport, heavy trucks, and buses is expressed in billions of vehicle miles traveled (bvmt). Capacity is expressed in billions of vehicle miles traveled per annum (bvmt/a). Activities for air passenger services, commuter rail, and intercity passenger rail are expressed in billions of passenger miles traveled (bpmt), and capacities are expressed in billions of passenger miles traveled per annum. Activities for freight services by intercity rail and water borne modes are measured in billions of ton miles, and capacities in billions of ton miles per annum.

Light duty vehicle capital cost and efficiency data were taken from the following sources.
Quality Metrics Report 2003 (QM2003—Patterson et al., 2002):

- Conventional
- Advanced diesel
- Hybrid with twice the miles per gallon fuel consumption of the conventional vehicle of the same type (2X)
- Hybrid (3X)
- Flex ethanol
- CNG dedicated
- Electric
- Fuel cell, hydrogen
- Fuel cell, gasoline

Annual Energy Outlook 2002 (EIA, 2002d):

- Flex methanol
- CNG Bi-fuel
- LPG Bi-fuel

DeCicco et al. (2001):

- Gasoline, moderate miles per gallon improvements
- Gasoline, advanced miles per gallon improvements

Availability and utilization parameters
CF: All vehicles are assumed to be used at a fixed average annual capacity, so CF values are simply set to 1.

IBOND: This parameter has been used to place an investment upper bound of zero, preventing investment in new capacity, on all technologies once a new vintage year for that technology becomes available. It has also been used to prevent investment in new capacity for all "existing" technologies, which represent residual installed capacity at the beginning of the model time horizon. An example of how this parameter is used is shown in Table 75.

LIFE: Values for light duty vehicles were taken from Table 6.10 of AEO2002 (Davis, 2001). All LDVs are assumed to have a lifetime of 15 years. Values for heavy trucks were taken from Table 6.11 of Davis, 2001. Values for buses were taken from the draft Climate Change Action Report (CCAR) data (draft of U.S. GCRIO, 2002).

START: For transport technologies, the start year represents the assumed first year of commercial availability (not technical viability) of a technology. For this initial effort on transport, the start date was taken from each of the primary sources for a given technology characterization. Start year data for heavy trucks and buses was taken from draft CCAR data.

Efficiency and cost parameters
EFF: Light duty vehicle efficiencies are expressed in billions of vehicle miles traveled per petajoule of energy input. As with INVCOST, new vehicle efficiency data from sources other than QM2003 was taken in the form of ratios of alternative technology efficiencies to conventional vehicle efficiencies which were then applied to the QM2003-derived conventional vehicles. The conversion from efficiencies in source units of miles per gallon gasoline equivalent to MARKAL units is

Table 75. Transportation IBOND Example.

MARKAL	MARKAL Description	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLCMMPG10	Car, gasoline, moderate mpg, compact - 2010					0	0	0	0	0
TLCMMPG15	Car, gasoline, moderate mpg, compact - 2015						0	0	0	0
TLCMMPG20	Car, gasoline,2moderate mpg, compact - 2010							0	0	0
TLCMMPG25	Car, gasoline, moderate mpg, compact - 2025								0	0
TLCMMPG30	Car, gasoline, moderate mpg, compact - 2030									0

$$EFF = \frac{mpg_t}{\frac{MMBTU}{gal} \times \frac{PJ}{MMBTU}} \times 10^{-9} = bvmt/PJ$$

where

mpg_t = miles per gallon, from source data,

$\frac{MMBTU}{gal}$ = million Btu per gallon of fuel, and

$\frac{PJ}{MMBTU}$ = petajoules per million Btu.

Because efficiencies for gasoline vehicles have been broadly constant within size classes since 1990, EFF for existing gasoline vehicles was set equal to the value for the "Conventional" vehicle in each size class. Efficiencies for existing diesel cars and light trucks were taken from AEO 1997 Supplemental Table 46, Summary of New Light-Duty Vehicle Size Class Attributes (EIA, 1997b). Efficiencies for methanol fuel cell vehicles were set equal to that for gasoline fuel cell vehicles in the same size class.

All values given by the data sources are EPA rated efficiencies. Efficiencies were adjusted to on road efficiencies using the AEO 2002 fuel efficiency degradation factors from Assumptions to AEO 2002, Table 29, Car and Light Truck Degradation Factors, (EIA, 2002c). Degradation factors are used by the AEO to convert EPA-rated fuel economy to actual "on the road" fuel economy. It takes into account three factors: increases in city/highway driving, increasing congestion levels, and rising highway speeds. The average degradation factors for cars are 0.74 in 2000 and 0.81 in 2025. For light trucks the value is 0.8.

Efficiency data for heavy trucks and buses were derived from draft CCAR data, expressed in miles per gallon gasoline equivalent. These values were transformed to MARKAL units of billion vehicle miles traveled per petajoule as described above for light-duty vehicles.

INVCOST: For light duty vehicles, investment costs refer to the average price that a consumer would pay for a vehicle.

Investment cost data from the QM2003 (Patterson, et al., 2002) were taken as given in Table A-30 and transformed as described below. To eliminate differences that could be introduced from different sources using different characterizations of conventional vehicles, values from other sources were converted into ratios of purchase price for alternative technologies to purchase price for the conventional vehicle in that size class. These ratios were then applied as multipliers to the conventional vehicle data derived from QM2003.

These sources provide investment costs in thousands of dollars per vehicle. These values are translated to the average cost in millions of 1995 dollars per billion vehicle miles traveled per annum capacity as described above using measures of average vehicle miles traveled by vehicle type extracted from Davis, 2001 Tables 7.1 and 7.2. These average vehicle miles traveled values are for 1995, and in the base EPANMD are assumed to be constant over the forecast horizon. (The user may choose to assume different average vmt measures by vehicle type over time and exogenously recalculate these measures based on those assumptions.)

The following relationship illustrates the calculation of INVCOST.

$$INVCOST = deflator \times \frac{cost_v}{vmt/a_v} \times \frac{10^9}{10^3} = mil.1995\$/bvmt/a$$

where

deflator = appropriate GDP implicit deflator,

$cost_v$ = purchase price of a given vehicle type, *v*, from source data in thousands od dollars, and

vmt/a_v = average measure of vehicle miles traveled per year for a given vehicle type, *v*.

INVCOSTs for "existing" vehicles are set identical to those for "conventional" vehicles in each size class in the year 2000. INVCOST for existing diesel cars and light trucks is set to 1.07 times that for existing compact and pickup, respectively. This value is the 1996 average ratio of diesel to gasoline new vehicle purchase price in AEO 1998 Table 50 (the first year this table was published). Because these are RESID vehicles and new investment is prohibited, this parameter does not affect model results and indeed is not used by the model for standard MARKAL runs.

Investment cost data for heavy trucks and buses were derived from draft CCAR data, expressed in 1999 dollars per vehicle. These values were converted to MARKAL units of millions of 1995 dollars per bvmt per annum using a fixed average yearly VMT as described above for light-duty vehicles.

FIXOM: Fixed operating and maintenance (O&M) costs ordinarily refer to those expenses which do not vary with levels of activity or use. However, because all light duty vehicles are assumed to be used at a fixed yearly activity level, FIXOM costs may also include those which may be thought of as varying with activity levels. For example, fixed O&M for personal transport would include routine maintenance such as oil changes, tune-ups, licensing fees and emissions tests, and routine insurance.

Data for most vehicle types were taken from the Quality Metrics reports as described above for INVCOST. To maintain compatibility of costs across vehicle types, FIXOM values for other vehicle types were set equal to those of Quality Metrics-derived vehicles:

- Flex methanol = Flex ethanol,
- CNG Bi-fuel = CNG dedicated,
- LPG Bi-fuel = CNG dedicated,
- Fuel Cell – methanol = Fuel cell – gasoline,
- Gasoline, moderate MPG improvements = Conventional,
- Gasoline, advanced MPG improvements = Conventional.

Fixed O&M values are converted to millions of 1995 dollars per billion vehicle miles traveled per annum as described above for INVCOST and illustrated in the relationship

$$FIXOM = deflator \times \frac{O\&M_v}{vmt/a_v} \times \frac{10^9}{10^6} = mil.1995\$/bvmt/a$$

where

$O\&M_v$ = fixed O&M costs for a given vehicle type, v, from source data.

Fixed O&M cost data for heavy trucks and buses were derived from draft CCAR data, expressed in 1999 dollars per vehicle. These values were transformed to MARKAL units of millions of 1995 dollars per vehicle miles traveled per annum using a fixed average yearly VMT as described above for light-duty vehicles.

Input and output parameters

MA(ENT): These types include (1) conventional gasoline, with existing and improved emissions controls; (2) diesel; (3) methanol, E85, and M95; (4) CNG and LPG; (5) electric; and (6) hydrogen. For dedicated, single-fuel vehicles, the value of this parameter is set to 1, and the energy carrier used is specified. For flexible and bi-fuel vehicles, an extra layer of process technologies is set up before the vehicles to allow the vehicle stock to use varying fractions of the permissible fuels:

- Flex ethanol – E85 and gasoline,
- Flex methanol – M95 and gasoline,
- CNG bi-fuel – CNG and gasoline, and
- LPG bi-fuel – LPG and gasoline.

OUT(DM): All light-duty vehicles service the demand TL, light duty vehicle transport.

Other MARKAL parameters

CAPUNIT: Activities for all light duty vehicles are measured in billions of vehicle miles traveled and capacities are measured in billions of vehicle miles traveled per annum, so CAPUNIT is set to 1.

RESID: RESID values are specified for the following light-duty vehicles:

- Car, gasoline, existing fleet of compacts,
- Car, diesel, existing fleet of full size,
- Car, gasoline, existing fleet of full size,
- SUV, gasoline, existing fleet,
- Minivan, gasoline, existing fleet,
- Pickup trucks and large vans, gasoline, existing fleet, and
- Light truck, Diesel, existing fleet.

RESID values for 1995 are based on billion vehicle miles traveled in 1995, taken from Edition 21 of the Transportation Energy Data Book (Davis, 2001), Tables 7.1 and 7.2. Total miles traveled were apportioned by fuel type using shares of total vehicle miles traveled derived from AEO1997 (EIA, 1997b) Supplemental Table 47. Because the fleet was assumed to be at the midpoint of its lifespan on average, sales shares from 1990 were used to apportion miles traveled among size classes (Edition 21 of the Transportation Energy Data Book Tables 7.5 and 7.6). Straight line projection was used to determine RESIDs for later model years.

RESID values are specified for the following heavy trucks and buses:

- Truck, heavy, existing diesel fleet,
- Truck, heavy, existing gasoline fleet,
- Truck, heavy, LPG,
- Bus, existing gasoline fleet,
- Bus, existing Diesel fleet,
- Bus, compressed natural gas, and
- Bus, alcohol fuel.

RESID values for 1995 are based on billions of vehicle miles traveled in 1995 or the nearest available year. For heavy trucks, this value (1997) is taken directly from Edition 21 of the Transportation Energy Data Book Table 8.6. Total miles traveled were apportioned by fuel type using shares of energy consumption by fuel taken from Edition 21 of the Transportation Energy Data Book Table 2.4.

For buses, billions of vehicle miles traveled was available only for transit buses, taken from Edition 21 of the Transportation Energy Data Book Table 8.12. Miles traveled for school and intercity buses were imputed from transit bus billions of vehicle miles traveled using ratios of energy consumption for transit, school, and intercity buses taken from Edition 21 of the Transportation Energy Data Book Tables 8.12 and 8.13. Values for all three bus types were then summed to get total bus billions of vehicle miles traveled. As with heavy trucks, total miles traveled were then apportioned by fuel type using shares of energy consumption by fuel taken from Edition 21 of the Transportation Energy Data Book Table 2.4.

Straight line projection was used to determine RESIDs for later model years.

10.4.8 Transportation Energy Carriers

Table 76. Transportation Sector Energy Carriers.

Name	Definition
ELC	Electricity
JTF	Fet fuel
M95	M95 fuel
MTHX	Fuel for M95/gasoline flex vehicles
E85	E85 fuel
ETHTL	Ethanol to transportation
ETHX	Fuel for E85/gasoline flex vehicles
LPGX	Fuel for LPG/gasoline flex vehicles
CNGTL	CNG to transportation
CNGX	Fuel for CNG/gasoline bi-fuel vehicles

Ten energy carriers go to the transportation sector end-use technologies. One of them, electricity (ELC), is universal and goes to all sectors.

10.4.9 Transportation Emissions Accounting

The emissions are tracked a little differently in the transportation sector than in the residential and commercial sector. Whereas in those sectors the emissions were tracked through a "dummy" process technology for each fuel type going to those sectors, in the transportation sector the emissions are tracked individually for each of the technologies.

10.4.10 Transportation Constraints

There are five constraints in the transportation sector that are used to apply specific car class splits to light duty vehicle demands. The splits were taken from Transportation Energy Data Book, Edition 21 (Davis, 2001) Table 7.5, Period Sales, Market Shares, and Sales Weighted Fuel Economies of New Domestic and Import Automobiles, Selected Sales Periods, 1976-2000. The percentage of total sales in units was calculated for compact cars, full size cars, SUVs, minivans, and pickups.

These constraints are percentage splits so their names begin with S_. The second and third letters in the constraint name are 'TL' for light duty transportation. The fourth letter represents the car class. The fuel split constraints with their values are listed in Table 77.

Table 77. Transportation Car Class Percentages.

Name	Definition	Percentage
S_TLC	Compact car split	25
S_TLF	Full-size car split	27
S_TLM	Minivan split	20
S_TLP	Pickup split	7
S_TLS	SUV split	21

10.5 Industrial Sector

The industrial sector was developed based on the United States region of the U.S. EIA's System for Analysis of Global Energy Markets (SAGE) model (EIA, 2003a), used by EIA to produce their International Energy Outlook 2002. SAGE model data were recalibrated to the EPA MARKAL model base year of 1995. The reader is referred to the EIA-DOE documentation of the SAGE model for a complete description of the industrial module. See the Section 2 for a general description of the model and Section 5 for details on the industrial sector in EIA, 2003a.

10.5.1 Industrial Data Sources

Original data for industrial sector technologies were taken from the EIA SAGE database; from Energy Statistics: OECD and Non-OECD Countries, and Energy Balances: OECD and Non-OECD Countries (IEA, 2003); from the EIA's 1998 Manufacturing Energy Consumption Survey (MECS) (EIA, 1998c); from the EIA's International Energy Outlook 2002 (EIA, 2002g); from EIA's National Energy Modeling System (NEMS) input data; from United Nations, "Statistical Yearbook (45th edition)" (UN, 1999); and from technical judgment by EIA modelers and Science Applications International Corporation (SAIC), consultants to EIA.

IEA Data contains data for the different industries, the other non-specified energy uses and the non-energy uses:

- IRONSTL: Iron and steel
- NONFERR: Non ferrous metals

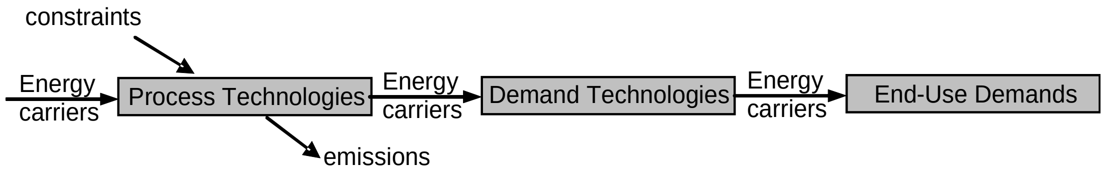


Figure 36. Industrial Sector RES.

- CHEMICAL: Chemicals
- PAPERPRO: Paper products
- NONMET: Non metal materials
- OTHER: Others industries (not from IEA but calculated)
- TOTIND: Total industry sector
- NECHEM: Feedstocks in petrochemicals
- ONONSPEC: Other non-specified
- NEINTREN: Non energy uses in industries
- NEOTHER: Non energy uses in other sectors

10.5.2 Industrial RES

Unlike most of the end-use sectors in the EPA MARKAL model, which consist of an end-use service demand layer and a layer of technologies that compete to service those demands, the industrial sector has a three layer structure consisting of one end-use demand layer and two technology layers. The RES for the industrial Sector is shown in Figure 36.

10.5.3 Industrial End-Use Demands

There are seven industrial end-use demands, listed in Table 78.

Table 78. Industrial Sector End-Use Demands.

Name	Definition
IIS	Iron and steel
INF	Nonferrous metals
ICH	Chemicals
ILP	Pulp and paper
INM	Nonmetal minerals
IOI	Other industries
NEO	Industrial and other nonenergy uses

- Chemicals,
- Iron and steel,
- Non-ferrous metals,
- Non-metal minerals,
- Pulp and paper, and
- Other industries (including transport equipment, machinery, mining, food and tobacco, construction, and textiles).
- Non-energy

The end-use demands are denoted in units of millions of tons, representing the physical output of the subsector, or petajoules, representing the total energy requirements.

Demand data, detailed in Table 79, are derived from the IEA database (IEA, 2003) and from UN, 1999, and values are projected using the EIA's International Energy Outlook 2002 (EIA, 2002g).

10.5.4 Industrial Demand Technologies.

The end-use demands are directly serviced by the first technology layer, which is a layer of dummy demand technologies representing the relative contributions of various energy services—including process heat, steam, machine drive, electrochemical, feedstock, and other—to the output (tons) or total energy requirements (petajoules) of the industry. Each end-use demand is serviced by only one dummy technology at any one time. However, this technology may change over time, representing structural change in the industry. In the current database, these technologies do not change over time.

Table 79. Industrial Sector Demand Values in the EPANMD.

Demand	Units	1995	2000	2005	2010	2015	2020	2025	2030	2035
I00	PJ	0	1	1	1	1	1	1	1	1
IIS	million tonnes	90	96	102	110	119	127	136	144	152
INF	million tonnes	7	7	8	8	9	10	11	12	13
ICH	PJ	8357	9689	11233	12797	14085	15361	16653	17789	18772
ILP	million tonnes	80	85	89	96	103	109	116	122	127
INM	PJ	1569	1662	1761	1867	1967	2064	2158	2239	2308
IOI	PJ	6728	7393	8124	9068	9980	10928	11938	12875	13734
NEO	PJ	3605	3736	3872	4001	4109	4213	4316	4405	4481

There are six "dummy" demand technologies, listed in Table 80.

Table 80. Industrial Sector Demand Technologies.

Name	Definition
IIS095	Iron and steel
INF095	Nonferrous materials
ICH095	Industrial chemicals
ILP095	Pulp and paper
INM095	Nonmetals
IOI095	Other industrial

Table 81 lists the relative contributions of various energy services.

10.5.5 Industrial Process Technologies

The second technology layer consists of the actual process technologies that provide these energy services. Many technologies, fueled by many different fuels, compete to provide the inputs to the first technology layer. For example, machine drive to the pulp and paper industry is supplied by the following set of technologies:

- Coal existing
- Distillate oil new
- Distillate oil existing
- Electric new
- Electric existing
- Electric high efficiency
- Electric improved efficiency
- Heavy oil new
- Heavy oil existing
- LPG existing
- Natural gas new
- Natural gas existing

Currently these technologies are very abstract, linking fuels to services. Only a few improved and high efficiency technologies are available. However, this structure is very flexible and could allow a user with sufficient data to characterize physical technologies of interest to include such technologies at this level of the structure. There are 289 of these process technologies in the industrial sector.

The naming convention for the industrial sector is illustrated in Table 82.

Table 81. Industrial Sector Demand Tech Energy Needs.

Industry	Electro-chemical	Industrial feedstocks	Machine Drives	Industrial Other	Process Heat	Industrial Steam
Chemicals	0.01	0.42	0.08	0.21	0.14	0.14
Iron and steel	0.08	1.26	1.24	3.06	7.08	0.91
Pulp and paper			5.63	23.92	1.93	1.57
Nonferrous	43.89		1.27	11.44	48.13	7.35
Nonmetals			0.07	0.16	0.75	0.02
Industrial other	0.01		0.19	0.62	0.13	0.04

Table 82. Industrial Sector Naming Convention.

Name Character Number and Description										
Technology Type			Industrial Sector			Energy Carrier				Year
1	2	Description	3	4		5	6	7		8, 9, 10
I	E	electrochemical	C	H	chemical	B	I	O	biomass	095
	F	feedstock	I	S	iron and steel	B	F	G	blast furnace gas	000
	M	machine drives	L	P	pulp and paper	C	O	A	coal	
	O	other	N	F	nonferrous	C	O	K	coke	
	P	process heat	N	M	nonmetal	D	S	T	distillate	
	S	steam	O	I	other	E	L	C	electric	
						E	L	H	high eff. electric	
						E	L	I	improved eff. electric	
						E	T	H	ethane	
						H	E	T	heat	
						H	F	O	fuel oil	
						L	P	G	LPG	
						N	A	P	naphtha	
						N	G	A	NGA	
						P	T	C	petroleum coke	

Examples of industrial process technologies are

IELPELC095	Electrochemical process pulp and paper electric, existing
IFCHETH095	Technology to convert ethane to non-energy petrochemical
IFCHNGA095	Technology to convert natural gas to non-energy, existing
IMCHELH000	Machine drive chemicals electric, high efficiency
IMISCOA095	Machine drive iron and steel coal, existing
IMLPLPG095	Machine drive pulp and paper LPG, existing
IONFCOA000	Other nonferrous metals coal, new
IONMDST095	Other nonmetals distillate oil, existing
IPLPBIO095	Process heat pulp and paper biomass, existing
IPNFCOK095	Process heat nonferrous metals coke, existing
ISCHHET095	Steam chemicals heat, existing
ISISNGA000	Steam iron and steel natural gas, new
ISNFDST000	Steam non-ferrous metals distillate oil, new

In addition, there are process technologies, listed in Table 83, that represent "dummy" processes that simply "convert" (or rename) energy carriers into industrial energy carriers. The remaining are process technologies that satisfy demand technology needs.

Table 83. Industrial Sector "Dummy" Process Technologies.

Process	Description	Incoming Energy Carrier	fraction	Outgoing Energy Carrier
INDBFG095	Blast furnace gas	CMET	0.8	INDBFG
		COAIEA	0.2	
INDBIO095	Biofuels	BIOWD-0	1	INDBIO
INDCOA095	Coal	COAIEA	1	INDCOA
INDCOK095	Coke	COKE	1	INDCOK
INDELC095	Electricity			INDELC
INDETH095	Ethane	PFDST	1	INDETH
INDHET095	Heat			INDHET
INDHFO095	Heavy fuel oil	DSHIEA	1	INDHFO
INDHYD095	Hydro	HYDRO-0	1	INDHYD
INDLPG095	LPG	LPGIEA	1	INDLPG
INDNAP095	Naphtha	PFDST	1	INDNAP
INDNGA095	NGA	NGAIEA	1	INDNGA
INDNUC095	Nuclear	NUCLWR-0	1	INDNUC
INDOIL095	Refined Petroleum	DSLIEA	0.85	INDOIL
		GSLI	0.15	
INDPTC095	Petroleum coke	NEMISC	1	INDPTC
INDSOL095	Aolar	SOLAR-0	1	INDSOL
INDWIN095	Wind	WIN-0	1	INDWIN

10.5.6 Conversion Technologies

Auto-production of ELC has been allocated to the industrial sector. These technologies, listed in Table 84, produce electricity for use in the industrial sector.

Table 84. Autoproduction Technologies in the Industrial Sector.

Name	Definition
EAELCBFG00	Autoproduction of ELC with BFG
EAELCBIO00	Autoproduction of ELC with BIO
EAELCCOA00	Autoproduction of ELC with COA
EAELCCOK00	Autoproduction of ELC with COK
EAELCETH00	Autoproduction of ELC with ETH
EAELCHFO00	Autoproduction of ELC with HFO
EAELCLPG00	Autoproduction of ELC with LPG
EAELCNAP00	Autoproduction of ELC with NAP
EAELCNGA00	Autoproduction of ELC with NGA
EAELCOIL00	Autoproduction of ELC with OIL
EAELCPTC00	Autoproduction of ELC with PTC
EAUTELC00	Autoproduction of ELC with other than cogeneration

The CHP processes refer to all electricity production and to heat production only if the heat is sold to third parties. In case of a CHP plant that is owned by a refinery or a petrochemical industry, the CHP line does not cover the heat production or the fuel use for this heat production. Consequently, auto-production of electricity and heat has been directly allocated to industry and refinery, based on some exogenous assumptions needed to recalculate the fuel use and heat production from CHP. It is not easy to reconstruct the fuel use and heat production by CHP from these data because there is no fixed power to heat ratio. Consequently, only heat sold to third parties can be calibrated to the IEA database. In order to model the fuel use and heat production by industrial CHP from these data, the following assumptions have been made:

- Inputs and outputs of auto-CHP, as provided by IEA, were shared between sectors (exogenous ratios), including refineries.
- Heat production associated with electricity production, as provided by IEA, has been calculated based on the electricity/heat ratio (REH). These are exogenous values from IEA (Table 223).
- Energy inputs associated with heat production have been calculated based on the efficiency of CHP (exogenous 0.8 for all sectors, all regions).
- Energy inputs to auto-CHP related to electricity production have been added to the industrial energy inputs (energy inputs related to heat auto-production do not need to be added as they are already included within the appropriate consuming sector).

Industrial sector CHP technologies are listed in Table 85.

Table 85. CHP Technologies in Industrial Sector.

Name	Definition
ESTMBFG000	Auto CHP with BFG existing
ESTMBIO000	Auto CHP with BIO existing
ESTMCOA000	Auto CHP with COA existing
ESTMCOK000	Auto CHP with COK existing
ESTMETH000	Auto CHP with ETH existing
ESTMHFO000	Auto CHP with HFO existing
ESTMLPG000	Auto CHP with LPG existing
ESTMNAP000	Auto CHP with NAP existing
ESTMNGA000	Auto CHP with NGA existing
ESTMOIL000	Auto CHP with OIL existing
ESTMPTC000	Auto CHP with PTC existing

10.5.7 Industrial Parameters

This section describes the parameters used to characterize industrial demand and process technologies in MARKAL and the calculations required to transform source data into MARKAL form. This is a summary of all parameters used and is not meant to indicate that all technologies have each of these parameters in their description.

All costs are expressed in millions of 1995 dollars. All energy quantities are expressed in petajoules. Capacities for CHP technologies are in gigawatts. Capacities for all other technologies are in petajoules per annum (PJ/a).

For demands denoted in million tons (IIS, ILP, and INF), the values for each input service are the number of petajoules needed to contribute to one million tons of output for the subsector. Data characterizing new technologies were developed for EIA by Science Applications International Corporation (SAIC).

Availability and utilization parameters
AF: Specifies the maximum annual availability fraction of a technology.

Auto Production	0.7
CHP	0.7
Electrochemical	0.8
Feedstocks	1
Motor Drives	0.25
Other	0.8
Process Heat	0.8
Steam	0.8

CF: All technologies are assumed to be used at a fixed average annual capacity, so CF values are simply set to 1.

IBOND: This parameter has been used to prevent investment in new capacity for all “existing” technologies, which represent residual installed capacity at the beginning of the model time horizon.

LIFE: Existing technologies are retired after a lifetime of 30 years. Existing CHP technologies are retired after a lifetime of 25 years, and existing electricity auto-production technologies after a lifetime of 50 years.

START: All new technologies become available in model year 2000.

Efficiency and cost parameters
EFF: Data characterizing technology efficiency was developed for EIA by SAIC.

INVCOST: Data characterizing technology investment cost were developed for EIA by SAIC. Units are millions of dollars per gigawatt for CHP technologies and millions of dollars per petajoule per annum for other technologies.

FIXOM: Data characterizing technology fixed operating and maintenance costs were developed for EIA by SAIC. Units are millions of dollars per gigawatt for CHP technologies and millions of dollars per petajoule per annum for other technologies.

Input and output parameters
MA(ENT): This parameter specifies the input energy carrier (ENT).

OUT(DM): This parameter specifies the end-use demand (DM) serviced by the technology.

INP(ENT)p: Efficiencies for most existing technologies are set to 1, so that these technologies are essentially simply accounting for the corresponding energy consumption for each service. Efficiencies for existing steam technologies are set to 0.81 (corresponding to INP values of 1.235.)

Other MARKAL parameters
CAPUNIT: Activities for all technologies are measured in petajoules and capacities are measured in petajoules per annum, so CAPUNIT is set to 1.

RESID: Calculated by multiplying the 1995 final energy by the efficiency and dividing by the availability.

REH: Specifies the ratio of electricity to heat output for CHP technologies. For new technologies, this value is set to 0.5.

10.5.8 Industrial Energy Carriers

There are 56 industrial-specific fuel carriers, which are listed in Table 86.

Table 86. Industrial Sector Energy Carriers.

Name	Definition
COAI	Coal to industry prior to emissions accounting
COAIEA	Coal to entire industrial sector after emis. accounting
DSHIEA	Emissions: fuel oil to industrial sector
DSLIEA	Diesel after NO_X emis. controls for industrial use
GSLIEA	Gasoline to industrial sector
LPGIEA	LPG to industrial sector after emissions accounting
NGAIEA	Nat. gas to industrial sector after emis. accounting
IECH	Industrial electrochemical process chemicals
IEIS	Industrial electrochemical process iron and steel
IELP	Industrial electrochemical process pulp and paper
IENF	Industrial electrochemical process nonferrous metals
IENM	Industrial electrochemical process nonmetals
IEOI	Industrial electrochemical process other industry
IFCH	Industrial chemical feedstock
IFIS	Industrial iron and steel feedstock
IMCH	Industrial machine drive chemicals
IMIS	Industrial machine drive iron and steel
IMLP	Industrial machine drive pulp and paper
IMNF	Industrial machine drive nonferrous metals
IMNM	Industrial machine drive nonmetals
IMOI	Industrial machine drive other industry
IOCH	Industrial other chemicals
IOIS	Industrial other iron and steel
IOLP	Industrial other pulp and paper
IONF	Industrial other nonferrous metals
IONM	Industrial other nonmetals
IOOI	Industrial other all other industry
IPCH	Industrial process heat chemicals
IPIS	Industrial process heat iron and steel
IPLP	Industrial process heat pulp and paper
IPNF	Industrial process heat nonferrous metals
IPNM	Industrial process heat nonmetals
IPOI	Industrial process heat other industry
ISCH	Industrial steam chemicals
ISIS	Industrial steam iron and steel
ISLP	Industrial steam pulp and paper
ISNF	Industrial steam nonferrous metals
ISNM	Industrial steam nonmetals
ISOI	Industrial steam other industry
INDBFG	Blast furnace gas (industrial)
INDBIO	Biofuels (industrial)
INDCOA	Coal (industrial)
INDCOK	Oven coke (industrial)
INDELC	Electricity (industrial)
INDETH	Ethane (industrial)
INDHET	Heat (industrial)
INDHFO	Heavy fuel oil (industrial)
INDHYD	Hydro (industrial)
INDLPG	Liquified petroleum gas (industrial)
INDNAP	Naphtha (industrial)
INDNGA	Natural gas mix (industrial)
INDNUC	Nuclear (industrial)
INDOIL	Refined petroleum products (industrial)
INDPTC	Petroleum coke (industrial)
INDSOL	Solar (industrial)
INDWIN	Wind (industrial)

10.5.9 Industrial Emissions Accounting

Industrial emissions are tracked in two different ways: CO_2, CH_4, and NO_X emissions are tracked at the technology level. SO_X, PM_{10}, and VOC emissions are tracked by fuel going into the industrial sector. All fuels with industrial-specific emission factors pass through a “dummy” process technology that tracks emissions. There are no costs associated with these “technologies;” they simply have an incoming energy carrier and an outgoing energy carrier. There are six of these for the industrial sector, as listed in Table 87. The first two letters in the names of these process technologies are ‘SE’ for Emissions. The last three letters are ‘IND for industrial. The letters in between represent the fuel type.

Table 87. Industrial Emissions “Dummy” Process Technologies.

Name	Definition
SECOAIND	Emissions: coal to industrial
SEDSHIND	Emissions: fuel oil to industrial
SEDSLIND	Emissions: Diesel to industrial
SEGSLIND	Emissions: gasoline to industrial
SELPGIND	Emissions: LPG to industrial
SENGAIND	Emissions: NGA to industrial

The emissions data assumptions and calculations are explained in Section 11.

Data were taken from Jaques (1992) and Jaques et al. (1997).

10.5.10 Industrial Constraints

A set of fuel switching constraints is used to force fuel switching to take place gradually over time. These constraints force a minimum share of each fuel for each energy service. 1995 minimum shares are set at 1995 actual values derived from the IEA database. The minimum shares then relax over time so that the 2000 values are 99.5% of the 1995 values; 2020 values are 80% of 1995 values; and 2045 values are 60% of 1995 values. Values for intermediate years are interpolated.

11 Emissions Data

An important capability of MARKAL is the ability to estimate the emissions that result from the various activities represented in the RES. MARKAL has the capability to estimate both the emissions of criteria pollutants as well as greenhouse gas emissions.

11.1 Emissions from Electricity Generation

Emission factors associated with generating electricity are listed in Tables 88–91. The CO_2 emission factors used in the model were taken from Table A-15 of EPA (2003). SO_2, NO_X, PM_{10}, and VOC values were taken from the 1997

Table 88. CO_2, PM_{10}, VOC, and NO_X Emission Factors from Generating Electricity as Used in the EPANMD.

Technology	CO_2	PM_{10}	VOC	NO_X	NO_X to Electric	
					LNB[a] retrofit	SCR[b] retrofit
Existing Steam Electric	25.2	7.02	1.1744	0.1935	0.1355	0.0193
New Steam Electric	25.2	7.02	1.1744	0.0215	—	—
IGCC	25.2	7.02	0.0292	0.0430	—	—
Atmospheric Fluidized Bed	25.2	7.02	0.0292	0.0215	—	—
Pressurized Fluidized Bed	25.2	7.02	0.0292	0.0215	—	—
Molten Carbonate Fuel Cell	25.2	7.02	0.0292	0.0000	—	—

[a] LNB = low NO_X burners.
[b] SCR = selective catalytic reduction.

Table 89. SO_2 Emission Factors from Generating Electricity as Used in the EPANMD.

Technology	Coal Type	Coal Sulfur Content		
		High	Medium	Low
New Steam Electric	Bituminous	0.12	0.05	0.02
New Steam Electric	Lignite	0.09	0.05	0.02
New Steam Electric	Subbituminous		0.04	0.02
Atmospheric Fluidized Bed	Bituminous	2.31	0.90	0.46
Atmospheric Fluidized Bed	Lignite	1.79	0.98	0.40
Atmospheric Fluidized Bed	Subbituminous		0.71	0.33
IGCC	Bituminous	2.31	0.90	0.46
GCC	Lignite	1.79	0.98	0.40
GCC	Subbituminous		0.71	0.33
Molten Carbonate Fuel Cell	All			
Pressurized Fluidized Bed	Bituminous	2.31	0.90	0.46
Pressurized Fluidized Bed	Lignite	1.79	0.98	0.40
Pressurized Fluidized Bed	Subbituminous		0.71	0.33

Table 90. Emission Factors from Coke as Used in the EPANMD.

Technology	Coal Type	Sulfur content	CO_2	SO_2
Coke	Met.	Low	25.0	0.420
Coke	Met	Medium	25.0	0.530
Imported Coke			24.7	

Table 91. Emission Factors from Coal Gasification as Used in the EPANMD.

Technology	CO_2
High Btu Gasification	25.2
Medium Btu Gasification	25.2
In-Situ Gasification	25.2

DOE MARKAL database with updates by the EPA's Tim Johnson, Joseph DeCarolis, and Samudra Vijay.

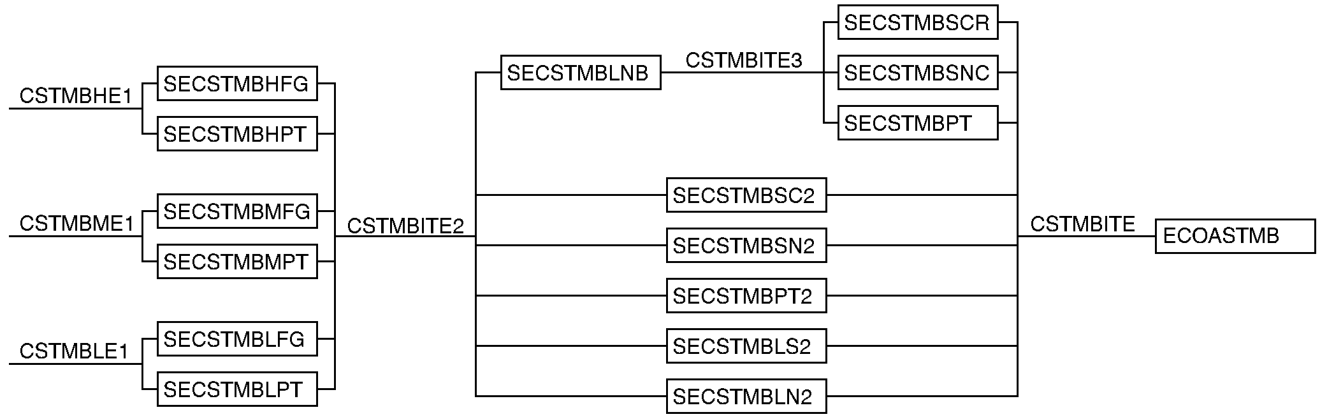
Both the Clean Air Act and more recent CAIR (Clean Air Interstate Rule) impose emissions constraints on SO_X and NO_X emissions from the electric power sector. Because coal plants accounted for roughly 41% of total installed electric generation capacity in 1995 and account for the bulk of electric sector SO_X/NO_X emissions, characterizing the amount of coal capacity with pre-existing controls as well as the cost and removal efficiency of new retrofits is extremely important to the overall performance of U.S. EPA's MARKAL model.

