EPA United States Environmental Protection Agency

EPA 600/B-13/203 | September 2013 | www.epa.gov/ord

EPA U.S. Nine-region MARKAL Database

Database Documentation

SCIENCE

Office of Research and Development

EPA/600/B-13/203
September 2013

EPA U.S. Nine-region MARKAL DATABASE

Database Documentation

By

Carol Lenox, Rebecca Dodder, Cynthia Gage, Ozge Kaplan, Dan Loughlin, Will Yelverton
Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
Cincinnati, OH 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

DISCLAIMER

Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

AEO	Annual Energy Outlook
APB	Atmospheric Protection Branch
APPCD	Air Pollution Prevention Control Division
B20	20% Biofuel Blend
BC	Black Carbon
bn-lum-yr	billion lumens per year
bn-pass-miles	billion passenger miles
bn-t-miles	billion ton miles
bn-vmt	billion vehicle miles traveled
CAFE	Corporate Average Fuel Economy
CAIR	Clean Air Interstate Rule
CAMD	Clean Air Markets Division
CARD	Center for Agriculture and Rural Development
CBECS	Commercial Buildings Energy Consumption Survey
CCS	Carbon Capture and Sequestration
CDD	Cooling Degree Day
CFL	Compact Fluorescent Light
CHIEF	Clearinghouse for Inventories and Emissions Factors
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
DOE	Department of Energy
E85	85% Ethanol Fuel Blend
ECAT	Energy and Climate Assessment Team
EIA	Energy Information Administration
EISA	Energy Independence and Security Act
EPA	Environmental Protection Agency
ERG	Eastern Research Group, Inc
ETSAP	Energy Technology Systems Analysis Program
FAME	Fatty Acid Methyl Esters
FAPRI	Food and Agricultural Policy Research Institute
FGD	Flue Gas Desulfurization
GHG	Greenhouse Gases
GW	Gigawatt
HDD	Heating Degree Day
ICLUS	Integrated and Climate Land Use Scenarios
IGCC	Integrated Gasification Combined Cycle
LDV	Light Duty Vehicles
LED	Light Emitting Diode
LFG	Landfill Gas
LNB	Low NO_x Burners
LPG	Liquid Petroleum Gas
MARKAL	MARket Allocation model
MATS	Mercury Air Toxics Standard
MECS	Manufacturing Energy Consumption Survey

MOVES	Motor Vehicle Emissions Simulator model
MSW	Municipal Solid Waste
MSW-DST	Municipal Solid Waste Decision Support Tool
Mt	million tons
mu	million units
NCDC	National Climatic Data Center
NEEDS	National Electric Energy Data System
NEI	National Emissions Inventory
NEMS	National Energy Modeling System
NGA	Natural Gas
NGCC	Natural Gas Combined Cycle
NGL	Natural Gas Liquids
NOAA	National Oceanic and Atmospheric Administration
NO_x	Nitrogen Oxide
NRC	National Research Council
NREL	National Renewable Energy Lab
NRMRL	National Risk Management Research Lab
O&M	Operating and Maintenance
OC	Organic Carbon
ORD	Office of Research and Development
ORNL	Oak Ridge National Laboratory
OTAQ	Office of Transportation Air Quality
PADD	Petroleum for Administration Defense Districts
PJ	Petajoules
PM	Particulate Matter
PSD	Prevention of Significant Deterioration
PV	Photovoltaic
RA	Rural Area
RECS	Residential Energy Consumption Survey
RES	Reference Energy System
RES	Reference Energy System
RPS	Renewable Portfolio Standard
RTI	Research Triangle Institute
SAGE	Systems for the Analysis of Global Energy model
SCR	Selective Catalytic Reduction
SEDS	State Energy Data Systems
SMR	Steam Methane Reform
SNCR	Selective Non-Catalytic Reduction
SO_x	Sulfur Oxide
SRI	Southern Research Institute
tcfm-hr	thousand cubic feet per minute per hour
UA	Urbanized Area
UC	Urban Cluster
USDA	United States Department of Agriculture
VMT	Vehicle Miles Traveled

1. Introduction

The evolution of the energy system in the United States is an important factor in future environmental outcomes including air quality and climate change. Given this, decision makers need to understand how a changing energy landscape will impact future air quality and contribute to meeting mitigation targets and adaptation goals. Energy scenario analyses, incorporating drivers of emissions such as technological advances, population growth, fuel availability and utilization, and consumer choice, give important insights into the environmental effects of the changing energy system. To perform such scenario analyses, a detailed representation of the energy system is needed. To address this need, the EPA's Energy and Climate Assessment Team (ECAT) developed a nine-region representation of the U.S. energy system for use in scenario analysis within the MARKAL modeling framework.