11.1.1 Data Sources

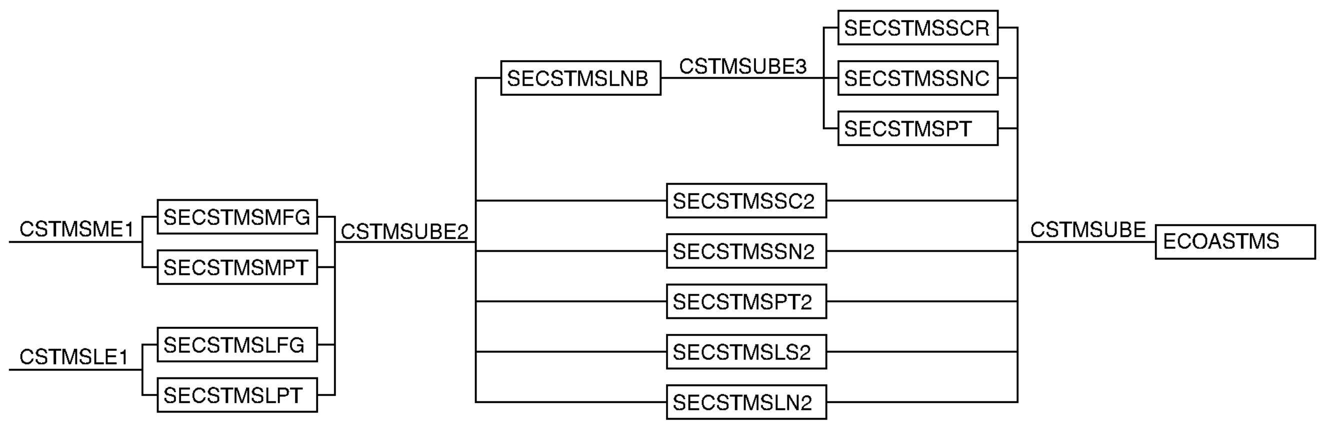
- Energy Information Administration (EIA) Form 767. See http://www.eia.doe.gov/cneaf/electricity/page/eia767.html
- EPA Clean Air Markets—Data and Maps. See http://cfpub.epa.gov/gdm/
- For estimating abatement cost of the residual coal-based power generation capacity, Coal Utility Environmental Cost, Version 3.0 (CUECost, Ver 3.0), an engineering-economic modeling tool developed by National Risk Management Laboratory of EPA, was used. CUECost can be used to estimate cost of retrofitting existing plants with NO_X and SO_X controls. The CUECost estimates are claimed to be within rough-order-of-magnitude (ROM) ±30% (accepted range for budgetary estimates). More details of CueCost can be found at http://www.epa.gov/ttn/catc/products.html#cccinfo

11.1.2 Modeling Structure

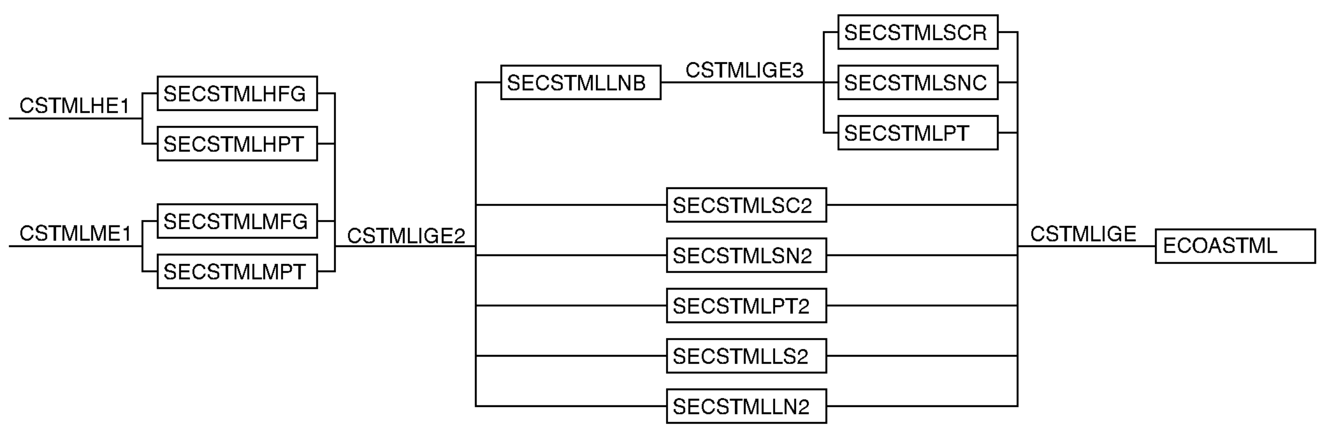
In U.S. EPA MARKAL, there are three coal types (bituminous, sub-bituminous, and lignite) as well as three sulfur levels (high, medium, and low). Because the cost and performance of SO_X control technologies varies by both coal type and sulfur levels, nine flue gas desulfurization (FGD) processes are provided in the model. Because NO_X emissions are insensitive to sulfur level, each NO_X control process was specified separately for each of the three coal types as illustrated in Figure 37.



a. Bituminous Coal Retrofits



b. Subbituminous Coal Retrofits



c. Lignite Retrofits

Figure 37. RES for Coal Retrofits

Note that no high-sulfur subbituminous coal exists and no low sulfur lignite coal exists.

The set of processes on the left hand side of Figure 37 represent sulfur control. For each level of sulfur content (high, medium, low), there are two options: FGD or a pass through (no control). The process naming convention is

- First 3 letters: SEC, emissions accounting for coal-related processes.
- Letters 4–6: STM, because the retrofits are part of a steam-based generation technology.
- Letter 7: Coal type, B=bituminous, S=subbituminous, L=lignite.
- Letter 8: Sulfur level, H=high, M=medium, L=low.
- Letters 9–10: control technology, FG=FGD, PT=pass through (no control).

After passing through the SO_X control processes, the coal energy carriers (CSTMBITE2, CSTMSUBE2, CSTMLIGE2) enter the NO_X control processes. There are three NO_X retrofit technologies explicitly captured in the model: Low NO_X burners (LNB), Selective Catalytic Reduction (SCR), and Selective Non-Catalytic Reduction (SNCR). LNB is a boiler retrofit, while SCR and SNCR operate on the flue gas. As a result, LNB can be used in conjunction with SCR or SNCR.

As of 2000, significant LNB retrofits to coal steam plants existed, but negligible amounts of SCR/SNCR were installed. As a result, residual LNB is characterized in the model while residual SCR/SNCR is not. In a given time period, if LNB is already installed, then SCR or SNCR can also be installed. See the upper right of the MARKAL diagrams above. The naming convention for these NO_X retrofits is

- First 3 letters: SEC, emissions accounting for coal-related processes.
- Letters 4–6: STM, because the retrofits are part of a steam-based generation technology.
- Letter 7: Coal type, B=bituminous, S=subbituminous, L=lignite.
- Letters 8–10: control technology, LNB=LNB, SCR=SCR to supplement LNB, SNC=SNCR to supplement LNB, PT=pass through (LNB only).

For the coal steam capacity that does not have LNB installed, there are several possible new retrofits: SCR only, SNCR only, pass through, an LNB-SCR combination, and an LNB-SNCR combination. The naming convention for these NO_X retrofits is

- First 3 letters: SEC, emissions accounting for coal-related processes.
- Letters 4–6: STM, because the retrofits are part of a steam-based generation technology.
- Letter 7: Coal type, B=bituminous, S=subbituminous, L=lignite.
- Letters 8–10: control technology, SC2=new SCR, SN2=new SNCR, PT2=pass through (no control), LS2=new LNB-SCR combination, and LN2=new LNB-SNCR combination.

It is important to note that there are two possible pathways to achieve combinations of LNB and SCR/SNCR. If LNB is already installed, SCR and SNCR can be retrofitted later. For example, in the case of bituminous coal, this possibility is represented by a combination of SECSTMBLNB and SECSTMBSCR or SECSTMBSNC. Or LNB and SCR/SNCR can be installed at the same time, which reduces the cost through integrated planning.

After the NO_X retrofits, the coal energy carrier (bituminous=CSTMBITE, sub-bituminous=CSTMSUBE, lignite=CSTMLIGE) proceeds to the coal steam plants, ECOASTMB=bituminous, ECOASTMS=subbituminous, and ECOASTML=lignite.

11.1.3 Methodology

Cost (capital and O&M) and emissions reductions for SO_X and NO_X retrofit technologies were estimated and included in the MARKAL representation shown above. Because the data had to be sorted by coal type and sulfur level, several data sources were required. The EPA Clean Air Markets data included boiler-level emissions data, capacity, and a description of installed control technology (if any) but did not include coal type or sulfur content. EIA-Form 860 contained the generator-level coal type and sulfur level, but not the emissions data. Because EIA Form 860 contains data on the generator level and EPA contains data on the boiler level, it is not possible to make a one-to-one mapping between EIA and EPA data. Instead, the coal type and coal sulfur content were drawn from the first generator listed under each unique plant ID in the EIA data, then associated with each of the boilers with the same plant ID in the EPA data: a Java script was implemented to do the matching, and the combined data set was saved as a comma-delimited file.

SO_X Control

Residual FGD/non-FGD capacity and emissions were estimated according to coal type, sulfur content, and presence of FGD using the autofilter feature in Excel. Sulfur content was divided into three categories: high (1.68 lbs SO_X/MBtu), medium (between 0.6 and 1.68 lbs SO_X / MBtu), and low (0.6 lbs SO_X/MBtu). Average SO_X rates were found by dividing the sum of the SO_X emissions (tons) from all boilers by the total heat generated by all boilers. FGD/non-FGD capacity was determined by summing the corresponding boiler capacities in millions of Btu per hour and converting to petajoules per year.

NO_X control

Residual LNB/non-LNB capacity and emissions were estimated according to coal type and the presence of LNB using the autofilter feature in Excel. Negligible amounts of SCR and SNCR existed prior to 2000, so their residual capacity was not included. Any boiler capacity with retrofits not explicitly captured as a separate NO_X control processes in MARKAL—such as over-fire air and water injection —were included under the "pass through" characterization. Average NO_X rates and NO_X control capacity were determined using the methodology described in the preceding paragraph.

11.1.4 Estimating the Cost and Removal Efficiency of New SO_X/NO_X Retrofits

To estimate both the capital and operating costs for new retrofit capacity, the CueCost model was used. A script was written to estimate the retrofit costs for various SO_X and NO_X control technologies for every boiler listed in the EPA Clean Air Markets data. The script took the data for each boiler listed in the EIA-EPA dataset and returned the retrofit cost and emissions rate for each of the SO_X/NO_X retrofits according to coal type and sulfur level (for SO_X retrofits). Emissions rates and variable O&M costs were weighted by the heat produced by each of the boilers, and the capital costs were weighted by boiler capacities to calculate representative values.

11.1.5 SO_X Retrofit Data Summary

A summary of all the data associated with SO_X retrofit is shown in Table 89.

11.2 Biomass Emissions

The biomass emission factors used in the EPANMD and listed in Table 93 were taken from the 1997 MARKAL database.

Table 93. Biomass CO_2 Emission Factors in the EPANMD..

Technology	CO_2 Emission Factor
Biomass into NGA	–15.2
Biomass into Methanol	–19.1
NGA into Methanol	8.536
NGA to the Pipeline	0.634

Table 92. SO_X Control Data Summary.

Parameter	Bituminous Coal					
	High Sulfur		Medium Sulfur		Low Sulfur	
	FGD (SECSTMBHFG)	Pass (SECSTMBHPT)	FGD (SECSTMBMFG)	Pass (SECSTMBMPT)	FGD (SECSTMBLFG)	Pass (SECSTMBLPT)
1995 Residual Capacity (PJ/yr)	2611		1226		1123	
2000 Residual Capacity (PJ/yr)	3160		1313		1093	
Equilibrium Emissions Rate (kT/PJ)	0.034	0.67	0.02	0.39	0.0095	0.19
Capital Cost (M$/PJ/yr)	2.55		2.11		2.29	
Variable O&M (M$/PJ)	0.327		0.264		0.316	
Parameter	**Subbituminous Coal**					
	High Sulfur		Medium Sulfur		Low Sulfur	
	FGD	Pass	FGD (SECSTMSMFG)	Pass (SECSTMSMPT)	FGD (SECSTMSLFG)	Pass (SECSTMSLPT)
1995 Residual Capacity (PJ/yr)	N/A		461		1350	
2000 Residual Capacity (PJ/yr)	N/A		1684		1718	
Equilibrium Emissions Rate (kT/PJ)	N/A	N/A	0.012	0.23	0.0075	0.13
Capital Cost (M$/PJ/yr)	N/A		1.83		1.97	
Variable O&M (M$/PJ)	N/A		0.192		0.245	
Parameter	**Lignite**					
	High Sulfur		Medium Sulfur		Low Sulfur	
	FGD (SECSTMLHFG)	Pass (SECSTMLHPT)	FGD (SECSTMLMFG)	Pass (SECSTMLMPT)	FGD	Pass
1995 Residual Capacity (PJ/yr)	63		306		N/A	
2000 Residual Capacity (PJ/yr)	149		1047		N/A	
Equilibrium Emissions Rate (kT/PJ)	0.023	0.71	0.016	0.36	N/A	N/A
Capital Cost (M$/PJ/yr)	1.85		1.69		N/A	
Variable O&M (M$/PJ)	0.237		0.237		N/A	

11.3 Commercial and Residential Emissions

For SO_2, NO_X, PM_{10}, and VOCs, the actual pollutant emissions in 1999 were taken from the EPA national inventory along with the actual energy consumption from EIA in 1999. Emission factors were obtained by dividing actual emissions by actual energy consumption. Where no pollutant information was provided, default IPCC emission factors were used. For LPG, AP-42 emission factors were used. For CO_2, IPCC emissions factors were used. The residential emission factors are listed in Table 94 and the commercial in Table 95.

Table 94. Residential Emission Factors (in lb/MMBtu) used in the EPANMD.

Fuel	SO_2	NO_X	PM_{10}	VOCs	CO_2
Natural Gas	0.0067	0.1756	0.0051	0.0093	129.7490
Coal	5.9358	1.1088	0.5200	0.0278	215.4939
Distillate Fuel Oil	0.1474	0.2643	0.0315	0.0090	168.7544
LPG	0.0011	0.01421	0.0019	0.0055	136.6120
Kerosene	0.1474	0.2643	0.0315	0.0090	168.7544
Wood	0.0279	0.1991	2.1207	2.9964	0.0000

Table 95. Commercial Emission Factors (in lb/MMBtu) used in the EPANMD.

Fuel	SO_2	NO_X	PM_{10}	VOCs	CO_2
Natural Gas	0.0067	0.1680	0.0051	0.0093	129.7490
Coal	5.9358	1.1088	0.5200	0.0278	215.4939
Distillate Fuel Oil	0.8262	0.2652	0.0315	0.0090	168.7544
LPG	0.0000	0.2077	0.0044	0.0033	136.6120
Residual Fuel Oil	4.3227	0.9106	0.2607	0.0770	168.7544
Biomass	0.0279	0.1991	2.1207	2.9964	0.0000

11.4 Industrial Emissions

For CO_2 emission factors, listed in Table 96, data were taken from Jaques, A.P., 1992, and Jaques, A., et al., 1997. Emission factors for SO_2, NO_X, PM_{10}, and VOCs, listed in Table 97, the actual pollutant emissions in 1999 were taken from the EPA national inventory along with the actual energy consumption from EIA in 1999. Emission factors were obtained by dividing actual emission by actual energy consumption. Where no pollutant information was provided, default IPCC emission factors were used. For LPG, AP-42 emission factors were used.

Table 97. Additional Industrial EPANMD Emission Factors (in lb/MMBtu).

1999	Fuel	SO_2	NO_X	PM_{10}	VOCs
	Coal	1.5072	0.6225	0.0849	0.0079
	Met. Coal to Coking	N/A	N/A	N/A	N/A
	Residual Fuel Oil	4.3227	0.9106	0.2607	0.0770
	Diesel (distillate)	0.3213	0.1484	0.0113	0.1051
	Gasoline	0.3213	0.1484	0.0113	0.1051
	LPG	0.0000	0.2077	0.0066	0.0033
	Misc. Petroleum	0.3213	0.1484	0.0113	0.1051
	Natural Gas	0.1409	0.2940	0.0104	0.0147
	Hydrocarb. Petrochem. Feedstock	N/A	N/A	N/A	N/A
	Biomass	0.0000	0.2326	0.0708	0.1163

11.5 Transportation Emissions

Vehicle emissions depend on fuel, propulsion technology (e.g., internal combustion engine or fuel cell), emissions control devices, and vehicle age (cumulative miles traveled) through degradation of control equipment. Because the existing vehicles represented the fleet as of the model start year, emissions from these vehicles will also change over time due to the earlier retirement of older, more polluting vehicles.

Emissions factors for existing vehicles were calculated from actual 1995 light-duty vehicle fleet emissions based on the EPA, 2000b. Vehicle stock turnover and annual VMT by vintage were calculated based on information from the Energy Information Administration (EIA, 1998, 2003a) and the Transportation Energy Data Book, Edition 21 (Davis, 2001). Degradation estimates were based on a variety of sources, depending on the pollutant, including the EPA Federal Test Procedure, EPA's Mobile 6 model (EPA, 1999, 2001a), and the American Council for an Energy Efficient Economy (ACEEE) Green Book methodology (DeCicco, J. and Kliesch, J., 2001).

For new internal combustion engine and hybrid vehicles, emissions factors were based on standards specifications for Tier 1, Low Emissions Vehicles (LEV), Ultra Low Emissions Vehicles (ULEV), Super Ultra Low Emissions Vehicles (SULEV), and Tier 2 compliant vehicles (EPA, 2000a). For Tier 2 compliant vehicles, emissions factors were derived from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, developed by the Argonne National Laboratory (Argonne National Labs, 2001). All hybrid vehicles were assumed to be SULEV compliant. For all other internal combustion

Table 96. Industrial CO_2 Emission Factors in the EPANMD.

Commodity	Description	Units	INDNGA	INDLPG	INDCOA	INDCOK	INDBFG	INDHFO	INDOIL	INDETH	INDNAP	INDPTC	INDBIO
INDCO2N	industrial CO_2	ktonne	15.200	16.364	25.200	25.200	25.200	20.182	19.170	15.200	19.279	27.300	0.584
INDCH4N	Industrial CH_4	tonne	0.130	1.180	0.542	0.542	0.542	0.720	2.143	0.127	1.320	0.542	0.020
INDN2ON	Industrial N_2O	tonne	0.620	9.000	1.805	1.805	1.805	3.110	3.836	0.620	3.360	1.805	8.647
CO_2	ICO_2	MtonneC	0.015	0.016	0.025	0.025	0.025	0.020	0.019	0.015	0.019	0.027	0.001

engine (ICE) vehicles, a mix of compliance levels was assumed based on national and state regulations. Degradation estimates were based on the Mobile 6 model, EPA,s Tier 2/Sulfur analysis (EPA 2001b), and the ACEEE Green Book methodology. The various transportation emission factors are listed in Tables 98 through 103.

Table 98. Airplane Emission Factors.

Fuel	CO_2 Mt/bpm[a]	NO_x kt/bpm	SO_x kt/bpm	VOC kt/bpm
Jet Fuel	0.119	0.64	0.0044	0.04
Gasoline	0.192	0.18	0.0044	1.19

[a] bpm = billion passenger miles

Table 99. Bus Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_x kt/bvmt	SO_x kt/bvmt	VOC kt/bvmt
Methanol	0.019		0.009	
CNG	0.002	15.715	0.064	3.069
DSL	0.020		0.012	62.559
GSL	0.019		0.009	

[a] bvmt = billion vehicle miles traveled

Table 100. Passenger Rail Emission Factors.

DSL Fuel	CO_2 Mt/bvmt[a]	NO_x kt/bvmt	SO_x kt/bvmt	VOC kt/bvmt
Commuter Rail	0.128	0.145	0.003	3.723
Inter-city Rail	0.094	0.145	0.003	3.723

[a] bvmt = billion vehicle miles traveled

Table 101. Shipping Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_x kt/bvmt	SO_x kt/bvmt	VOC kt/bvmt
Rail Freight, DSL	0.086	0.145	0.003	3.723
Shipping, Fuel Oil	0.169	0.168	0.575	5.136
Shipping, DSL	0.162	0.250	0.017	9.846

[a] bvmt = billion vehicle miles traveled

Table 102. Heavy Truck Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_x kt/bvmt	PM_{10} kt/bvmt	SO_x kt/bvmt	VOC kt/bvmt
GSL, existing	0.445	11.483	0.257	0.174	6.034
GSL, new	0.415	10.865		0.030	1.726
DSL, existing	0.476	16.097	0.521	0.140	1.497
DSL, 2000	0.444	14.101		0.206	0.852
DSL, 2000, imp mpg (20%)	0.370	14.101		0.206	0.852
DSL, 2000, imp mpg (40%)	0.317	14.101		0.206	0.852
DSL, 2010	0.416	0.429		0.009	0.258
DSL, 2010, imp mpg (10%)	0.380	0.429		0.009	0.258
DSL, 2010, imp mpg (20%)	0.346	0.429		0.009	0.258
DSL, 2020	0.386	0.429		0.009	0.258
DSL, 2020, imp mpg (10%)	0.350	0.429		0.009	0.258
DSL, 2020, imp mpg (20%)	0.321	0.429		0.009	0.258
LPG	0.383	15.715		0.048	4.158
Methanol	0.000	15.715		0.064	4.853
CNG	0.321	15.715		0.032	3.069

[a] bvmt = billion vehicle miles traveled

Table 103. Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_x kt/bvmt	PM_{10} kt/bvmt	SO_x kt/bvmt	VOC kt/bvmt
TLC2HYB05	0.071	0.056	0.002	0.015	0.033
TLC2HYB10	0.057	0.056	0.002	0.015	0.033
TLC2HYB15	0.052	0.056	0.002	0.015	0.033
TLC2HYB20	0.048	0.056	0.002	0.015	0.033
TLC2HYB25	0.044	0.056	0.002	0.015	0.033
TLC2HYB30	0.044	0.056	0.002	0.015	0.033
TLC2HYB35	0.043	0.056	0.002	0.015	0.033
TLC3HYB15	0.039	0.056	0.002	0.015	0.033
TLC3HYB20	0.033	0.056	0.002	0.015	0.033
TLC3HYB25	0.030	0.056	0.002	0.015	0.033
TLC3HYB30	0.029	0.056	0.002	0.015	0.033
TLC3HYB35	0.029	0.056	0.002	0.015	0.033
TLCADSL05	0.076	0.265	0.020	0.059	0.560
TLCADSL10	0.072	0.265	0.020	0.059	0.560
TLCADSL15	0.071	0.265	0.020	0.059	0.560
TLCADSL20	0.071	0.265	0.020	0.059	0.560
TLCADSL25	0.070	0.265	0.020	0.059	0.560
TLCADSL30	0.069	0.265	0.020	0.059	0.560
TLCADSL35	0.069	0.265	0.020	0.059	0.560
TLCAMPG10	0.058	0.287	0.019	0.015	0.123
TLCAMPG15	0.057	0.287	0.019	0.015	0.123
TLCAMPG20	0.057	0.287	0.019	0.015	0.123
TLCAMPG25	0.056	0.288	0.018	0.015	0.122
TLCAMPG30	0.056	0.288	0.018	0.015	0.122
TLCAMPG35	0.055	0.288	0.018	0.015	0.122
TLCCNG05	0.078	0.248	0.001	0.001	0.045
TLCCNG10	0.074	0.248	0.001	0.001	0.045
TLCCNX00	0.089	0.365	0.005	0.004	0.120
TLCCNX10	0.079	0.257	0.005	0.004	0.064
TLCCNX20	0.078	0.099	0.006	0.004	0.075
TLCCONV00	0.103	0.717	0.019	0.015	0.345
TLCCONV05	0.096	0.287	0.019	0.015	0.123
TLCCONV10	0.091	0.287	0.019	0.015	0.123
TLCCONV15	0.090	0.287	0.019	0.015	0.123
TLCCONV20	0.089	0.287	0.019	0.015	0.123
TLCCONV25	0.089	0.288	0.018	0.015	0.122
TLCCONV30	0.088	0.288	0.018	0.015	0.122
TLCCONV35	0.087	0.288	0.018	0.015	0.122
TLCELC05	0.000	0.000	0.000	0.000	0.000
TLCELC10	0.000	0.000	0.000	0.000	0.000

[a] bvmt = billion vehicle miles traveled

continued

Table 103 (continued). Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_X kt/bvmt	PM_{10} kt/bvmt	SO_X kt/bvmt	VOC kt/bvmt
TLCETHX05	0.099	0.248	0.005	0.005	0.176
TLCETHX10	0.094	0.248	0.005	0.005	0.176
TLCETHX15	0.094	0.248	0.005	0.005	0.176
TLCETHX20	0.094	0.248	0.005	0.005	0.176
TLCETHX25	0.094	0.248	0.005	0.005	0.176
TLCETHX30	0.094	0.248	0.005	0.005	0.176
TLCETHX35	0.094	0.248	0.005	0.005	0.176
TLCFCH20	0.000	0.000	0.000	0.000	0.000
TLCFCH25	0.000	0.000	0.000	0.000	0.000
TLCFCM10	0.045	0.007	0.000	0.000	0.038
TLCFCM20	0.040	0.007	0.000	0.000	0.038
TLCLPGX00	0.101	0.365	0.006	0.004	0.144
TLCLPGX10	0.090	0.257	0.006	0.004	0.088
TLCLPGX20	0.087	0.099	0.006	0.004	0.080
TLCMMPG10	0.064	0.287	0.019	0.015	0.123
TLCMMPG15	0.064	0.287	0.019	0.015	0.123
TLCMMPG20	0.063	0.287	0.019	0.015	0.123
TLCMMPG25	0.062	0.288	0.018	0.015	0.122
TLCMMPG30	0.062	0.288	0.018	0.015	0.122
TLCMMPG35	0.061	0.288	0.018	0.015	0.122
TLCMTHX00	0.101	0.248	0.005	0.005	0.176
TLCMTHX10	0.089	0.248	0.005	0.005	0.176
TLCMTHX20	0.085	0.036	0.006	0.003	0.125
TLECGSL	0.104	1.752	0.030	0.032	2.949
TLEFDSL	0.115	3.531	0.673	0.225	0.912
TLEFGSL	0.119	1.752	0.030	0.032	2.949
TLEMGSL	0.120	1.314	0.031	0.038	2.953
TLEPDSL	0.148	3.531	0.757	0.253	2.279
TLEPGSL	0.145	1.857	0.039	0.040	3.412
TLESGSL	0.152	1.340	0.018	0.036	2.912
TLF2HYB05	0.074	0.056	0.002	0.015	0.033
TLF2HYB10	0.065	0.056	0.002	0.015	0.033
TLF2HYB15	0.059	0.056	0.002	0.015	0.033
TLF2HYB20	0.054	0.056	0.002	0.015	0.033
TLF2HYB25	0.050	0.056	0.002	0.015	0.033
TLF2HYB30	0.050	0.056	0.002	0.015	0.033
TLF2HYB35	0.050	0.056	0.002	0.015	0.033
TLF3HYB10	0.052	0.056	0.002	0.015	0.033
TLF3HYB15	0.045	0.056	0.002	0.015	0.033
TLF3HYB20	0.038	0.056	0.002	0.015	0.033
TLF3HYB35	0.034	0.056	0.002	0.015	0.033
TLF3HYB30	0.033	0.056	0.002	0.015	0.033
TLF3HYB35	0.033	0.056	0.002	0.015	0.033
TLFADSL05	0.084	0.265	0.020	0.059	0.560
TLFADSL10	0.080	0.265	0.020	0.059	0.560
TLFADSL15	0.079	0.265	0.020	0.059	0.560
TLFADSL20	0.078	0.265	0.020	0.059	0.560
TLFADSL25	0.077	0.265	0.020	0.059	0.560
TLFADSL30	0.076	0.265	0.020	0.059	0.560
TLFADSL35	0.076	0.265	0.020	0.059	0.560
TLFAMMP10	0.060	0.287	0.019	0.015	0.123
TLFAMMP15	0.059	0.287	0.019	0.015	0.123
TLFAMMP20	0.058	0.287	0.019	0.015	0.123
TLFAMMP25	0.058	0.287	0.019	0.015	0.123
TLFAMMP30	0.057	0.287	0.019	0.015	0.123
TLFAMMP35	0.057	0.287	0.019	0.015	0.123

[a] bvmt = billion vehicle miles traveled

continued

Table 103 (continued). Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_X kt/bvmt	PM_{10} kt/bvmt	SO_X kt/bvmt	VOC kt/bvmt
TLFCNG05	0.090	0.248	0.001	0.001	0.045
TLFCNG10	0.085	0.248	0.001	0.001	0.045
TLFCNGX00	0.098	0.365	0.005	0.004	0.120
TLFCNGX10	0.090	0.365	0.005	0.004	0.120
TLFCNGX20	0.090	0.206	0.006	0.004	0.130
TLFCONV00	0.118	0.717	0.019	0.015	0.345
TLFCONV05	0.110	0.287	0.019	0.015	0.123
TLFCONV10	0.105	0.287	0.019	0.015	0.123
TLFCONV15	0.103	0.287	0.019	0.015	0.123
TLFCONV20	0.102	0.287	0.019	0.015	0.123
TLFCONV25	0.101	0.288	0.018	0.015	0.122
TLFCONV30	0.100	0.288	0.018	0.015	0.122
TLFCONV35	0.099	0.288	0.018	0.015	0.122
TLFCELC10	0.000	0.000	0.000	0.000	0.000
TLFETHX00	0.122	0.248	0.005	0.005	0.176
TLFETHX10	0.108	0.248	0.005	0.005	0.176
TLFFCG10	0.051	0.007	0.000	0.000	0.057
TLFFCG20	0.045	0.007	0.000	0.000	0.057
TLFFCG25	038	0.007	0.000	0.000	0.057
TLFFCH20	0.000	0.000	0.000	0.000	0.000
TLFFCH25	0.000	0.000	0.000	0.000	0.000
TLFFCM10	0.052	0.007	0.000	0.000	0.038
TLFFCM20	0.046	0.007	0.000	0.000	0.038
TLFLPGX00	0.108	0.248	0.001	0.000	0.077
TLFLPGX10	0.103	0.248	0.001	0.000	0.077
TLFLPGX20	0.100	0.036	0.002	0.000	0.065
TLFMMPG10	0.067	0.287	0.019	0.015	0.123
TLFMMPG15	0.066	0.287	0.019	0.015	0.123
TLFMMPG20	0.065	0.287	0.019	0.015	0.123
TLFMMPG25	0.065	0.288	0.018	0.015	0.122
TLFMMPG30	0.064	0.288	0.018	0.015	0.122
TLFMMPG35	0.063	0.288	0.018	0.015	0.122
TLFMTHX00	0.116	0.248	0.005	0.005	0.176
TLFMTHX10	0.102	0.248	0.005	0.005	0.176
TLFMTHX20	0.098	0.036	0.006	0.003	0.125
TLM2HYB10	0.072	0.057	0.002	0.021	0.169
TLM2HYB15	0.064	0.057	0.002	0.021	0.169
TLM2HYB20	0.058	0.057	0.002	0.021	0.169
TLM2HYB25	0.054	0.057	0.002	0.021	0.169
TLM2HYB30	0.055	0.057	0.002	0.021	0.169
TLM2HYB35	0.055	0.057	0.002	0.021	0.169
TLM3HYB15	0.054	0.057	0.002	0.021	0.169
TLM3HYB20	0.047	0.057	0.002	0.021	0.169
TLM3HYB25	0.036	0.057	0.002	0.021	0.169
TLM3HYB30	0.036	0.057	0.002	0.021	0.169
TLM3HYB35	0.036	0.057	0.002	0.021	0.169
TLMADSL10	0.087	0.493	0.044	0.080	0.872
TLMADSL15	0.085	0.493	0.044	0.080	0.872
TLMADSL20	0.083	0.493	0.044	0.080	0.872
TLMADSL25	0.083	0.493	0.044	0.080	0.872
TLMADSL30	0.083	0.493	0.044	0.080	0.872
TLMADSL35	0.084	0.493	0.044	0.080	0.872
TLMAMPG10	0.062	0.196	0.028	0.021	0.545
TLMAMPG15	0.060	0.196	0.028	0.021	0.545
TLMAMPG20	0.058	0.196	0.028	0.021	0.545
TLMAMPG25	0.059	0.194	0.027	0.021	0.545

[a] bvmt = billion vehicle miles traveled

continued

Table 103 (continued). Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_X kt/bvmt	PM_{10} kt/bvmt	SO_X kt/bvmt	VOC kt/bvmt
TLMAMPG30	0.059	0.194	0.027	0.021	0.545
TLMAMPG35	0.059	0.194	0.027	0.021	0.545
TLMCNG05	0.096	0.541	0.001	0.001	0.085
TLMCNG15	0.090	0.060	0.002	0.001	0.062
TLMCNGX00	0.104	0.524	0.008	0.006	0.376
TLMCNGX10	0.103	0.454	0.008	0.006	0.200
TLMCNGX20	0.098	0.163	0.009	0.006	0.359
TLMCONV00	0.120	0.472	0.028	0.021	1.249
TLMCONV05	0.118	0.196	0.028	0.021	0.545
TLMCONV10	0.115	0.196	0.028	0.021	0.545
TLMCONV15	0.111	0.196	0.028	0.021	0.545
TLMCONV20	0.108	0.196	0.028	0.021	0.545
TLMCONV25	0.109	0.194	0.027	0.021	0.545
TLMCONV30	0.109	0.194	0.027	0.021	0.545
TLMCONV35	0.109	0.194	0.027	0.021	0.545
TLMELC10	0.000	0.000	0.000	0.000	0.000
TLMELC20	0.000	0.000	0.000	0.000	0.000
TLMETHX00	0.125	0.499	0.006	0.007	0.268
TLMETHX10	0.119	0.499	0.006	0.007	0.268
TLMETHX20	0.112	0.499	0.006	0.007	0.268
TLMFCG10	0.060	0.012	0.000	0.000	0.060
TLMFCG15	0.054	0.012	0.000	0.000	0.060
TLMFCG20	0.048	0.012	0.000	0.000	0.060
TLMFCH15	0.000	0.000	0.000	0.000	0.000
TLMFCH20	0.000	0.000	0.000	0.000	0.000
TLMFCH25	0.000	0.000	0.000	0.000	0.000
TLMFCM10	0.061	0.012	0.000	0.000	0.040
TLMFCM20	0.049	0.012	0.000	0.000	0.040
TLMLPGX00	0.118	0.499	0.002	0.000	0.172
TLMLPGX10	0.115	0.499	0.002	0.000	0.172
TLMLPGX20	0.106	0.060	0.002	0.000	0.071
TLMMMPG10	0.074	0.196	0.028	0.021	0.545
TLMMMPG15	0.074	0.196	0.028	0.021	0.545
TLMMMPG20	0.070	0.196	0.028	0.021	0.545
TLMMMPG25	0.070	0.194	0.027	0.021	0.545
TLMMMPG30	0.070	0.194	0.027	0.021	0.545
TLMMMPG35	0.071	0.194	0.027	0.021	0.545
TLMMTHX00	0.118	0.499	0.006	0.007	0.268
TLMMTHX10	0.112	0.499	0.006	0.007	0.268
TLMMTHX20	0.103	0.060	0.007	0.004	0.133
TLP2HYB10	0.081	0.103	0.002	0.021	0.328
TLP2HYB15	0.076	0.103	0.002	0.021	0.328
TLP2HYB20	0.069	0.103	0.002	0.021	0.328
TLP2HYB25	0.065	0.103	0.002	0.021	0.328
TLP2HYB30	0.065	0.103	0.002	0.021	0.328
TLP2HYB35	0.065	0.103	0.002	0.021	0.328
TLP3HYB20	0.053	0.103	0.002	0.021	0.328
TLP3HYB25	0.043	0.103	0.002	0.021	0.328
TLP3HYB30	0.043	0.103	0.002	0.021	0.328
TLP3HYB35	0.043	0.103	0.002	0.021	0.328
TLPADSL05	0.108	0.493	0.044	0.080	0.872
TLPADSL10	0.104	0.493	0.044	0.080	0.872
TLPADSL15	0.101	0.493	0.044	0.080	0.872
TLPADSL20	0.098	0.493	0.044	0.080	0.872
TLPADSL25	0.099	0.493	0.044	0.080	0.872
TLPADSL30	0.099	0.493	0.044	0.080	0.872

[a] bvmt = billion vehicle miles traveled

continued

Table 103 (continued). Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_X kt/bvmt	PM_{10} kt/bvmt	SO_X kt/bvmt	VOC kt/bvmt
TLPADSL35	0.100	0.493	0.044	0.080	0.872
TLPAMPG10	0.085	0.209	0.028	0.021	0.511
TLPAMPG15	0.082	0.209	0.028	0.021	0.511
TLPAMPG20	0.080	0.209	0.028	0.021	0.511
TLPAMPG25	0.080	0.208	0.027	0.021	0.513
TLPAMPG30	0.081	0.208	0.027	0.021	0.513
TLPAMPG35	0.081	0.208	0.027	0.021	0.513
TLPCNG05	0.116	0.932	0.001	0.001	0.159
TLPCNG15	0.107	0.106	0.003	0.001	0.068
TLPCNGX00	0.127	0.812	0.008	0.006	0.387
TLPCNGX10	0.120	0.812	0.008	0.006	0.387
TLPCNGX20	0.115	0.193	0.010	0.006	0.320
TLPCONV00	0.146	0.454	0.028	0.021	1.074
TLPCONV05	0.141	0.209	0.028	0.021	0.511
TLPCONV10	0.136	0.209	0.028	0.021	0.511
TLPCONV15	0.132	0.209	0.028	0.021	0.511
TLPCONV20	0.129	0.209	0.028	0.021	0.511
TLPCONV25	0.129	0.208	0.027	0.021	0.513
TLPCONV30	0.130	0.208	0.027	0.021	0.513
TLPCONV35	0.130	0.208	0.027	0.021	0.513
TLPELC05	0.000	0.000	0.000	0.000	0.000
TLPELC15	0.000	0.000	0.000	0.000	0.000
TLPELC25	0.000	0.000	0.000	0.000	0.000
TLPETHX05	0.146	0.807	0.006	0.007	0.467
TLPETHX10	0.141	0.807	0.006	0.007	0.467
TLPETHX20	0.134	0.807	0.006	0.007	0.467
TLPFCH15	0.000	0.000	0.000	0.000	0.000
TLPFCH20	0.000	0.000	0.000	0.000	0.000
TLPFCH25	0.000	0.000	0.000	0.000	0.000
TLPFCM10	0.073	0.021	0.000	0.000	0.044
TLPFCM20	0.062	0.021	0.000	0.000	0.044
TLPLPGX00	0.144	0.807	0.002	0.000	0.348
TLPLPGX10	0.135	0.807	0.002	0.000	0.348
TLPLPGX20	0.126	0.106	0.003	0.000	0.081
TLPMMPG10	0.100	0.209	0.028	0.021	0.511
TLPMMPG15	0.097	0.209	0.028	0.021	0.511
TLPMMPG20	0.094	0.209	0.028	0.021	0.511
TLPMMPG25	0.094	0.208	0.027	0.021	0.513
TLPMMPG30	0.095	0.208	0.027	0.021	0.513
TLPMMPG35	0.095	0.208	0.027	0.021	0.513
TLPMTHX00	0.144	0.807	0.006	0.007	0.467
TLPMTHX10	0.134	0.807	0.006	0.007	0.467
TLPMTHX20	0.123	0.106	0.010	0.004	0.148
TLS2HYB05	0.108	0.156	0.002	0.020	0.054
TLS2HYB10	0.088	0.156	0.002	0.020	0.054
TLS2HYB15	0.078	0.156	0.002	0.020	0.054
TLS2HYB20	0.071	0.156	0.002	0.020	0.054
TLS2HYB25	0.067	0.156	0.002	0.020	0.054
TLS2HYB30	0.067	0.156	0.002	0.020	0.054
TLS2HYB35	0.068	0.156	0.002	0.020	0.054
TLS3HYB15	0.068	0.156	0.002	0.020	0.054
TLS3HYB20	0.058	0.156	0.002	0.020	0.054
TLS3HYB25	0.045	0.156	0.002	0.020	0.054
TLS3HYB30	0.045	0.156	0.002	0.020	0.054
TLS3HYB35	0.045	0.156	0.002	0.020	0.054
TLSADSL05	0.112	0.493	0.044	0.080	0.872

[a] bvmt = billion vehicle miles traveled

continued

Table 103 (concluded). Light Duty Vehicle Emission Factors.

Fuel	CO_2 Mt/bvmt[a]	NO_X kt/bvmt	PM_{10} kt/bvmt	SO_X kt/bvmt	VOC kt/bvmt
TLSADSL10	0.107	0.493	0.044	0.080	0.872
TLSADSL15	0.104	0.493	0.044	0.080	0.872
TLSADSL20	0.102	0.493	0.044	0.080	0.872
TLSADSL25	0.102	0.493	0.044	0.080	0.872
TLSADSL30	0.103	0.493	0.044	0.080	0.872
TLSADSL35	0.103	0.493	0.044	0.080	0.872
TLSAMPG10	0.071	0.508	0.028	0.020	0.186
TLSAMPG15	0.069	0.508	0.028	0.020	0.186
TLSAMPG20	0.067	0.508	0.028	0.020	0.186
TLSAMPG25	0.068	0.508	0.027	0.020	0.185
TLSAMPG30	0.068	0.508	0.027	0.020	0.185
TLSAMPG35	0.068	0.508	0.027	0.020	0.185
TLSCNG05	0.120	0.512	0.001	0.001	0.079
TLSCNG15	0.110	0.056	0.002	0.001	0.062
TLSCNGX00	0.132	0.564	0.005	0.005	0.146
TLSCNGX10	0.124	0.456	0.005	0.005	0.090
TLSCNGX20	0.119	0.114	0.006	0.004	0.077
TLSCONV00	0.153	1.151	0.028	0.020	0.449
TLSCONV05	0.146	0.508	0.028	0.020	0.186
TLSCONV10	0.141	0.508	0.028	0.020	0.186
TLSCONV15	0.137	0.508	0.028	0.020	0.186
TLSCONV20	0.134	0.508	0.028	0.020	0.186
TLSCONV25	0.134	0.508	0.027	0.020	0.185
TLSCONV30	0.135	0.508	0.027	0.020	0.185
TLSCONV35	0.135	0.508	0.027	0.020	0.185
TLSELC10	0.000	0.000	0.000	0.000	0.000
TLSELC20	0.000	0.000	0.000	0.000	0.000
TLSETHX05	0.152	0.477	0.006	0.006	0.254
TLSETHX15	0.138	0.056	0.007	0.004	0.132
TLSFCG10	0.075	0.011	0.000	0.000	0.059
TLSFCG20	0.0064	0.011	0.000	0.000	0.059
TLSFCH15	0.000	0.000	0.000	0.000	0.000
TLSFCH20	0.000	0.000	0.000	0.000	0.000
TLSFCH25	0.000	0.000	0.000	0.000	0.000
TLSFCM10	0.076	0.011	0.000	0.000	0.040
TLSFCM20	0.064	0.011	0.000	0.000	0.040
TLSLPGX00	0.150	0.477	0.002	0.000	0.160
TLSLPGX10	0.140	0.477	0.002	0.000	0.160
TLSLPGX20	0.130	0.056	0.002	0.000	0.070
TLSMMPG10	0.083	0.508	0.028	0.020	0.186
TLSMMPG15	0.080	0.508	0.028	0.020	0.186
TLSMMPG20	0.079	0.508	0.028	0.020	0.186
TLSMMPG25	0.079	0.508	0.027	0.020	0.185
TLSMMPG30	0.079	0.508	0.027	0.020	0.185
TLSMMPG35	0.079	0.508	0.027	0.020	0.185
TLSMTHX00	0.156	0.477	0.006	0.007	0.254
TLSMTHX10	0.142	0.477	0.006	0.007	0.254
TLSMTHX20	0.132	0.056	0.007	0.004	0.132

[a] bvmt = billion vehicle miles traveled

12 Hydrogen Use in the Transportation Sector

The enhancement of the EPANMD with the hydrogen infrastructure represents the addition of a set of new technologies to the database. The H_2 production module incorporates H_2 pathway and cost data provided in the 2004 National Resources Council (NRC) report entitled *The H_2 Economy: Opportunities, Costs, Barriers, and R&D Needs*.

Note: Users are required to select **MARKAL + ETL + Lumpy Investment** model variants when running the H_2 submodule.

12.1 Hydrogen RES

Potential H_2 pathways, from feedstock to end-use by H_2-FCVs, are shown in Figure 38. Note: CCS stands for carbon capture and sequestration technologies.

12.2 Hydrogen Production Technologies

12.2.1 Energy Consumption and Investment Costs

The NRC report (National Research Council, 2004) assumes three scales of H_2 production: central plant, midsize plant, and onsite generation at the refueling station. For each pathway, the capital cost of H_2 production technologies is calculated as the sum of the production (including compression), distribution (e.g., liquefaction, storage, pipeline cost, and liquid H_2 tanker cost), and dispensing costs (e.g., compression, storage, and dispensing). The production pathways are summarized in Table 104. Other detailed assumptions on the plant size, configuration, fuel transportation and storage, cost, and emissions can be found in Appendix E of NRC, 2004.

The H_2 production technologies are integrated into the industrial sector of the model. Thus, feedstock usage and emissions are attributed to that sector. Electricity required in H_2 production, in contrast, is produced by the electricity generation sector of the model. Thus, fuel usage and emissions associated with grid electricity are captured in that sector. The lifetime of the hydrogen production technologies are 40, 30, and 20 years for central, midsize, and onsite generation plant, respectively. Energy inputs and investment costs for hydrogen production technologies are listed in Table 105.

12.2.2 Emissions

The values of emissions associated with hydrogen production technologies and listed in Table 106 are taken from Contadini, et al., 2000; S&T Consultants Inc., 2003; and Mann, M., and P. L. Spath, 1997. The unit of emissions is kilotonnes per petajoule except CO_2 emission which are in million tonnes per petajoule. There is no information available on the emissions of hydrogen technologies with carbon capture and sequestration (CCS). These technologies include steam methane reforming (SMR), coal gasification, and biomass for hydrogen production. Thus, the emis-

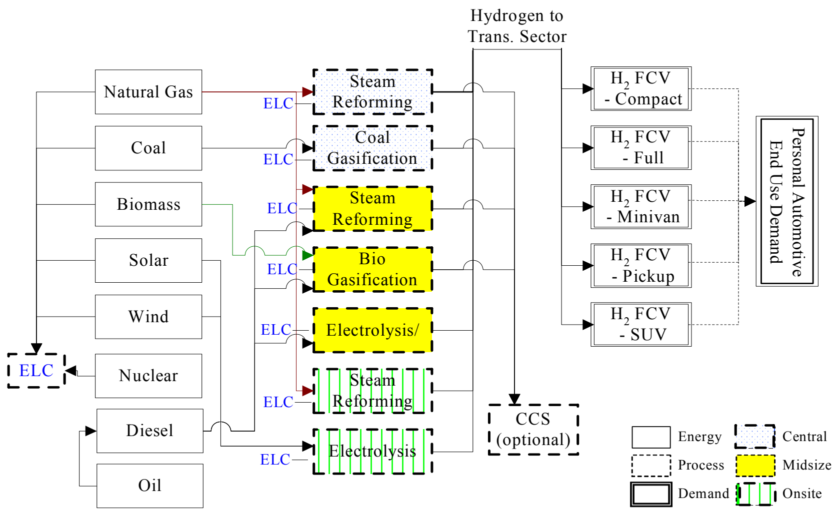


Figure 38. Hydrogen RES.

Table 104. Hydrogen Production Pathways.

Scale	Primary Energy Source	Production Method	Options for Carbon Capture	Abbreviation
Centrtal Station (GH2[b])	Natural gas	Steam reforming	Yes	CSMR, CSMRCCS[c]
	Coal	Gasification	Yes	CCG, CCGCCS
Midsize (LH2[d])	Natural gas	Steam reforming	Yes	MSMR, MSMRCCS
	Biomass	Gasification	Yes	MBIO, MBIOCCS
	Electricity (grid)	Electrolysis		MELE
Distributed (GH2)	Natural gas	Steam reforming		DMSR
	Electricity (grid)	Electrolysis		DELE
	Wind	Electrolysis		DWT
	Wind and grid hybrid	Electrolysis		DWTELE
	Solar	Electrolysis		DPV
	Solar and grid hybrid	Electrolysis		DPVELE

[a] Source: modified from National Research Council, 2004.
[b] GH2 = gaseous H_2.
[c] CCS = carbon capture and sequestration.
[d] LH2 = liquid H_2.

Table 105. Energy Inputs and Investment Costs for Hydrogen Production Technologies.

Technology	AF	INVCOST (Million 1995$/(PJ/yr capacity))	FIXOM (Million 1995$/(PJ/yr))	INP(ENT)p (PJ/PJ)					
H2CSMR	0.98	34.08	2.50	NGAIEA_N	1.04	ELEC	0.42		
H2CSMRCCS	0.9	36.37	3.22	NGAIEA_N	1.10	ELEC	0.45		
H2CCG	0.9	44.77	3.26	COAI	1.39	ELEC	0.47		
H2CCGCCS	0.9	46.13	4.61	COAI	1.39	ELEC	0.51		
H2MSMR	0.98	67.33	5.48	NGAIEA_N	1.10	ELEC	0.39	DSLTH2	0.01
H2MSMRCCS	0.98	74.15	6.43	NGAIEA_N	1.15	ELEC	0.42	DSLTH2	0.01
H2MBIO	0.9	155.03	11.43	BIOWD-0	2.69	ELEC	0.55	DSLTH2	0.01
H2MBIOCCS	0.9	157.56	13.59	BIOWD-0	2.69	ELEC	0.63	DSLTH2	0.01
H2MELE	0.9	123.07	9.29			ELEC	1.99	DSLTH2	0.01
H2DSMR	0.9	82.63	2.75	NGAIEA_N	1.32	ELEC	0.07		
H2DELE	0.9	112.00	3.73			ELEC	1.65		
H2DWT	0.27	89.61	9.96	ELCWTH2	1.65				
H2DPV	0.18	86.33	14.39	ELCPVH2	1.65				
H2DWTELE	0.9	120.24	4.01	ELCWTH2	0.50	ELEC	1.16		
H2DPVELE	0.9	120.55	4.02	ELCPVH2	0.33	ELEC	1.34		

Table 106. Emissions Associated with Hydrogen Production Technologies.

Technology	Emissions (kt/PJ)						
	COI[a]	CO_2[b]	NOI[a]	PM_{10}	VOC	SOI[a]	SO_2[c]
H2CSMR	15.79	0.0158	0.0056	0.0002	0.0001		
H2CSMRCCS	1.67	0.0017	0.0056	0.0002	0.0001		
H2CCG	34.95	0.0350	0.1329	0.0010	0.1424	0.0351	0.0351
H2CCGCCS	3.50	0.0035	0.1329	0.0010	0.1424	0.0070	0.0070
H2MSMR	16.71	0.0167	0.0056	0.0002	0.0001		
H2MSMRCCS	1.74	0.0017	0.0056	0.0002	0.0001		
H2MBIO			0.1329	0.0010	0.1424	0.0351	0.0351
H2MBIOCCS	-58.64	-0.0586	0.1329	0.0010	0.1424	0.0070	0.0070
H2DSMR	20.04	0.0200	0.0056	0.0002	0.0001		

[a] From the industrial sector.
[b] Mt/PJ as carbon rather than CO_2.
[c] As sulfur rather that SO_2.

sions of these technologies with CCS are assumed to be the same as the corresponding technologies without CCS, except sulfur emissions are 50% lower in those technologies with CCS.

12.3 Additional Model Configuration

Additional modeling techniques and constraints are applied within the H_2 module of the EPANMD MARKAL technology database.

12.3.1 Endogenous Technological Learning (ETL)

Technological learning refers to the phenomenon by which the performance, productivity, and cost of a technology improves as the technology is applied and knowledge and experience accumulate. In energy system models with ETL, learning is generally represented by a "learning curve" or "experience curve", where the unit cost of production declines at a constant rate as experience with the technology grows. A common form for a learning curve is

$$Y = a\,x^{-b}$$

Where Y is the estimated average direct unit cost for the first x units; a is the direct unit cost needed to make the first unit; and b (b>0) is a parametric constant.

An 80 percent "progress ratio", corresponding to a value of 0.32 for b, is a typical value that has been used in many applications. This implies that the cost of technology will be reduced to 80 percent of its original value for each cumulative capacity doubling. We use a relatively conservative progress ratio of 90 percent for all H_2 production technologies, and 92 percent for H_2 technologies with CCS. The maturity of each type of H_2 production technology is characterized by its current cumulative capacity, which is obtained from Suresh, et al., 2001. ETL parameters are listed in Table 107.

Table 107. ETL Parameters.

Technology	ETL-CUMCAP0	ETL-CUMCAPMAX	ETL-INDIC	ETL-INVCOST0	ETL-NUMSEG	ETL-PROGRATIO
H2CSMR	9.5	10,000.00	1	34.0807	6	0.9
H2CSMRCCS	9.5	10,000.00	1	36.3731	6	0.92
H2CCG	0.4	10,000.00	1	45.8629	6	0.9
H2CCGCCS	0.4	10,000.00	1	46.1309	6	0.92
H2MSMR	0.05	10,000.00	1	67.3284	6	0.9
H2MSMRCCS	0.05	10,000.00	1	74.1488	6	0.92
H2MBIO	0.01	10,000.00	1	155.0333	6	0.9
H2MBIOCCS	0.01	10,000.00	1	157.575	6	0.92
H2MELE	0.01	10,000.00	1	123.0731	6	0.9
H2DSMR	0.05	10,000.00	1	82.6329	6	0.9
H2DELE	0.01	10,000.00	1	111.9987	6	0.9
H2DWT	0.01	10,000.00	1	89.6067	6	0.9
H2DPV	0.01	10,000.00	1	86.3251	6	0.9
H2DWTELC	0.01	10,000.00	1	120.2375	6	0.9
H2DPVELC	0.01	10,000.00	1	120.5506	6	0.9

12.3.2 Lumpy Investment

H_2 production technologies, especially SMR, exhibit substantial economies-of-scale. For example, the unit cost of H_2 production at a central plant is much less than that of distributed production. On the other hand, a large capital investment is required to build the central plant and the supporting infrastructure to deliver fuel to refueling stations. MARKAL, in its standard configuration, is a linear programming (LP) model, and thus represents the capacities of various technologies as continuous values. Consequently, the model may produce a result in which only a fraction of a central plant and the supporting infrastructure are built, producing an unrealistic solution. To provide more realistic investments, a mixed-integer programming-based "lumpy investment" option is used. Each time a new lump of investment is made for a central plant or a midsize plant, the cost would include the necessary infrastructure (e.g., pipeline, tanker, trucks, driver hours, cryo-liquefaction, storage, and refueling stations), as described by the NRC report (2004). The sizes of investments in new capacity are assumed to be 394×10^6 kg of H_2 per year (52.6 PJ/yr) for a central plant and 7.9×10^6 kg per year (1.05 PJ/yr) for a midsize plant.

12.3.3 Constraints Added to Address H_2 Transition Issues

Due to the substantial transportation and distribution infrastructure barriers faced by central and midsize plants, some experts predict that distributed generation at refueling stations will likely be used to meet initial demands before a full-scale H_2 infrastructure is established. These stations could serve remote, less populated areas where weak economies-of-scale are justified by high H_2 delivery costs and low demand. Thus, constraints are added to the model to require that for the first year at least 20% and 5% of yearly H_2 demand must be provided by distributed and midsize plants, respectively. The minimum share constraints are relaxed gradually and approach zero by 2030.

13 Model Quality Control Processes

To ensure an accurate representation the EPANMD, the database has been constructed and evaluated in the following ways:

1. Data were chosen using the established quality guidelines outlined in the Quality Assurance Project Plan developed for this project. See Appendix A: Data Source Characterizations.
2. Data are fully documented and have been run through quality control checks to ensure accurate transmission of raw data into the MARKAL database.
3. Database was subject to a sector-by-sector peer review and a full model peer review.
4. A base EPANMD MARKAL run was assessed against the results of the AEO 2002. The run was set up using the same assumptions as those used in the AEO.

13.1 Data Quality

Wherever possible, data were taken from NEMS input data underlying the AEO 2002 (EIA, 2002d). AEO data were selected for the Reference Energy System because it is a nationally recognized source of technology data, widely used where reference or default data are required. In some cases, AEO data were not available in a form that could be utilized for the EPANMD. Table 108, below, lists the data sources used for each sector, as well as the number of technologies/resources in each sector.

For cases where metadata exist that describe precision, accuracy, completeness, or other uncertainty measures with respect to the data, the data collector can use this information to assess data quality. In cases where no QA descriptions are available, the data collector must accept the data on an as-is basis. The primary sources of the information are ultimately responsible for the quality of their data. However, it is recognized that each source organization may have different levels of resources available to accomplish their mission or may have differing commitments to quality assurance within their organization, and consequently data quality may vary from place to place in ways that we cannot quantify.

As the majority of the EPANMD Base Case data come from EIA, the quality level of the data drawn from them is of particular interest. EIA has performance standards to ensure the quality (i.e., objectivity, utility, and integrity) of information it disseminates to the public. Quality is ensured and maximized at levels appropriate to the nature and timeliness of the disseminated information. EIA also strives for transparency about information and methods in

Table 108. Primary Data Sources Used in Developing the Database.

Sector	Data Source	Data Quality[a]	Number of Technologies/Resources
Transportation	OTT Quality Metrics	A	15 personal vehicles in 5 size classes; 40 other passenger and freight technologies
	DeCicco et al., 2001	B	
Commercial	NEMS	A	300
Residential	NEMS	A	135
Industrial	SAGE	A	~100
Electricity	NEMS	A	45
	EPRI TAG	C	
Resource Supply	NEMS	A	25 coal types, 10 imported petroleum products, domestic and imported oil and natural gas

a Data quality definitions can be found in Appendix A.

order to improve understanding and to facilitate reproducibility of the information. For a complete description of EIA's Quality Guidelines see EIA, 2002h.

For the transportation base case sector the data are drawn from the U.S. Department of Energy's Office of Transportation Technologies Quality Metrics assessment. QM describes the analytical process used in estimating future energy, environmental, and economic benefits of U.S. DOE Energy Efficiency and Renewable Energy programs. QM seeks to monitor and measure the impacts of all DOE EE/RE programs and to summarize their overall national effects. QM has been an active annual DOE EE/RE-wide analysis and review procedure since 1995 (DOE, 2003).

Data for the electricity sector were drawn from NEMS with supplemental data pulled from the Electric Power Research Institute Technical Assessment Guide (EPRI, 1993). EPRI is a non-profit energy research consortium providing scientific research, technology development, and product implementation for the energy industry. The TAG is a standard reference work for the energy industry that characterizes key electric generation technologies and their operation, costs, environmental impacts, etc.

The industrial sector representation was adapted from the characterization used in EIA's SAGE model (EIA, 2003b).

13.2 Data Documentation

A primary concern of ISA-W is that the data are fully documented, are translated properly into the database with required units properly calculated, and are an accurate representation of the information provided in the reference source. ISA-W is committed to using conversion methodologies that are consistent with generally accepted professional standards. In all work to transform original data into the units and form needed for the MARKAL model, the conversion factors used are available in the supporting documentation.

The database manager followed a standard procedure to validate the data in each workbook. The procedure is:

1. Build MARKAL bulk upload sheets. Bulk upload is a feature of the MARKAL that enables data to be directly taken from Excel spreadsheets into the model database.
2. Put workbook spreadsheets in standardized format with the raw data spreadsheet at the end and the bulk upload sheets at the front. In between, the spreadsheets are ordered so that the flow from raw data form to the MARKAL form can be easily followed.
3. Clean up individual spreadsheets to make them easy to understand, including naming cells used in calculations and re-ordering the placement of cells.
4. Check all links used in the spreadsheets.
5. Check all calculations.

Completed workbooks were given to an ISA-W team member for review before distribution. During that review, random checks of 5% of the data were done to check for errors. Additionally, during the peer review process, reviewers were asked to confirm that the original data were accurately carried through the conversions to the final MARKAL format.

Upon completion the bulk upload of each workbook into the database, a random check of 10% of the data parameters, comparing the EPANMD with the Excel documents was done by an ISA-W team member to ensure that the bulk upload was performed correctly.

13.3 Peer Review

Each sector's data and documentation were then sent to several experts in that sector for review. Peer review questions included:

- Has an appropriate data source for the sector been used?
- Has that data been used appropriately?
- Do the relative costs and performance of the technologies/resources look reasonable?
- Are there technologies that should be included that have not, or that have been included that should not?

Table 109 lists the peer reviewers by sector.

In general, peer review responses indicated that the data sources and ISA-W use of the data were appropriate. Several minor errors and omissions were identified and corrected. The reviewers also made several suggestions for future technologies that could be examined through scenario analysis in sectors beyond transportation.

Additionally, a full-model peer review was performed by two seasoned MARKAL users:

- Paul Friley of the Energy, Environmental, and Economic Analysis Group of Brookhaven National Laboratory
- Lessly Goudarzi, President, OnLocation/Energy Systems Consulting

Peer review comments and responses are summarized in Appendix C.

Table 109. Sector Peer Reviewers.

Sector	Invited	Accepted	Responded	Individuals
Residential	11	7	3	John Cymbalsky (EIA/DOE) Jonathon Koomey (LBNL) Jim Sullivan/Glenn Chinery (EPA/CPPD)
Transportation	9	6	5	Roger Gorham (EPA/OTAQ) Therese Langer (ACEEE) Steve Plotkin (ANL) John DiCicco (EDF) Don Hanson (ANL)/Marc Melaina (U. Mich)
Resource Supply	13	4	4	Floyd Boilanger (DOE/NETL) Casey Delhotal (EPA/CPPD) Russell Jones (API) John Conti/Kaydes (EIA/DOE)
Electricity	16	9	3	Floyd Boilanger (DOE/NETL) Dallas Burtraw (RFF) Russell Noble (Southern Companies)
Commercial	11	5	4	Jim Sullivan (EPA/CPPD) Harvey Sachs (ACEEE) Erin Boedecker (EIA/DOE) Jonathon Koomey (LBNL)

14 Calibration

Following the incorporation of peer review comments and any necessary changes into the Reference Energy System database, the model was run for comparison and calibration to AEO 2002 results. AEO 2002 was selected as a calibration benchmark for two reasons. First, the Annual Energy Outlook is a nationally recognized short- to mid-term energy technology and consumption forecast which is widely used where a reference forecast is required. Second, much of our Reference Energy System data were derived from AEO 2002 input data.

The goals of the calibration were

- to ensure that the model was producing reasonable results, given its input assumptions,
- to determine whether the model was providing a plausible, consistent representation of the key features of the U.S. energy system,
- in cases where our results differed from AEO results, to be able to identify why the differences exist, and
- to identify any significant errors in the construction or characterization of the Reference Energy System.

The results from the EPANMD for total energy consumption, consumption by sector, and within sector by use were compared to the AEO 2002, Table A1, Table A2, and Tables A4-A9, respectively. Broad trends (upward, downward, or changing over the time horizon) were also compared to see if the EPANMD results tracked with the AEO trends. Finally, the degree of quantitative match between the EPANMD results and AEO 2002 were compared.

The model used to produce AEO 2002, the National Energy Modeling System (NEMS), differs in many respects from MARKAL. In general, sectors are modeled in more detail, more aspects of consumer and producer behavior are simulated, and NEMS is generally more conservative about switching fuels and technology types than is MARKAL. Therefore, unconstrained MARKAL results are not expected to match AEO results exactly.

In some cases, constraints were added to force MARKAL to track AEO more closely. The decision to use constraints to force MARKAL to track AEO involves trade-offs between desired model characteristics. On the one hand, it is desirable that the EPANMD's behavior is realistic in that it represents real constraints and inflexibilities in the energy system. On the other hand, AEO results are a simulation of NEMS modelers' judgment about the most likely direction of the energy system, whereas the EPANMD is being used to explore a variety of scenarios for the system's future evolution. Therefore the EPANMD should not be forced to track AEO so closely that it lacks the flexibility to respond with different outcomes to differing input assumptions.

Constraints have been added where there is an underlying feature of the energy system that an unconstrained MARKAL run does not represent. These constraints are highlighted within the model to make them easily adjustable by the user.

Examples of these constraints include

- Commercial and residential heating technology fuel splits were implemented equivalent to AEO 2002 shares with a 3% relaxation rate,
- Growth constraint placed on wind electricity generation based on AEO 2002 growth rate, and

- Added Transportation LDV class splits.

The next step in the calibration process was to compare fuel prices in each sector and add price mark-ups where needed. Fuel markups reflect any additional taxes or costs associated with fuels that are not captured by the MARKAL model.

The markups are currently in the EPANMD are

Markup	Amount M 1995$/PJ
DSH to Commercial, Electric, Industrial, and Transportation Sectors	1
DSL to Commercial, Industrial, and Residential Sectors	2
DSL to Electric Sector	5
DSL to Transportation Sector	3
GSL to Transportation Sector	6
LPG to Industrial, Residential, and Transportation Sectors	5

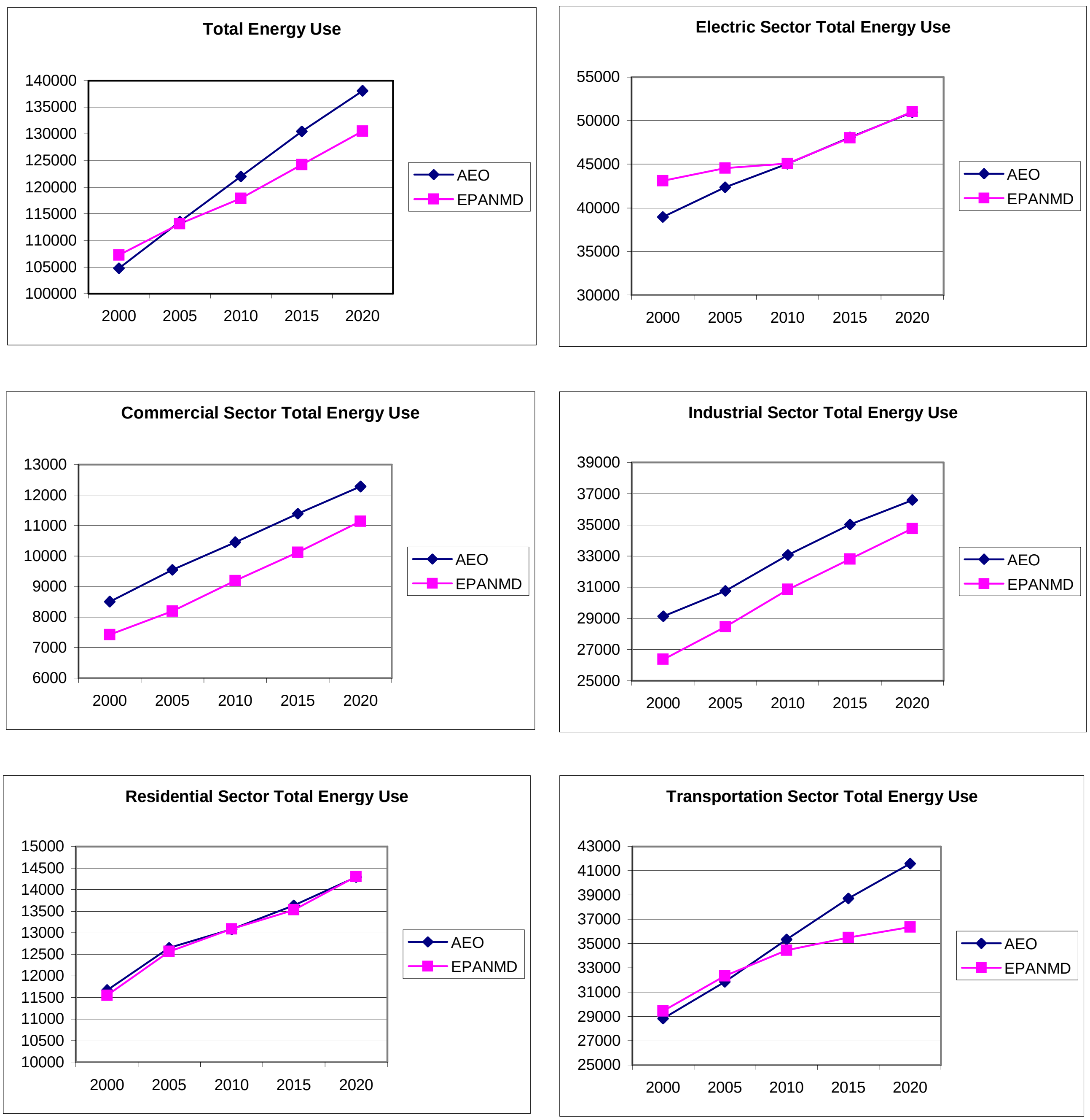


Figure 39. Comparison of EPANMD to AEO2002: Sector Specific Energy Use in PJ.

As illustrated in Figure 39, total energy consumption in the EPANMD is within 20% of AEO2002 values. The largest deviation from the AEO occurs with gasoline (GSL) consumption. Looking at sector specific use, the difference occurs in the transportation sector.

Figures 40 and 41 show the comparison between the AEO2002 and the EPANMD in system-wide consumption of fuels.

The 2002 AEO transportation results are very pessimistic and only allow a small penetration of non-conventional technologies. As the transportation sector is one of the sectors that is the focus of this research, it is desirable to not restrict the EPANMD model to the level that the AEO is restricted, which caused the deviation of EPANMD from the AEO 2002 in the transportation sector. So as one last calibration step, the EPANMD was run with a new scenario in which the constraints on the transportation vehicles were limited to the technology penetration levels in the AEO 2002. This brought the EPANMD gasoline consumption numbers to within 10% of the AEO numbers. With this result, the EPA MARKALmodel is deemed to be "calibrated".

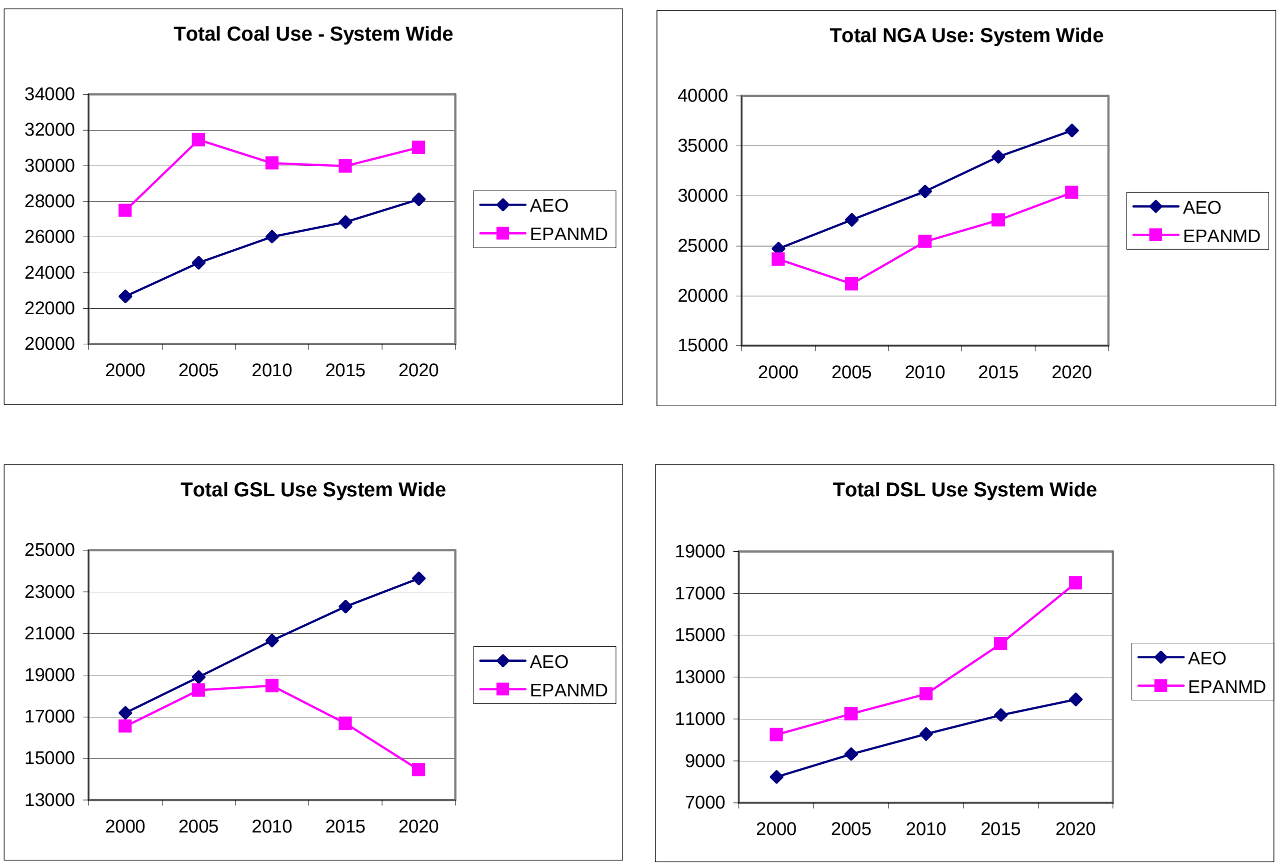


Figure 40. Comparison of EPANMD to AEO2002: System-Wide Coal, Natural Gas, Gasoline, and Diesel Use in PJ.

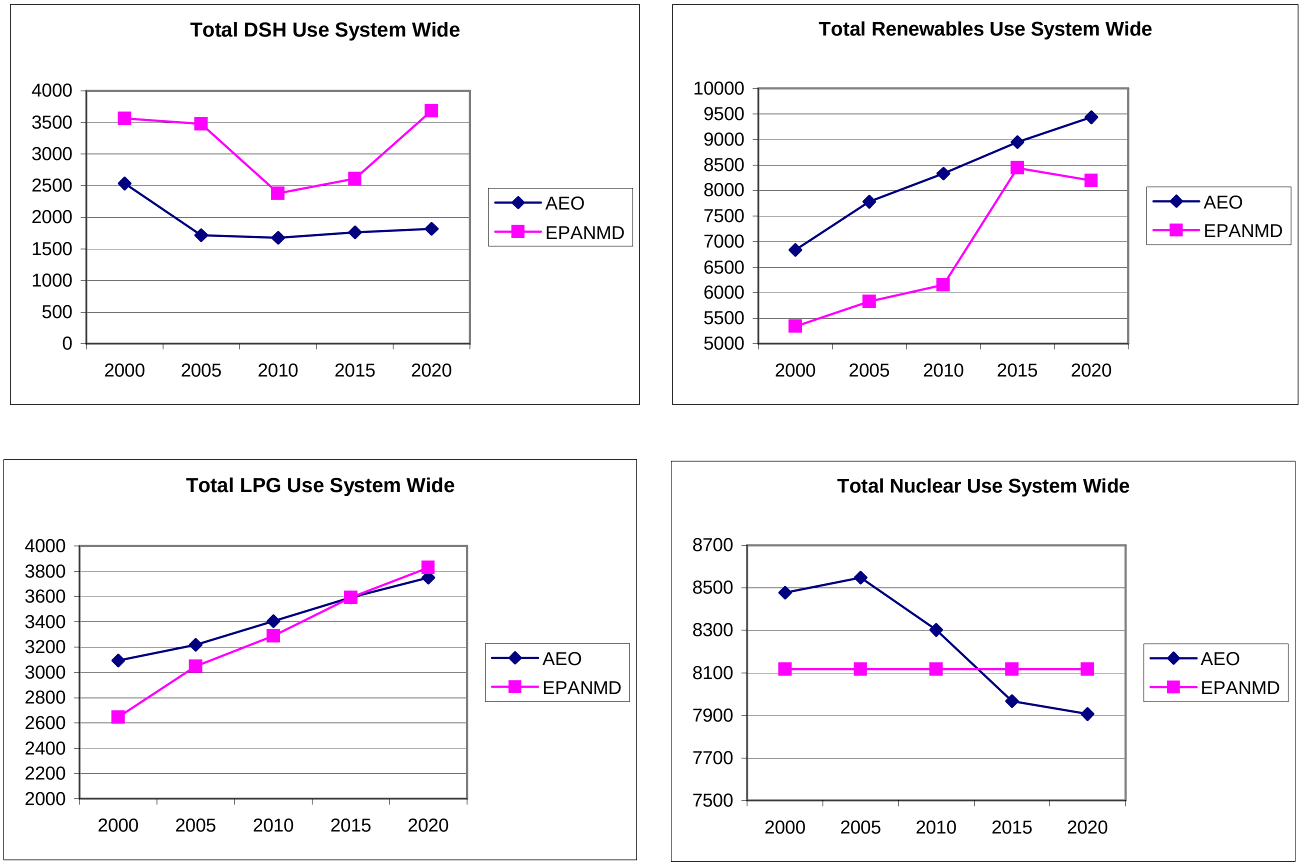


Figure 41. Comparison of EPANMD to AEO2002: System-Wide Fuel Oil, Renewables, Liquid Petroleum Gas, and Nuclear Use in PJ.

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Appendix A
Data Source Characterization

Sources that may be used when gathering secondary data fall under seven general classifications.

a) Federal Organizations and Laboratories

A variety of Federal organizations collect data that may be applicable to the assessments that will be performed under this project. The two primary organizations are the Energy Information Administration (EIA) for energy and technology data to be used in MARKAL and the Environmental Protection Agency for emissions data. EIA was established in 1977 as an independent authority from DOE for data collection and from the rest of the Federal government with respect to the context of the EIA reports. EIA is mandated to collect, assemble, evaluate, and analyze energy information and to provide energy information and projections to the Federal and state governments and the public. EIA authority was expanded in the Energy Policy Act of 1992 to data collection and analysis of several additional areas including energy consumption, alternative fuels and alternatively fueled vehicles, and electricity production from renewable energy sources.

Federal labs that have data appropriate to the transportation and energy sectors include National Renewable Energy Laboratory (NREL), Lawrence Berkley Laboratories (LBL), Oak Ridge National Laboratories (ORNL), the Transportation Research Board (National Academy of Sciences), and others.

b) State Agencies

State agencies collect data that may be applicable to the assessments like Federal organizations do. Examples include Southern California Air Quality Management District, various energy and state transportation departments, and NESCAUM (Northeast States for Coordinated Air Use Management).

c) Academic Studies

Academic institutions collect data that may be applicable to the assessments. An example is the University of California –Davis, Transportation Studies Department.

d) Research Studies from Non-Governmental Organizations

Example organizations include The Pew Center, Tyndall Center, Cato Institute, and the Stockholm Environmental Institute.

e) Journal Articles and Conference Proceedings

Journal articles that are peer-reviewed are more desirable than non-peer-reviewed articles. Journals may be published independently or in association with an industry or trade organization. Independently published journals such as Energy Policy and Nature are considered more desirable than peer-reviewed journals of trade associations. Conference proceedings, such as the Annual Conference of the Transportation Research Board and the Annual U.S. Hydrogen Meeting and Exposition, may be of a lower quality since many have not been peer-reviewed.

f) Manufacturer or Trade Literature

In some cases manufacturer product literature may be the primary source for technology performance and cost information. Other trade literature may provide statistical information on new products. Literature from trade societies or industry associations provides another format for gathering technology information. Examples of such groups include the Society of Automotive Engineers and the Electric Vehicle Association of America.

g) Individual Estimates

There may be some instances where there are insufficient data from the above sources to fully specify a future technology as required in MARKAL. Thus a value must be estimated. When this occurs, documentation of the approach that clearly shows the derivation of the value will be required.