ECAT 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 purpose of this document is to describe in detail the database, hereafter referred to as the EPA U.S. Nine-region MARKAL Database (EPAUS9r). The EPAUS9r was originally developed to aid in technology assessment as part of a larger Air Quality Assessment being performed by EPA ORD (see "Demonstration of a Scenario Approach for Technology Assessment: Transportation Sector;" EPA-600/R-04/135, January 2004). In recent years, the MARKAL modeling framework has been used to research such questions as: What are the impacts of future energy and technology options on air quality and climate change? What energy technology future pathways most effectively mitigate climate change and minimize unintended consequences, such as pollutant emissions? What are the effects of human choice on the demand side of the energy system?

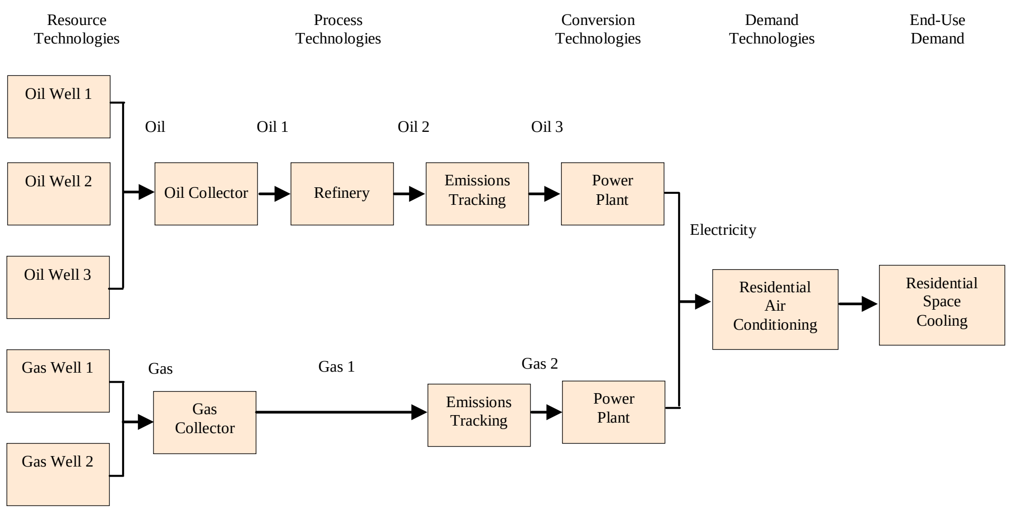
2. MARKAL

2.1 Model Description

The MARKet ALlocation (MARKAL) model is a data-driven, bottom-up energy systems economic optimization model. The initial version of the 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). ETSAP is a group of modelers and developers that meets every six months to discuss model developments, extensions, and applications. MARKAL, therefore, benefits from an active and interactive group of users and developers. For a detailed description of MARKAL, see the ETSAP MARKAL users manual at http://www.etsap.org/documentation.asp .

The basis of the MARKAL model structure is a network diagram called a Reference Energy System (RES), which depicts an energy system from resource supply to end-use demand (Figure 2.1). The RES divides an energy system up into technology stages, energy carriers, and user demands. The four technology stages represented are resource, process, conversion, and demand technologies. Resource technologies represent the extraction cost and availability of resources such as coal, oil, and natural gas. Conversion technologies represent the conversion of fuel inputs into electricity. Process technologies represent other means of converting resources into end-use fuels including refineries and coal-to-liquid processes. Demand technologies represent the technologies that meet specific user demands, such as vehicles, air conditioners, and water heaters. 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 air conditioning, and automobile passenger miles traveled. The stages are connected by the various forms of energy, called energy carriers, produced and consumed by the system.

Figure 2.1: Example of a Simple Reference Energy System



The EPAUS9r is a distinct representation of the U.S. energy system designed to be used within the MARKAL model structure. The database characterizes the flow of energy associated with the extraction or import of resources, the conversion of these resources into useful energy, and the use of the energy in meeting end-use demands within and between the nine census regions of the United States. A MARKAL model run optimizes technology penetrations and fuel use within this representation over the specified time horizon using linear programming techniques to minimize the net present value of the energy system while satisfying the specified demands, subject to any constraints a user wishes to impose. Outputs of the model include the technological mix at time intervals into the future, the total system cost, criteria and greenhouse gas (GHG) emissions, and estimates of energy commodity prices. A single MARKAL model run generates a least cost pathway to satisfy energy demands. Using scenario analyses, the model can also be used to explore how the least cost pathway changes in response to various input changes, such as the introduction of new energy efficient technologies or a new policy to stimulate CO_2 reductions.