All data sources are reviewed for any known bias towards any technology or any obvious corporate influence in the research. Documentation of data source will include the study objective and the researchers involved. For the purposes of this project, data quality of the sources listed in Section 3.1 are ranked as follows:

Rank	Quality	Source
A	Highest	Federal and state agencies and laboratories
B	Second	Independent journal articles, academic studies, and manufacturer product literature
C	Third	N0n-governmental organizations , trade journal articles, and conference proceedings: peer reviewed
D	Fourth	Conference proceedings and other trade literature: not peer reviewed
E	Lowest	Individual estimates

Appendix B
Detailed Sector Data

COAL RESOURCE SUPPLY

MARKAL	Technology Name	START year	CUM PJ	COST 95USmillion$/PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCABHS1	Coal --App., Bit., High Sulfur, Surface, Stp 1	1995	53774	0.806	0.806	0.749	0.743	0.736	0.728	0.728	0.728	0.728
MINCABHS2	Coal --App., Bit., High Sulfur, Surface, Stp 2	1995	4388	0.827	0.827	0.769	0.763	0.756	0.748	0.748	0.748	0.748
MINCABHS3	Coal --App., Bit., High Sulfur, Surface, Stp 3	1995	4586	0.849	0.849	0.790	0.783	0.776	0.768	0.768	0.768	0.768
MINCABHS4	Coal --App., Bit., High Sulfur, Surface, Stp 4	1995	3825	0.867	0.867	0.806	0.799	0.792	0.783	0.783	0.783	0.783
MINCABHS5	Coal --App., Bit., High Sulfur, Surface, Stp 5	1995	1957	0.875	0.875	0.814	0.807	0.800	0.791	0.791	0.791	0.791
MINCABHS6	Coal --App., Bit., High Sulfur, Surface, Stp 6	1995	4035	0.893	0.893	0.830	0.823	0.816	0.807	0.807	0.807	0.807
MINCABHS7	Coal --App., Bit., High Sulfur, Surface, Stp 7	1995	5222	0.915	0.915	0.850	0.843	0.835	0.827	0.827	0.827	0.827
MINCABHS8	Coal --App., Bit., High Sulfur, Surface, Stp 8	1995	5450	0.936	0.936	0.871	0.863	0.855	0.846	0.846	0.846	0.846
MINCABHU1	Coal --App., Bit., High Sulfur, Undergrd, Stp 1	1995	279273	0.801	0.801	0.747	0.742	0.736	0.728	0.728	0.728	0.728
MINCABHU2	Coal --App., Bit., High Sulfur, Undergrd, Stp 2	1995	28070	0.823	0.823	0.767	0.763	0.756	0.748	0.748	0.748	0.748
MINCABHU3	Coal --App., Bit., High Sulfur, Undergrd, Stp 3	1995	29956	0.844	0.844	0.787	0.783	0.776	0.768	0.768	0.768	0.768
MINCABHU4	Coal --App., Bit., High Sulfur, Undergrd, Stp 4	1995	25383	0.862	0.862	0.803	0.799	0.792	0.783	0.783	0.783	0.783
MINCABHU5	Coal --App., Bit., High Sulfur, Undergrd, Stp 5	1995	13152	0.870	0.870	0.811	0.807	0.800	0.791	0.791	0.791	0.791
MINCABHU6	Coal --App., Bit., High Sulfur, Undergrd, Stp 6	1995	27337	0.888	0.888	0.827	0.823	0.816	0.807	0.807	0.807	0.807
MINCABHU7	Coal --App., Bit., High Sulfur, Undergrd, Stp 7	1995	36065	0.909	0.909	0.847	0.843	0.835	0.827	0.827	0.827	0.827
MINCABHU8	Coal --App., Bit., High Sulfur, Undergrd, Stp 8	1995	38237	0.931	0.931	0.867	0.863	0.855	0.846	0.846	0.846	0.846
MINCABLS1	Coal --App., Bitum., Low Sulfur, Surface, Stp 1	1995	64693	0.909	0.909	0.845	0.811	0.802	0.783	0.783	0.783	0.783
MINCABLS2	Coal --App., Bitum., Low Sulfur, Surface, Stp 2	1995	5491	0.936	0.936	0.869	0.833	0.824	0.806	0.806	0.806	0.806
MINCABLS3	Coal --App., Bitum., Low Sulfur, Surface, Stp 3	1995	5759	0.960	0.960	0.892	0.855	0.846	0.827	0.827	0.827	0.827
MINCABLS4	Coal --App., Bitum., Low Sulfur, Surface, Stp 4	1995	19974	0.980	0.980	0.847	0.873	0.864	0.844	0.844	0.844	0.844
MINCABLS5	Coal --App., Bitum., Low Sulfur, Surface, Stp 5	1995	2462	0.991	0.991	0.920	0.882	0.872	0.851	0.851	0.851	0.851
MINCABLS6	Coal --App., Bitum., Low Sulfur, Surface, Stp 6	1995	5082	1.010	1.010	0.939	0.899	0.890	0.870	0.870	0.870	0.870
MINCABLS7	Coal --App., Bitum., Low Sulfur, Surface, Stp 7	1995	6605	1.035	1.035	0.961	0.922	0.911	0.890	0.890	0.890	0.890
MINCABLS8	Coal --App., Bitum., Low Sulfur, Surface, Stp 8	1995	6891	1.060	1.060	0.984	0.943	0.933	0.912	0.912	0.912	0.912
MINCABLU1	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 1	1995	111482	0.872	0.872	0.841	0.845	0.831	0.806	0.806	0.806	0.806
MINCABLU2	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 2	1995	14246	0.894	0.894	0.873	0.881	0.867	0.839	0.839	0.839	0.839
MINCABLU3	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 3	1995	15479	0.918	0.918	0.898	0.906	0.891	0.862	0.862	0.862	0.862
MINCABLU4	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 4	1995	13316	0.936	0.936	0.917	0.926	0.911	0.881	0.881	0.881	0.881
MINCABLU5	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 5	1995	6966	0.946	0.946	0.927	0.936	0.921	0.891	0.891	0.891	0.891
MINCABLU6	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 6	1995	14623	0.965	0.965	0.946	0.955	0.940	0.909	0.909	0.909	0.909
MINCABLU7	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 7	1995	19569	0.989	0.989	0.970	0.980	0.964	0.933	0.933	0.933	0.933
MINCABLU8	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 8	1995	21049	1.012	1.012	0.994	1.005	0.988	0.956	0.956	0.956	0.956
MINCABMS1	Coal --App., Bitum., Med Sulfur, Surface, Stp 1	1995	97229	0.807	0.807	0.774	0.768	0.758	0.747	0.747	0.747	0.747
MINCABMS2	Coal --App., Bitum., Med Sulfur, Surface, Stp 2	1995	6951	0.828	0.828	0.795	0.789	0.779	0.768	0.768	0.768	0.768
MINCABMS3	Coal --App., Bitum., Med Sulfur, Surface, Stp 3	1995	7241	0.850	0.850	0.816	0.810	0.800	0.788	0.788	0.788	0.788

continued

MARKAL	Technology Name	START year	CUM PJ	COST 95USmillion$/PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCABMS4	Coal --App., Bitum., Med Sulfur, Surface, Stp 4	1995	6007	0.868	0.868	0.833	0.827	0.816	0.804	0.804	0.804	0.804
MINCABMS5	Coal --App., Bitum., Med Sulfur, Surface, Stp 5	1995	3069	0.876	0.876	0.841	0.835	0.824	0.813	0.813	0.813	0.813
MINCABMS6	Coal --App., Bitum., Med Sulfur, Surface, Stp 6	1995	6292	0.894	0.894	0.858	0.851	0.841	0.829	0.829	0.829	0.829
MINCABMS7	Coal --App., Bitum., Med Sulfur, Surface, Stp 7	1995	8136	0.915	0.915	0.879	0.872	0.861	0.849	0.849	0.849	0.849
MINCABMS8	Coal --App., Bitum., Med Sulfur, Surface, Stp 8	1995	8440	0.937	0.937	0.900	0.893	0.882	0.869	0.869	0.869	0.869
MINCABMU1	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 1	1995	199260	0.782	0.782	0.755	0.737	0.723	0.705	0.705	0.705	0.705
MINCABMU2	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 2	1995	19904	0.804	0.804	0.776	0.758	0.743	0.724	0.724	0.724	0.724
MINCABMU3	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 3	1995	21249	0.825	0.825	0.797	0.778	0.763	0.743	0.743	0.743	0.743
MINCABMU4	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 4	1995	18002	0.842	0.842	0.813	0.474	0.779	0.758	0.758	0.758	0.758
MINCABMU5	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 5	1995	9321	0.851	0.851	0.821	0.802	0.787	0.765	0.765	0.765	0.765
MINCABMU6	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 6	1995	19382	0.868	0.868	0.838	0.818	0.802	0.781	0.781	0.781	0.781
MINCABMU7	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 7	1995	25570	0.889	0.889	0.858	0.838	0.822	0.800	0.800	0.800	0.800
MINCABMU8	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 8	1995	27117	0.868	0.868	0.878	0.857	0.841	0.819	0.819	0.819	0.819
MINCAGHS1	Coal --App., Gob, High Sulfur, Stp 1	1995	14545	0.841	0.841	0.895	0.890	0.904	0.914	0.914	0.914	0.914
MINCAGHS2	Coal --App., Gob, High Sulfur, Stp 2	1995	952	0.864	0.864	0.919	0.914	0.928	0.939	0.939	0.939	0.939
MINCAGHS3	Coal --App., Gob, High Sulfur, Stp 3	1995	988	0.887	0.887	0.943	0.938	0.953	0.964	0.964	0.964	0.964
MINCAGHS4	Coal --App., Gob, High Sulfur, Stp 4	1995	817	0.905	0.905	0.962	0.958	0.972	0.984	0.984	0.984	0.984
MINCAGHS5	Coal --App., Gob, High Sulfur, Stp 5	1995	419	0.914	0.914	0.972	0.967	0.982	0.993	0.993	0.993	0.993
MINCAGHS6	Coal --App., Gob, High Sulfur, Stp 6	1995	852	0.932	0.932	0.991	0.987	1.002	1.013	1.013	1.013	1.013
MINCAGHS7	Coal --App., Gob, High Sulfur, Stp 7	1995	1100	0.955	0.955	1.016	1.011	1.026	1.038	1.038	1.038	1.038
MINCAGHS8	Coal --App., Gob, High Sulfur, Stp 8	1995	1137	0.978	0.978	1.040	1.035	1.051	1.063	1.063	1.063	1.063
MINCALMS1	Coal --App., Lignite, Med. Sulfur, Surface, Stp 1	1995	2622	0.677	0.677	0.716	0.740	0.760	0.774	0.774	0.774	0.774
MINCALMS2	Coal --App., Lignite, Med. Sulfur, Surface, Stp 2	1995	116	0.706	0.706	0.736	0.760	0.781	0.795	0.795	0.795	0.795
MINCALMS3	Coal --App., Lignite, Med. Sulfur, Surface, Stp 3	1995	118	0.725	0.725	0.755	0.780	0.801	0.816	0.816	0.816	0.816
MINCALMS4	Coal --App., Lignite, Med. Sulfur, Surface, Stp 4	1995	98	0.739	0.739	0.771	0.796	0.818	0.832	0.832	0.832	0.832
MINCALMS5	Coal --App., Lignite, Med. Sulfur, Surface, Stp 5	1995	49	0.747	0.747	0.778	0.804	0.826	0.841	0.841	0.841	0.841
MINCALMS6	Coal --App., Lignite, Med. Sulfur, Surface, Stp 6	1995	98	0.762	0.762	0.794	0.820	0.842	0.858	0.858	0.858	0.858
MINCALMS7	Coal --App., Lignite, Med. Sulfur, Surface, Stp 7	1995	128	0.780	0.780	0.813	0.840	0.863	0.878	0.878	0.878	0.878
MINCALMS8	Coal --App., Lignite, Med. Sulfur, Surface, Stp 8	1995	128	0.799	0.799	0.832	0.860	0.883	0.899	0.899	0.899	0.899
MINCAMLU1	Coal --App., Met., Low Sul., Undergrd, Stp 1	1995	1372	1.299	1.299	1.253	1.243	1.187	1.160	1.160	1.160	1.160
MINCAMLU2	Coal --App., Met., Low Sul., Undergrd, Stp 2	1995	153	1.334	1.334	1.287	1.277	1.219	1.192	1.192	1.192	1.192
MINCAMLU3	Coal --App., Met., Low Sul., Undergrd, Stp 3	1995	165	1.369	1.369	1.321	1.310	1.251	1.223	1.223	1.223	1.223
MINCAMLU4	Coal --App., Met., Low Sul., Undergrd, Stp 4	1995	140	1.397	1.397	1.348	1.337	1.277	1.248	1.248	1.248	1.248
MINCAMLU5	Coal --App., Met., Low Sul., Undergrd, Stp 5	1995	73	1.411	1.411	1.361	1.350	1.290	1.260	1.260	1.260	1.260
MINCAMLU6	Coal --App., Met., Low Sul., Undergrd, Stp 6	1995	152	1.439	1.439	1.388	1.377	1.315	1.286	1.286	1.286	1.286
MINCAMLU7	Coal --App., Met., Low Sul., Undergrd, Stp 7	1995	201	1.474	1.474	1.422	1.411	1.347	1.317	1.317	1.317	1.317
MINCAMLU8	Coal --App., Met., Low Sul., Undergrd, Stp 8	1995	215	1.509	1.509	1.456	1.445	1.379	1.348	1.348	1.348	1.348
MINCAMMU1	Coal --App., Met., Med Sul., Undergrd, Stp 1	1995	1978	0.881	0.881	0.839	0.825	0.816	0.809	0.809	0.809	0.809
MINCAMMU2	Coal --App., Met., Med Sul., Undergrd, Stp 2	1995	256	0.916	0.916	0.874	0.859	0.849	0.840	0.840	0.840	0.840

continued

		START	CUM	COST								
		year	PJ	95USmillion$/PJ								
MARKAL	Technology Name			1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCAMMU3	Coal --App., Met., Med Sul., Undergrd, Stp 3	1995	278	0.941	0.941	0.898	0.882	0.872	0.863	0.863	0.863	0.863
MINCAMMU4	Coal --App., Met., Med Sul., Undergrd, Stp 4	1995	240	0.961	0.961	0.917	0.901	0.891	0.881	0.881	0.881	0.881
MINCAMMU5	Coal --App., Met., Med Sul., Undergrd, Stp 5	1995	125	0.971	0.971	0.927	0.911	0.900	0.891	0.891	0.891	0.891
MINCAMMU6	Coal --App., Met., Med Sul., Undergrd, Stp 6	1995	263	0.991	0.991	0.946	0.930	0.919	0.909	0.909	0.909	0.909
MINCAMMU7	Coal --App., Met., Med Sul., Undergrd, Stp 7	1995	352	1.016	1.016	0.970	0.953	0.942	0.932	0.932	0.932	0.932
MINCAMMU8	Coal --App., Met., Med Sul., Undergrd, Stp 8	1995	378	1.041	1.041	0.994	0.977	0.965	0.955	0.955	0.955	0.955
MINCDLMS1	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 1	1995	76571	0.497	0.497	0.469	0.457	0.451	0.448	0.448	0.448	0.448
MINCDLMS2	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 2	1995	5185	0.511	0.511	0.481	0.469	0.463	0.461	0.461	0.461	0.461
MINCDLMS3	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 3	1995	5390	0.524	0.524	0.494	0.481	0.475	0.473	0.473	0.473	0.473
MINCDLMS4	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 4	1995	4461	0.535	0.535	0.504	0.491	0.485	0.482	0.482	0.482	0.482
MINCDLMS5	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 5	1995	2265	0.540	0.540	0.509	0.496	0.489	0.487	0.487	0.487	0.487
MINCDLMS6	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 6	1995	4665	0.551	0.551	0.519	0.506	0.499	0.497	0.497	0.497	0.497
MINCDLMS7	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 7	1995	6016	0.565	0.565	0.532	0.518	0.511	0.509	0.509	0.509	0.509
MINCDLMS8	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 8	1995	6234	0.578	0.578	0.545	0.531	0.524	0.521	0.521	0.521	0.521
MINCGLHS1	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 1	1995	8104	0.740	0.740	0.709	0.700	0.681	0.673	0.673	0.673	0.673
MINCGLHS2	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 2	1995	635	0.760	0.760	0.729	0.718	0.699	0.691	0.691	0.691	0.691
MINCGLHS3	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 3	1995	663	0.780	0.780	0.748	0.737	0.717	0.709	0.709	0.709	0.709
MINCGLHS4	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 4	1995	552	0.796	0.796	0.763	0.752	0.732	0.724	0.724	0.724	0.724
MINCGLHS5	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 5	1995	282	0.804	0.804	0.771	0.760	0.739	0.731	0.731	0.731	0.731
MINCGLHS6	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 6	1995	581	0.819	0.819	0.786	0.775	0.754	0.745	0.745	0.745	0.745
MINCGLHS7	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 7	1995	754	0.839	0.839	0.805	0.794	0.773	0.764	0.764	0.764	0.764
MINCGLHS8	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 8	1995	784	0.859	0.859	0.824	0.813	0.791	0.782	0.782	0.782	0.782
MINCGLMS1	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 1	1995	36365	0.859	0.859	0.836	0.779	0.740	0.726	0.726	0.726	0.726
MINCGLMS2	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 2	1995	2921	0.883	0.883	0.859	0.800	0.760	0.746	0.746	0.746	0.746
MINCGLMS3	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 3	1995	3059	0.906	0.906	0.881	0.821	0.780	0.765	0.765	0.765	0.765
MINCGLMS4	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 4	1995	2546	0.925	0.925	0.900	0.838	0.796	0.781	0.781	0.781	0.781
MINCGLMS5	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 5	1995	1301	0.934	0.934	0.909	0.846	0.804	0.789	0.789	0.789	0.789
MINCGLMS6	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 6	1995	2680	0.952	0.952	0.927	0.863	0.820	0.805	0.805	0.805	0.805
MINCGLMS7	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 7	1995	3478	0.976	0.976	0.949	0.884	0.840	0.824	0.824	0.824	0.824
MINCGLMS8	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 8	1995	3622	0.999	0.999	0.972	0.905	0.860	0.844	0.844	0.844	0.844
MINCIBHS1	Coal --Interior, Bit., High Sulfur, Surface, Stp 1	1995	218250	0.799	0.799	0.787	0.793	0.777	0.768	0.768	0.768	0.768
MINCIBHS2	Coal --Interior, Bit., High Sulfur, Surface, Stp 2	1995	16508	0.820	0.820	0.808	0.814	0.797	0.788	0.788	0.788	0.788
MINCIBHS3	Coal --Interior, Bit., High Sulfur, Surface, Stp 3	1995	17215	0.841	0.841	0.829	0.836	0.818	0.809	0.809	0.809	0.809
MINCIBHS4	Coal --Interior, Bit., High Sulfur, Surface, Stp 4	1995	14313	0.859	0.859	0.846	0.853	0.835	0.826	0.826	0.826	0.826
MINCIBHS5	Coal --Interior, Bit., High Sulfur, Surface, Stp 5	1995	7312	0.868	0.868	0.854	0.861	0.843	0.834	0.834	0.834	0.834
MINCIBHS6	Coal --Interior, Bit., High Sulfur, Surface, Stp 6	1995	15011	0.885	0.885	0.871	0.878	0.860	0.850	0.850	0.850	0.850
MINCIBHS7	Coal --Interior, Bit., High Sulfur, Surface, Stp 7	1995	19452	0.906	0.906	0.893	0.900	0.881	0.871	0.871	0.871	0.871
MINCIBHS8	Coal --Interior, Bit., High Sulfur, Surface, Stp 8	1995	20249	0.928	0.928	0.914	0.921	0.902	0.892	0.892	0.892	0.892
MINCIBHU1	Coal --Interior, Bit., High Sul., Undergrd, Stp 1	1995	545253	0.725	0.725	0.712	0.710	0.697	0.692	0.692	0.692	0.692

continued

		START	CUM	COST								
		year	PJ	95USmillion$/PJ								
MARKAL	**Technology Name**			**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINCIBHU2	Coal --Interior, Bit., High Sul., Undergrd, Stp 2	1995	50352	0.745	0.745	0.731	0.730	0.716	0.711	0.711	0.711	0.711
MINCIBHU3	Coal --Interior, Bit., High Sul., Undergrd, Stp 3	1995	53464	0.764	0.764	0.750	0.749	0.734	0.729	0.729	0.729	0.729
MINCIBHU4	Coal --Interior, Bit., High Sul., Undergrd, Stp 4	1995	45116	0.780	0.780	0.765	0.764	0.749	0.744	0.744	0.744	0.744
MINCIBHU5	Coal --Interior, Bit., High Sul., Undergrd, Stp 5	1995	23285	0.788	0.788	0.773	0.772	0.757	0.752	0.752	0.752	0.752
MINCIBHU6	Coal --Interior, Bit., High Sul., Undergrd, Stp 6	1995	48319	0.804	0.804	0.788	0.787	0.772	0.767	0.767	0.767	0.767
MINCIBHU7	Coal --Interior, Bit., High Sul., Undergrd, Stp 7	1995	63514	0.823	0.823	0.808	0.806	0.791	0.786	0.786	0.786	0.786
MINCIBHU8	Coal --Interior, Bit., High Sul., Undergrd, Stp 8	1995	67069	0.843	0.843	0.827	0.825	0.810	0.804	0.804	0.804	0.804
MINCIBMS1	Coal --Interior, Bit., Med Sulfur, Surface, Stp 1	1995	57046	0.801	0.801	0.776	0.758	0.742	0.737	0.737	0.737	0.737
MINCIBMS2	Coal --Interior, Bit., Med Sulfur, Surface, Stp 2	1995	6068	0.822	0.822	0.797	0.778	0.762	0.757	0.757	0.757	0.757
MINCIBMS3	Coal --Interior, Bit., Med Sulfur, Surface, Stp 3	1995	6432	0.844	0.844	0.818	0.799	0.782	0.777	0.777	0.777	0.777
MINCIBMS4	Coal --Interior, Bit., Med Sulfur, Surface, Stp 4	1995	5431	0.861	0.861	0.835	0.815	0.798	0.793	0.793	0.793	0.793
MINCIBMS5	Coal --Interior, Bit., Med Sulfur, Surface, Stp 5	1995	2803	0.870	0.870	0.843	0.823	0.806	0.801	0.801	0.801	0.801
MINCIBMS6	Coal --Interior, Bit., Med Sulfur, Surface, Stp 6	1995	5794	0.887	0.887	0.860	0.840	0.822	0.817	0.817	0.817	0.817
MINCIBMS7	Coal --Interior, Bit., Med Sulfur, Surface, Stp 7	1995	7621	0.909	0.909	0.881	0.860	0.842	0.837	0.837	0.837	0.837
MINCIBMS8	Coal --Interior, Bit., Med Sulfur, Surface, Stp 8	1995	8010	0.930	0.930	0.902	0.881	0.862	0.857	0.857	0.857	0.857
MINCIBMU1	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 1	1995	39197	0.808	0.808	0.773	0.743	0.729	0.720	0.720	0.720	0.720
MINCIBMU2	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 2	1995	4201	0.829	0.829	0.794	0.763	0.749	0.739	0.739	0.739	0.739
MINCIBMU3	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 3	1995	4506	0.851	0.851	0.815	0.783	0.768	0.759	0.759	0.759	0.759
MINCIBMU4	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 4	1995	3828	0.869	0.869	0.832	0.800	0.784	0.774	0.774	0.774	0.774
MINCIBMU5	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 5	1995	1985	0.877	0.877	0.840	0.808	0.792	0.782	0.782	0.782	0.782
MINCIBMU6	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 6	1995	4140	0.895	0.895	0.857	0.824	0.808	0.798	0.798	0.798	0.798
MINCIBMU7	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 7	1995	5478	0.917	0.917	0.878	0.844	0.827	0.817	0.817	0.817	0.817
MINCIBMU8	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 8	1995	5827	0.938	0.938	0.899	0.864	0.847	0.837	0.837	0.837	0.837
MINCNSMS1	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 1	1995	56020	1.377	1.377	1.380	1.387	1.394	1.396	1.396	1.396	1.396
MINCNSMS2	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 2	1995	6191	1.413	1.413	1.417	1.424	1.431	1.434	1.434	1.434	1.434
MINCNSMS3	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 3	1995	6586	1.450	1.450	1.455	1.462	1.469	1.472	1.472	1.472	1.472
MINCNSMS4	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 4	1995	5563	1.480	1.480	1.484	1.492	1.499	1.502	1.502	1.502	1.502
MINCNSMS5	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 5	1995	2862	1.495	1.495	1.499	1.507	1.514	1.517	1.517	1.517	1.517
MINCNSMS6	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 6	1995	5938	1.525	1.525	1.529	1.537	1.544	1.547	1.547	1.547	1.547
MINCNSMS7	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 7	1995	7822	1.562	1.562	1.567	1.574	1.582	1.585	1.585	1.585	1.585
MINCNSMS8	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 8	1995	8223	1.599	1.599	1.604	1.612	1.620	1.623	1.623	1.623	1.623
MINCPBLU1	Coal --Power River, Bit., Low Sul, Undergrd, Stp 1	1995	23225	6.314	6.314	0.795	0.748	0.729	0.705	0.705	0.705	0.705
MINCPBLU2	Coal --Power River, Bit., Low Sul, Undergrd, Stp 2	1995	2649	0.725	0.725	0.795	0.767	0.748	0.724	0.724	0.724	0.724
MINCPBLU3	Coal --Power River, Bit., Low Sul, Undergrd, Stp 3	1995	2949	0.743	0.743	0.816	0.789	0.770	0.743	0.743	0.743	0.743
MINCPBLU4	Coal --Power River, Bit., Low Sul, Undergrd, Stp 4	1995	2749	0.759	0.759	0.833	0.804	0.785	0.758	0.758	0.758	0.758
MINCPBLU5	Coal --Power River, Bit., Low Sul, Undergrd, Stp 5	1995	1150	0.754	0.754	0.842	0.812	0.791	0.766	0.766	0.766	0.766
MINCPBLU6	Coal --Power River, Bit., Low Sul, Undergrd, Stp 6	1995	2299	0.752	0.752	0.857	0.829	0.809	0.781	0.781	0.781	0.781
MINCPBLU7	Coal --Power River, Bit., Low Sul, Undergrd, Stp 7	1995	3099	0.771	0.771	0.879	0.849	0.827	0.800	0.800	0.800	0.800
MINCPBLU8	Coal --Power River, Bit., Low Sul, Undergrd, Stp 8	1995	2333	0.789	0.789	0.899	0.870	0.847	0.820	0.820	0.820	0.820

continued

MARKAL	Technology Name	START year	CUM PJ	COST 95USmillion$/PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCPSLS1	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 1	1995	325906	0.254	0.254	0.224	0.211	0.220	0.230	0.230	0.230	0.230
MINCPSLS2	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 2	1995	21541	0.261	0.261	0.230	0.216	0.226	0.236	0.236	0.236	0.236
MINCPSLS3	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 3	1995	22374	0.267	0.267	0.236	0.222	0.232	0.243	0.243	0.243	0.243
MINCPSLS4	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 4	1995	18509	0.273	0.273	0.241	0.227	0.237	0.248	0.248	0.248	0.248
MINCPSLS5	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 5	1995	9357	0.276	0.276	0.243	0.229	0.239	0.250	0.250	0.250	0.250
MINCPSLS6	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 6	1995	19303	0.281	0.281	0.248	0.233	0.244	0.255	0.255	0.255	0.255
MINCPSLS7	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 7	1995	24904	0.288	0.288	0.254	0.239	0.250	0.261	0.261	0.261	0.261
MINCPSLS8	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 8	1995	25776	0.295	0.295	0.260	0.245	0.256	0.267	0.267	0.267	0.267
MINCPSMS1	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 1	1995	173838	0.372	0.372	0.315	0.305	0.300	0.310	0.310	0.310	0.310
MINCPSMS2	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 2	1995	24880	0.379	0.379	0.323	0.313	0.308	0.319	0.319	0.319	0.319
MINCPSMS3	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 3	1995	26931	0.388	0.388	0.332	0.321	0.316	0.327	0.327	0.327	0.327
MINCPSMS4	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 4	1995	23044	0.396	0.396	0.338	0.328	0.323	0.334	0.334	0.334	0.334
MINCPSMS5	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 5	1995	11943	0.400	0.400	0.342	0.331	0.326	0.337	0.337	0.337	0.337
MINCPSMS6	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 6	1995	25085	0.408	0.408	0.349	0.337	0.332	0.344	0.344	0.344	0.344
MINCPSMS7	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 7	1995	33332	0.418	0.418	0.357	0.346	0.340	0.352	0.352	0.352	0.352
MINCPSMS8	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 8	1995	35560	0.427	0.427	0.366	0.354	0.349	0.361	0.361	0.361	0.361
MINCRBLU1	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 1	1995	69411	0.604	0.604	0.607	0.583	0.574	0.564	0.564	0.564	0.564
MINCRBLU2	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 2	1995	5828	0.620	0.620	0.623	0.598	0.589	0.579	0.579	0.579	0.579
MINCRBLU3	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 3	1995	6160	0.637	0.637	0.640	0.614	0.605	0.594	0.594	0.594	0.594
MINCRBLU4	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 4	1995	5173	0.650	0.650	0.653	0.627	0.617	0.607	0.607	0.607	0.607
MINCRBLU5	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 5	1995	2662	0.656	0.656	0.659	0.633	0.624	0.613	0.613	0.613	0.613
MINCRBLU6	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 6	1995	5507	0.669	0.669	0.672	0.645	0.636	0.625	0.625	0.625	0.625
MINCRBLU7	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 7	1995	7211	0.686	0.686	0.689	0.661	0.651	0.640	0.640	0.640	0.640
MINCRBLU8	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 8	1995	7585	0.702	0.702	0.705	0.677	0.667	0.655	0.655	0.655	0.655
MINCRSLS1	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 1	1995	101	0.817	0.817	0.702	0.606	0.547	0.537	0.537	0.537	0.537
MINCRSLS2	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 2	1995	7	0.839	0.839	0.721	0.622	0.562	0.552	0.552	0.552	0.552
MINCRSLS3	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 3	1995	7	0.861	0.861	0.740	0.639	0.576	0.566	0.566	0.566	0.566
MINCRSLS4	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 4	1995	6	0.879	0.879	0.755	0.652	0.588	0.578	0.578	0.578	0.578
MINCRSLS5	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 5	1995	3	0.887	0.887	0.762	0.659	0.594	0.584	0.584	0.584	0.584
MINCRSLS6	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 6	1995	6	0.905	0.905	0.778	0.671	0.606	0.595	0.595	0.595	0.595
MINCRSLS7	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 7	1995	8	0.927	0.927	0.797	0.688	0.621	0.610	0.610	0.610	0.610
MINCRSLS8	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 8	1995	8	0.949	0.949	0.816	0.704	0.635	0.624	0.624	0.624	0.624
MINCSBLS1	Coal --Southwest, Bit, Low Sul., Surface. Stp 1	1995	6959	0.792	0.792	0.748	0.742	0.746	0.746	0.746	0.746	0.746
MINCSBLS2	Coal --Southwest, Bit, Low Sul., Surface. Stp 2	1995	471	0.813	0.813	0.768	0.762	0.766	0.766	0.766	0.766	0.766
MINCSBLS3	Coal --Southwest, Bit, Low Sul., Surface. Stp 3	1995	488	0.834	0.834	0.788	0.783	0.786	0.786	0.786	0.786	0.786
MINCSBLS4	Coal --Southwest, Bit, Low Sul., Surface. Stp 4	1995	404	0.852	0.852	0.804	0.799	0.803	0.802	0.802	0.802	0.802
MINCSBLS5	Coal --Southwest, Bit, Low Sul., Surface. Stp 5	1995	206	0.860	0.860	0.812	0.807	0.811	0.811	0.811	0.811	0.811
MINCSBLS6	Coal --Southwest, Bit, Low Sul., Surface. Stp 6	1995	423	0.877	0.877	0.828	0.823	0.827	0.827	0.827	0.827	0.827
MINCSBLS7	Coal --Southwest, Bit, Low Sul., Surface. Stp 7	1995	545	0.899	0.899	0.849	0.843	0.847	0.847	0.847	0.847	0.847

continued

MARKAL	Technology Name	START year	CUM PJ	COST 95USmillion$/PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCSBLS8	Coal --Southwest, Bit, Low Sul., Surface. Stp 8	1995	565	0.920	0.920	0.869	0.863	0.867	0.867	0.867	0.867	0.867
MINCSSMS1	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 1	1995	22215	0.927	0.927	0.916	0.923	0.905	0.898	0.898	0.898	0.898
MINCSSMS2	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 2	1995	1493	0.952	0.952	0.941	0.948	0.930	0.922	0.922	0.922	0.922
MINCSSMS3	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 3	1995	1552	0.978	0.978	0.966	0.973	0.954	0.947	0.947	0.947	0.947
MINCSSMS4	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 4	1995	1284	0.998	0.998	0.986	0.993	0.974	0.966	0.966	0.966	0.966
MINCSSMS5	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 5	1995	655	1.008	1.008	0.996	1.003	0.984	0.976	0.976	0.976	0.976
MINCSSMS6	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 6	1995	1341	1.028	1.028	1.015	1.023	1.003	0.995	0.995	0.995	0.995
MINCSSMS7	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 7	1995	1732	1.053	1.053	1.040	1.048	1.028	1.020	1.020	1.020	1.020
MINCSSMS8	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 8	1995	1794	1.078	1.078	1.065	1.072	1.052	1.044	1.044	1.044	1.044

MARKAL	Technology Name	BOUND(BD)Or PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCABHS1	Coal --App., Bit., High Sulfur, Surface, Stp 1	327.23	327.23	269.85	267.70	249.05	236.61	236.61	236.61	236.61
MINCABHS2	Coal --App., Bit., High Sulfur, Surface, Stp 2	26.39	26.39	22.03	21.93	20.39	19.47	19.47	19.47	19.47
MINCABHS3	Coal --App., Bit., High Sulfur, Surface, Stp 3	27.56	27.56	23.06	22.95	21.36	20.24	20.24	20.24	20.24
MINCABHS4	Coal --App., Bit., High Sulfur, Surface, Stp 4	23.00	23.00	19.21	19.16	17.78	16.91	16.91	16.91	16.91
MINCABHS5	Coal --App., Bit., High Sulfur, Surface, Stp 5	11.78	11.78	9.84	9.84	9.07	8.62	8.62	8.62	8.62
MINCABHS6	Coal --App., Bit., High Sulfur, Surface, Stp 6	24.18	24.18	20.29	20.13	18.80	17.93	17.93	17.93	17.93
MINCABHS7	Coal --App., Bit., High Sulfur, Surface, Stp 7	31.35	31.35	26.28	26.08	24.28	23.14	23.14	23.14	23.14
MINCABHS8	Coal --App., Bit., High Sulfur, Surface, Stp 8	32.69	32.69	27.46	27.26	25.31	24.17	24.17	24.17	24.17
MINCABHU1	Coal --App., Bit., High Sulfur, Undergrd, Stp 1	826.91	826.91	741.96	822.14	848.27	851.84	851.84	851.84	851.84
MINCABHU2	Coal --App., Bit., High Sulfur, Undergrd, Stp 2	82.59	82.59	74.65	82.69	85.46	85.82	85.82	85.82	85.82
MINCABHU3	Coal --App., Bit., High Sulfur, Undergrd, Stp 3	88.07	88.07	79.67	88.33	91.14	91.62	91.62	91.62	91.62
MINCABHU4	Coal --App., Bit., High Sulfur, Undergrd, Stp 4	74.60	74.60	67.47	74.80	77.26	77.70	77.70	77.70	77.70
MINCABHU5	Coal --App., Bit., High Sulfur, Undergrd, Stp 5	38.63	38.63	34.99	38.78	39.96	40.30	40.30	40.30	40.30
MINCABHU6	Coal --App., Bit., High Sulfur, Undergrd, Stp 6	80.28	80.28	72.70	80.54	83.25	83.68	83.68	83.68	83.68
MINCABHU7	Coal --App., Bit., High Sulfur, Undergrd, Stp 7	105.90	105.90	95.91	106.31	109.79	110.41	110.41	110.41	110.41
MINCABHU8	Coal --App., Bit., High Sulfur, Undergrd, Stp 8	112.25	112.25	101.65	112.71	116.45	117.07	117.07	117.07	117.07
MINCABLS1	Coal --App., Bitum., Low Sulfur, Surface, Stp 1	829.22	829.22	736.29	659.68	630.21	581.92	581.92	581.92	581.92
MINCABLS2	Coal --App., Bitum., Low Sulfur, Surface, Stp 2	69.45	69.45	62.39	56.13	53.85	49.92	49.92	49.92	49.92
MINCABLS3	Coal --App., Bitum., Low Sulfur, Surface, Stp 3	72.90	72.90	65.42	58.84	56.45	52.40	52.40	52.40	52.40
MINCABLS4	Coal --App., Bitum., Low Sulfur, Surface, Stp 4	60.84	60.84	860.06	49.28	47.21	43.90	43.90	43.90	43.90
MINCABLS5	Coal --App., Bitum., Low Sulfur, Surface, Stp 5	31.37	31.37	27.88	25.22	24.11	22.22	22.22	22.22	22.22
MINCABLS6	Coal --App., Bitum., Low Sulfur, Surface, Stp 6	64.24	64.24	57.72	51.94	49.81	46.29	46.29	46.29	46.29
MINCABLS7	Coal --App., Bitum., Low Sulfur, Surface, Stp 7	83.67	83.67	74.92	67.60	64.73	60.01	60.01	60.01	60.01
MINCABLS8	Coal --App., Bitum., Low Sulfur, Surface, Stp 8	87.22	87.22	78.27	70.42	67.55	62.67	62.67	62.67	62.67
MINCABLU1	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 1	744.32	744.32	749.76	735.64	735.30	644.64	644.64	644.64	644.64

continued

MARKAL	Technology Name	BOUND(BD)Or PJ 1995	2000	2005	2010	2015	2020	2025	2030	2035
MINCABLU2	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 2	91.77	91.77	95.37	95.04	95.26	83.83	83.83	83.83	83.83
MINCABLU3	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 3	99.35	99.35	103.64	103.40	103.73	91.07	91.07	91.07	91.07
MINCABLU4	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 4	85.19	85.19	89.11	89.04	89.32	78.52	78.52	78.52	78.52
MINCABLU5	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 5	44.61	44.61	46.59	46.51	46.78	41.07	41.07	41.07	41.07
MINCABLU6	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 6	93.35	93.35	97.64	97.77	98.26	86.46	86.46	86.46	86.46
MINCABLU7	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 7	124.58	124.58	130.70	130.97	131.58	115.78	115.78	115.78	115.78
MINCABLU8	Coal --App., Bitum., Low Sulfur, Undergrd, Stp 8	133.65	133.65	140.50	141.03	141.68	124.69	124.69	124.69	124.69
MINCABMS1	Coal --App., Bitum., Med Sulfur, Surface, Stp 1	1947.42	1947.42	1924.82	1966.21	1866.14	1795.75	1795.75	1795.75	1795.75
MINCABMS2	Coal --App., Bitum., Med Sulfur, Surface, Stp 2	138.88	138.88	137.62	140.65	133.57	128.43	128.43	128.43	128.43
MINCABMS3	Coal --App., Bitum., Med Sulfur, Surface, Stp 3	144.68	144.68	143.32	146.51	139.16	133.88	133.88	133.88	133.88
MINCABMS4	Coal --App., Bitum., Med Sulfur, Surface, Stp 4	120.06	120.06	118.90	121.61	115.37	111.03	111.03	111.03	111.03
MINCABMS5	Coal --App., Bitum., Med Sulfur, Surface, Stp 5	61.32	61.32	60.82	62.10	58.93	56.70	56.70	56.70	56.70
MINCABMS6	Coal --App., Bitum., Med Sulfur, Surface, Stp 6	125.81	125.81	124.55	127.32	120.92	116.22	116.22	116.22	116.22
MINCABMS7	Coal --App., Bitum., Med Sulfur, Surface, Stp 7	162.51	162.51	161.17	164.67	156.32	150.33	150.33	150.33	150.33
MINCABMS8	Coal --App., Bitum., Med Sulfur, Surface, Stp 8	168.58	168.58	167.18	170.91	162.07	155.96	155.96	155.96	155.96
MINCABMU1	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 1	2838.37	2838.37	3014.43	2973.15	2903.93	2977.40	2977.40	2977.40	2977.40
MINCABMU2	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 2	283.62	283.62	301.19	296.71	290.07	297.52	297.52	297.52	297.52
MINCABMU3	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 3	302.90	302.90	321.45	316.67	309.61	317.74	317.74	317.74	317.74
MINCABMU4	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 4	256.57	256.57	272.34	268.32	262.30	269.20	269.20	269.20	269.20
MINCABMU5	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 5	132.92	132.92	141.07	138.91	135.80	139.25	139.25	139.25	139.25
MINCABMU6	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 6	276.22	276.22	293.18	288.86	282.43	289.87	289.87	289.87	289.87
MINCABMU7	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 7	364.55	364.55	386.89	381.05	372.46	382.38	382.38	382.38	382.38
MINCABMU8	Coal --App., Bitum., Med Sulfur, Undergrd, Stp 8	386.63	386.63	410.22	404.09	395.12	405.41	405.41	405.41	405.41
MINCAGHS1	Coal --App., Gob, High Sulfur, Stp 1	100.09	100.09	126.71	127.05	126.42	126.33	126.33	126.33	126.33
MINCAGHS2	Coal --App., Gob, High Sulfur, Stp 2	6.53	6.53	8.29	8.34	8.26	8.26	8.26	8.26	8.26
MINCAGHS3	Coal --App., Gob, High Sulfur, Stp 3	6.77	6.77	8.60	8.66	8.60	8.57	8.57	8.57	8.57
MINCAGHS4	Coal --App., Gob, High Sulfur, Stp 4	5.61	5.61	7.13	7.16	7.08	7.08	7.08	7.08	7.08
MINCAGHS5	Coal --App., Gob, High Sulfur, Stp 5	2.86	2.86	3.65	3.67	3.65	3.67	3.67	3.67	3.67
MINCAGHS6	Coal --App., Gob, High Sulfur, Stp 6	5.82	5.82	7.42	7.48	7.42	7.39	7.39	7.39	7.39
MINCAGHS7	Coal --App., Gob, High Sulfur, Stp 7	7.53	7.53	9.60	9.60	9.57	9.57	9.57	9.57	9.57
MINCAGHS8	Coal --App., Gob, High Sulfur, Stp 8	7.79	7.79	9.91	9.94	9.91	9.88	9.88	9.88	9.88
MINCALMS1	Coal --App., Lignite, Med. Sulfur, Surface, Stp 1	25.99	25.99	33.14	35.14	35.14	35.28	35.28	35.28	35.28
MINCALMS2	Coal --App., Lignite, Med. Sulfur, Surface, Stp 2	1.00	1.00	1.49	1.57	1.62	1.62	1.62	1.62	1.62
MINCALMS3	Coal --App., Lignite, Med. Sulfur, Surface, Stp 3	1.03	1.03	1.52	1.62	1.62	1.62	1.62	1.62	1.62
MINCALMS4	Coal --App., Lignite, Med. Sulfur, Surface, Stp 4	0.87	0.87	1.25	1.35	1.35	1.35	1.35	1.35	1.35
MINCALMS5	Coal --App., Lignite, Med. Sulfur, Surface, Stp 5	0.43	0.43	0.62	0.68	0.68	0.68	0.68	0.68	0.68
MINCALMS6	Coal --App., Lignite, Med. Sulfur, Surface, Stp 6	0.87	0.87	1.25	1.35	1.35	1.35	1.35	1.35	1.35
MINCALMS7	Coal --App., Lignite, Med. Sulfur, Surface, Stp 7	1.14	1.14	1.65	1.76	1.76	1.76	1.76	1.76	1.76
MINCALMS8	Coal --App., Lignite, Med. Sulfur, Surface, Stp 8	1.14	1.14	1.65	1.76	1.76	1.76	1.76	1.76	1.76