2.2 MARKAL Data Needs

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

- Time horizon
- System-wide global parameters
- Energy service demands
- Energy carriers
- Resource technology profiles
- Process and demand technology profiles
- Environmental emission factors
- User-defined constraints

2.2.1 Time Horizon

The time horizon constitutes a user-defined number of time periods with each period having the same number of years. For the EPAUS9r, the time horizon extends from 2005 to 2055 divided into 5-year time periods.

2.2.2 System-wide Parameters

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

- Cost discounting - All costs must be entered in the same monetary unit and discounted to a common year; 2005 U.S. dollars for the EPAUS9r.
- Subdivision of the year into load fractions - MARKAL subdivides the year into three seasons Z (summer, winter, intermediate) and 4 times of day Y (day am, day pm, night, and peak).

2.2.3 End-Use Demands

End-use demands describe the specific energy services to be delivered to individuals or commercial entities in the economy. Examples of end-use demands include residential space cooling, 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 EPAUS9r, demand for the majority of transport services is specified in miles traveled, demand for lighting is specified in billion lumens per year, and 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 profile by season/day-night-peak (for end use demands that use electricity).

2.2.4 Energy Carriers

Energy carriers are the various forms of energy produced and consumed in the RES. Energy carriers can include fossil fuels, such as coal with different sulfur content, crude oil, refined oil products, natural gas, electricity, synthetic fuels produced by model processes, and renewable energy (e.g., biomass, solar, wind, geothermal, and hydro). Energy carriers provide the interconnections between the various technologies in the reference energy system by flowing out of one or more technologies and into others. The model requires that the total amount of each energy carrier produced in any time period is greater than or equal to the total amount consumed. Key energy carrier related data include:

- transmission efficiency
- investment and operation and maintenance cost for electricity transmission and distribution systems
- reserve margin or amount of installed electricity production capacity above the highest average annual demand

2.2.5 Resource Technologies

Resource technologies are the entry points for raw fuels into and out of the energy system, including 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. Key resource technology data include:

- bounds indicating the size of each step on each resource supply curve
- a corresponding resource supply cost for each supply step
- 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)
- cost of transporting resources, either within a region or from region to region.

2.2.6 Process, Conversion, and Demand Technologies

Process technologies are those technologies 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 conversion technologies, which model electricity production (e.g. conversion of one form of energy to another, as in coal to electricity). Conversion plants are distinguished from other types of technologies by the fact that they operate on a seasonal/day-night basis. 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:

- 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
- fuel delivery costs corresponding to any sectoral difference in the price of an energy carrier
- 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)
- 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-peak) availability for operation or a fixed percent annual (or season/day-night-peak) capacity utilization per unit of installed capacity
- existing installed capacity at the start of the model time horizon
- limits on capacity in the form of incremental new investment (absolute or growth rate) or total installed capacity
- "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).

2.2.7 Environmental Emissions

The EPAUS9r database tracks the production of emissions according to the activity, installed capacity, or new investment in capacity of a resource or technology. 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.

2.2.8 User-defined Constraints

User-defined constraints are used in the model to set upper, lower, and fixed limits on the use of fuel types or technology groups. These constraints have three components:

- right hand side value, which specifies the constant value that the constraint is to adhere to in each period,
- relationship type (upper, lower, fixed), and
- left hand side value, which defines a numeric coefficient (positive or negative) for each decision variable for each period.

2.3 MARKAL Set Definitions and Naming Conventions

The MARKAL structure uses a pre-defined set of definitions and naming conventions to organize the RES. Each set represents technologies, energy carriers, or constraints of a similar type. Within any given set, MARKAL has a number of mandatory parameters that need to be specified in the model. The main set memberships are listed in Table 2.1.