continued

		BOUND(BD)Or								
		PJ								
MARKAL	**Technology Name**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINCAMLU1	Coal --App., Met., Low Sul., Undergrd, Stp 1	103.66	103.66	92.57	90.09	75.50	68.14	68.14	68.14	68.14
MINCAMLU2	Coal --App., Met., Low Sul., Undergrd, Stp 2	11.42	11.42	10.29	9.95	8.48	7.82	7.82	7.82	7.82
MINCAMLU3	Coal --App., Met., Low Sul., Undergrd, Stp 3	12.22	12.22	11.08	10.80	9.10	8.39	8.39	8.39	8.39
MINCAMLU4	Coal --App., Met., Low Sul., Undergrd, Stp 4	10.41	10.41	9.44	9.10	7.80	6.97	6.97	6.97	6.97
MINCAMLU5	Coal --App., Met., Low Sul., Undergrd, Stp 5	5.43	5.43	4.86	4.75	4.02	3.68	3.68	3.68	3.68
MINCAMLU6	Coal --App., Met., Low Sul., Undergrd, Stp 6	11.31	11.31	10.24	9.95	8.43	7.63	7.63	7.63	7.63
MINCAMLU7	Coal --App., Met., Low Sul., Undergrd, Stp 7	14.93	14.93	13.46	13.18	11.25	10.08	10.08	10.08	10.08
MINCAMLU8	Coal --App., Met., Low Sul., Undergrd, Stp 8	16.06	16.06	14.42	14.14	11.93	10.93	10.93	10.93	10.93
MINCAMMU1	Coal --App., Met., Med Sul., Undergrd, Stp 1	1140.58	1140.58	1059.99	1042.97	1033.98	1028.29	1028.29	1028.29	1028.29
MINCAMMU2	Coal --App., Met., Med Sul., Undergrd, Stp 2	145.45	145.45	137.48	135.67	134.53	133.65	133.65	133.65	133.65
MINCAMMU3	Coal --App., Met., Med Sul., Undergrd, Stp 3	157.89	157.89	149.63	147.60	146.30	145.34	145.34	145.34	145.34
MINCAMMU4	Coal --App., Met., Med Sul., Undergrd, Stp 4	135.72	135.72	128.65	126.96	126.00	125.17	125.17	125.17	125.17
MINCAMMU5	Coal --App., Met., Med Sul., Undergrd, Stp 5	71.03	71.03	67.41	66.56	65.88	65.50	65.50	65.50	65.50
MINCAMMU6	Coal --App., Met., Med Sul., Undergrd, Stp 6	148.79	148.79	141.21	139.45	138.38	137.23	137.23	137.23	137.23
MINCAMMU7	Coal --App., Met., Med Sul., Undergrd, Stp 7	199.00	199.00	189.05	186.62	185.09	183.79	183.79	183.79	183.79
MINCAMMU8	Coal --App., Met., Med Sul., Undergrd, Stp 8	213.76	213.76	203.53	200.81	199.12	197.74	197.74	197.74	197.74
MINCDLMS1	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 1	369.81	369.81	385.21	387.80	391.56	392.20	392.20	392.20	392.20
MINCDLMS2	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 2	25.06	25.06	26.07	26.24	26.52	26.57	26.57	26.57	26.57
MINCDLMS3	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 3	26.07	26.07	27.14	27.28	27.53	27.60	27.60	27.60	27.60
MINCDLMS4	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 4	21.58	21.58	22.45	22.59	22.79	22.83	22.83	22.83	22.83
MINCDLMS5	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 5	10.95	10.95	11.39	11.48	11.56	11.60	11.60	11.60	11.60
MINCDLMS6	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 6	22.56	22.56	23.49	23.60	23.85	23.85	23.85	23.85	23.85
MINCDLMS7	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 7	29.10	29.10	30.28	30.48	30.73	30.78	30.78	30.78	30.78
MINCDLMS8	Coal --Dakota, Lignite, Med. Sulf., Surface, Stp 8	30.14	30.14	31.38	31.57	31.85	31.90	31.90	31.90	31.90
MINCGLHS1	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 1	261.51	261.51	248.88	242.06	217.07	208.49	208.49	208.49	208.49
MINCGLHS2	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 2	20.35	20.35	19.48	18.99	17.05	16.46	16.46	16.46	16.46
MINCGLHS3	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 3	21.25	21.25	20.35	19.81	17.84	17.14	17.14	17.14	17.14
MINCGLHS4	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 4	17.68	17.68	16.94	16.51	14.84	14.28	14.28	14.28	14.28
MINCGLHS5	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 5	9.03	9.03	8.65	8.43	7.58	7.28	7.28	7.28	7.28
MINCGLHS6	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 6	18.58	18.58	17.79	17.38	15.66	15.05	15.05	15.05	15.05
MINCGLHS7	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 7	24.12	24.12	23.11	22.51	20.30	19.51	19.51	19.51	19.51
MINCGLHS8	Coal --Gulf, Lignite, High Sulfur, Surface, Stp 8	25.10	25.10	24.01	23.38	21.12	20.33	20.33	20.33	20.33
MINCGLMS1	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 1	345.20	345.20	334.67	268.91	224.11	206.11	206.11	206.11	206.11
MINCGLMS2	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 2	27.37	27.37	26.67	21.69	18.22	16.83	16.83	16.83	16.83
MINCGLMS3	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 3	28.64	28.64	27.94	22.71	19.06	17.64	17.64	17.64	17.64
MINCGLMS4	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 4	23.85	23.85	23.20	18.90	15.89	14.71	14.71	14.71	14.71
MINCGLMS5	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 5	12.16	12.16	11.86	9.66	8.12	7.54	7.54	7.54	7.54
MINCGLMS6	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 6	25.07	25.07	24.42	19.90	16.76	15.48	15.48	15.48	15.48
MINCGLMS7	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 7	32.54	32.54	31.73	25.83	21.71	20.08	20.08	20.08	20.08

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					BOUND(BD)Or PJ					
MARKAL	**Technology Name**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINCGLMS8	Coal --Gulf, Lignite, Med. Sulfur, Surface, Stp 8	33.90	33.90	33.03	26.91	22.63	20.89	20.89	20.89	20.89
MINCIBHS1	Coal --Interior, Bit., High Sulfur, Surface, Stp 1	694.92	694.92	717.78	766.16	709.97	692.09	692.09	692.09	692.09
MINCIBHS2	Coal --Interior, Bit., High Sulfur, Surface, Stp 2	52.44	52.44	54.21	57.96	53.79	52.45	52.45	52.45	52.45
MINCIBHS3	Coal --Interior, Bit., High Sulfur, Surface, Stp 3	54.67	54.67	56.59	60.47	56.07	54.66	54.66	54.66	54.66
MINCIBHS4	Coal --Interior, Bit., High Sulfur, Surface, Stp 4	45.43	45.43	47.07	50.24	46.64	45.46	45.46	45.46	45.46
MINCIBHS5	Coal --Interior, Bit., High Sulfur, Surface, Stp 5	23.29	23.29	24.03	25.64	23.84	23.16	23.16	23.16	23.16
MINCIBHS6	Coal --Interior, Bit., High Sulfur, Surface, Stp 6	47.62	47.62	49.39	52.66	48.87	47.76	47.76	47.76	47.76
MINCIBHS7	Coal --Interior, Bit., High Sulfur, Surface, Stp 7	61.76	61.76	63.95	68.31	63.34	61.80	61.80	61.80	61.80
MINCIBHS8	Coal --Interior, Bit., High Sulfur, Surface, Stp 8	64.19	64.19	66.58	71.13	66.01	64.34	64.34	64.34	64.34
MINCIBHU1	Coal --Interior, Bit., High Sul., Undergrd, Stp 1	650.99	650.99	690.16	775.67	810.30	841.56	841.56	841.56	841.56
MINCIBHU2	Coal --Interior, Bit., High Sul., Undergrd, Stp 2	60.07	60.07	63.67	71.67	74.85	77.77	77.77	77.77	77.77
MINCIBHU3	Coal --Interior, Bit., High Sul., Undergrd, Stp 3	63.81	63.81	67.65	76.08	79.49	82.51	82.51	82.51	82.51
MINCIBHU4	Coal --Interior, Bit., High Sul., Undergrd, Stp 4	53.86	53.86	57.08	64.14	67.03	69.72	69.72	69.72	69.72
MINCIBHU5	Coal --Interior, Bit., High Sul., Undergrd, Stp 5	27.81	27.81	29.51	33.07	34.63	35.92	35.92	35.92	35.92
MINCIBHU6	Coal --Interior, Bit., High Sul., Undergrd, Stp 6	57.70	57.70	61.11	68.74	71.82	74.61	74.61	74.61	74.61
MINCIBHU7	Coal --Interior, Bit., High Sul., Undergrd, Stp 7	75.80	75.80	80.39	90.34	94.41	98.06	98.06	98.06	98.06
MINCIBHU8	Coal --Interior, Bit., High Sul., Undergrd, Stp 8	80.06	80.06	84.84	95.41	99.67	103.59	103.59	103.59	103.59
MINCIBMS1	Coal --Interior, Bit., Med Sulfur, Surface, Stp 1	146.72	146.72	135.59	123.84	107.48	105.20	105.20	105.20	105.20
MINCIBMS2	Coal --Interior, Bit., Med Sulfur, Surface, Stp 2	15.25	15.25	14.29	13.24	11.61	11.43	11.43	11.43	11.43
MINCIBMS3	Coal --Interior, Bit., Med Sulfur, Surface, Stp 3	16.12	16.12	15.16	14.10	12.33	12.07	12.07	12.07	12.07
MINCIBMS4	Coal --Interior, Bit., Med Sulfur, Surface, Stp 4	13.62	13.62	12.81	11.85	10.41	10.23	10.23	10.23	10.23
MINCIBMS5	Coal --Interior, Bit., Med Sulfur, Surface, Stp 5	7.05	7.05	6.57	6.14	5.37	5.28	5.28	5.28	5.28
MINCIBMS6	Coal --Interior, Bit., Med Sulfur, Surface, Stp 6	14.48	14.48	13.67	12.61	11.13	10.95	10.95	10.95	10.95
MINCIBMS7	Coal --Interior, Bit., Med Sulfur, Surface, Stp 7	18.99	18.99	17.94	16.60	14.68	14.47	14.47	14.47	14.47
MINCIBMS8	Coal --Interior, Bit., Med Sulfur, Surface, Stp 8	20.00	20.00	18.80	17.46	15.44	15.19	15.19	15.19	15.19
MINCIBMU1	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 1	402.55	402.55	370.94	343.56	351.95	366.36	366.36	366.36	366.36
MINCIBMU2	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 2	42.69	42.69	39.57	36.93	37.94	39.57	39.57	39.57	39.57
MINCIBMU3	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 3	45.66	45.66	42.45	39.62	40.72	42.53	42.53	42.53	42.53
MINCIBMU4	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 4	38.80	38.80	36.02	33.67	34.63	36.13	36.13	36.13	36.13
MINCIBMU5	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 5	20.10	20.10	18.66	17.51	17.99	18.71	18.71	18.71	18.71
MINCIBMU6	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 6	41.97	41.97	38.95	36.40	37.46	39.09	39.09	39.09	39.09
MINCIBMU7	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 7	55.45	55.45	51.56	48.20	49.59	51.72	51.72	51.72	51.72
MINCIBMU8	Coal --Interior, Bit., Med. Sulfur, Undergrd Stp 8	58.95	58.95	54.82	51.22	52.76	55.08	55.08	55.08	55.08
MINCNSMS1	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 1	72.15	72.15	80.77	82.39	84.05	85.31	85.31	85.31	85.31
MINCNSMS2	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 2	8.02	8.02	8.94	9.08	9.24	9.44	9.44	9.44	9.44
MINCNSMS3	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 3	8.51	8.51	9.54	9.71	9.87	9.94	9.94	9.94	9.94
MINCNSMS4	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 4	7.19	7.19	8.05	8.18	8.32	8.45	8.45	8.45	8.45
MINCNSMS5	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 5	3.68	3.68	4.14	4.27	4.27	4.31	4.31	4.31	4.31
MINCNSMS6	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 6	7.69	7.69	8.58	8.75	8.88	9.00	9.00	9.00	9.00

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		BOUND(BD)Or PJ								
MARKAL	**Technology Name**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINCNSMS7	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 7	10.17	10.17	11.33	11.50	11.69	11.82	11.82	11.82	11.82
MINCNSMS8	Coal --Northwest: Sub-bit, Med Sul., Surface. Stp 8	10.67	10.67	11.89	12.06	12.36	12.42	12.42	12.42	12.42
MINCPBLU1	Coal --Power River, Bit., Low Sul, Undergrd, Stp 1	14.59	14.59	2.27	2.14	1.36	0.76	0.76	0.76	0.76
MINCPBLU2	Coal --Power River, Bit., Low Sul, Undergrd, Stp 2	1.32	1.32	0.18	0.45	0.23	0.23	0.23	0.23	0.23
MINCPBLU3	Coal --Power River, Bit., Low Sul, Undergrd, Stp 3	1.45	1.45	0.18	0.50	0.32	0.23	0.23	0.23	0.23
MINCPBLU4	Coal --Power River, Bit., Low Sul, Undergrd, Stp 4	1.36	1.36	0.18	0.45	0.27	0.23	0.23	0.23	0.23
MINCPBLU5	Coal --Power River, Bit., Low Sul, Undergrd, Stp 5	0.50	0.50	0.09	0.23	0.23	0.00	0.00	0.00	0.00
MINCPBLU6	Coal --Power River, Bit., Low Sul, Undergrd, Stp 6	0.82	0.82	0.23	0.50	0.32	0.23	0.23	0.23	0.23
MINCPBLU7	Coal --Power River, Bit., Low Sul, Undergrd, Stp 7	1.14	1.14	0.27	0.73	0.45	0.23	0.23	0.23	0.23
MINCPBLU8	Coal --Power River, Bit., Low Sul, Undergrd, Stp 8	0.23	0.23	0.32	0.77	0.50	0.30	0.30	0.30	0.30
MINCPSLS1	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 1	5558.13	5558.13	6888.87	7972.84	9068.54	9991.33	9991.33	9991.33	9991.33
MINCPSLS2	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 2	369.08	369.08	455.16	525.43	598.82	660.94	660.94	660.94	660.94
MINCPSLS3	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 3	383.39	383.39	472.78	545.73	621.90	686.50	686.50	686.50	686.50
MINCPSLS4	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 4	317.19	317.19	391.13	451.38	514.50	567.98	567.98	567.98	567.98
MINCPSLS5	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 5	160.61	160.61	197.68	227.99	260.02	287.20	287.20	287.20	287.20
MINCPSLS6	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 6	330.91	330.91	407.90	470.68	536.52	592.32	592.32	592.32	592.32
MINCPSLS7	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 7	427.05	427.05	526.24	607.19	692.17	764.23	764.23	764.23	764.23
MINCPSLS8	Coal --Power R, Sub-Bit, Low Sul, Surface, Stp 8	441.99	441.99	544.74	628.40	716.36	790.96	790.96	790.96	790.96
MINCPSMS1	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 1	484.53	484.53	328.49	329.68	281.69	344.52	344.52	344.52	344.52
MINCPSMS2	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 2	61.30	61.30	47.80	49.81	43.36	50.89	50.89	50.89	50.89
MINCPSMS3	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 3	65.73	65.73	51.75	54.10	47.20	55.24	55.24	55.24	55.24
MINCPSMS4	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 4	55.89	55.89	44.33	46.42	40.49	47.35	47.35	47.35	47.35
MINCPSMS5	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 5	28.86	28.86	22.97	24.09	21.07	24.55	24.55	24.55	24.55
MINCPSMS6	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 6	60.37	60.37	48.25	50.71	44.30	51.64	51.64	51.64	51.64
MINCPSMS7	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 7	79.72	79.72	64.21	67.56	59.02	68.67	68.67	68.67	68.67
MINCPSMS8	Coal --Power R, Sub-Bit, Med Sul, Surface, Stp 8	84.56	84.56	68.53	72.22	63.20	73.33	73.33	73.33	73.33
MINCRBLU1	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 1	1054.46	1054.46	1420.54	1454.27	1509.43	1527.51	1527.51	1527.51	1527.51
MINCRBLU2	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 2	88.74	88.74	119.61	122.09	126.62	127.87	127.87	127.87	127.87
MINCRBLU3	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 3	93.81	93.81	126.37	129.10	133.82	135.17	135.17	135.17	135.17
MINCRBLU4	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 4	78.76	78.76	106.17	108.41	112.35	113.51	113.51	113.51	113.51
MINCRBLU5	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 5	40.60	40.60	54.67	55.69	57.78	58.42	58.42	58.42	58.42
MINCRBLU6	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 6	83.88	83.88	113.08	115.32	119.56	120.81	120.81	120.81	120.81
MINCRBLU7	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 7	109.87	109.87	148.09	151.05	156.56	158.13	158.13	158.13	158.13
MINCRBLU8	Coal --Rocky Mtns, Bit., Low Sul., Undergrd, Stp 8	115.62	115.62	155.73	158.89	164.64	166.41	166.41	166.41	166.41
MINCRSLS1	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 1	189.11	189.11	138.46	100.34	80.09	76.61	76.61	76.61	76.61
MINCRSLS2	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 2	12.36	12.36	8.98	6.42	5.12	4.84	4.84	4.84	4.84
MINCRSLS3	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 3	12.79	12.79	9.37	6.63	5.33	4.99	4.99	4.99	4.99
MINCRSLS4	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 4	10.62	10.62	7.72	5.51	4.38	4.12	4.12	4.12	4.12
MINCRSLS5	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 5	5.42	5.42	3.95	2.86	2.17	2.17	2.17	2.17	2.17

continued

		BOUND(BD)Or PJ								
MARKAL	**Technology Name**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINCRSLS6	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 6	11.10	11.10	8.02	5.77	4.51	4.34	4.34	4.34	4.34
MINCRSLS7	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 7	14.22	14.22	10.36	7.42	5.90	5.64	5.64	5.64	5.64
MINCRSLS8	Coal --Rocky Mtn, Sub-Bit, Low Sul., Surface. Stp 8	14.79	14.79	10.67	7.72	6.07	5.85	5.85	5.85	5.85
MINCSBLS1	Coal --Southwest, Bit, Low Sul., Surface. Stp 1	343.76	343.76	306.43	299.39	299.61	297.60	297.60	297.60	297.60
MINCSBLS2	Coal --Southwest, Bit, Low Sul., Surface. Stp 2	23.26	23.26	20.71	20.21	20.26	20.17	20.17	20.17	20.17
MINCSBLS3	Coal --Southwest, Bit, Low Sul., Surface. Stp 3	24.11	24.11	21.51	21.02	21.06	20.84	20.84	20.84	20.84
MINCSBLS4	Coal --Southwest, Bit, Low Sul., Surface. Stp 4	20.03	20.03	17.79	17.39	17.39	17.26	17.26	17.26	17.26
MINCSBLS5	Coal --Southwest, Bit, Low Sul., Surface. Stp 5	10.17	10.17	9.10	8.87	8.87	8.74	8.74	8.74	8.74
MINCSBLS6	Coal --Southwest, Bit, Low Sul., Surface. Stp 6	20.93	20.93	18.60	18.15	18.15	18.15	18.15	18.15	18.15
MINCSBLS7	Coal --Southwest, Bit, Low Sul., Surface. Stp 7	26.98	26.98	23.98	23.49	23.44	23.31	23.31	23.31	23.31
MINCSBLS8	Coal --Southwest, Bit, Low Sul., Surface. Stp 8	27.92	27.92	24.87	24.34	24.29	24.20	24.20	24.20	24.20
MINCSSMS1	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 1	311.10	311.10	306.94	310.98	293.49	282.75	282.75	282.75	282.75
MINCSSMS2	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 2	20.88	20.88	20.58	20.92	19.77	19.01	19.01	19.01	19.01
MINCSSMS3	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 3	21.77	21.77	21.46	21.69	20.54	19.71	19.71	19.71	19.71
MINCSSMS4	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 4	17.99	17.99	17.72	17.99	16.95	16.31	16.31	16.31	16.31
MINCSSMS5	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 5	9.17	9.17	9.13	9.17	8.63	8.28	8.28	8.28	8.28
MINCSSMS6	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 6	18.76	18.76	18.53	18.80	17.69	17.08	17.08	17.08	17.08
MINCSSMS7	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 7	24.24	24.24	23.93	24.27	22.89	22.03	22.03	22.03	22.03
MINCSSMS8	Coal --Southwest, Sub-bit, Med Sul., Surface. Stp 8	25.12	25.12	24.81	25.12	23.73	22.80	22.80	22.80	22.80

DOMESTIC OIL AND GAS RESOURCE SUPPLY

		START	**COST**								
			1995	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
MINOIL1	Domestic crude oil -Lower 48-Step1	1995	2.941	3.180	3.409	2.646	2.646	2.646	2.721	2.798	2.877
MINOIL2	Domestic crude oil -Lower 48-Step2	1995	0.000	0.000	0.000	3.503	3.599	3.701	3.806	3.914	4.025
MINOIL3	Domestic crude oil -Lower 48-Step3	1995	0.000	0.000	0.000	4.501	4.565	4.586	4.716	4.850	4.987
MINOILA	Domestic crude oil - Alaska - Step1	1995	2.941	3.180	3.409	2.646	2.646	2.646	2.721	2.798	2.877
MINOILB	Domestic crude oil - Alaska - Step2	1995	0.000	0.000	0.000	3.503	3.599	3.701	3.806	3.914	4.025
MINOILC	Domestic crude oil - Alaska - Step3	1995	0.000	0.000	0.000	4.501	4.565	4.586	4.716	4.850	4.987
MINNGA1	Domestic Dry Natural Gas- Step 1	1995	1.835	2.517	2.255	2.255	2.442	2.493	2.647	2.811	2.985
MINNGA2	Domestic Dry Natural Gas- Step 2	1995	0.000	0.000	0.000	2.416	2.603	2.764	2.935	3.117	3.310
MINNGA3	Domestic Dry Natural Gas- Step 3	1995	0.000	0.000	0.000	2.806	2.849	3.095	3.286	3.489	3.705
MINNGL1	Domestic Natural Gas Plant Liquids- Step 1	1995	3.411	3.688	3.954	3.069	3.069	3.069	3.156	3.245	3.337
MINNGL2	Domestic Natural Gas Plant Liquids- Step 2	1995	0.000	0.000	0.000	4.064	4.175	4.294	4.415	4.540	4.669
MINNGL3	Domestic Natural Gas Plant Liquids- Step 3	1995	0.000	0.000	0.000	5.221	5.296	5.320	5.471	5.626	5.785

		BOUND(BD)Or								
		1995	2000	2005	2010	2015	2020	2025	2030	2035
MINOIL1	Domestic crude oil -Lower 48-Step1	11467.064	10972.332	10229.675	9068.227	9023.556	8621.517	8399.026	8182.277	7971.121
MINOIL2	Domestic crude oil -Lower 48-Step2	0.000	0.000	0.000	714.737	1362.468	1496.481	1457.862	1420.240	1383.588
MINOIL3	Domestic crude oil -Lower 48-Step3	0.000	0.000	0.000	871.086	1183.783	1764.507	1718.972	1674.611	1631.395
MINOILA	Domestic crude oil - Alaska - Step1	3265.455	2328.480	1786.843	1541.152	1987.863	2412.238	2948.291	3603.466	4404.237
MINOILB	Domestic crude oil - Alaska - Step2	0.000	0.000	0.000	22.336	22.336	44.671	54.598	66.731	81.560
MINOILC	Domestic crude oil - Alaska - Step3	0.000	0.000	0.000	44.671	44.671	44.671	54.598	66.731	81.560
MINNGA1	Domestic Dry Natural Gas- Step 1	20179.731	20764.816	22439.965	24888.771	27399.804	29520.467	31945.011	34568.686	37407.846
MINNGA2	Domestic Dry Natural Gas- Step 2	0.000	0.000	0.000	559.180	1118.359	1339.921	1449.970	1569.058	1697.926
MINNGA3	Domestic Dry Natural Gas- Step 3	0.000	0.000	0.000	611.932	654.135	495.876	536.603	580.675	628.366
MINNGL1	Domestic Natural Gas Plant Liquids- Step 1	2677.324	2781.342	3210.980	3557.705	3904.431	4175.781	4492.128	4832.441	5198.535
MINNGL2	Domestic Natural Gas Plant Liquids- Step 2	0.000	0.000	0.000	30.150	75.375	105.525	113.519	122.119	131.371
MINNGL3	Domestic Natural Gas Plant Liquids- Step 3	0.000	0.000	0.000	15.075	30.150	60.300	64.868	69.783	75.069

IMPORTED CRUDE OIL

			START year	COST $95million/PJ								
				1995	2000	2005	2010	2015	2020	2025	2030	2035
IMPOILHH1	Imported Oil--high sulfur, heavy gravity--Step 1	FHH	1995	2.420	2.745	2.986	3.088	3.156	3.293	3.429	3.572	3.720
IMPOILHH2	Imported Oil--high sulfur, heavy gravity--Step 2	FHH	1995	2.563	2.912	3.214	3.359	3.543	3.695	3.846	4.004	4.168
IMPOILHH3	Imported Oil--high sulfur, heavy gravity--Step 3	FHH	1995	2.699	3.098	3.406	3.413	3.592	3.743	3.895	4.052	4.215
IMPOILHL1	Imported Oil--high sulfur, low gravity--Step 1	FHL	1995	2.580	2.930	3.156	3.302	3.449	3.603	3.758	3.920	4.088
IMPOILHL2	Imported Oil--high sulfur, low gravity--Step 2	FHL	1995	2.731	3.106	3.323	3.400	3.520	3.677	3.834	3.998	4.169
IMPOILHL3	Imported Oil--high sulfur, low gravity--Step 3	FHL	1995	2.890	3.306	3.530	3.567	3.780	3.936	4.091	4.253	4.421
IMPOILHV1	Imported Oil--high sulfur, very high grav--Step 1	FHV	1995	1.916	2.241	2.536	2.626	2.718	2.853	2.989	3.130	3.279
IMPOILHV2	Imported Oil--high sulfur, very high grav--Step 2	FHV	1995	2.042	2.391	2.643	2.730	2.898	3.043	3.188	3.340	3.499
IMPOILHV3	Imported Oil--high sulfur, very high grav--Step 3	FHV	1995	2.172	2.535	2.808	2.854	3.055	3.147	3.240	3.335	3.434
IMPOILLL1	Imported Oil--low sulfur, low gravity--Step 1	FLL	1995	2.951	3.239	3.532	3.678	3.880	4.065	4.249	4.442	4.644
IMPOILLL2	Imported Oil--low sulfur, low gravity--Step 2	FLL	1995	3.128	3.445	3.783	4.033	4.243	4.470	4.697	4.936	5.187
IMPOILLL3	Imported Oil--low sulfur, low gravity--Step 3	FLL	1995	3.285	3.661	3.957	4.058	4.336	4.574	4.812	5.063	5.326
IMPOILMH1	Imported Oil--medium sulfur, heavy gravity--Step 1	FMH	1995	2.718	3.031	3.335	3.488	3.616	3.748	3.880	4.017	4.159
IMPOILMH2	Imported Oil--medium sulfur, heavy gravity--Step 2	FMH	1995	2.873	3.202	3.508	3.617	3.746	3.870	3.993	4.121	4.253
IMPOILMH3	Imported Oil--medium sulfur, heavy gravity--Step 3	FMH	1995	3.031	3.442	3.745	3.827	4.101	4.284	4.468	4.660	4.860

			BOUND(BD)Or PJ								
			1995	2000	2005	2010	2015	2020	2025	2030	2035
IMPOILHH1	Imported Oil--high sulfur, heavy gravity--Step 1	FHH	2254.3	2444.3	2659.1	3047.1	4502.1	6015.0	8036.3	10736.9	14345.0
IMPOILHH2	Imported Oil--high sulfur, heavy gravity--Step 2	FHH	2126.0	2305.4	2483.5	2873.7	4245.5	5671.9	7577.4	10123.0	13524.0
IMPOILHH3	Imported Oil--high sulfur, heavy gravity--Step 3	FHH	2332.0	2559.1	2795.3	3186.8	4701.3	6276.6	8379.6	11187.4	14935.9
IMPOILHL1	Imported Oil--high sulfur, low gravity--Step 1	FHL	2918.2	4539.8	5650.1	6774.8	9947.2	13537.8	18424.5	25075.2	34126.5
IMPOILHL2	Imported Oil--high sulfur, low gravity--Step 2	FHL	2751.2	4280.3	5327.0	6387.6	9378.4	12763.6	17370.8	23641.0	32174.6
IMPOILHL3	Imported Oil--high sulfur, low gravity--Step 3	FHL	3025.6	4691.1	5827.5	6991.8	10205.9	13873.8	18860.1	25638.5	34852.9
IMPOILHV1	Imported Oil--high sulfur, very high grav--Step 1	FHV	680.0	785.7	867.7	1016.5	1483.0	1998.0	2691.9	3626.7	4886.1
IMPOILHV2	Imported Oil--high sulfur, very high grav--Step 2	FHV	638.5	741.4	818.4	958.7	1398.2	1883.5	2537.3	3418.0	4604.4
IMPOILHV3	Imported Oil--high sulfur, very high grav--Step 3	FHV	694.3	813.9	899.8	1053.5	1538.7	2073.9	2795.1	3767.1	5077.2
IMPOILLL1	Imported Oil--low sulfur, low gravity--Step 1	FLL	2302.7	2373.6	2485.9	2772.8	4105.8	5412.6	7135.2	9406.2	12399.9
IMPOILLL2	Imported Oil--low sulfur, low gravity--Step 2	FLL	2171.1	2224.0	2343.7	2614.4	3871.1	5103.3	6727.9	8869.5	11693.0
IMPOILLL3	Imported Oil--low sulfur, low gravity--Step 3	FLL	2393.6	2550.0	2658.5	3012.2	4151.7	5412.3	7055.8	9198.3	11991.5
IMPOILMH1	Imported Oil--medium sulfur, heavy gravity--Step 1	FMH	993.4	1048.4	1115.3	1263.3	1855.3	2440.6	3210.6	4223.5	5556.0
IMPOILMH2	Imported Oil--medium sulfur, heavy gravity--Step 2	FMH	937.6	989.6	1031.9	1219.6	1741.4	2301.5	3041.9	4020.5	5313.8
IMPOILMH3	Imported Oil--medium sulfur, heavy gravity--Step 3	FMH	1071.7	1220.5	1457.5	1497.3	2100.8	2727.6	3541.4	4598.0	5969.8

IMPORTED REFINED PRODUCTS

		START year	COST 95m$/PJ								
			1995	2000	2005	2010	2015	2020	2025	2030	2035
IMPDHO1	Imported Diesel, Heating Oil--Step 1	1995	3.460	3.894	4.243	4.385	4.665	4.771	4.879	4.987	5.098
IMPDHO2	Imported Diesel, Heating Oil--Step 2	1995	3.697	4.181	4.519	4.645	4.761	4.870	4.980	5.091	5.204
IMPDHO3	Imported Diesel, Heating Oil--Step 3	1995	3.917	4.457	4.821	4.976	5.127	5.244	5.363	5.482	5.603
IMPDSLL1	Imported Low Sulfur Diesel--Step 1	1995	3.700	3.974	4.064	4.550	4.672	4.771	4.885	5.011	5.140
IMPDSLL2	Imported Low Sulfur Diesel--Step 2	1995	3.973	4.285	4.492	4.970	5.126	5.234	5.359	5.498	5.639
IMPDSLL3	Imported Low Sulfur Diesel--Step 3	1995	4.248	4.655	4.877	5.282	5.432	5.546	5.679	5.826	5.976
IMPDSLU1	Imported Ultra-low Sulfur Diesel--Step 1	2005	0.000	34.969	45.034	21.928	22.064	22.064	22.064	22.064	22.064
IMPDSLU2	Imported Ultra-low Sulfur Diesel--Step 2	2005	0.000	32.980	43.880	20.299	22.064	22.064	22.064	22.064	22.064
IMPDSLU3	Imported Ultra-low Sulfur Diesel--Step 3	2005	0.000	31.989	49.562	50.000	77.223	77.223	77.223	77.223	77.223
IMPPFDST1	Imported Petroleum Feedstocks--Step 1	1995	2.818	3.207	3.531	3.559	3.611	3.680	3.737	3.801	3.866
IMPPFDST2	Imported Petroleum Feedstocks--Step 2	1995	3.036	3.451	3.817	3.906	4.015	4.092	4.155	4.226	4.298
IMPPFDST3	Imported Petroleum Feedstocks--Step 3	1995	3.246	3.702	4.100	4.187	4.292	4.374	4.442	4.518	4.595
IMPGSL1	Imported Reform. and Conventional Gasoline--Step 1	1995	7.508	5.851	6.395	9.044	10.140	10.350	10.888	11.435	12.010
IMPGSL2	Imported Reform. and Conventional Gasoline--Step 2	1995	8.000	6.194	6.796	9.898	11.011	11.239	11.824	12.418	13.043
IMPGSL3	Imported Reform. and Conventional Gasoline--Step 3	1995	8.494	7.596	9.607	12.026	11.987	12.235	12.872	13.520	14.201
IMPJTF1	Imported Jet Fuel--Step 1	1995	3.618	4.163	4.361	4.452	4.547	4.663	4.794	4.927	5.064
IMPJTF2	Imported Jet Fuel--Step 2	1995	3.847	4.470	4.700	4.796	4.892	5.018	5.158	5.302	5.449

continued

		START	COST								
		year	95m$/PJ								
			1995	2000	2005	2010	2015	2020	2025	2030	2035
IMPJTF3	Imported Jet Fuel--Step 3	1995	4.128	4.758	5.000	5.086	5.207	5.340	5.490	5.643	5.800
IMPKER1	Imported Kerosene and Other Refined Prod.--Step 1	1995	2.490	2.944	3.335	3.393	3.475	3.567	3.650	3.731	3.814
IMPKER2	Imported Kerosene and Other Refined Prod.--Step 2	1995	2.694	3.157	3.554	3.675	3.752	3.851	3.941	4.028	4.118
IMPKER3	Imported Kerosene and Other Refined Prod.--Step 3	1995	2.898	3.429	3.818	3.917	4.072	4.180	4.278	4.373	4.470
IMPLPG1	Imported Liquified Petroleum Gas--Step 1	1995	3.035	3.769	4.281	4.249	4.315	4.394	4.470	4.553	4.638
IMPLPG2	Imported Liquified Petroleum Gas--Step 2	1995	3.273	4.032	4.571	4.663	4.817	4.904	4.989	5.082	5.177
IMPLPG3	Imported Liquified Petroleum Gas--Step 3	1995	3.547	4.292	4.836	4.894	5.020	5.111	5.199	5.296	5.395
IMPMETH1	Imported Methanol--Step 1	1995	3.992	4.410	4.843	5.000	5.175	5.346	5.529	5.716	5.911
IMPMETH2	Imported Methanol--Step 2	1995	4.270	4.715	5.155	5.330	5.547	5.731	5.927	6.128	6.336
IMPMETH3	Imported Methanol--Step 3	1995	4.548	5.022	5.489	5.716	5.935	6.132	6.341	6.557	6.779
IMPDSHH1	Imported High Sulfur Fuel Oil--Step 1	1995	1.567	1.889	2.189	2.216	2.310	2.387	2.484	2.584	2.687
IMPDSHH2	Imported High Sulfur Fuel Oil--Step 2	1995	1.701	2.063	2.375	2.425	2.473	2.555	2.660	2.767	2.878
IMPDSHH3	Imported High Sulfur Fuel Oil--Step 3	1995	1.827	2.206	2.537	2.594	2.708	2.797	2.912	3.029	3.150
IMPDSHL1	Imported Low Sulfur Fuel Oil--Step 1	1996	1.997	2.340	2.654	2.716	2.809	2.877	2.946	3.016	3.087
IMPDSHL2	Imported Low Sulfur Fuel Oil--Step 2	1997	2.155	2.526	2.839	2.914	3.000	3.074	3.147	3.222	3.298
IMPDSHL3	Imported Low Sulfur Fuel Oil--Step 3	1998	2.314	2.706	3.017	3.120	3.214	3.293	3.371	3.451	3.533
IMPNGA1	Imported Natural Gas- Step1	1995	1.761	3.337	2.270	2.372	2.549	2.668	2.898	3.148	3.420
IMPNGA2	Imported Natural Gas- Step2	1995	0.000	0.000	0.000	2.465	2.651	2.880	3.128	3.398	3.691
IMPNGA3	Imported Natural Gas- Step3	1995	0.000	0.000	0.000	2.609	2.812	3.125	3.395	3.688	4.006

BOUND(BD)Or		1995	2005	2010	2015	2020	2025	2030	2035
IMPDHO1	Imported Diesel, Heating Oil--Step 1	197.3	312.1	464.6	700.8	953.9	1272.5	1696.5	2261.7
IMPDHO2	Imported Diesel, Heating Oil--Step 2	187.8	295.1	438.9	661.8	900.8	1201.7	1602.1	2135.9
IMPDHO3	Imported Diesel, Heating Oil--Step 3	182.1	286.5	425.9	641.8	873.6	1165.4	1553.7	2071.3
IMPDSLL1	Imported Low Sulfur Diesel--Step 1	477.3	198.3	585.7	1811.8	2523.3	3455.2	4751.8	6534.8
IMPDSLL2	Imported Low Sulfur Diesel--Step 2	450.3	198.3	554.1	1707.9	2378.5	3257.0	4479.1	6159.9
IMPDSLL3	Imported Low Sulfur Diesel--Step 3	436.9	281.3	581.3	1656.7	2307.3	3159.5	4345.0	5975.4
IMPDSLU1	Imported Ultra-low Sulfur Diesel--Step 1	0.0	63.6	62.6	64.5	63.6	62.7	61.5	60.4
IMPDSLU2	Imported Ultra-low Sulfur Diesel--Step 2	0.0	68.8	68.5	69.9	68.9	67.8	66.6	65.4
IMPDSLU3	Imported Ultra-low Sulfur Diesel--Step 3	0.0	72.4	72.0	74.4	73.3	72.2	70.9	69.7
IMPPFDST1	Imported Petroleum Feedstocks--Step 1	419.7	436.5	515.9	749.3	1030.2	1406.8	1914.8	2606.2
IMPPFDST2	Imported Petroleum Feedstocks--Step 2	396.2	412.7	494.3	716.6	985.1	1345.2	1831.0	2492.2
IMPPFDST3	Imported Petroleum Feedstocks--Step 3	384.5	402.8	477.6	691.3	950.4	1297.8	1766.4	2404.2
IMPGSL1	Imported Reform. and Conventional Gasoline--Step 1	763.3	659.2	906.7	1386.8	1907.5	2688.9	3783.1	5322.5
IMPGSL2	Imported Reform. and Conventional Gasoline--Step 2	721.9	623.7	877.7	1328.0	1826.6	2574.9	3622.6	5096.8
IMPGSL3	Imported Reform. and Conventional Gasoline--Step 3	700.9	808.5	1003.4	1315.2	1809.1	2550.2	3588.0	5048.2

continued

BOUND(BD)Or		1995	2005	2010	2015	2020	2025	2030	2035
IMPJTF1	Imported Jet Fuel--Step 1	179.6	549.9	800.8	1221.4	1711.4	2406.4	3381.5	4751.6
IMPJTF2	Imported Jet Fuel--Step 2	171.1	518.4	754.1	1150.7	1612.3	2267.1	3185.6	4476.4
IMPJTF3	Imported Jet Fuel--Step 3	166.4	502.9	731.6	1116.0	1563.7	2198.7	3089.6	4341.5
IMPKER1	Imported Kerosene and Other Refined Prod.--Step 1	65.3	95.2	139.8	212.4	269.5	357.4	474.2	629.2
IMPKER2	Imported Kerosene and Other Refined Prod.--Step 2	63.8	91.8	150.9	215.4	273.4	362.5	481.1	638.3
IMPKER3	Imported Kerosene and Other Refined Prod.--Step 3	62.2	143.6	195.2	206.7	262.4	347.9	461.6	612.5
IMPLPG1	Imported Liquified Petroleum Gas--Step 1	129.7	223.2	286.5	432.3	593.6	811.5	1111.3	1521.8
IMPLPG2	Imported Liquified Petroleum Gas--Step 2	123.9	212.0	271.6	409.5	562.3	768.7	1052.7	1441.6
IMPLPG3	Imported Liquified Petroleum Gas--Step 3	120.6	206.0	264.0	397.7	546.1	746.5	1022.3	1400.0
IMPMETH1	Imported Methanol--Step 1	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4
IMPMETH2	Imported Methanol--Step 2	50.4	50.4	50.4	50.4	50.4	50.4	50.4	50.4
IMPMETH3	Imported Methanol--Step 3	49.4	49.4	49.4	49.4	49.4	49.4	49.4	49.4
IMPDSHH1	Imported High Sulfur Fuel Oil--Step 1	433.7	558.8	564.4	795.8	1118.6	1573.4	2207.7	3097.9
IMPDSHH2	Imported High Sulfur Fuel Oil--Step 2	409.6	531.7	532.3	750.8	1055.3	1484.3	2082.8	2922.6
IMPDSHH3	Imported High Sulfur Fuel Oil--Step 3	397.2	522.2	532.4	728.6	1024.1	1440.5	2021.3	2836.3
IMPDSHL1	Imported Low Sulfur Fuel Oil--Step 1	360.8	478.7	643.4	984.4	1340.6	1808.0	2435.6	3280.9
IMPDSHL2	Imported Low Sulfur Fuel Oil--Step 2	341.6	452.6	607.6	929.0	1265.3	1706.4	2298.6	3096.4
IMPDSHL3	Imported Low Sulfur Fuel Oil--Step 3	331.6	439.4	589.7	901.8	1228.1	1656.3	2231.2	3005.6
IMPNGA1	Imported Natural Gas- Step1	2977.4	5285.6	5675.9	6045.2	5992.4	6151.1	6314.1	6481.3
IMPNGA2	Imported Natural Gas- Step2	0.0	0.0	274.3	327.1	548.6	563.1	578.0	593.4
IMPNGA3	Imported Natural Gas- Step3	0.0	0.0	474.8	738.5	812.4	833.9	856.0	878.6