Table 2.1: Set Definitions in MARKAL

Set Name	Set Definition
TCH	**Technologies**
SRCENCP	**Resource Technology**
SEP_EXP	Export
SEP_IMP	Import
SEP_MIN	Extraction
SEP_RNW	Renewable
SEP_STK	Stockpile
PRC	**Process Technology**
PRE	Energy
PRW	Material (weight)
CON	**Conversion Technology**
ELE	Electric Conversion
BAS	Baseload
NBN	Non-baseload
STG	Storage
DMD	**Demand Technology**
ENV	**Emissions**

Set Name	Set Definition
ENT	**Energy Carrier**
ENC	Standard
ECV	Conversion
EFS	Fossil
ENU	Nuclear
ERN	Renewable
ESY	Synthetic
ELC	Electric
LTH	District Heat
FEQ	Fossil Equivalent
DM	**Demand**
DM_COM	Commercial
DM_IND	Industrial
DM_RES	Residential
DM_TRN	Transportation
ADRATIO	**User Defined Constraints**
REG_ADR	Regional Constraint
XARAT	Cross Region Constraint

In addition to pre-defined sets, standard naming conventions are used to name the technologies used in the model. For example, domestically mined fossil fuel step curves start with MIN (a standard convention) followed by the energy type and the supply step (i.e. MINNGAD6 is the name for the 6th step in the supply curve for domestically mined natural gas). The technology naming conventions are listed in Table 2.2.

Table 2.2: Technology Naming Conventions in MARKAL

Resource Technologies (SRCENCP)	Process Technologies (PRC)	Conversion Technologies (CON)	Demand Technologies (DMD)
MIN = Fossil Fuels RNW = Renewables IMP = Imports EXP = Exports STK = Stockpiles	P = Process SC = Collectors SE = Emissions Tracking X = Transportation Tracking ZZ = Dummy	E = Electric Conversion	COM = Commercial IND = Industrial RES = Residential TRN = Transportation

The general rule for energy carrier naming conventions is to use a three- to four-character core name for each principal energy carrier. The specific names for energy carriers would then add on a two- or three-character descriptor to the core name. The core names are listed in Table 2.3.

Table 2.3: Energy Carrier Names in the EPAUS9R

Resource	Core Name	Resource	Core Name
Agricultural Residues	AGR	Ethanol	ETH
Asphalt	ASP	Geothermal	GEO
Biodiesel	BDL	Highway Diesel	DSL
Biomass - corn stover	BSTV	Hydrogen	H2
Biomass - primary mill residue	BPMR	Hydropower	HYD
Biomass - soybean oil	BSYO	Jet Fuel	JTF
Biomass - timber	BTIM	Kerosene	KER
Biomass - ag residues	BAGR	Landfill Gas	LFG
Biomass - corn grain	BCRN	Liquid Petroleum Gas	LPG
Biomass Energy Crop - grasses	BECG	Natural Gas	NGA
Biomass Energy Crop - woody	BECW	Natural Gas Liquids	NGL
Biomass Forest Residues	BFSR	Nuclear	NUC
Biomass - municipal solid waste	BMSW	Oil	OIL
Biomass - urban wood waste	BUWW	Petrochemical Feedstocks	PFS
Coal	COA	Petroleum Coke	PTC
Coke	COK	Reformulated Gasoline	GSR
Compressed Natural Gas	CNG	Residual Fuel Oil	RFH
Conventional Gasoline	GSC	Solar	SOL
Distillate Heating Oil	DSH	Ultra-low Sulfur Diesel	DSU
Electricity	ELC	Wind	WND

3. The EPA Nine-region Database for MARKAL

3.1 Structure Overview

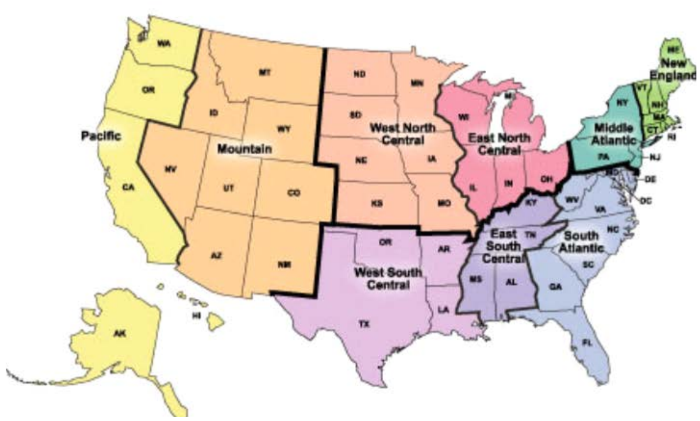
The EPAUS9r was developed around the nine U.S. Census divisions and covers a modeling horizon from 2005 to 2055. The nine divisions, considered regions in the database, were chosen based on the fact that the primary source for data populating the database, the U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) (EIA, 2012c), uses these same nine divisions.