ELECTRIC GENERATION

MARKAL	Technology Name	START year	HEAT RATE Btu/kwh	VAROM 95mills/kwh	FIXOM 95$/KW	LIFE Technical Lifetime years	AF Availability Fraction dec fraction	AF_TID Fraction of unavailability that is forced dec fraction	PEAK(CON) Fraction of capacity for peak and reserve dec fraction
ECOAIGC00	Integrated Coal Gasif. Combined Cycle -- 2000	2000	7969	0.73	29.98	30	0.85	0.37	0.90
ECOAIGC05	Integrated Coal Gasif. Combined Cycle -- 2005	2005	7469	0.73	29.98	30	0.85	0.37	0.90
ECOAIGC10	Integrated Coal Gasif. Combined Cycle -- 2010	2010	6968	0.73	29.98	30	0.85	0.37	0.90
ECOAPFB	Pressurized Fluidized Bed	2010	9228	3.10	38.11	40	0.85	0.50	0.80
ECOASTMB	Existing Bituminous Coal Steam	1995	11990	2.78	14.21	40	0.85	0.37	0.96
ECOASTMS	Existing Sub-Bituminous Coal Steam	1995	11990	2.78	14.21	40	0.85	0.37	0.96
ECOASTML	Existing Lignite Steam	1995	11990	2.78	14.21	40	0.85	0.37	0.96
ECOACFP00	Pulverized Coal -- 2000	2000	9419	3.10	21.48	40	0.85	0.37	0.96

continued

MARKAL	Technology Name	START year	HEAT RATE Btu/kwh	VAROM 95mills/kwh	FIXOM 95$/KW	LIFE Technical Lifetime years	AF Availability Fraction dec fraction	AF_TID Fraction of unavailability that is forced dec fraction	PEAK(CON) Fraction of capacity for peak and reserve dec fraction
ECOACFP05	Pulverized Coal -- 2005	2005	9253	3.10	21.48	40	0.85	0.37	0.96
ECOACFP10	Pulverized Coal -- 2010	2010	9087	3.10	21.48	40	0.85	0.37	0.96
ECOACFPR	Repowered Existing Coal Powered Facilities	2000	11990	3.10	32.73	30	0.85	0.37	0.87
ENGADGB05	Distributed Generation--Base--2005	2005	10991	13.87	3.69	30	0.84	0.63	0.96
ENGADGB10	Distributed Generation--Base--2010	2010	9210	13.87	3.69	30	0.84	0.63	0.96
ENGADGP	Distributed Generation--Peak	2005	10620	21.20	11.53	30	0.84	0.63	0.96
ESOLPVR	Photovolataic--Residential	1995	10280	0.00	118.28	20	see Timeslice	see Timeslice	0.30
EWINLWT	Local Wind Turbine	1995	10263	7.45	8.51	20	see Timeslice	see Timeslice	0.30
ECOAMCFC	Coal Gasification Molten Carb Fuel Cell	2005	7575	24.83	34.49	30	0.87	0.80	0.60
ENGAFC	Gas Fuel Cell	2005	5744	1.91	13.75	20	0.87	0.80	0.60
EMTHFC	Methanol Fuel Cell	2000	8530	12.00	8.39	20	0.87	0.80	0.60
ENGAGCE	Existing Natural Gas Combined Cycle	1995	8030	0.48	14.31	30	0.91	0.57	1.00
ENGAGC00	Natural Gas Combined Cycle--2000	2000	7687	0.48	14.33	30	0.91	0.57	0.94
ENGAGC05	Natural Gas Combined Cycle--2005	2005	7343	0.48	14.33	30	0.91	0.57	0.94
ENGAGC10	Natural Gas Combined Cycle--2010	2010	7000	0.48	14.33	30	0.91	0.57	0.94
ENGAAGC05	Natural Gas Advanced Combined Cycle--2005	2005	6639	0.48	13.27	30	0.91	0.57	0.86
ENGAAGC10	Natural Gas Advanced Combined Cycle--2010	2010	6350	0.48	13.27	30	0.91	0.57	0.86
ENGASTM	Natural Gas Steam	1995	9500	0.48	28.61	40	0.85	0.37	0.96
ENGACTE	Existing Natural Gas Combustion Turbine	1995	11900	0.09	5.91	30	0.92	0.47	0.96
ENGACT00	Natural Gas Combustion Turbine--2000	2000	11467	0.09	5.92	30	0.92	0.47	0.96
ENGACT05	Natural Gas Combustion Turbine--2005	2005	11033	0.09	5.92	30	0.92	0.47	0.96
ENGACT10	Natural Gas Combustion Turbine--2010	2010	10600	0.09	5.92	30	0.92	0.47	0.96
ENGAACT05	Natural Gas Advanced Combustion Turbine--2005	2005	8567	0.09	8.41	30	0.92	0.47	0.94
ENGAACT10	Natural Gas Advanced Combustion Turbine--2010	2010	8000	0.09	8.41	30	0.92	0.47	0.94
ENUCCONV	Conventional Nuclear	1995	10800	0.29	77.05	40	0.80	0.42	0.85
ENUCADV	Advanced Nuclear	2005	10400	0.39	52.52	40	0.85	0.38	0.85
EDSLICE	Diesel internal combustion engine	1995	13648	8.07	0.78	20	0.84	0.63	0.96
EDSHSTM	Residual Fuel Oil Steam	1995	9500	0.48	28.61	40	0.85	0.37	0.98
EDSLCT	Distillate Oil Combustion Turbine	1995	11900	0.09	5.91	30	0.92	0.47	0.96
EHYDROPS	Hydroelectric Pumped Storage	1995	10280	2.40	15.18	50	see Timeslice	1.00	0.95
EBIOCC	Biomass Gasification Combined Cycle	1995	8911	2.66	41.25	30	0.80	0.80	0.84
EGEOBCFS	Geothermal Binary Cycle and Flashed Steam	1995	32173	0.00	64.31	30	0.64	1.00	0.63
EHYDRO	Hydroelectric	1995	10280	4.07	12.90	60	0.44	0.10	0.94
EBMSWLG	Municipal Solid Waste-Landfill Gas	1995	13648	0.01	88.39	30	see Timeslice	see Timeslice	0.90
ESOLCT	Solar Central Thermal	1995	10280	0.00	43.93	30	see Timeslice	see Timeslice	0.30
ESOLCPV	Central Photovoltaic	1995	10280	0.00	9.04	30	see Timeslice	see Timeslice	0.50
EWINCELC	Wind Central Electric	1995	10280	0.00	23.44	30	see Timeslice	see Timeslice	0.30

		CAPITAL COST				
		95$/KW	95$/KW	95$/KW	95$/KW	95$/KW
MARKAL	**Technology Name**	**2000**	**2005**	**2010**	**2015**	**2020**
ECOAIGC00	Integrated Coal Gasif. Combined Cycle -- 2000	1338	0	0	0	0
ECOAIGC05	Integrated Coal Gasif. Combined Cycle -- 2005	0	1315	0	0	0
ECOAIGC10	Integrated Coal Gasif. Combined Cycle -- 2010	0	0	1287	1260	1221
ECOAPFB	Pressurized Fluidized Bed	1570	1570	1570	1570	1570
ECOASTMB	Existing Bituminous Coal Steam	1710	1710	1710	1710	1710
ECOASTMS	Existing Sub-Bituminous Coal Steam	1761	1761	1761	1761	1761
ECOASTML	Existing Lignite Steam	1572	1572	1572	1572	1572
ECOACFP00	Pulverized Coal -- 2000	1119	0	0	0	0
ECOACFP05	Pulverized Coal -- 2005	0	1110	0	0	0
ECOACFP10	Pulverized Coal -- 2010	0	0	1083	1068	1056
ECOACFPR	Repowered Existing Coal Powered Facilities	510	510	510	510	510
ENGADGB05	Distributed Generation--Base--2005	0	623	0	0	0
ENGADGB10	Distributed Generation--Base--2010	0	0	623	623	623
ENGADGP	Distributed Generation--Peak	0	559	559	559	559
ESOLPVR	Photovolataic--Residential	7519	6380	5240	3891	3891
EWINLWT	Local Wind Turbine	1246	1246	1246	1246	1246
ECOAMCFC	Coal Gasification Molten Carb Fuel Cell	2683	2683	2683	2683	2683
ENGAFC	Gas Fuel Cell	2091	2091	2091	2091	2091
EMTHFC	Methanol Fuel Cell	1290	1290	1290	1290	1290
ENGAGCE	Existing Natural Gas Combined Cycle	434	434	434	434	434
ENGAGC00	Natural Gas Combined Cycle--2000	456	0	0	0	0
ENGAGC05	Natural Gas Combined Cycle--2005	0	453	0	0	0
ENGAGC10	Natural Gas Combined Cycle--2010	0	0	448	443	438
ENGAAGC05	Natural Gas Advanced Combined Cycle--2005	0	572	0	0	0
ENGAAGC10	Natural Gas Advanced Combined Cycle--2010	0	0	526	505	493
ENGASTM	Natural Gas Steam	959	959	959	959	959
ENGACTE	Existing Natural Gas Combustion Turbine	322	322	322	322	322
ENGACT00	Natural Gas Combustion Turbine--2000	339	0	0	0	0
ENGACT05	Natural Gas Combustion Turbine--2005	0	336	0	0	0
ENGACT10	Natural Gas Combustion Turbine--2010	0	0	333	329	326
ENGAACT05	Natural Gas Advanced Combustion Turbine--2005	0	446	0	0	0
ENGAACT10	Natural Gas Advanced Combustion Turbine--2010	0	0	384	365	362
ENUCCONV	Conventional Nuclear	3445	3445	3445	3445	3445
ENUCADV	Advanced Nuclear	2144	2144	2144	2144	2144
EDSLICE	Diesel internal combustion engine	376	376	376	376	376
EDSHSTM	Residual Fuel Oil Steam	959	959	959	959	959
EDSLCT	Distillate Oil Combustion Turbine	322	322	322	322	322
EHYDROPS	Hydroelectric Pumped Storage	1615	1615	1615	1615	1615
EBIOCC	Biomass Gasification Combined Cycle	1725	1556	1424	1376	1303

continued

MARKAL	Technology Name	CAPITAL COST 95$/KW 2000	95$/KW 2005	95$/KW 2010	95$/KW 2015	95$/KW 2020
EGEOBCFS	Geothermal Binary Cycle and Flashed Steam	1746	1695	1586	1680	2026
EHYDRO	Hydroelectric	929	929	929	929	929
EBMSWLG	Municipal Solid Waste-Landfill Gas	1429	1417	1402	1387	1373
ESOLCT	Solar Central Thermal	2539	2454	2348	2243	2137
ESOLCPV	Central Photovoltaic	3830	2722	2404	2293	2219
EWINCELC	Wind Central Electric	982	921	907	876	826

*A capital cost of zero indicates that the technology is not available for purchase in that model year.

COMMERCIAL SECTOR

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000Btu CL: lumens/watt	LIFE years
CC01	Air Source heat pump for cooling - Installed base	1995	0.00	0.00	2.78	14
CC02	Air Source heat pump for cooling - current standard	1995	0.00	0.00	2.93	14
CC03	Air Source heat pump for cooling - 2000 typical	2000	0.00	0.00	2.93	14
CC04	Air Source heat pump for cooling - 2000 high	2000	0.00	0.00	4.40	14
CC05	Air Source heat pump for cooling - 2005 typical	2005	0.00	0.00	3.52	14
CC06	Air Source heat pump for cooling - 2005 high	2005	0.00	0.00	5.28	14
CC07	Air Source heat pump for cooling - 2010 typical	2010	0.00	0.00	3.52	14
CC08	Air Source heat pump for cooling - 2010 high	2010	0.00	0.00	5.28	14
CC09	Air Source heat pump for cooling - 2020 typical	2020	0.00	0.00	3.81	14
CC10	Air Source heat pump for cooling - 2020 high	2020	0.00	0.00	5.28	14
CC11	Ground Source HP for cooling - installed base	1995	0.00	0.00	3.96	20
CC12	Ground Source heat pump for cooling -2000 typical	2000	0.00	0.00	3.96	20
CC13	Ground Source heat pump for cooling - 2000 high	2000	0.00	0.00	6.15	20
CC14	Ground Source heat pump for cooling - 2005 typical	2005	0.00	0.00	3.96	20
CC15	Ground Source heat pump for cooling - 2005 high	2005	0.00	0.00	6.15	20
CC16	Ground Source heat pump for cooling - 2010 typical	2010	0.00	0.00	3.96	20
CC17	Ground Source heat pump for cooling - 2010 high	2010	0.00	0.00	6.15	20
CC18	Ground Source heat pump for cooling - 2020 typical	2020	0.00	0.00	4.40	20
CC19	Ground Source heat pump for cooling - 2020 high	2020	0.00	0.00	6.15	20
CC20	Elec. reciprocating chiller-Installed base-stnd	1995	51.04	2.75	2.50	24
CC21	Electric reciprocating chiller - 2000 typical	2000	51.04	2.75	2.86	24
CC22	Electric reciprocating chiller - 2000 high	2000	61.04	2.75	3.50	24
CC23	Electric reciprocating chiller - 2005 typical	2005	51.04	2.75	2.86	24

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000Btu CL: lumens/watt	LIFE years
CC24	Electric reciprocating chiller - 2005 high	2005	61.04	2.75	3.60	24
CC25	Electric reciprocating chiller - 2010 typical	2010	51.04	2.75	2.86	24
CC26	Electric reciprocating chiller - 2010 high	2010	61.04	2.75	3.60	24
CC27	Electric reciprocating chiller - 2020 typical	2020	51.04	2.75	2.90	24
CC28	Electric reciprocating chiller - 2020 high	2020	61.04	2.75	3.80	24
CC29	Electric centrifugal chillers - Installed base	1995	39.58	1.88	4.60	24
CC30	Electric centrifugal chillers - Current standard	1995	39.58	1.88	4.80	24
CC31	Electric centrifugal chillers - 2000 typical	2000	39.58	1.88	5.90	24
CC32	Electric centrifugal chillers - 2000 high	2000	52.92	1.88	7.30	24
CC33	Electric centrifugal chillers - 2005 typical	2005	43.75	1.88	6.40	24
CC34	Electric centrifugal chillers - 2005 high	2005	56.25	1.88	7.30	24
CC35	Electric centrifugal chillers - 2010 typical	2010	43.75	1.88	6.40	24
CC36	Electric centrifugal chillers - 2010 high	2010	56.25	1.88	7.30	24
CC37	Electric centrifugal chillers - 2020 typical	2020	43.75	1.88	7.00	24
CC38	Electric centrifugal chillers - 2020 high	2020	47.92	1.88	7.30	24
CC39	Elec. rooftop AC - Installed base	1995	83.33	1.39	2.60	15
CC40	Elec. rooftop AC - 2000 typical - standard	1995	83.33	1.39	2.60	15
CC41	Electric rooftop air conditioner - 2000 high	2000	161.11	1.39	4.30	15
CC42	Electric rooftop air conditioner - 2005 typical	2005	83.33	1.39	2.60	15
CC43	Electric rooftop air conditioner - 2005 high	2005	161.11	1.39	4.40	15
CC44	Electric rooftop air conditioner - 2010 typical	2010	94.44	1.39	3.00	15
CC45	Electric rooftop air conditioner - 2010 high	2010	161.11	1.39	4.40	15
CC46	Electric rooftop air conditioner - 2020 typical	2020	94.44	1.39	3.00	15
CC47	Electric rooftop air conditioner - 2020 high	2020	161.11	1.39	4.40	15
CC48	Wall/Window - Room A/C - Installed base	1995	47.14	0.95	2.40	12
CC49	Wall/Window - Room A/C - 2000 Low	1995	47.14	0.95	2.64	12
CC50	Wall/Window - Room A/C - 2000 typical	2000	50.43	0.95	2.93	12
CC51	Wall/Window - Room A/C - 2000 high Efficiency	2000	72.38	0.95	3.37	12
CC52	Wall/Window - Room A/C - 2005 Typical	2005	50.43	0.95	2.93	12
CC53	Wall/Window - Room A/C - 2005 High Efficiency	2005	72.38	0.95	3.52	12
CC54	Wall/Window - Room A/C - 2020 Typical	2020	58.33	0.95	3.22	12
CC55	Central A/C - Res. type - Installed base	1995	49.52	2.86	2.81	14
CC56	Central A/C - Res. type - Current standard	1995	49.52	2.86	2.93	14
CC57	Central A/C - Res. type - 2000 typical	2000	49.52	2.86	2.93	14
CC58	Central A/C - Res. type - 2000 high Efficiency	2000	83.33	2.86	5.28	14
CC59	Central A/C - Res. type - 2005 Typical	2005	54.76	2.86	3.52	14
CC60	Central A/C - Res. type - 2005 High	2005	83.33	2.86	5.28	14
CC61	Central A/C - Res. type - 2010 Typical	2010	54.76	2.86	3.52	14

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CC62	Central A/C - Res. type - 2010 High	2010	83.33	2.86	5.28	14
CC63	Central A/C - Res. type - 2020 Typical	2020	54.76	2.86	3.81	14
CC64	Central A/C - Res. type - 2020 High	2020	83.33	2.86	5.28	14
CC65	Gas heat pump for cooling - 1995 engine driven	1995	243.19	4.98	7.57	13
CC66	Gas heat pump for cooling - 2005 absorption	2005	173.61	4.17	0.70	15
CC67	Gas engine rooftop AC - installed base	1995	104.17	4.58	0.59	30
CC68	Gas engine rooftop AC - 2000 typical	2000	104.17	4.58	0.70	30
CC69	Gas engine rooftop AC - 2000 high	2000	150.00	4.58	1.30	30
CC70	Gas engine rooftop AC - 2005 typical	2005	104.17	4.58	0.70	30
CC71	Gas engine rooftop AC - 2005 high	2005	141.67	4.58	1.30	30
CC72	Gas engine rooftop AC - 2010 typical	2010	104.17	4.58	0.70	30
CC73	Gas engine rooftop AC - 2010 high	2010	141.67	4.58	1.30	30
CC74	Gas-fired chiller - Installed base	1995	52.08	0.63	1.00	20
CC75	Gas-fired chiller - 2000 absorption	1995	78.75	1.33	1.00	20
CC76	Gas-fired chiller - 2000 engine driven	2000	69.38	2.50	2.00	25
CC77	Gas-fired chiller - 2005 absorption	2005	78.75	1.33	1.00	20
CC78	Gas-fired chiller - 2005 engine driven	2005	66.67	2.50	2.10	25
CC79	Gas-fired chiller - 2020 absorption	2020	78.75	1.33	1.00	20
CC80	Gas-fired chiller - 2020 engine driven	2020	66.67	2.50	2.20	25
CK01	Range, Electric, 4 burner, oven, 11" griddle	1995	35.21	0.29	0.70	10
CK02	Range, Electric-induction, 4 burner, oven, 11" gri	2000	41.17	0.29	0.80	10
CK03	Range, Gas, 4 burner, oven, 11" griddle	1995	25.26	0.29	0.45	10
CK04	Range, Gas, 4 powered burners, convect. oven, 11"	1995	34.41	0.29	0.60	10
CH01	Air Source heat pump for heating - Installed Base	1995	81.39	3.33	1.88	14
CH02	Air Source heat pump for heating - current standard	1995	81.39	3.33	1.99	14
CH03	Air Source heat pump for heating - 2000 typical	2000	97.92	3.33	2.20	14
CH04	Air Source heat pump for heating - 2000 high	2000	155.56	3.33	2.87	14
CH05	Air Source heat pump for heating - 2005 typical	2005	97.22	3.33	2.20	14
CH06	Air Source heat pump for heating - 2005 high	2005	155.56	3.33	2.89	14
CH07	Air Source heat pump for heating - 2010 typical	2010	97.22	3.33	2.20	14
CH08	Air Source heat pump for heating - 2010 high	2010	155.56	3.33	2.87	14
CH09	Air Source heat pump for heating - 2020 typical	2020	97.22	3.33	2.29	14
CH10	Air Source heat pump for heating - 2020 high	2020	150.00	3.33	2.93	14
CH11	Ground Source HP for heating - Installed Base	1995	187.50	1.46	3.40	20
CH12	Ground Source heat pump for heating -2000 typical	2000	187.50	1.46	3.40	20
CH13	Ground Source heat pump for heating - 2000 high	2000	229.17	1.46	4.00	20
CH14	Ground Source heat pump for heating - 2005 typical	2005	166.67	1.46	3.40	20
CH15	Ground Source heat pump for heating - 2005 high	2005	229.17	1.46	4.30	20

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CH16	Ground Source heat pump for heating - 2010 typical	2010	166.67	1.46	3.40	20
CH17	Ground Source heat pump for heating - 2010 high	2010	208.33	1.46	4.30	20
CH18	Ground Source heat pump for heating - 2020 typical	2020	166.67	1.46	3.80	20
CH19	Ground Source heat pump for heating - 2020 high	2020	197.92	1.46	4.50	20
CH20	Electric boiler - Installed Base	1995	21.83	0.14	0.94	21
CH21	Other electric packaged spc heat	1995	19.77	3.49	0.93	18
CH22	Other electric packaged spc heat - new	1995	14.92	3.49	0.96	18
CH23	Gas heat pump for heating - 1995 engine driven	1995	243.19	4.98	4.10	13
CH24	Gas heat pump for heating - 2005 absorption	2005	173.61	4.17	1.40	15
CH25	Gas heat pump for heating - 2020 absorption	2020	173.61	4.17	1.50	15
CH26	Gas furnace - Installed Base	1995	9.76	1.07	0.70	15
CH27	Gas furnace - current standard	1995	9.11	1.00	0.75	15
CH28	Gas furnace - 2000 high	2000	14.82	0.88	0.86	15
CH29	Gas furnace - 2003 standard	2005	8.81	0.97	0.78	15
CH30	Gas furnace - 2005 high	2005	14.16	0.84	0.90	15
CH31	Gas furnace - 2010 typical	2010	8.70	0.96	0.79	15
CH32	Gas furnace - 2010 high	2010	14.16	0.84	0.90	15
CH33	Gas boiler - Installed Base	1995	19.40	0.59	0.70	25
CH34	Gas boiler - Current standard	1995	18.11	0.55	0.75	25
CH35	Gas boiler - 2000 high	2000	33.82	0.69	0.82	25
CH36	Gas boiler - 2005 typical	2005	17.87	0.55	0.76	25
CH37	Gas boiler - 2005 high	2005	31.68	0.67	0.85	25
CH38	Gas boiler - 2010 typical	2010	17.87	0.55	0.76	25
CH39	Gas boiler - 2010 high	2010	31.68	0.67	0.85	25
CH40	Oil furnace - Installed Base	1995	14.25	1.00	0.70	15
CH41	Oil furnace - Current standard	1995	14.25	1.00	0.76	15
CH42	Oil furnace - 1998 intro	2000	23.46	1.00	0.77	15
CH43	Oil furnace - 2000 intro	2000	23.75	1.00	0.82	15
CH44	Oil furnace - Meets 2003 standard	2005	14.25	1.00	0.79	15
CH45	Oil furnace - 2010 intro	2010	22.69	1.00	0.85	15
CH46	Oil boiler - Installed base	1995	16.84	0.14	0.73	20
CH47	Oil boiler - 2000 typical and stnd	1995	15.76	0.13	0.78	20
CH48	Oil boiler - 2000 high	2000	18.83	0.12	0.83	20
CH49	Oil boiler - 2005 typical	2005	15.76	0.13	0.78	20
CH50	Oil boiler - 2005 high	2005	18.83	0.12	0.83	20
CW01	Res. style solar water heater - 1995	1995	270.98	1.96	2.08	20
CW02	Heat pump water heater - 2000 typical	1995	200.00	10.71	2.00	12
CW03	Heat pump water heater - 2000 high	2000	300.00	10.71	2.50	12
CW04	Heat pump water heater - 2005 typical	2005	200.00	10.71	2.00	12

continued

MARKAL	Technology Name	**START** year	**INVCOST** 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	**FIXOM** 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	**EFFICIENCY** Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	**LIFE** years
CW05	Heat pump water heater - 2005 high	2005	189.29	10.71	2.60	12
CW06	Heat pump water heater - 2010 typical	2010	200.00	10.71	2.00	12
CW07	Heat pump water heater - 2020 typical	2020	167.86	10.71	2.20	12
CW08	Elec. resistance water heater - Installed base	1995	13.71	0.34	0.95	14
CW09	Elec. resistance water heater - typical-standard	1995	13.43	0.34	0.97	14
CW10	Elec. resistance water heater - typical-standard	2005	20.81	0.34	0.97	14
CW11	Gas water heater - Installed base	1995	14.86	1.01	0.74	12
CW12	Gas water heater - Current standard	1995	15.13	0.99	0.76	12
CW13	Gas water heater - 2000 typical	2000	14.74	0.96	0.78	12
CW14	Gas water heater - 2000 high	2000	22.58	0.54	0.93	20
CW15	Gas water heater - 2005 typical	2005	14.74	0.96	0.78	12
CW16	Gas water heater - 2005 high	2005	21.51	0.54	0.93	20
CW17	Gas water heater - 2010 typical	2010	14.74	0.96	0.78	12
CW18	Gas water heater - 2010 high	2010	21.51	0.54	0.93	20
CW19	Gas water heater - 2020 typical	2020	14.74	0.96	0.78	12
CW20	Gas water heater - 2020 high	2020	21.51	0.54	0.93	20
CW21	Oil water heater - installed base	1995	25.67	0.51	0.73	15
CW22	Oil water heater - current high effic	1995	39.38	0.79	0.78	15
CL01	Incandescent 1150 lumens, 75 watts	1995	53.26	30.65	15.30	12
CL02	CFL-low end 1200 lumens 20 watts	1995	60.87	7.92	59.50	12
CL03	CFL 1200 lumens, 20 watts	1995	61.46	7.22	67.10	12
CL04	Halogen 1280 lumens, 90 watts	1995	56.82	6.94	14.20	12
CL05	Halogen IR 60 Watt	1995	69.03	18.74	19.20	12
CL06	Hafnium carbide filament 1550 lumens, 23 watts	2005	65.07	2.53	30.30	12
CL07	Coated filament 1150 lumens, 24 watts	2010	65.07	2.53	47.90	12
CL08	F40T12 - Standard Magnetic	1995	27.69	0.73	49.20	14
CL09	F40T12 - Efficient Magnetic	1995	18.95	0.56	59.00	14
CL10	F40T12 - Efficient Magnetic ES	1995	24.93	0.79	55.70	14
CL11	Halogen 4024 Lumens 209 Watts	1995	11.89	3.50	20.00	12
CL12	F40T12 - Electronic ES	1995	27.36	0.74	65.30	14
CL13	F32T8 - Magnetic	1995	21.86	0.74	65.50	14
CL14	F32T8 - Electronic	1995	25.59	0.80	76.80	14
CL15	F32T8 -Electronic -Controls	1995	37.92	0.80	109.70	14
CL16	F32T8 -Electronic -Reflector	1995	26.96	0.69	88.30	14
CL17	Scotopic Lighting	1995	38.99	0.90	123.00	14
CL18	Electrodeless Lamp	2015	29.72	0.41	152.80	20
CL19	F96T12 - Standard Magnetic	1995	15.89	0.91	55.00	14
CL20	F96T12 - Efficient Magnetic	1995	12.25	0.45	66.70	14

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CL21	F96T12 - Efficient Magnetic ES	1995	14.87	0.57	70.60	14
CL22	F96T12 - Electronic	1995	15.50	0.49	73.90	14
CL23	F96T12 - Electronic ES	1995	17.23	0.57	81.80	14
CL24	F96T12 - Standard Magnetic HO	1995	13.71	0.86	49.00	12
CL25	F96T12 - Efficient Magnetic HO/ES	1995	13.31	0.72	61.20	12
CL26	F96T12 - Electronic HO	1995	13.33	0.50	67.30	12
CL27	F96T12 - Electronic HO ES	1995	14.93	0.74	69.40	12
CL28	Scotopic Lamp	1995	40.61	0.86	123.00	12
CL29	Electrodeless Lamp	2015	31.43	1.19	152.80	20
CL30	Mercury Vapor	1995	33.81	0.82	40.20	15
CL31	Metal Halide	1995	16.98	0.40	69.60	15
CL32	High Pressure Sodium	1995	19.63	0.56	89.70	15
CL33	Sulfur Lamp	2005	15.84	0.29	100.00	15
CL34	F40T12 - Efficient Magnetic ES	1995	24.93	0.74	55.70	14
CL35	F32T8 - Magnetic	1995	21.86	0.74	65.50	14
CR01	Centralized Refrig. Base System	1995	909.63	30.70	1.82	10
CR02	Centrl Rfg Sys w/Evaporative Condenser	1995	916.09	33.98	1.88	10
CR03	Centrl Rfg Sys w/Floating Head Pressure	1995	916.91	30.70	1.88	10
CR04	Centrl Rfg Sys w/Ambient Subcooling	1995	915.18	30.70	1.83	10
CR05	Centrl Rfg Sys w/Mechanical Subcooling	1995	916.91	30.70	1.85	10
CR06	Centrl Rfg Sys w/Hot Gas Defrost	1995	913.08	35.25	1.88	10
CR07	Centrl Rfg Sys w/Antisweat Htr Controls	1995	916.46	30.70	1.90	10
CR08	Centrl Rfg Sys w/Hi-Eff Lighting	1995	913.14	30.70	1.86	10
CR09	Centrl Rfg Sys w/Hi-Eff Fan Blades	1995	909.89	30.70	1.88	10
CR10	Centrl Rfg Sys w/PSC Evap Fan Motors	1995	916.54	30.70	1.95	10
CR11	Centrl Rfg Sys w/ECM Evap Fan Motors	2005	921.09	30.70	1.99	10
CR12	Walk-In Cooler-Installed Base	1995	729.54	6.42	2.46	18
CR13	Walk-In Cooler w/Floating Head Pressure	2005	734.23	6.42	3.01	18
CR14	Walk-In Cooler w/Ambient Subcooling	1995	743.70	6.42	2.70	18
CR15	Walk-In Cooler w/Antisweat Heat Controls	1995	743.03	6.42	2.52	18
CR16	Walk-In Cooler w/Evap Fan Shutdown	1995	732.24	6.42	2.57	18
CR17	Walk-In Cooler w/PSC Evap Fan Motor	1995	733.85	6.42	2.59	18
CR18	Walk-In Cooler w/ECM Evap Fan Motor	2005	739.03	6.42	2.68	18
CR19	Walk-In Cooler w/ECM Condns Fan Motor	2005	731.15	6.42	2.51	18
CR20	Walk-In Cooler w/Elec. Ballasts	1995	731.69	6.42	2.48	18
CR21	Walk-In Cooler w/High-Eff. Fan Blades	1995	732.78	6.42	2.62	18
CR22	Walk-In Cooler w/FHP,ECM Fans, Shutdown & Ambnt	2010	759.50	6.42	3.59	18
CR23	Walk-In Freezer-Installed Base	1995	2399.11	21.19	0.73	18
CR24	Walk-In Fzr w/Hot Gas Defrost	1995	2419.44	21.19	0.76	18

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY btu/btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CR25	Walk-In Fzr w/Antisweat Heat Controls	1995	2522.14	21.19	0.78	18
CR26	Walk-In Fzr w/Evap Fan Shutdown	1995	2423.71	21.19	0.76	18
CR27	Walk-In Fzr w/PSC Evap Fan Motor	1995	2413.87	21.19	0.82	18
CR28	Walk-In Fzr w/ECM Evap Fan Motor	2005	2423.71	21.19	0.85	18
CR29	Walk-In Fzr w/PSC Condns Fan Motor	1995	2404.52	21.19	0.77	18
CR30	Walk-In Fzr w/ECM Condns Fan Motor	2005	2410.92	21.19	0.79	18
CR31	Walk-In Fzr w/High-Eff. Fan Blades	1995	2407.22	21.19	0.77	18
CR32	Walk-In Fzr w/HER,ECM Fans, Shutdown & HG Dfst	2005	2677.40	21.19	1.09	18
CR33	Reach-In Refrig-Installed Base	1995	3377.97	8.11	0.48	10
CR34	Reach-In Rfg w/Thicker Insulation	1995	3513.13	8.11	0.49	10
CR35	Reach-In Rfg w/Improved Insulation	1995	3940.97	8.11	0.48	10
CR36	Reach-In Rfg w/ECM Evap Fan Motor	1995	3442.83	8.11	0.52	10
CR37	Reach-In Rfg w/ECM Condns Fan Motor	1995	3407.69	8.11	0.50	10
CR38	Reach-In Rfg w/High-Eff. Compressor	1995	3399.59	8.11	0.54	10
CR39	Reach-In Rfg w/ECM Compressor Motor	2005	3513.09	8.11	0.53	10
CR40	Reach-In Rfg w/High-Eff. Fan Blades	1995	3382.02	8.11	0.50	10
CR41	Reach-In Freezer-Installed Base	1995	2118.06	8.18	0.56	10
CR42	Reach-In Fzr w/Thicker Insulation	1995	2198.99	8.18	0.58	10
CR43	Reach-In Fzr w/Improved Insulation	1995	2719.79	8.18	0.57	10
CR44	Reach-In Fzr w/ECM Evap Fan Motor	1995	2141.18	8.18	0.57	10
CR45	Reach-In Fzr w/ECM Condns Fan Motor	1995	2141.18	8.18	0.58	10
CR46	Reach-In Fzr w/High-Eff. Compressor	1995	2141.18	8.18	0.67	10
CR47	Reach-In Fzr w/ECM Compressor Motor	2005	2223.97	8.18	0.66	10
CR48	Reach-In Fzr w/Hot Gas Defrost	2005	2197.98	8.18	0.60	10
CR49	Reach-In Fzr w/Liquid-Suction Ht Xchng	1995	2190.28	8.18	0.58	10
CR50	Reach-In Fzr w/High-Eff. Fan Blades	1995	2119.99	8.18	0.57	10
CR51	Ice Machine-Installed Base	1995	2190.44	128.85	0.44	8
CR52	Ice Machine w/Thicker Insulation	1995	2241.98	128.85	0.46	8
CR53	Ice Machine w/Improved Insulation	1995	2221.36	128.85	0.45	8
CR54	Ice Machine w/ECM Evap Fan Motor	1995	2249.71	128.85	0.46	8
CR55	Ice Machine w/ECM Condns Fan Motor	1995	2242.37	128.85	0.45	8
CR56	Ice Machine w/High-Eff. Compressor	1995	2319.28	128.85	0.46	8
CR57	Ice Machine w/ECM Compressor Motor	2005	2216.21	128.85	0.45	8
CR58	Ice Machine w/High-Eff. Fan Blades	1995	2194.31	128.85	0.44	8
CR59	Beverage Merchandiser-Installed Base	1995	1428.74	8.11	0.70	10
CR60	Bvg Mrchsr w/PSC Evap Fan Motor	1995	1502.22	8.11	0.91	10
CR61	Bvg Mrchsr w/ECM Evap Fan Motor	1995	1551.20	8.11	0.98	10
CR62	Bvg Mrchsr w/PSC Condns Fan Motor	1995	1465.48	8.11	0.72	10
CR63	Bvg Mrchsr w/ECM Condns Fan Motor	1995	1489.97	8.11	0.73	10