The technologies chosen for inclusion in the database are commercially available technologies with historical data for investment costs, efficiencies, and operating and maintenance costs. Most of these technologies were drawn from the AEO. Other technologies not yet represented in the AEO are included based on development team expertise. Data for these technologies were derived from other widely recognized authoritative sources. Emerging technologies are analyzed by the research team using a scenario analysis approach in which a range of costs and efficiencies for a new technology are modeled. Those technologies are not included in the base database.

Essentially, each of the nine-regions in the database has its own conventional RES. The nine RES structures are then interconnected through a series of trade technology links, so that, for example, petroleum products refined in Region 2 can be traded to be used in Region 3. The naming conventions used are essentially the same from one region to another, facilitating regional and cross-region analysis. The regions are identified by the letter R and the number of the region, as given in the Figure 3.1:

Figure 3.1: EPAUS9r Regions

	EPAUS9r Regions
R1	New England
R2	Middle Atlantic
R3	East North Central
R4	West North Central
R5	South Atlantic
R6	East South Central
R7	West South Central
R8	Mountain
R9	Pacific



In addition to the nine interconnected RES structures, there is a "dummy" supply region named R0, for coal and imported fuels. For each of the nine-regions, there will be an export option in R0 linked to an associated import option in the region for each commodity. Along the import path for each commodity entering a region, a transportation cost is added and existing limitations on the supply of each resource are specified, either directly on the "supply link" or by means of regional infrastructure and transportation process technologies where the expansion of the supply infrastructure capacity requires investment.

3.2 Organization of Data

The EPAUS9r was developed using ANSWER, which 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).

Software
All data and results referenced in this document were based on the following software versions:

ANSWER Version 6.4.22 and Gams ScrPRD version 5.9e - available from Noble-SoftSystem (www.noblesoft.com.au/)

GAMS version 22.7 and XPRESS/GAMS solver - available from GAMS Development Corporation (www.gams.com)

EPAUS9r_2012 version 1.0 - available from the EPA

All data for the EPAUS9r is organized and transformed from raw data to MARKAL ready data in Excel workbooks. There are 21 workbooks that make up the database listed in Table 3.1. The appendices of this document contain detailed descriptions of each of the workbooks.

Table 3.1 EPAUS9r Workbooks

ANSWER Scenario Name	Excel Workbook Name	Description
COAL	EPAUS9R_[YR]_Coal_vx.x	Coal resource supply
OIL	EPAUS9R_[YR]_Oil_vx.x	Domestic and imported oil and imported refined products
NATGAS	EPAUS9R_[YR]_NatGas_vx.x	Domestic and imported natural gas and natural gas liquids
BIOFUEL	EPAUS9R_[YR]_Biofuel_vx.x	Biofuel production technologies
BIOMASS	EPAUS9R_[YR]_Biomass_vx.x	Biomass resource supply
MSW	EPAUS9R_[YR]_MSW_vx.x	Municipal solid waste resource supply
ELC	EPAUS9R_[YR]_ELC_vx.x	Electric sector technologies
ELC_TRDX	EPAUS9R_TRD_ELC_vx.x	Electric sector regional trading
REF	EPAUS9R_[YR]_REF_vx.x	Refineries
UNCNV	EPAUS9R_[YR]_UNCNV_vx.x	Unconventional fuel processes
H2	EPAUS9R_[YR]_H2_vx.x	Hydrogen production and distribution

H2TRD	EPAUS9R_[YR]_TRD_H2_vx.x	Hydrogen regional trading
RES	EPAUS9R_[YR]_RES_vx.x	Residential sector
COM	EPAUS9R_[YR]_COM_vx.x	Commercial sector
INDUST	EPAUS9R_[YR]_IND_vx.x	Industrial sector
INBIO	EPAUS9R_[YR]_INDBIO_vx.x	Industrial biofuels
TRN_HDV	EPAUS9R_[YR]_TRN_HDV_vx.x	Transportation sector - heavy duty vehicles
TRN_LDV	EPAUS9R_[YR]_TRN_LDV_vx.x	Transportation sector - light duty vehicles
TRN_OH	EPAUS9R_[YR]_TRN_OH_vx.x	Transportation sector - off-highway vehicles
FUELS	EPAUS9R_[YR]_FUELS_vx.x	Energy carrier connections for emissions tracking
AQREG	EPAUS9R_[YR]_AQREG_vx.x	Air quality regulations
CSAPR	EPAUS9R_[YR]_CSAPR-MATS_vx.x	Cross state air pollution rule and Mercury and air toxics standard
CAIRMATS	EPAUS9R_[YR]_CAIR-MATS_vx.x	Clean air interstate rule and Mercury and air toxics standard