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CR64	Bvg Mrchsr w/High-Eff. Compressor	1995	1445.07	8.11	0.77	10
CR65	Bvg Mrchsr w/ECM Compressor Motor	2005	1530.79	8.11	0.75	10
CR66	Bvg Mrchsr w/Electronic Ballasts	1995	1459.36	8.11	0.77	10
CR67	Bvg Mrchsr w/High-Eff. Fan Blades	1995	1431.80	8.11	0.75	10
CR68	Bvg Mrchsr w/ECM Evap Fan Motor&Hi-Eff Cmprsr	1995	1567.53	8.11	1.08	10
CR69	Refrigerated Vending Machine-Installed Base	1995	3348.66	15.63	0.48	8
CR70	Rfg Vend Mach w/Thicker Insulation	1995	3456.58	15.63	0.51	8
CR71	Rfg Vend Mach w/PSC Evap Fan Motor	1995	3419.57	15.63	0.54	8
CR72	Rfg Vend Mach w/ECM Evap Fan Motor	1995	3458.97	15.63	0.55	8
CR73	Rfg Vend Mach w/PSC Condns Fan Motor	1995	3419.57	15.63	0.49	8
CR74	Rfg Vend Mach w/ECM Condns Fan Motor	1995	3458.97	15.63	0.50	8
CR75	Rfg Vend Mach w/High-Eff. Compressor	1995	3380.18	15.63	0.53	8
CR76	Rfg Vend Mach w/ECM Compressor Motor	2005	3545.64	15.63	0.51	8
CR77	Rfg Vend Mach w/Electronic Ballasts	1995	3407.75	15.63	0.53	8
CR78	Rfg Vend Mach w/High-Eff. Fan Blades	1995	3352.60	15.63	0.50	8
CR79	Rfg Vend Mach w/ECM Evap Fan Motor&Hi-Eff Cmprsr	1995	3490.49	15.63	0.65	8
CV01	CAV 7000 cfm System - 1992 Installed Base	1995	3068.42	47.02	0.56	15
CV02	CAV 7000 cfm System - 1995 Typical	1995	3089.12	49.06	0.59	15
CV03	CAV 7000 cfm System - 1995 High	1995	3649.49	49.06	0.61	20
CV04	CAV 7000 cfm System - 2000 High	2000	3672.06	53.84	0.62	20
CV05	CAV 7000 cfm System - 2005 Typical	2005	3074.92	59.16	0.59	15
CV06	CAV 7000 cfm System - 2005 High	2005	3662.32	59.16	0.63	20
CV07	CAV 7000 cfm System - 2010 Typical	2010	3061.25	64.95	0.61	15
CV08	CAV 7000 cfm System - 2010 High	2010	3642.49	64.95	0.63	20
CV09	CAV 7000 cfm System - 2015 Typical	2015	3018.52	71.45	0.61	15
CV10	CAV 7000 cfm System - 2015 High	2015	3584.19	71.45	0.63	20
CV11	CAV 15,000 cfm System - 1992 Installed Base	1995	4273.54	94.46	0.22	15
CV12	CAV 15,000 cfm System - 1995 Typical	1995	4305.53	98.45	0.25	15
CV13	CAV 15,000 cfm System - 1995 High	1995	4688.78	98.45	0.32	20
CV14	CAV 15,000 cfm System - 2000 Typical	2000	3848.72	95.80	0.32	15
CV15	CAV 15,000 cfm System - 2000 High	2000	4732.50	108.18	0.33	20
CV16	CAV 15,000 cfm System - 2005 Typical	2005	4345.26	118.88	0.31	15
CV17	CAV 15,000 cfm System - 2005 High	2005	4728.27	118.84	0.35	20
CV18	CAV 15,000 cfm System - 2010 Typical	2010	4340.62	130.60	0.32	15
CV19	CAV 15,000 cfm System - 2010 High	2010	4716.86	130.60	0.36	20
CV20	CAV 15,000 cfm System - 2015 Typical	2015	4320.69	143.51	0.33	15
CV21	CAV 15,000 cfm System - 2015 High	2015	4686.86	143.51	0.36	20
CV22	Multi-Zone - 1992 Installed Base	1995	8300.37	19.99	0.21	20
CV23	VAV 30,000 cfm System - 1992 Installed Base	1995	3025.17	80.38	0.24	15

continued

MARKAL	Technology Name	START year	INVCOST 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	FIXOM 2001$/1000Btu/hr CV: /1000cfm CL: /1000lumen	EFFICIENCY Btu/Btu CV: 1000cfm hrs/1000btu CL: lumens/watt	LIFE years
CV24	VAV 30,000 cfm System - 1995 Typical	1995	3037.66	83.81	0.27	15
CV25	VAV 30,000 cfm System - 1995 High	1995	3611.63	83.81	0.50	20
CV26	VAV 30,000 cfm System - 2000 Typical	2000	3332.67	92.12	0.48	15
CV27	VAV 30,000 cfm System - 2005 Typical	2005	3310.89	101.16	0.48	15
CV28	VAV 30,000 cfm System - 2005 High	2005	3522.35	101.15	0.50	20
CV29	VAV 30,000 cfm System - 2010 Typical	2010	3284.69	111.14	0.50	15
CV30	VAV 30,000 cfm System - 2010 High	2010	3559.87	111.13	0.56	20
CV31	VAV 30,000 cfm System - 2015 Typical	2015	3243.60	122.10	0.50	15
CV32	VAV 30,000 cfm System - 2015 High	2015	3448.40	122.10	0.56	20
CV33	Multi-Zone - 1992 Installed Base	1995	8300.37	19.99	0.21	20
CV34	VAV 55,000 cfm System - 1992 Installed Base	1995	3641.55	126.62	0.26	15
CV35	VAV 55,000 cfm System - 1995 Typical	1995	3663.25	132.01	0.32	15
CV36	VAV 55,000 cfm System - 1995 High	1995	4054.35	132.01	0.56	20
CV37	VAV 55,000 cfm System - 2000 Typical	2000	3827.41	145.08	0.54	15
CV38	VAV 55,000 cfm System - 2005 Typical	2005	3830.21	159.38	0.54	15
CV39	VAV 55,000 cfm System - 2005 High	2005	4061.00	159.38	0.56	20
CV40	VAV 55,000 cfm System - 2010 Typical	2010	3821.13	175.11	0.55	15
CV41	VAV 55,000 cfm System - 2010 High	2010	4026.37	175.09	0.60	20
CV42	VAV 55,000 cfm System - 2015 Typical	2015	3788.78	192.37	0.55	15
CV43	VAV 55,000 cfm System - 2015 High	2015	3995.29	192.37	0.67	20
CV44	Fan Coil Unit - 1992 Installed Base	1995	5228.23	198.65	0.56	20
CV45	Fan Coil Unit - 1995 Current Standard	1995	5295.27	207.04	0.39	20
CV46	Fan Coil Unit - 1995 Typical	1995	5295.27	207.04	0.77	20
CV47	Fan Coil Unit - 1995 High	1995	6994.52	207.02	0.83	20
CV48	Fan Coil Unit - 2005 Typical	2005	5282.09	250.11	0.77	20
CV49	Fan Coil Unit - 2005 High	2005	7020.84	250.11	0.91	20
CV50	Fan Coil Unit - 2010 Typical	2010	5209.09	275.24	0.77	20
CV51	Fan Coil Unit - 2010 High	2010	6916.74	275.24	0.91	20
CV52	Fan Coil Unit - 2015 Typical	2015	5177.99	302.75	0.83	20
CV53	Fan Coil Unit - 2015 High	2015	6840.16	302.75	1.00	20

RESIDENTIAL SECTOR

MARKAL	Technology Name	START year	LIFE years	CF dec fraction	Capital cost 98$/unit	Efficiency
RH01	space heating, electric furnace, existing	1995	30	0.16	1351	
RH02	space heating, electric furnace	1995	30	0.16	1351	1
RH03	space heating, electric heat pump, existing	1995	15	0.16	1963	
RH04	space heating, electric heat pump #1 - 1995	1995	15	0.16	1963	1.99
RH05	space heating, electric heat pump #1 - 2010	2010	15	0.16	2345	2.2
RH06	space heating, electric heat pump #2 - 1995	1995	15	0.16	2362	2.2
RH07	space heating, electric heat pump #2 - 2010	2010	15	0.16	2580	2.38
RH08	space heating, electric heat pump #2 - 2020	2020	15	0.16	2600	2.46
RH09	space heating, electric heat pump #3 - 1995	1995	15	0.16	3057	2.54
RH10	space heating, electric heat pump #3 - 2020	2020	15	0.16	2982	2.61
RH11	space heating, electric heat pump #4 - 1995	1995	15	0.16	3752	2.87
RH12	space heating, electric heat pump #4 - 2020	2020	15	0.16	3618	2.93
RH13	space heating, gas furnace, existing	1995	30	0.16	1200	
RH14	space heating, gas furnace #1 - 1995	1995	30	0.16	1200	0.78
RH15	space heating, gas furnace #2 - 1995	1995	30	0.16	1300	0.8
RH16	space heating, gas furnace #3 - 1995	1995	30	0.16	1400	0.82
RH17	space heating, gas furnace #4 - 1995	1995	30	0.16	1900	0.92
RH18	space heating, gas furnace #4 - 2005	2005	30	0.16	1800	0.92
RH19	space heating, gas furnace #4 - 2010	2010	30	0.16	1700	0.92
RH20	space heating, gas furnace #4 - 2020	2020	30	0.16	1600	0.92
RH21	space heating, gas furnace #5 - 1995	1995	30	0.16	2700	0.97
RH22	space heating, gas furnace #5 - 2005	2005	30	0.16	2200	0.97
RH23	space heating, gas furnace #5 - 2010	2010	30	0.16	1950	0.97
RH24	space heating, gas furnace #5 - 2020	2020	30	0.16	1700	0.97
RH25	space heating, gas radiator #1 - 1995	1995	30	0.16	2480	0.8
RH26	space heating, gas radiator #2 - 1995	1995	30	0.16	3065	0.87
RH27	space heating, gas radiator #2 - 2010	2010	30	0.16	3065	0.89
RH28	space heating, gas radiator #3 - 1995	1995	30	0.16	3650	0.95
RH29	space heating, gas radiator #3 - 2010	2010	30	0.16	3650	0.97
RH30	space heating, kerosene furnace #1 - 1995	1995	30	0.16	2052	0.65
RH31	space heating, kerosene furnace #2 - 1995	1995	30	0.16	2661	0.7
RH32	space heating, kerosene furnace #3 - 1995	1995	30	0.16	4217	0.8
RH33	space heating, LPG furnace #1 - 1995	1995	30	0.16	1200	0.78
RH34	space heating, LPG furnace #2 - 1995	1995	30	0.16	1300	0.8
RH35	space heating, LPG furnace #3 - 1995	1995	30	0.16	1400	0.82
RH36	space heating, LPG furnace #4 - 1995	1995	30	0.16	1900	0.92
RH37	space heating, LPG furnace #4 - 2005	2005	30	0.16	1800	0.92
RH38	space heating, LPG furnace #4 - 2010	2010	30	0.16	1700	0.92
RH39	space heating, LPG furnace #4 - 2020	2020	30	0.16	1600	0.92

continued

MARKAL	Technology Name	START year	LIFE years	CF dec fraction	Capital cost 98$/unit	Efficiency
RH40	space heating, LPG furnace #5 - 1995	1995	30	0.16	2700	0.97
RH41	space heating, LPG furnace #5 - 2005	2005	30	0.16	2200	0.97
RH42	space heating, LPG furnace #5 - 2010	2010	30	0.16	1950	0.97
RH43	space heating, LPG furnace #5 - 2020	2020	30	0.16	1700	0.97
RH44	space heating, Dist furnace, existing	1995	30	0.16	1300	
RH45	space heating, Dist furnace #1 - 1995	1995	30	0.16	1300	0.8
RH46	space heating, Dist furnace #2 - 1995	1995	30	0.16	1400	0.82
RH47	space heating, Dist furnace #3 - 1995	1995	30	0.16	1900	0.87
RH48	space heating, Dist radiator, existing	1995	30	0.16	2480	
RH49	space heating, Dist radiator #1 - 1995	1995	30	0.16	2480	0.8
RH50	space heating, Dist radiator #2 - 1995	1995	30	0.16	3065	0.87
RH51	space heating, Dist radiator #2 - 2010	2010	30	0.16	3065	0.89
RH52	space heating, Dist radiator #3 - 1995	1995	30	0.16	3650	0.95
RH53	space heating, Dist radiator #3 - 2010	2010	30	0.16	3650	0.97
RH54	space heating, Wood heater	1995	30	0.16	1700	1
RH55	space heating, Geothermal heat pump #1 - 1995	1995	15	0.16	7410	3.4
RH56	space heating, Geothermal heat pump #1 - 2005	2005	15	0.16	6760	3.4
RH57	space heating, Geothermal heat pump #1 - 2020	2020	15	0.16	6760	3.8
RH58	space heating, Geothermal heat pump #2 - 1995	1995	15	0.16	8541	4
RH59	space heating, Geothermal heat pump #2 - 2010	2010	15	0.16	7891	4.3
RH60	space heating, Geothermal heat pump #2 - 2020	2020	15	0.16	7735	4.5
RH61	space heating, Gas heat pump - 1995	1995	15	0.16	4355	1.4
RH62	space heating, Gas heat pump - 2020	2020	15	0.16	4355	1.5
RH63	space heating, gas radiator, existing	1995	30	0.16	2480	
RC01	space cooling, room a/c, existing	1995	15	0.15	540	
RC02	space cooling, room a/c #1 - 1995	1995	15	0.15	540	2.55
RC03	space cooling, room a/c #1 - 2005	2005	15	0.15	540	2.83
RC04	space cooling, room a/c #2 - 1995	1995	15	0.15	584	2.93
RC05	space cooling, room a/c #2 - 2020	2020	15	0.15	575	3.22
RC06	space cooling, room a/c #3 - 1995	1995	15	0.15	760	3.37
RC07	space cooling, room a/c #3 - 2005	2005	15	0.15	760	3.52
RC08	space cooling, central a/c, existing	1995	15	0.15	2080	
RC09	space cooling, central air #1 - 1995	1995	15	0.15	2080	2.93
RC10	space cooling, central air #1 - 2010	2010	15	0.15	2300	3.52
RC11	space cooling, central air #2 - 1995	1995	15	0.15	2435	3.52
RC12	space cooling, central air #2 - 2010	2010	15	0.15	2500	3.81
RC13	space cooling, central air #2 - 2020	2020	15	0.15	2540	4.1
RC14	space cooling, central air #3 - 1995	1995	15	0.15	2968	4.4
RC15	space cooling, central air #3 - 2005	2005	15	0.15	2900	4.4
RC16	space cooling, central air #3 - 2020	2020	15	0.15	3020	4.69

continued

MARKAL	Technology Name	START year	LIFE years	CF dec fraction	Capital cost 98$/unit	Efficiency
RC17	space cooling, central air #4 - 1995	1995	15	0.15	3500	5.28
RC18	space cooling, electric heat pump, existing	1995	15	0.15	0	
RC19	space cooling, electric heat pump #1 - 1995	1995	15	0.15	0	2.93
RC20	space cooling, electric heat pump #1 - 2010	2010	15	0.15	0	3.52
RC21	space cooling, electric heat pump #2 - 1995	1995	15	0.15	0	3.52
RC22	space cooling, electric heat pump #2 - 2010	2010	15	0.15	0	3.81
RC23	space cooling, electric heat pump #2 - 2020	2020	15	0.15	0	4.1
RC24	space cooling, electric heat pump #3 - 1995	1995	15	0.15	0	4.4
RC25	space cooling, electric heat pump #3 - 2020	2020	15	0.15	0	4.69
RC26	space cooling, electric heat pump #4 - 1995	1995	15	0.15	0	5.28
RC27	space cooling, electric heat pump #4 - 2020	2020	15	0.15	0	5.28
RC28	space cooling, geothermal heat pump #1 -1995	1995	15	0.15	0	13.5
RC29	space cooling, geothermal heat pump #1 -2005	2005	15	0.15	0	13.5
RC30	space cooling, geothermal heat pump #1 -2020	2020	15	0.15	0	15.8
RC31	space cooling, geothermal heat pump #2 -1995	1995	15	0.15	0	21
RC32	space cooling, geothermal heat pump #2 - 2010	2010	15	0.15	0	21
RC33	space cooling, geothermal heat pump #2 -2020	2020	15	0.15	0	21
RC34	space cooling, gas heat pump - 1995	1995	15	0.15	0	1.4
RC35	space cooling, gas heat pump - 2020	2020	15	0.15	0	1.5
RW01	water heater, gas, existing	1995	20	0.1	326	
RW02	water heater, gas #1 - 1995	1997	20	0.1	326	0.54
RW03	water heater, gas #1 - 2005	2005	20	0.1	380	0.59
RW04	water heater, gas #2 - 1995	1995	20	0.1	370	0.58
RW05	water heater, gas #2 - 2005	2005	20	0.1	380	0.59
RW06	water heater, gas #3 - 1995	1995	20	0.1	500	0.6
RW07	water heater, gas #3 - 2005	2005	20	0.1	390	0.6
RW08	water heater, gas #4 - 1995	1995	20	0.1	2100	0.86
RW09	water heater, gas #4 - 2005	2005	20	0.1	2000	0.86
RW10	water heater, electric, existing	1995	20	0.1	337	
RW11	water heater, electric #1 - 1995	1995	20	0.1	337	0.86
RW12	water heater, electric #1 - 2005	2005	20	0.1	500	0.9
RW13	water heater, electric #2 - 1995	1995	20	0.1	337	0.88
RW14	water heater, electric #2 - 2005	2005	20	0.1	500	0.9
RW15	water heater, electric #3 - 1995	1995	20	0.1	590	0.95
RW16	water heater, electric #3 - 2005	2005	20	0.1	550	0.95
RW17	water heater, electric #4 - 1995	1995	20	0.1	1175	2
RW18	water heater, electric #4 - 2020	2020	20	0.1	950	2.2
RW19	water heater, electric #5 - 1995	1995	20	0.1	1200	2.6
RW20	water heater, electric #5 - 2005	2005	20	0.1	1100	2.6

Continued

MARKAL	Technology Name	START year	LIFE years	CF dec fraction	Capital cost 98$/unit	Efficiency
RW21	water heater, distillate, existing	1995	20	0.1	725	
RW22	water heater, distillate #1 - 1995	1995	20	0.1	725	0.53
RW23	water heater, distillate #2 - 1995	1995	20	0.1	779	0.58
RW24	water heater, LPG #1 - 1995	1995	20	0.1	326	0.54
RW25	water heater, LPG #1 - 2005	2005	20	0.1	480	0.59
RW26	water heater, LPG #2 - 1995	1995	20	0.1	370	0.58
RW27	water heater, LPG #2 - 2005	2005	20	0.1	480	0.59
RW28	water heater, LPG #3 - 1995	1995	20	0.1	500	0.6
RW29	water heater, LPG #3 - 2005	2005	20	0.1	490	0.6
RW30	water heater, LPG #4 - 1995	1995	20	0.1	1860	0.86
RW31	water heater, LPG #4 - 2005	2005	20	0.1	1610	0.86
RW32	water heater, solar #1 - 1995	1995	20	0.1	3200	2
RW33	water heater, solar #1 - 2005	2005	20	0.1	2867	2
RW34	water heater, solar #1 - 2010	2010	20	0.1	2533	2
RW35	water heater, solar #1 - 2020	2020	20	0.1	2200	2
RR01	refrigeration, existing	1995	15	1	600	
RR02	refrigeration #1 - 1995	1995	15	1	600	690
RR03	refrigeration #1 - 2005	2005	15	1	600	478
RR04	refrigeration #2 - 1995	1995	15	1	650	660
RR05	refrigeration #2 - 2005	2005	15	1	650	460
RR06	refrigeration #3 - 1995	1995	15	1	950	515
RR07	refrigeration #3 - 2000	2000	15	1	650	460
RR08	refrigeration #3 - 2005	2005	15	1	950	400
RR09	refrigeration TID - 1995	1995	15	1	1314	843
RR10	refrigeration TID - 2005	2005	15	1	1314	577
RF01	freezing, existing	1995	15	1	381	
RF02	freezing #1 – 1995	1995	15	1	381	472
RF03	freezing #1 - 2005	2005	15	1	381	394
RF04	freezing #2 - 1995	1995	15	1	420	350
RF05	freezing #3 - 1995	1995	15	1	500	302
RF06	freezing UP - 1995	1995	15	1	381	617
RF07	freezing UP - 2005	2005	15	1	381	520

Lighting MARKAL	Technology Name	START year	LIFE years	CF dec fraction
RL01	Incandescent Lighting	1995	15	1
RL02	Baseline Fluorescent	1995	15	1
RL03	Fluorescent, elec ballast, rapid start	2000	15	1
		Relative Efficiency	**Variable O&M cents/kwh out**	**Variable O&M cents/kwh in**
RL01	Incandescent Lighting	1	0.699424046	0.7
RL02	Baseline Fluorescent	4.6	0.322894168	0.1
RL03	Fluorescent, elec ballast, rapid start	5.4	0.322894168	0.1

TRANSPORTATION SECTOR – LDV

		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLECGSL	Car, Gasoline, Existing fleet of compacts	400	31.0	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLEFDSL	Car, Diesel, Existing fleet	450	29.9	20.60	20.60	21.66	22.08	22.43	22.69	22.69	22.69	22.69
TLEFGSL	Car, Gasoline, Existing fleet of full size	450	27.0	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLESGSL	SUV, Gasoline, Existing Fleet	450	20.0	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLEMGSL	Minivan, Gasoline, Existing Fleet	450	25.5	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLEPGSL	Pickups and large vans, Gasoline, Existing Fleet	500	21.0	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLEPDSL	Light truck, Diesel, Existing fleet	450	22.1	21.34	21.34	22.14	22.48	22.79	23.01	23.01	23.01	23.01
TLCCONV00	Car, Gasoline, Conventional, Compacts - 2000	400	31.0	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV05	Car, Gasoline, Conventional, Compacts - 2005	400	33.0	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV10	Car, Gasoline, Conventional, Compacts - 2010	400	34.5	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV15	Car, Gasoline, Conventional, Compacts - 2015	400	34.4	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV20	Car, Gasoline, Conventional, Compacts - 2020	400	34.4	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV25	Car, Gasoline, Conventional, Compacts - 2025	400	34.4	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV30	Car, Gasoline, Conventional, Compacts - 2030	400	34.4	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCCONV35	Car, Gasoline, Conventional, Compacts - 2035	400	34.4	19.25	19.25	20.24	20.64	20.96	21.21	21.21	21.21	21.21
TLCMMPG10	Car, Gasoline, Moderate MPG, Compact -2010	400	49.0	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCMMPG15	Car, Gasoline, Moderate MPG, Compact -2015	400	48.9	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCMMPG20	Car, Gasoline, Moderate MPG, Compact -2020	400	48.9	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCMMPG25	Car, Gasoline, Moderate MPG, Compact -2025	400	48.9	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCMMPG30	Car, Gasoline, Moderate MPG, Compact -2030	400	48.9	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCMMPG35	Car, Gasoline, Moderate MPG, Compact -2035	400	48.9	0.00	0.00	0.00	22.00	22.34	22.61	22.61	22.61	22.61
TLCAMPG10	Car, Gasoline, Advanced MPG, Compact -2010	400	54.2	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86
TLCAMPG15	Car, Gasoline, Advanced MPG, Compact -2015	400	54.1	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86
TLCAMPG20	Car, Gasoline, Advanced MPG, Compact -2020	400	54.0	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86

continued

		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLCAMPG25	Car, Gasoline, Advanced MPG, Compact -2025	400	54.0	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86
TLCAMPG30	Car, Gasoline, Advanced MPG, Compact -2030	400	54.0	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86
TLCAMPG35	Car, Gasoline, Advanced MPG, Compact -2035	400	54.0	0.00	0.00	0.00	22.25	22.59	22.86	22.86	22.86	22.86
TLCADSL05	Car, Advanced diesel, Compact - 2005	400	44.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL10	Car, Advanced diesel, Compact - 2010	400	46.6	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL15	Car, Advanced diesel, Compact - 2015	400	46.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL20	Car, Advanced diesel, Compact - 2020	400	46.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL25	Car, Advanced diesel, Compact - 2025	400	46.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL30	Car, Advanced diesel, Compact - 2030	400	46.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCADSL35	Car, Advanced diesel, Compact - 2035	400	46.5	0.00	0.00	21.66	22.08	22.43	22.70	22.70	22.70	22.70
TLCFCH20	Car, Fuel cell-Hydrogen, Compact - 2020	420	92.9	0.00	0.00	0.00	0.00	0.00	27.58	24.40	24.40	24.40
TLCFCH25	Car, Fuel cell-Hydrogen, Compact - 2025	420	103.2	0.00	0.00	0.00	0.00	0.00	27.58	24.40	24.40	24.40
TLCCNG05	Car, CNG dedicated, Compact - 2005	360	33.0	0.00	0.00	21.86	22.29	22.64	22.91	22.91	22.91	22.91
TLCCNG10	Car, CNG dedicated, Compact - 2010	360	34.5	0.00	0.00	21.86	22.29	22.64	22.91	22.91	22.91	22.91
TLCELC05	Car, Electric, Compact - 2005	240	131.8	0.00	0.00	54.65	39.22	31.44	31.82	31.82	31.82	31.82
TLCELC10	Car, Electric, Compact - 2010	240	138.0	0.00	0.00	54.65	39.22	31.44	31.82	31.82	31.82	31.82
TLC2HYB05	Car, Hybrid (2X), Compact - 2005	420	44.5	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB10	Car, Hybrid (2X), Compact - 2010	420	55.2	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB15	Car, Hybrid (2X), Compact - 2015	420	60.3	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB20	Car, Hybrid (2X), Compact - 2020	420	64.5	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB25	Car, Hybrid (2X), Compact - 2025	420	68.8	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB30	Car, Hybrid (2X), Compact - 2030	420	68.8	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC2HYB35	Car, Hybrid (2X), Compact - 2035	420	68.8	0.00	0.00	25.31	24.77	24.10	23.76	22.27	22.27	22.27
TLC3HYB15	Car, Hybrid (3X), Compact - 2015	420	79.2	0.00	0.00	0.00	0.00	26.20	25.46	23.34	23.34	23.34
TLC3HYB20	Car, Hybrid (3X), Compact – 2020	420	92.9	0.00	0.00	0.00	0.00	26.20	25.46	23.34	23.34	23.34
TLC3HYB25	Car, Hybrid (3X), Compact – 2025	420	103.2	0.00	0.00	0.00	0.00	26.20	25.46	23.34	23.34	23.34
TLC3HYB30	Car, Hybrid (3X), Compact – 2030	420	103.2	0.00	0.00	0.00	0.00	26.20	25.46	23.34	23.34	23.34
TLC3HYB35	Car, Hybrid (3X), Compact – 2035	420	103.2	0.00	0.00	0.00	0.00	26.20	25.46	23.34	23.34	23.34
TLCETHX05	Car, Flex Ethanol, Compact - 2005	400	33.0	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX10	Car, Flex Ethanol, Compact - 2010	400	34.5	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX15	Car, Flex Ethanol, Compact - 2015	400	34.4	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX20	Car, Flex Ethanol, Compact - 2020	400	34.4	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX25	Car, Flex Ethanol, Compact - 2025	400	34.4	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX30	Car, Flex Ethanol, Compact - 2030	400	34.4	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCETHX35	Car, Flex Ethanol, Compact - 2035	400	34.4	19.44	19.44	20.44	20.85	21.17	21.42	21.42	21.42	21.42
TLCMTHX00	Car, Flex Methanol, Compact - 2000	400	31.6	21.52	21.52	22.52	22.93	23.24	23.47	23.47	23.47	23.47
TLCMTHX10	Car, Flex Methanol, Compact - 2010	400	35.1	21.52	21.52	22.52	22.93	23.24	23.47	23.47	23.47	23.47
TLCMTHX20	Car, Flex Methanol, Compact - 2020	400	35.3	21.52	21.52	22.52	22.93	23.24	23.47	23.47	23.47	23.47
TLCCNGX00	Car. CNG Bi-fuel, Compact - 2000	360	30.9	25.78	25.78	26.88	27.40	27.84	28.19	28.19	28.19	28.19

continued

		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLCCNGX10	Car. CNG Bi-fuel, Compact - 2010	360	34.0	25.78	25.78	26.88	27.40	27.84	28.19	28.19	28.19	28.19
TLCCNGX20	Car. CNG Bi-fuel, Compact - 2020	360	33.6	25.78	25.78	26.88	27.40	27.84	28.19	28.19	28.19	28.19
TLCLPGX00	Car, LPG Bi-fuel, Compact -2000	360	31.0	24.13	24.13	25.18	25.65	26.03	26.33	26.33	26.33	26.33
TLCLPGX10	Car, LPG Bi-fuel, Compact -2010	360	34.3	24.13	24.13	25.18	25.65	26.03	26.33	26.33	26.33	26.33
TLCLPGX20	Car, LPG Bi-fuel, Compact -2020	360	34.2	24.13	24.13	25.18	25.65	26.03	26.33	26.33	26.33	26.33
TLCFCM10	Car, Fuel Cell Methanol, Compact - 2010	420	67.0	0.00	0.00	0.00	28.68	28.68	28.63	25.45	25.45	25.45
TLCFCM20	Car, Fuel Cell Methanol, Compact - 2020	420	74.6	0.00	0.00	0.00	28.68	28.68	28.63	25.45	25.45	25.45
TLFCONV00	Car, Gasoline, Conventional, Full size - 2000	450	27.0	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV05	Car, Gasoline, Conventional, Full size - 2005	450	28.7	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV10	Car, Gasoline, Conventional, Full size - 2010	450	30.0	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV15	Car, Gasoline, Conventional, Full size - 2015	450	30.1	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV20	Car, Gasoline, Conventional, Full size - 2020	450	30.2	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV25	Car, Gasoline, Conventional, Full size - 2025	450	30.2	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV30	Car, Gasoline, Conventional, Full size - 2030	450	30.2	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFCONV35	Car, Gasoline, Conventional, Full size - 2035	450	30.2	25.36	25.36	26.40	26.82	27.14	27.39	27.39	27.39	27.39
TLFMMPG10	Car, Gasoline, Moderate MPG for full size -2010	450	46.8	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFMMPG15	Car, Gasoline, Moderate MPG for full size -2015	450	46.9	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFMMPG20	Car, Gasoline, Moderate MPG for full size -2020	450	47.0	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFMMPG25	Car, Gasoline, Moderate MPG for full size -2025	450	47.0	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFMMPG30	Car, Gasoline, Moderate MPG for full size -2030	450	47.0	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFMMPG35	Car, Gasoline, Moderate MPG for full size -2035	450	47.0	0.00	0.00	0.00	28.24	28.58	28.84	28.84	28.84	28.84
TLFAMMP10	Car, Gasoline, Advanced MPG for full size -2010	450	52.5	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFAMMP15	Car, Gasoline, Advanced MPG for full size -2015	450	52.6	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFAMMP20	Car, Gasoline, Advanced MPG for full size -2020	450	52.8	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFAMMP25	Car, Gasoline, Advanced MPG for full size -2025	450	52.8	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFAMMP30	Car, Gasoline, Advanced MPG for full size -2030	450	52.8	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFAMMP35	Car, Gasoline, Advanced MPG for full size -2035	450	52.8	0.00	0.00	0.00	28.59	28.93	29.20	29.20	29.20	29.20
TLFADSL05	Car, Advanced diesel, Full size - 2005	450	40.2	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL10	Car, Advanced diesel, Full size - 2010	450	42.0	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL15	Car, Advanced diesel, Full size - 2015	450	42.1	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL20	Car, Advanced diesel, Full size - 2020	450	42.2	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL25	Car, Advanced diesel, Full size - 2025	450	42.2	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL30	Car, Advanced diesel, Full size - 2030	450	42.2	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFADSL35	Car, Advanced diesel, Full size - 2035	450	42.2	0.00	0.00	28.24	28.16	28.50	28.76	28.76	28.76	28.76
TLFETHX00	Car, Flex Ethanol, Full size - 2000	450	27.0	25.61	25.61	26.66	27.09	27.41	27.66	27.66	27.66	27.66
TLFETHX10	Car, Flex Ethanol, Full size - 2010	450	30.0	25.61	25.61	26.66	27.09	27.41	27.66	27.66	27.66	27.66
TLFFCH20	Car, Fuel cell-Hydrogen, Full size - 2020	473	75.4	0.00	0.00	0.00	0.00	0.00	34.24	31.50	31.50	31.50
TLFFCH25	Car, Fuel cell-Hydrogen, Full size - 2025	473	90.5	0.00	0.00	0.00	0.00	0.00	34.24	31.50	31.50	31.50
TLFFCG10	Car, Fuel Cell-gasoline, Full size - 2010	473	58.3	0.00	0.00	0.00	37.27	37.13	36.98	32.87	0.00	0.00
TLFFCG20	Car, Fuel Cell-gasoline, Full size - 2020	473	64.9	0.00	0.00	0.00	37.27	37.13	36.98	32.87	0.00	0.00

continued

		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLFFCG25	Car, Fuel Cell-gasoline, Full size - 2025	473	75.4	0.00	0.00	0.00	37.27	37.13	36.98	32.87	0.00	0.00
TLFCNG05	Car, CNG Dedicated, Full size - 2005	405	28.7	0.00	0.00	28.16	27.89	28.23	28.49	28.49	28.49	28.49
TLFCNG10	Car, CNG Dedicated, Full size - 2010	405	30.0	0.00	0.00	28.16	27.89	28.23	28.49	28.49	28.49	28.49
TLFELC10	Car, Electric, Full size - 2010	270	120.0	0.00	0.00	0.00	47.82	40.71	40.96	40.96	40.96	40.96
TLF2HYB05	Car, Hybrid (2X), Full size - 2005	473	43.1	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB10	Car, Hybrid (2X), Full size - 2010	473	48.0	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB15	Car, Hybrid (2X), Full size - 2015	473	52.6	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB20	Car, Hybrid (2X), Full size - 2020	473	56.6	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB25	Car, Hybrid (2X), Full size - 2025	473	60.3	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB30	Car, Hybrid (2X), Full size - 2030	473	60.3	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF2HYB35	Car, Hybrid (2X), Full size - 2035	473	60.3	0.00	0.00	33.00	32.18	31.21	29.99	28.76	28.76	28.76
TLF3HYB10	Car, Hybrid (3X), Full size - 2010	473	60.0	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLF3HYB15	Car, Hybrid (3X), Full size - 2015	473	69.1	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLF3HYB20	Car, Hybrid (3X), Full size - 2020	473	81.4	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLF3HYB25	Car, Hybrid (3X), Full size - 2025	473	90.5	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLF3HYB30	Car, Hybrid (3X), Full size - 2030	473	90.5	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLF3HYB35	Car, Hybrid (3X), Full size - 2035	473	90.5	0.00	0.00	0.00	34.87	32.57	31.35	30.13	30.13	30.13
TLFMTHX00	Car, Flex Methanol, Full Size - 2000	450	27.6	27.80	27.80	28.85	29.28	29.62	29.89	29.89	29.89	29.89
TLFMTHX10	Car, Flex Methanol, Full Size - 2010	450	30.8	27.80	27.80	28.85	29.28	29.62	29.89	29.89	29.89	29.89
TLFMTHX20	Car, Flex Methanol, Full Size - 2020	450	30.8	27.80	27.80	28.85	29.28	29.62	29.89	29.89	29.89	29.89
TLFCNGX00	Car. CNG Bi-fuel, Full Size - 2000	405	26.9	31.88	31.88	33.15	33.78	34.31	34.70	34.70	34.70	34.70
TLFCNGX10	Car. CNG Bi-fuel, Full Size - 2010	405	29.1	31.88	31.88	33.15	33.78	34.31	34.70	34.70	34.70	34.70
TLFCNGX20	Car. CNG Bi-fuel, Full Size - 2020	405	28.5	31.88	31.88	33.15	33.78	34.31	34.70	34.70	34.70	34.70
TLFLPGX00	Car, LPG Bi-fuel, Full Size -2000	405	26.9	30.55	30.55	31.73	32.27	32.70	33.00	33.00	33.00	33.00
TLFLPGX10	Car, LPG Bi-fuel, Full Size -2010	405	29.7	30.55	30.55	31.73	32.27	32.70	33.00	33.00	33.00	33.00
TLFLPGX20	Car, LPG Bi-fuel, Full Size -2020	405	29.5	30.55	30.55	31.73	32.27	32.70	33.00	33.00	33.00	33.00
TLFFCM10	Car, Fuel Cell Methanol, Full Size - 2010	473	58.3	0.00	0.00	0.00	37.27	37.13	36.98	32.87	32.87	32.87
TLFFCM20	Car, Fuel Cell Methanol, Full Size - 2020	473	64.9	0.00	0.00	0.00	37.27	37.13	36.98	32.87	32.87	32.87
TLSCONV00	SUV, Conventional - 2000	450	20.0	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV05	SUV, Conventional - 2005	450	21.0	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV10	SUV, Conventional - 2010	450	21.9	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV15	SUV, Conventional - 2015	450	22.7	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV20	SUV, Conventional - 2020	450	23.3	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV25	SUV, Conventional - 2025	450	23.3	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV30	SUV, Conventional - 2030	450	23.3	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSCONV35	SUV, Conventional - 2035	450	23.3	26.91	26.91	27.78	28.14	28.47	28.69	28.69	28.69	28.69
TLSMMPG10	SUV, Moderate MPG - 2010	450	37.3	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04
TLSMMPG15	SUV, Moderate MPG - 2015	450	38.6	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04
TLSMMPG20	SUV, Moderate MPG - 2020	450	39.6	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04
TLSMMPG25	SUV, Moderate MPG - 2025	450	39.6	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04