3.3 Units

All costs in the database are given in units of year 2005 million U.S. dollars. Energy carrier use is given in terms of petajoules (PJ). Most end use demands are also given in terms of PJ, with the following exceptions:

- Commercial and residential lighting – billion lumens per year (bn-lum-yr)
- Commercial ventilation – thousand cubic feet per minute per hour (tcfm-hr)
- Residential refrigerators and freezers – million units (mu)
- Transportation cars and trucks – billion vehicle miles (bn-vmt)
- Transportation air and passenger rail – billion passenger miles (bn-pass-miles)
- Transportation shipping and freight rail – billion ton miles (bn-t-miles)

3.4 Important Assumptions

There are a number of important assumptions that are used throughout the model database (sector specific assumptions are discussed in the sector explanations).

- The long-term annual discount rate (**DISCOUNT**) applied to the economy as a whole is 5%. This discount rate is overridden anytime there is a discount rate (**DISCRATE**) applied to a specific technology.

- The fraction of the year (**QHR(Z)(Y)**) specifies the year by season (Z) and time-of-day (Y) that best describes the electrical load through the typical year. Table 3.2 lists the seasonal fractions used in the database.

Table 3.2: Fractions Used for QHR(Z)(Y) Values in the EPAUS9R

I-DAM	Intermediate day - AM	0.0822
I-DPM	Intermediate night - PM	0.0957
I-N	Intermediate night	0.1532
I-P	Summer peak	0.0032
S-DAM	Summer day – AM	0.0975
S-DPM	Summer day – PM	0.1087
S-N	Summer night	0.1253
S-P	Summer peak	0.0027
W-DAM	Winter day – AM	0.0815
W-DPM	Winter day – PM	0.1087
W-N	Winter night	0.1381
W-P	Winter peak	0.0032

- The average transmission efficiency (**TE(ENT)**) of each energy carrier is assumed to 100% unless otherwise stated. This value is based on the fact that, for most energy carriers, there is no loss of fuel in transporting from one technology to another (i.e. a rail car transporting coal from the mine to a power plant). For electricity, losses do occur across transmission lines. In the model, these losses are represented with a transmission efficiency of 93.5%. This value is based on EIA data found in the State Electricity Profiles.

- The reserve capacity (**(E)RESERVE**) for electricity is 0.15.

3.5 Emissions Tracking

The EPAUS9r tracks sectoral emissions for: CO_2, NO_x, PM_{10}, $PM_{2.5}$, SO_2, VOC, CH_4, CO, Organic Carbon (OC), and Black Carbon (BC). For the residential, commercial, electricity production, and industrial sectors, emissions are tracked on the fuels coming into the sector. In the transportation sector, emissions are tracked on the transportation technologies. In addition to emissions, the database tracks water use in the electric sector.

3.6 Solving a model run

A MARKAL model run optimizes by finding the least cost pathway for meeting the specified energy service demands utilizing available resources and technologies while satisfying any pre-defined constraints.

The available fuel resources are characterized using supply curves. The costs and cumulative amounts for a given supply curve step come from several different resources including the

AEO reference case and the *U.S. Billion Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry* (DOE, 2011a).

Technologies which convert resource supplies into end-use technology fuels and the end-use technologies themselves are chosen by the model based on four variables: technology costs (investment, variable O&M, and fixed O&M costs), technology efficiency, hurdle rates, and user-defined constraints.

Technology costs and efficiencies are largely drawn from the AEO.

Technology specific hurdle rates (**DISCRATE**) are applied differentially to base and advanced technologies and are chosen to best simulate the consumer's reluctance to purchase certain technologies or use certain fuels.

User-defined constraints include both fuel and technology shares. Fuel shares are the percentage of a given demand that must be met by a certain fuel type, and technology shares are the percentage of a given demand that must be met by a certain technology type. In MARKAL, these shares are set for the year 2010 based on historical data in the AEO. After 2010, shares are relaxed in order to give the model freedom to switch to different fuels and/or different technologies. Other user-defined constraints with the EPAUS9r include renewable portfolio standards (RPS) and regulation induced emissions limits.

A scenario run taking all of this data into account will typically take thirty minutes to an hour depending upon the computer hardware being used.

3.7 Sectoral Descriptions

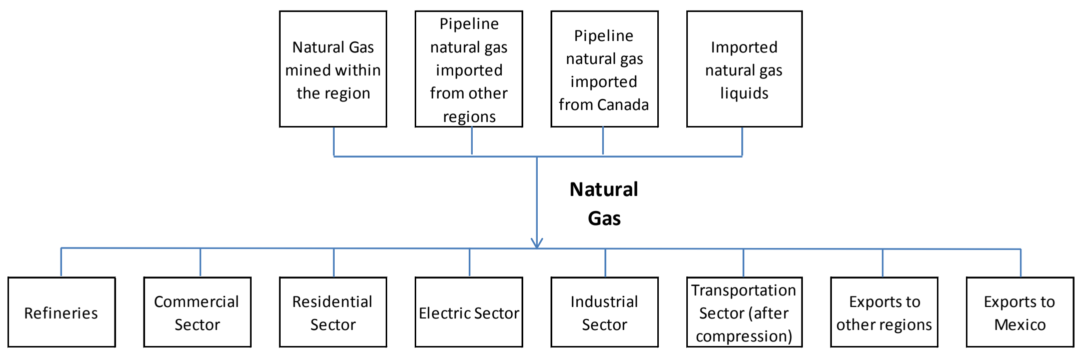
The descriptions below give a general overview of each of the sectors within the database. Detailed calculations for the MARKAL parameters used in the database can be found in the appendices at the end of this report.

3.7.1 Resource Supply – Natural Gas

There are three sources for natural gas in the EPAUS9r: domestically mined natural gas, imported liquid natural gas, and pipeline imported Canadian natural gas. These supplies are characterized in the database using a series of supply curves.

Schematic of Natural Gas Supply
Figure 3.2 shows a schematic of the flow of natural gas in the database within a given region.

Figure 3.2 Natural Gas Supply Flow



Natural Gas Supply Curves

The naming convention for each supply step begins with three letters, either MIN for domestically mined resources or IMP for imported resources, followed by NGA, a letter describing the type (D for domestic, C for Canadian, and L for liquid), and the step number. Within the database there are a total of nine supply curves used to represent all of the natural gas available to the model. These include a unique domestic natural gas supply curve in each of the regions 2 through 8 and two supply curves in Region 0 (R0), one for imported liquid natural gas and one for Canadian natural gas. The resources in R0 are apportioned to the census regions based on historical data via export and import technologies.

Each of the supply curves has six steps characterized by five parameters: cost (**COST**), upper bound (**BOUND(BD)Or**), cumulative available resource (**CUM**), annual supply growth rate (**GROWTHr**), and annual supply decrease rate (**DECAYr**). The costs and upper bounds for step 3 are based on the AEO reference case data for regional and imported price and expected production or import level. The costs and bounds for the other steps are calculated based on step 3 using price and quantity elasticities from the EIA National Energy Modeling System (NEMS) Natural Gas Transmission and Distribution module (EIA, 2012a). The cumulative resource amount is determined using proved natural gas reserve data from the EIA (EIA, 2012b). Upper bounds on natural gas use are set in the years 2005 and 2010. Beyond those years the supply from a specific step on the curve is allowed to grow or decline based on historical natural gas production and imports as reported by EIA. It is important to note that imported gas supply data are based on net imports and, as of the year 2020, the United States is set to become a net exporter of liquid natural gas. Therefore, the upper bound on availability of imported liquid natural gas becomes zero after the 2015 time period.

Natural Gas Transport

During a MARKAL run, domestic natural gas is collected as needed from the various supply steps and sent through a collector technology where transportation costs are applied and wet domestic natural gas is separated into dry natural gas (NGA) and natural gas plant liquids (NGL). In this process it is assumed that for every PJ of wet natural gas, 89.89% is converted into NGA and 10.11% is converted into NGL. NGL goes into refineries as energy inputs to the refinery process. NGA is delivered to sectors within the region or traded between regions through trade technologies. The RES has two pipeline technologies for regional trading of natural gas: existing pipelines with an upper bound on capacity and new pipeline technology that can add to the existing capacity for an additional cost.

NGA from Canada is imported via pipelines into regions 1,2,4,8, and 9. Similar to regional trading, imported Canadian gas has two pipeline technologies, existing and new, through which to transport the gas. Imported liquid natural gas is shipped into existing terminals in regions 1, 2, 5, and 7. Like the natural gas pipelines, the existing terminals have an upper bound on capacity. Additional terminal capacity can be purchased at a given cost.