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		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLSMMPG30	SUV, Moderate MPG - 2030	450	39.6	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04
TLSMMPG35	SUV, Moderate MPG - 2035	450	39.6	0.00	0.00	0.00	29.46	29.81	30.04	30.04	30.04	30.04
TLSAMPG10	SUV, Advanced MPG - 2010	450	43.4	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSAMPG15	SUV, Advanced MPG - 2015	450	44.9	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSAMPG20	SUV, Advanced MPG - 2020	450	46.2	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSAMPG25	SUV, Advanced MPG - 2025	450	46.2	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSAMPG30	SUV, Advanced MPG - 2030	450	46.2	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSAMPG35	SUV, Advanced MPG - 2035	450	46.2	0.00	0.00	0.00	30.11	30.46	30.70	30.70	30.70	30.70
TLSADSL05	SUV, Advanced diesel - 2005	450	29.4	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL10	SUV, Advanced diesel - 2010	450	30.7	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL15	SUV, Advanced diesel - 2015	450	31.8	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL20	SUV, Advanced diesel - 2020	450	32.6	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL25	SUV, Advanced diesel - 2025	450	32.6	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL30	SUV, Advanced diesel - 2030	450	32.6	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSADSL35	SUV, Advanced diesel - 2035	450	32.6	0.00	0.00	29.96	30.11	30.44	30.66	30.66	30.66	30.66
TLSETHX05	SUV, Flex Ethanol - 2005	450	21.0	0.00	0.00	28.06	28.42	28.75	28.98	28.98	28.98	28.98
TLSETHX15	SUV, Flex Ethanol - 2015	450	22.7	0.00	0.00	28.06	28.42	28.75	28.98	28.98	28.98	28.98
TLSFCH15	SUV, Fuel Cell-Hydrogen - 2015	473	52.2	0.00	0.00	0.00	0.00	38.18	35.86	32.99	32.99	32.99
TLSFCH20	SUV, Fuel Cell-Hydrogen - 2020	473	58.3	0.00	0.00	0.00	0.00	38.18	35.86	32.99	32.99	32.99
TLSFCH25	SUV, Fuel Cell-Hydrogen - 2025	473	69.9	0.00	0.00	0.00	0.00	38.18	35.86	32.99	32.99	32.99
TLSFCG10	SUV, Fuel cell-Gasoline - 2010	473	39.3	0.00	0.00	0.00	39.12	38.93	38.73	0.00	0.00	0.00
TLSFCG20	SUV, Fuel cell-Gasoline - 2020	473	46.6	0.00	0.00	0.00	39.12	38.93	38.73	0.00	0.00	0.00
TLSCNG05	SUV, CNG dedicated - 2005	405	21.0	0.00	0.00	29.17	29.53	29.86	30.08	30.08	30.08	30.08
TLSCNG15	SUV, CNG dedicated - 2015	405	22.7	0.00	0.00	29.17	29.53	29.86	30.08	30.08	30.08	30.08
TLSELC10	SUV, Electric - 2010	270	87.7	0.00	0.00	0.00	42.21	41.19	40.17	40.17	40.17	40.17
TLSELC20	SUV, Electric - 2020	270	93.2	0.00	0.00	0.00	42.21	41.19	40.17	40.17	40.17	40.17
TLS2HYB05	SUV, Hybrid (2X) - 2005	473	28.4	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB10	SUV, Hybrid (2X) - 2010	473	35.1	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB15	SUV, Hybrid (2X) - 2015	473	39.7	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB20	SUV, Hybrid (2X) - 2020	473	43.7	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB25	SUV, Hybrid (2X) - 2025	473	46.6	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB30	SUV, Hybrid (2X) - 2030	473	46.6	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS2HYB35	SUV, Hybrid (2X) - 2035	473	46.6	0.00	0.00	34.02	33.77	32.74	31.43	30.13	30.13	30.13
TLS3HYB15	SUV, Hybrid (3X) - 2015	473	45.4	0.00	0.00	0.00	0.00	35.58	34.43	31.56	31.56	31.56
TLS3HYB20	SUV, Hybrid (3X) - 2020	473	53.6	0.00	0.00	0.00	0.00	35.58	34.43	31.56	31.56	31.56
TLS3HYB25	SUV, Hybrid (3X) - 2025	473	69.9	0.00	0.00	0.00	0.00	35.58	34.43	31.56	31.56	31.56
TLS3HYB30	SUV, Hybrid (3X) - 2030	473	69.9	0.00	0.00	0.00	0.00	35.58	34.43	31.56	31.56	31.56
TLS3HYB35	SUV, Hybrid (3X) - 2035	473	69.9	0.00	0.00	0.00	0.00	35.58	34.43	31.56	31.56	31.56
TLSMTHX00	SUV, Flex Methanol - 2000	450	20.4	31.94	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06
TLSMTHX10	SUV, Flex Methanol - 2010	450	22.5	31.94	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06

continued

		FIXOM (1999$/vehicle)	EFF (mpg)	Capital Costs (Thousands of 1999$/vehicle) 1995	2000	2005	2010	2015	2020	2025	2030	2035
TLSMTHX20	SUV, Flex Methanol - 2020	450	23.9	31.94	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06
TLSCNGX00	SUV. CNG Bi-fuel - 2000	405	20.0	32.65	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06
TLSCNGX10	SUV. CNG Bi-fuel - 2010	405	21.4	32.65	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06
TLSCNGX20	SUV. CNG Bi-fuel - 2020	405	22.3	32.65	29.32	30.16	30.50	30.84	31.06	31.06	31.06	31.06
TLSLPGX00	SUV, LPG Bi-fuel -2000	405	20.0	31.80	31.80	32.71	33.16	33.58	33.83	33.83	33.83	33.83
TLSLPGX10	SUV, LPG Bi-fuel -2010	405	21.7	31.80	31.80	32.71	33.16	33.58	33.83	33.83	33.83	33.83
TLSLPGX20	SUV, LPG Bi-fuel -2020	405	23.0	31.80	31.80	32.71	33.16	33.58	33.83	33.83	33.83	33.83
TLSFCM10	SUV, Fuel Cell Methanol - 2010	473	39.3	0.00	0.00	0.00	39.12	38.93	38.73	38.73	38.73	38.73
TLSFCM20	SUV, Fuel Cell Methanol - 2020	473	46.6	0.00	0.00	0.00	39.12	38.93	38.73	38.73	38.73	38.73
TLMCONV00	Minivan, Conventional - 2000	450	25.5	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV05	Minivan, Conventional - 2005	450	26.2	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV10	Minivan, Conventional - 2010	450	27.0	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV15	Minivan, Conventional - 2015	450	27.8	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV20	Minivan, Conventional - 2020	450	28.8	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV25	Minivan, Conventional - 2025	450	28.8	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV30	Minivan, Conventional - 2030	450	28.8	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMCONV35	Minivan, Conventional - 2035	450	28.8	24.69	24.69	25.54	25.85	26.16	26.41	26.41	26.41	26.41
TLMMMPG10	Minivan, Moderate MPG - 2010	450	41.8	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMMMPG15	Minivan, Moderate MPG - 2015	450	41.8	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMMMPG20	Minivan, Moderate MPG - 2020	450	44.6	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMMMPG25	Minivan, Moderate MPG - 2025	450	44.6	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMMMPG30	Minivan, Moderate MPG - 2030	450	44.6	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMMMPG35	Minivan, Moderate MPG - 2035	450	44.6	0.00	0.00	0.00	27.01	27.34	27.60	27.60	27.60	27.60
TLMAMPG10	Minivan, Advanced MPG - 2010	450	49.9	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMAMPG15	Minivan, Advanced MPG - 2015	450	51.5	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMAMPG20	Minivan, Advanced MPG - 2020	450	53.2	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMAMPG25	Minivan, Advanced MPG - 2025	450	53.2	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMAMPG30	Minivan, Advanced MPG - 2030	450	53.2	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMAMPG35	Minivan, Advanced MPG - 2035	450	53.2	0.00	0.00	0.00	27.53	27.86	28.13	28.13	28.13	28.13
TLMADSL10	Minivan, Advanced diesel - 2010	450	37.7	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMADSL15	Minivan, Advanced diesel - 2015	450	39.0	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMADSL20	Minivan, Advanced diesel - 2020	450	40.3	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMADSL25	Minivan, Advanced diesel - 2025	450	40.3	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMADSL30	Minivan, Advanced diesel - 2030	450	40.3	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMADSL35	Minivan, Advanced diesel - 2035	450	40.3	0.00	0.00	0.00	27.66	27.96	28.22	28.22	28.22	28.22
TLMETHX00	Minivan, Flex Ethanol - 2000	450	25.5	24.94	24.94	25.80	26.11	26.42	26.67	26.67	26.67	26.67
TLMETHX10	Minivan, Flex Ethanol - 2010	450	27.0	24.94	24.94	25.80	26.11	26.42	26.67	26.67	26.67	26.67
TLMETHX20	Minivan, Flex Ethanol - 2020	450	28.8	24.94	24.94	25.80	26.11	26.42	26.67	26.67	26.67	26.67
TLMFCH15	Minivan, Fuel cell-Hydrogen - 2015	495	58.0	0.00	0.00	0.00	0.00	34.86	33.01	30.37	30.37	30.37
TLMFCH20	Minivan, Fuel cell-Hydrogen - 2020	495	72.0	0.00	0.00	0.00	0.00	34.86	33.01	30.37	30.37	30.37

continued

		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLMFCH25	Minivan, Fuel cell-Hydrogen - 2025	495	86.4	0.00	0.00	0.00	0.00	34.86	33.01	30.37	30.37	30.37
TLMFCG10	Minivan, Fuel cell-Gasoline - 2010	450	49.0	0.00	0.00	0.00	34.66	34.49	34.33	0.00	0.00	0.00
TLMFCG15	Minivan, Fuel cell-Gasoline - 2015	450	55.2	0.00	0.00	0.00	34.66	34.49	34.33	0.00	0.00	0.00
TLMFCG20	Minivan, Fuel cell-Gasoline - 2020	450	61.9	0.00	0.00	0.00	34.66	34.49	34.33	0.00	0.00	0.00
TLMCNG05	Minivan, CNG dedicated - 2005	405	26.2	0.00	0.00	26.82	27.14	27.46	27.73	27.73	27.73	27.73
TLMCNG15	Minivan, CNG dedicated - 2015	405	27.8	0.00	0.00	26.82	27.14	27.46	27.73	27.73	27.73	27.73
TLMELC10	Minivan, Electric - 2010	270	107.8	0.00	0.00	0.00	46.11	39.23	39.49	39.49	39.49	39.49
TLMELC20	Minivan, Electric - 2020	270	115.1	0.00	0.00	0.00	46.11	39.23	39.49	39.49	39.49	39.49
TLM2HYB10	Minivan, Hybrid (2X) - 2010	473	43.1	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM2HYB15	Minivan, Hybrid (2X) - 2015	473	48.7	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM2HYB20	Minivan, Hybrid (2X) - 2020	473	54.0	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM2HYB25	Minivan, Hybrid (2X) - 2025	473	57.6	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM2HYB30	Minivan, Hybrid (2X) - 2030	473	57.6	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM2HYB35	Minivan, Hybrid (2X) - 2035	473	57.6	0.00	0.00	0.00	31.02	30.08	28.90	27.73	27.73	27.73
TLM3HYB15	Minivan, Hybrid (3X) - 2015	495	57.1	0.00	0.00	0.00	0.00	32.33	30.90	29.05	29.05	29.05
TLM3HYB20	Minivan, Hybrid (3X) - 2020	495	66.2	0.00	0.00	0.00	0.00	32.33	30.90	29.05	29.05	29.05
TLM3HYB25	Minivan, Hybrid (3X) - 2025	495	86.4	0.00	0.00	0.00	0.00	32.33	30.90	29.05	29.05	29.05
TLM3HYB30	Minivan, Hybrid (3X) - 2030	495	86.4	0.00	0.00	0.00	0.00	32.33	30.90	29.05	29.05	29.05
TLM3HYB35	Minivan, Hybrid (3X) - 2035	495	86.4	0.00	0.00	0.00	0.00	32.33	30.90	29.05	29.05	29.05
TLMMTHX00	Minivan, Flex Methanol - 2000	450	26.2	26.90	26.90	27.73	28.02	28.34	28.59	28.59	28.59	28.59
TLMMTHX10	Minivan, Flex Methanol - 2010	450	27.7	26.90	26.90	27.73	28.02	28.34	28.59	28.59	28.59	28.59
TLMMTHX20	Minivan, Flex Methanol - 2020	450	29.6	26.90	26.90	27.73	28.02	28.34	28.59	28.59	28.59	28.59
TLMCNGX00	Minivan. CNG Bi-fuel - 2000	405	25.4	30.15	30.15	31.22	31.73	32.21	32.54	32.54	32.54	32.54
TLMCNGX10	Minivan. CNG Bi-fuel - 2010	405	25.9	30.15	30.15	31.22	31.73	32.21	32.54	32.54	32.54	32.54
TLMCNGX20	Minivan. CNG Bi-fuel - 2020	405	27.2	30.15	30.15	31.22	31.73	32.21	32.54	32.54	32.54	32.54
TLMLPGX00	Minivan, LPG Bi-fuel -2000	405	25.4	29.34	29.34	30.33	30.74	31.09	31.37	31.37	31.37	31.37
TLMLPGX10	Minivan, LPG Bi-fuel -2010	405	26.5	29.34	29.34	30.33	30.74	31.09	31.37	31.37	31.37	31.37
TLMLPGX20	Minivan, LPG Bi-fuel -2020	405	28.3	29.34	29.34	30.33	30.74	31.09	31.37	31.37	31.37	31.37
TLMFCM10	Minivan, Fuel Cell Methanol - 2010	450	49.0	0.00	0.00	0.00	34.66	34.49	34.33	34.33	34.33	34.33
TLMFCM20	Minivan, Fuel Cell Methanol - 2020	450	61.9	0.00	0.00	0.00	34.66	34.49	34.33	34.33	34.33	34.33
TLPCONV00	Pickups and large vans, Conventional - 2000	500	21.0	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV05	Pickups and large vans, Conventional - 2005	500	21.8	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV10	Pickups and large vans, Conventional - 2010	500	22.7	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV15	Pickups and large vans, Conventional - 2015	500	23.4	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV20	Pickups and large vans, Conventional - 2020	500	24.2	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV25	Pickups and large vans, Conventional - 2025	500	24.2	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV30	Pickups and large vans, Conventional - 2030	500	24.2	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPCONV35	Pickups and large vans, Conventional - 2035	500	24.2	19.94	19.94	20.69	21.01	21.30	21.50	21.50	21.50	21.50
TLPMMPG10	Pickups and large vans, Moderate MPG - 2010	500	31.0	0.00	0.00	0.00	22.38	22.68	22.90	22.90	22.90	22.90
TLPMMPG15	Pickups and large vans, Moderate MPG - 2015	500	32.1	0.00	0.00	0.00	21.96	22.26	22.47	22.90	22.90	22.90

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		FIXOM	EFF	Capital Costs (Thousands of 1999$/vehicle)								
		(1999$/vehicle)	(mpg)	1995	2000	2005	2010	2015	2020	2025	2030	2035
TLPMMPG20	Pickups and large vans, Moderate MPG - 2020	500	33.1	0.00	0.00	0.00	22.00	22.30	22.51	22.90	22.90	22.90
TLPMMPG25	Pickups and large vans, Moderate MPG - 2025	500	33.1	0.00	0.00	0.00	0.00	0.00	0.00	22.90	22.90	22.90
TLPMMPG30	Pickups and large vans, Moderate MPG - 2030	500	33.1	0.00	0.00	0.00	0.00	0.00	0.00	22.90	22.90	22.90
TLPMMPG35	Pickups and large vans, Moderate MPG - 2035	500	33.1	0.00	0.00	0.00	22.65	22.96	23.18	22.90	22.90	22.90
TLPAMPG10	Pickups and large vans, Advanced MPG - 2010	500	36.5	0.00	0.00	0.00	23.07	23.39	23.61	23.61	23.61	23.61
TLPAMPG15	Pickups and large vans, Advanced MPG - 2015	500	37.7	0.00	0.00	0.00	22.38	22.68	22.90	23.61	23.61	23.61
TLPAMPG20	Pickups and large vans, Advanced MPG - 2020	500	38.9	0.00	0.00	0.00	22.48	22.79	23.01	23.61	23.61	23.61
TLPAMPG25	Pickups and large vans, Advanced MPG - 2025	500	38.9	0.00	0.00	0.00	0.00	0.00	0.00	23.61	23.61	23.61
TLPAMPG30	Pickups and large vans, Advanced MPG - 2030	500	38.9	0.00	0.00	0.00	0.00	0.00	0.00	23.61	23.61	23.61
TLPAMPG35	Pickups and large vans, Advanced MPG - 2035	500	38.9	0.00	0.00	0.00	23.34	23.62	23.80	23.61	23.61	23.61
TLPADSL05	Pickups and large vans, Advanced diesel - 2005	500	30.5	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL10	Pickups and large vans, Advanced diesel - 2010	500	31.7	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL15	Pickups and large vans, Advanced diesel - 2015	500	32.8	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL20	Pickups and large vans, Advanced diesel - 2020	500	33.8	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL25	Pickups and large vans, Advanced diesel - 2025	500	33.8	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL30	Pickups and large vans, Advanced diesel - 2030	500	33.8	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPADSL35	Pickups and large vans, Advanced diesel - 2035	500	33.8	0.00	0.00	22.28	22.49	22.79	23.01	23.01	23.01	23.01
TLPETHX05	Pickups and large vans, Flex Ethanol - 2005	500	21.8	0.00	0.00	20.90	21.22	21.51	21.72	21.72	21.72	21.72
TLPETHX10	Pickups and large vans, Flex Ethanol - 2010	500	22.7	0.00	0.00	20.90	21.22	21.51	21.72	21.72	21.72	21.72
TLPETHX20	Pickups and large vans, Flex Ethanol - 2020	500	24.2	0.00	0.00	20.90	21.22	21.51	21.72	21.72	21.72	21.72
TLPFCH15	Pickups and large vans, Fuel cell-Hydrogen - 2015	525	51.3	0.00	0.00	0.00	0.00	27.91	26.88	24.73	24.73	24.73
TLPFCH20	Pickups and large vans, Fuel cell-Hydrogen - 2020	525	60.4	0.00	0.00	0.00	0.00	27.91	26.88	24.73	24.73	24.73
TLPFCH25	Pickups and large vans, Fuel cell-Hydrogen - 2025	525	72.5	0.00	0.00	0.00	0.00	27.91	26.88	24.73	24.73	24.73
TLPCNG05	Pickups and large vans, CNG dedicated - 2005	450	21.8	0.00	0.00	22.76	23.12	23.43	23.65	23.65	23.65	23.65
TLPCNG15	Pickups and large vans, CNG dedicated - 2015	450	23.4	0.00	0.00	22.76	23.12	23.43	23.65	23.65	23.65	23.65
TLPELC05	Pickups and large vans, Electric - 2005	300	87.3	0.00	0.00	55.86	39.93	31.94	32.26	32.26	32.26	32.26
TLPELC15	Pickups and large vans, Electric - 2015	300	93.7	0.00	0.00	55.86	39.93	31.94	32.26	32.26	32.26	32.26
TLPELC25	Pickups and large vans, Electric - 2025	300	96.6	0.00	0.00	55.86	39.93	31.94	32.26	32.26	32.26	32.26
TLP2HYB10	Pickups and large vans, Hybrid (2X) - 2010	525	37.9	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP2HYB15	Pickups and large vans, Hybrid (2X) - 2015	525	41.0	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP2HYB20	Pickups and large vans, Hybrid (2X) - 2020	525	45.3	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP2HYB25	Pickups and large vans, Hybrid (2X) - 2025	525	48.3	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP2HYB30	Pickups and large vans, Hybrid (2X) - 2030	525	48.3	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP2HYB35	Pickups and large vans, Hybrid (2X) - 2035	525	48.3	0.00	0.00	0.00	24.90	24.49	23.53	22.58	22.58	22.58
TLP3HYB20	Pickups and large vans, Hybrid (3X) - 2020	525	59.1	0.00	0.00	0.00	0.00	0.00	25.34	23.65	23.65	23.65
TLP3HYB25	Pickups and large vans, Hybrid (3X) - 2025	525	72.5	0.00	0.00	0.00	0.00	0.00	25.34	23.65	23.65	23.65
TLP3HYB30	Pickups and large vans, Hybrid (3X) - 2030	525	72.5	0.00	0.00	0.00	0.00	0.00	25.34	23.65	23.65	23.65
TLP3HYB35	Pickups and large vans, Hybrid (3X) - 2035	525	72.5	0.00	0.00	0.00	0.00	0.00	25.34	23.65	23.65	23.65
TLPMTHX00	Pickups and large vans, Flex Methanol - 2000	500	21.5	22.30	22.30	23.05	23.34	23.64	23.85	23.85	23.85	23.85

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		FIXOM (1999$/vehicle)	EFF (mpg)	Capital Costs (Thousands of 1999$/vehicle) 1995	2000	2005	2010	2015	2020	2025	2030	2035
TLPMTHX10	Pickups and large vans, Flex Methanol - 2010	500	23.3	22.30	22.30	23.05	23.34	23.64	23.85	23.85	23.85	23.85
TLPMTHX20	Pickups and large vans, Flex Methanol - 2020	500	24.8	22.30	22.30	23.05	23.34	23.64	23.85	23.85	23.85	23.85
TLPCNGX00	Pickups and large vans. CNG Bi-fuel - 2000	450	20.9	24.65	24.65	25.47	25.88	26.35	26.65	26.65	26.65	26.65
TLPCNGX10	Pickups and large vans. CNG Bi-fuel - 2010	450	22.2	24.65	24.65	25.47	25.88	26.35	26.65	26.65	26.65	26.65
TLPCNGX20	Pickups and large vans. CNG Bi-fuel - 2020	450	23.1	24.65	24.65	25.47	25.88	26.35	26.65	26.65	26.65	26.65
TLPLPGX00	Pickups and large vans, LPG Bi-fuel -2000	450	21.0	24.53	24.53	25.32	25.69	26.09	26.32	26.32	26.32	26.32
TLPLPGX10	Pickups and large vans, LPG Bi-fuel -2010	450	22.5	24.53	24.53	25.32	25.69	26.09	26.32	26.32	26.32	26.32
TLPLPGX20	Pickups and large vans, LPG Bi-fuel -2020	450	23.7	24.53	24.53	25.32	25.69	26.09	26.32	26.32	26.32	26.32
TLPFCM10	Pickups and large vans, Fuel Cell Methanol - 2010	525	40.6	0.00	0.00	0.00	29.21	29.13	29.03	29.03	29.03	29.03
TLPFCM20	Pickups and large vans, Fuel Cell Methanol - 2020	525	48.3	0.00	0.00	0.00	29.21	29.13	29.03	29.03	29.03	29.03

TRANSPORTATION – OTHER

		START	LIFE	INVCOST (1999$/vehicle)	FIXOM (1999$/vehicle)	EFF (mpg)
THDSL00	Truck, Heavy, Diesel - 2000	1995	29	133311	6667	6.0
THDSL20P00	Truck, Heavy, Diesel + 20% MPG - 2000	2000	29	134213	6712	7.2
THDSL40P00	Truck, Heavy, Diesel + 40% MPG - 2000	2005	29	136919	6845	8.4
THEDSL	Truck, Heavy, Existing Diesel Fleet	1995	29	133311	6667	5.6
THGSL	Truck, Heavy, Gasoline	1995	29	133311	6667	6.0
THEGSL	Truck, Heavy, Existing Gasoline Fleet	1995	29	133311	6667	5.6
THCNG	Truck, Heavy, Compressed Natural Gas	1995	29	133311	6667	5.6
THALC	Truck, Heavy, Alcohol Fuel	1995	29	133311	6667	5.6
THLPG	Truck, Heavy, LPG	1995	29	133311	6667	5.6
THDSL10	Truck, Heavy, Diesel - 2010	2010	29	135023	6750	6.4
THDSL10P10	Truck, Heavy, Diesel + 10% MPG - 2010	2010	29	138654	6932	7.0
THDSL20P10	Truck, Heavy, Diesel + 20% MPG - 2010	2010	29	144291	7216	7.7
THDSL20	Truck, Heavy, Diesel - 2020	2020	29	139086	6956	6.9
THDSL10P20	Truck, Heavy, Diesel + 10% MPG - 2020	2020	29	145173	7258	7.6
THDSL20P20	Truck, Heavy, Diesel + 20% MPG - 2020	2020	29	153425	7673	8.3

continued

		START	LIFE	INVCOST (1999$/vehicle)	FIXOM (1999$/vehicle)	EFF (mpg)
TBGSL	Bus, Gasoline	1995	15	134717	6736	6.1
TBGSL10P	Bus, Gasoline + 10% MPG	2000	15	161667	8083	7.3
TBGSL20P	Bus, Gasoline + 20% MPG	2005	15	188601	9431	8.6
TBEGSL	Bus, Existing Gasoline Fleet	1995	15	134717	6736	6.1
TBDSL	Bus, Diesel	1995	15	134717	6736	6.7
TBDSL10P	Bus, Diesel + 10% MPG	2000	15	161667	8083	8.0
TBDSL20P	Bus, Diesel + 20% MPG	2005	15	188601	9431	9.5
TBEDSL	Bus, Existing Diesel Fleet	1995	15	134717	6736	6.7
TBCNG	Bus, Compressed Natural Gas	1995	15	134717	6736	6.1
TBALC	Bus, Alcohol Fuel	1995	15	134717	6736	4.0

INDUSTRIAL SECTOR

	RESID PJ/a	FIXOM 95million$/PJ/a	INVCOST 95million$/PJ/a	LIFE yrs
IECHELC095	149.0178738	1	10	30
IEISELC095	8.636712775	17.80524207	144.7271013	30
IELPELC095	0	0	0	30
IENFELC095	360.6244699	5.280005828	81.47506288	30
IENMELC095	0	0	0	30
IEOIELC095	83.233584	0	0	30
IMCHCOA095	0	0.55	25.64060403	20
IMCHDST095	0	0.55	1.824540844	20
IMCHELC095	2316.163525	0.7425	2.46313014	20
IMCHHFO095	0	0.66	2.189449013	20
IMCHLPG095	0	1	10	20
IMCHNGA095	272.8648467	1	10	20
IMISCOA095	0	0.55	28.48956003	20
IMISDST095	0	2.564060403	25.64060403	20
IMISELC095	436.6721979	0.182454084	1.824540844	20
IMISHFO095	0	1	10	20
IMISLPG095	0	1	10	20
IMISNGA095	8.392043243	2.848956003	28.48956003	20
IMLPDST095	0	2.564060403	25.64060403	20
IMLPELC095	1733.695265	0.182454084	1.824540844	20
IMLPHFO095	0	1	10	20
IMLPNGA095	74.3008107	2.848956003	28.48956003	20
IMNFDST095	0	2.564060403	25.64060403	20
IMNFELC095	33.35255213	0.182454084	1.824540844	20

continued

	RESID	FIXOM	INVCOST	LIFE
	PJ/a	95million$/PJ/a	95million$/PJ/a	yrs
IMNFHFO095	0	1	10	20
IMNFLPG095	0	2.848956003	28.48956003	20
IMNMDST095	0	2.564060403	25.64060403	20
IMNMELC095	398.415888	0.182454084	1.824540844	20
IMNMHFO095	0	1	10	20
IMNMNGA095	40.31251601	2.848956003	28.48956003	20
IMOIDST095	302.1947616	2.564060403	25.64060403	20
IMOIELC095	4661.080704	0.182454084	1.824540844	20
IMOIHFO095	0	1	10	20
IMOILPG095	9.7384968	1	10	20
IMOINGA095	227.1881068	2.848956003	28.48956003	20
IOCHBIO095	0	0.532883935	3.086336814	30
IOCHCOA095	0	0.532883935	3.086336814	30
IOCHCOK095	0	0.532883935	3.086336814	30
IOCHDST095	250.08	0.532883935	2.939368394	30
IOCHELC095	172.4349683	0.435995946	2.777703132	30
IOCHETH095	0	0.532883935	3.086336814	30
IOCHHFO095	141.52	0.532883935	3.086336814	30
IOCHLPG095	0	0.435995946	2.658792759	30
IOCHNAP095	0	0.532883935	3.086336814	30
IOCHNGA095	1585.80828	0.479595541	2.658792759	30
IOISBFG095	191.8548765	0.532883935	3.256085339	30
IOISBIO095	0	0.532883935	3.086336814	30
IOISCOA095	0	0.532883935	3.256085339	30
IOISDST095	4.106666667	0.532883935	3.256085339	30
IOISELC095	34.5468511	0.479595541	2.805026361	30
IOISHFO095	43.74	0.532883935	3.256085339	30
IOISNGA095	69.49660811	0.532883935	3.101033656	30
IOLPBIO095	809.8652844	1.332209836	3.517353333	30
IOLPCOA095	167.2779209	1.332209836	3.517353333	30
IOLPCOK095	0	1.332209836	3.517353333	30
IOLPDST095	73.9648	0.532883935	2.791550265	30
IOLPELC095	63.7387965	0.343960653	2.29307102	30
IOLPHFO095	193.5576	0.532883935	2.931127778	30
IOLPLPG095	11.042685	0.479595541	2.522378122	30
IOLPNGA095	1082.980754	0.479595541	2.522378122	30
IONFBIO095	0	0.532883935	3.086336814	30
IONFCOA095	0	0.308633681	3.086336814	30
IONFCOK095	0	0.308633681	3.086336814	30
IONFDST095	61.49333333	0.293936839	2.939368394	30

continued

	RESID PJ/a	FIXOM 95million$/PJ/a	INVCOST 95million$/PJ/a	LIFE yrs
IONFELC095	10.42267254	0.370360418	3.703604177	30
IONFHFO095	0	0.308633681	3.086336814	30
IONFNGA095	22.087975	0.265879276	2.658792759	30
IONMBIO095	0	0.532883935	3.086336814	30
IONMCOA095	229.3279507	0.532883935	3.708288202	30
IONMCOK095	0	0.532883935	3.708288202	30
IONMDST095	17.728	0.532883935	3.53170305	30
IONMELC095	15.25101468	0.437088148	2.913920989	30
IONMHFO095	0	0.532883935	3.708288202	30
IONMLPG095	3.7942875	0.479595541	3.205313088	30
IONMNGA095	46.19142459	0.479595541	3.205313088	30
IOOIBIO095	1413.273181	0.532883935	3.086336814	30
IOOICOA095	229.0242978	1.332209836	3.703604177	30
IOOICOK095	0	1.332209836	3.703604177	30
IOOIDST095	314.78621	0.532883935	2.939368394	30
IOOIELC095	312.12594	0.506239738	2.932019973	30
IOOIHFO095	195.12	0.532883935	3.086336814	30
IOOILPG095	18.2596815	0.479595541	2.658792759	30
IOOINGA095	2768.855051	0.479595541	2.658792759	30
IOOIPTC095	0	1.332209836	3.703604177	30
IPCHCOA095	0	0.55	3.438622354	30
IPCHCOK095	0	0.55	3.438622354	30
IPCHDST095	0	0.55	3.118931841	30
IPCHELC095	44.70536215	0.55	3.111134511	30
IPCHHFO095	0	0.55	3.274878433	30
IPCHLPG095	0	0.55	2.947390589	30
IPCHNGA095	1394.934072	0.55	2.947390589	30
IPISBFG095	82.2235185	2.637627067	20.9512423	30
IPISCOA095	44.4481155	2.637627067	20.9512423	30
IPISDST095	1.026666667	2.392405503	19.00339438	30
IPISELC095	134.7327193	2.386424489	18.95588589	30
IPISHFO095	8.1	2.512025778	19.9535641	30
IPISLPG095	4.867155	0.55	5.5	30
IPISNGA095	519.2576757	2.2608232	17.95820769	30
IPLPBIO095	0	5.426002005	122.9897887	30
IPLPCOA095	0	5.426002005	122.9897887	30
IPLPDST095	0	4.921543769	111.5553639	30
IPLPELC095	31.86939825	4.909239909	111.2764755	30
IPLPHFO095	28.9224	5.167620957	117.1331321	30
IPLPLPG095	0	4.650858861	105.4198189	30
IPLPNGA095	133.2770792	4.650858861	105.4198189	30

continued

	RESID PJ/a	FIXOM 95million$/PJ/a	INVCOST 95million$/PJ/a	LIFE yrs
IPNFCOA095	0	23.52764423	235.2764423	30
IPNFCOK095	0	23.52764423	235.2764423	30
IPNFDST095	15.37333333	21.34026688	213.4026688	30
IPNFELC095	0	21.28691621	212.8691621	30
IPNFHFO095	0	22.40728022	224.0728022	30
IPNFLPG095	4.60548	0.4	201.665522	30
IPNFNGA095	375.495575	20.1665522	201.665522	30
IPNMCOA095	767.7500957	3.362440329	37.36044811	30
IPNMCOK095	0	3.362440329	37.36044811	30
IPNMDST095	141.824	3.049832498	33.88702776	30
IPNMELC095	24.900993	3.042207917	33.80231019	30
IPNMHFO095	9.68	3.202324123	35.58137915	30
IPNMLPG095	3.7942875	2.882091711	32.02324123	30
IPNMNGA095	516.5041114	2.882091711	32.02324123	30
IPNMPTC095	0	3.362440329	37.36044811	30
IPOICOA095	0	2.23001031	22.0998663	30
IPOICOK095	0	2.23001031	22.0998663	30
IPOIDST095	157.393105	2.022685088	20.0452302	30
IPOIELC095	208.08396	2.017628376	19.99511713	30
IPOIHFO095	0	2.123819343	21.04749171	30
IPOILPG095	30.4328025	1.911437408	18.94274254	30
IPOINGA095	709.9628336	1.911437408	18.94274254	30
ISCHCOA095	213.21279	0.55	3.703604177	30
ISCHDST095	0	0.55	2.939368394	30
ISCHELC095	17.03061415	0.55	2.777703132	30
ISCHHFO095	0	0.55	3.086336814	30
ISCHNGA095	1077.247676	0.55	2.658792759	30
ISISBFG095	0	1.332209836	3.907302406	30
ISISCOA095	2.3393745	1.332209836	3.907302406	30
ISISDST095	1.026666667	0.532883935	3.101033656	30
ISISHFO095	2.16	0.532883935	3.256085339	30
ISISNGA095	87.8542027	0.479595541	2.805026361	30
ISLPBIO095	0	4.157909991	13.85969997	30
ISLPCOA095	14.54590616	1.332209836	3.517353333	30
ISLPDST095	7.3152	0.532883935	2.791550265	30
ISLPELC095	0	0.343960653	2.29307102	30
ISLPHFO095	0	0.532883935	2.931127778	30
ISLPNGA095	93.29395544	0.479595541	2.522378122	30
ISNFCOA095	0	1.332209836	3.703604177	30
ISNFDST095	15.37333333	0.532883935	2.939368394	30
ISNFHFO095	0	0.532883935	3.086336814	30

continued

	RESID PJ/a	FIXOM 95million$/PJ/a	INVCOST 95million$/PJ/a	LIFE yrs
ISNFNGA095	44.17595	0.479595541	2.658792759	30
ISNMCOA095	0	1.332209836	4.449945842	30
ISNMDST095	17.728	0.532883935	3.53170305	30
ISNMELC095	1.349647317	0.437088148	2.913920989	30
ISNMHFO095	0	0.532883935	3.708288202	30
ISNMNGA095	27.99480278	0.479595541	3.205313088	30
ISOICOA095	28.30637388	1.332209836	3.703604177	30
ISOIDST095	220.350347	0.532883935	2.939368394	30
ISOIELC095	20.808396	0.506239738	2.932019973	30
ISOIHFO095	0	0.532883935	3.086336814	30
ISOILPG095	9.12984075	0.479595541	2.658792759	30
ISOINGA095	0	0.479595541	2.658792759	30

INDUSTRIAL COGEN

	LIFE yrs	RESID gw
EAELCBFG00	50	0.0244618
EAELCBIO00	50	3.9328115
EAELCCOA00	50	1.4758643
EAELCCOK00	50	0
EAELCETH00	50	0
EAELCHFO00	50	0.2349967
EAELCLPG00	50	0
EAELCNAP00	50	0
EAELCNGA00	50	2.0622962
EAELCOIL00	50	0
EAELCPTC00	50	0
EAUTELC00	50	3.0631115
ESTMBFG000	25	0.3937748
ESTMBIO000	25	59.970291
ESTMCOA000	25	9.2036518
ESTMCOK000	25	0
ESTMETH000	25	0
ESTMHFO000	25	0
ESTMLPG000	25	0
ESTMNAP000	25	0
ESTMNGA000	25	30.996367
ESTMOIL000	25	0
ESTMPTC000	25	0

Appendix C
Peer Review Comments and Responses

General and Documentation

COMMENT: Update data and calibration on a regular basis (every 2 years) and adjust the starting year from 1995 to 2000.
RESPONSE: The model is currently being updated from 2002 NEMS data to 2005 NEMS data, with the model time frame running from 2000 to 2040. Once this is complete, the model data will be updated and the model will be recalibrated every 2 years.

COMMENT: Growth bounds should be imposed on major technologies
RESPONSE: In our base model we are attempting to constrain the model runs as little as possible. In certain cases we have bound the growth of classes of technologies; for example, car classes are constrained over the model time horizon so that subcompact cars do not take over the whole sector. We have also implemented constraints in the electric sector to keep IGCC plants from coming on too fast. Where appropriate, as we do technology assessment, we will add constraints to certain technologies based on our research results. Current model runs with a minimum of constraints calibrate well to the AEO 2002.

COMMENT: Include nuclear energy supply in primary energy tables so that there will be proper accounting in the total primary energy supply tables in ANSWER.
RESPONSE: Nuclear tracking has been added to the primary energy supply table.

COMMENT: Documentation

- Provide link to ETSAP's MARKAL documentation web page to our documentation
- Add "systems and software" requirements section
- Add data summaries as an appendix
- Correct table numbering errors
- Too much variation in style

RESPONSE: Corrected and improved document according to comments.

COMMENT: In certain model run, the model is importing a large volume of electricity.
RESPONSE: Our imported electricity is represented in three cost steps with three import technologies. In addition, we have a dummy imported electricity technology in the model which is used to debug any problems. It was found that the cost was set too low on this dummy technology, and under certain emissions constraints the model was using a large volume of this dummy import. We reset the cost to a much higher value, causing the model to stop importing this resource.

COMMENT: The SO_X limit is set at 4,500 thousand metric tons after 2010. What is the basis for this limit?
RESPONSE: This limit is based on the CAAA90 (Clean Air Amendment Acts of 1990).

Electric Sector

COMMENT: Existing steam coal capacity is, on average, dispatched at a very low rate.
RESPONSE: We have since done a major overhaul of our representation of the existing steam coal technologies which has resulted in the model now dispatching these technologies at an appropriate rate. We found two main causes for the low dispatch which we have since resolved.

1 We had residual capacity for existing steam electric technologies, but not for the retrofit technologies that were needed to minimize the NO_X and SO_X emissions. In order for the model to utilize these retrofits, it was having to pay the capital costs, and thus, it was finding other electric generation technologies more cost effective. Our model now includes residual capacity for both the existing steam electric plants and their retrofits.
2 Our representation of the existing steam electric plant retrofits was very limited. Our model now includes a wide variety of retrofit options along with the appropriate residual capacities and costs.

COMMENT: Results lean towards baseload generating technologies in meeting seasonal demands.
RESPONSE: This is a weakness of MARKAL in general; the limitation to 6 time slices tends to wash out seasonal demands. One option we considered was to treat the seasonal/day-night slices in MARKAL as slabs of a load duration curve. Instead, we have decided to push development in MARKAL to include more time slices, in order to better capture the variation in dispatch associated with season and time of day.

COMMENT: Not clear how FR(z)(y) electricity shape load data were derived
RESPONSE: The current electricity load data were from the original 1997 DOE database. However, with the expansion of time slices in MARKAL, we will be mapping NEMS demand data into the new MARKAL time slices. At that time, we will carefully assess different ways to perform this NEMS to MARKAL data mapping.

COMMENT: There are no carbon sequestering technologies.
RESPONSE: Carbon sequestration was not a focus of our base model development. We are currently doing an intensive technology assessment of the electric sector, and in that assessment carbon sequestration will be closely looked at and added as an alternative scenario to our base scenario.

Demand Side

COMMENT: Use the EFF_I (efficiency tied to investment vintage) parameter for end-use technologies.
RESPONSE: This parameter would help to minimize the number of technologies needed to represent different efficiencies of the same technology type, mainly in the transportation sector where we have a different technology for each time period. The problem with using EFF_I in this case is although it ties efficiency to investment vintage, it does not tie emissions, which change over time. If we were counting our emissions at the fuel level, this would not be a problem, but we account for emissions at the technology level. Therefore, EFF_I would not be useful.

COMMENT: Reduce the level of technology detail in minor energy demands in the Commercial Sector.
RESPONSE: We had a large variety of technologies within the smaller Commercial sub-demands that were competing with each other inappropriately. For example, Walk-In Freezers were competing with Ice Machines to meet the Commercial Freezing demand. We have since implemented constraints that line up with the AEO distributed results for each sub-demand area. In our example, we now have various Walk-In Freezers competing against each other for the share of Freezing demand that the AEO says is met by Walk-In Freezers only. We have implemented these constraints in the following sub-demands: Lighting, Refrigeration, Freezing, Cooking, and Ventillation.

COMMENT: The Residential and Commercial shell/conservation packages are not modeled in the database. While improvements in new and existing building shells over time may be implicit in the specification of the service demands, it may be more transparent to represent them separately and allow the model to endogenously respond to changes in fuel prices.
RESPONSE: As stated in the reviewers comment, the building shell improvements are implicit in the calculation of the service demands. As the Residential and Commercial sectors are not our areas of focus for our current technology assessment, we prefer to keep the model as is. We will look into this in future model development.

COMMENT: Add compact fluorescent lighting in the residential sector
RESPONSE: Our model currently represents three types of residential lighting: incandescent, baseline fluorescent, and electric ballast fluorescent. The data for these technologies came from the 1997 DOE MARKAL model. In future model development, we will develop more up-to-date technology representations for Residential Lighting

COMMENT: Investigate sources other than NEMS/AEO for emerging technologies
RESPONSE: Our base model is set up primarily using data from the NEMS AEO. As we do in-depth technology assessment, alternative data sources are investigated and used. This is evidenced in our hydrogen fuel cell technology assessment in the transportation sector, where the bulk of the hydrogen data came from sources other than the AEO.

Supply Side

COMMENT: Examine reducing the number of coal supply steps for the single region model or including appropriate coal delivery costs to enable the different coal supply regions to correctly compete.
RESPONSE: We are developing the coal delivery costs to input into our model.

COMMENT: Increase the number of supply steps for natural gas, both domestic and import
RESPONSE: The data we currently have available to us limit the number of supply steps we are able to develop for natural gas. Our future model development includes investing the resources needed to develop better supply step representations for natural gas and renewables.

COMMENT: Expand representation of renewable generation technologies

- Geothermal: no capacity or growth constraints
- Wind resources: low average capacity factors, is the set of technologies to small

RESPONSE: We are in the process of updating and reviewing our representation of renewables. We are investigating novel techniques for representing intermittent renewables coupled with storage in MARKAL. In addition, we are reviewing and updating the geothermal and biomass resource supply.

Technical Report Data

(Please read instructions on the reverse before completing)

1.REPORT NO. EPA-600/R-06/057	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE EPA U.S. National MARKAL Database: Database Documentation		5. REPORT DATE February 2006
		6. PERFORMING ORGANIZATION CODE
7. AUTHORS Carol Shay, Joseph DeCarolis, Dan Loughlin, Cynthia Gage, Sonia Yeh, Samudra Vijay, and Evelyn Wright		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. In-house
12. SPONSORING AGENCY NAME AND ADDRESS U. S. EPA, Office of Research and Development Air Pollution Prevention and Control Division Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final: 01/2002 – 01/2006
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

This document describes the database used in EPA's National Model, which is a MARKAL model developed to aid in technology assessment as part of a larger Air Quality Assessment being performed by EPA's Office of Research and Development. The MARKAL (MARket ALlocation) model was developed in the late 1970s at Brookhaven National Laboratory. In 1978, the International Energy Agency adopted MARKAL and created the Energy Technology and Systems Analysis Program (ETSAP), which is a group of modelers and developers that meet every six months to discuss model developments, extensions, and applications. MARKAL is a dynamic, data-driven energy/economic model of a region over a time span of several decades. The economy is modeled as a system of processes that have material, energy, and monetary flows between them and that represent all activities necessary to provide products and services for that region. Each process can choose from among a set of alternate technologies to complete the process, and each technology is characterized quantitatively by energy, emission, and monetary characteristics. Both the supply and demand sides are integrated, so that one side responds automatically to changes in the other. The model selects that combination of technologies that minimizes total energy system cost. The characteristics and constraints associated with the alternate technologies for each process are put into the model as a database, which is defined by the user. This document describes that database for the U.S. EPA MARKAL model.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFICATION/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Software Database Energy System MARKAL	Pollution Control Stationary Sources	

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