Natural Gas Export to Mexico

In the RES, the U.S. is also able to export NGA to Mexico. This is represented in the database RES by trading NGA from regions 7, 8 and 9 into R0. Historical data are used to set the value for how much exported natural gas comes from each region.

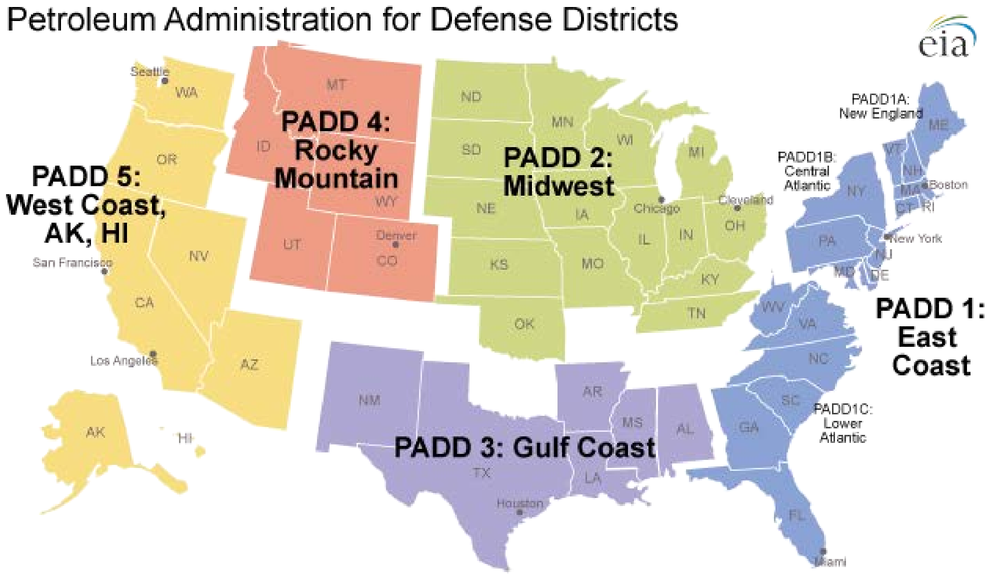
3.7.2 Resource Supply – Oil and Refined Products (Including Refineries)

The EPAUS9r represents three different sources for refined petroleum products: domestic and imported crude oil supply processed through a refinery and imported products that are already refined. Similar to natural gas, these supplies are characterized in the database using a series of supply curves.

Crude Oil

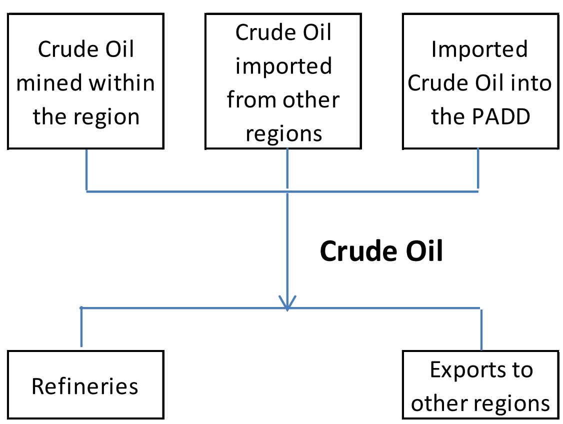
Both imported and domestic crude oil are represented in the model by stepwise supply curves. There are seven supply curves for domestic oil including a unique curve in each of the regions 2 through 8. For imported oil, there are five crude grades, each of which has a separate supply curve for each Petroleum Administration for Defense District (PADD), for a total of 25 unique curves located in Region 0. Imported oil is apportioned to the regions in which the PADD resides. For example, oil imported into PADD 2 is sent to regions 3 and 4. Figure 3.3 shows the states that fall in each district.

Figure 3.3 PADD Breakout



Schematic of Crude Oil Supply
Figure 3.4 shows a schematic of the flow of crude oil in the database within a given region.

Figure 3.4 Crude Oil Flow



Crude Oil Supply Curve
There are five steps for each of the supply curves. The curves are characterized using five parameters: cost (**COST**), upper bound (**BOUND(BD)Or**), cumulative available resource (**CUM**), annual supply growth rate (**GROWTHr**), and annual supply decrease rate (**DECAYr**). The costs and upper bounds for step 3 are based on the AEO reference case data for price and expected production or import level. The costs and bounds for the other steps are calculated based on step 3 using price and quantity elasticities from the NEMS Natural Gas

Transmission and Distribution module. The cumulative resource amount is determined using proved crude oil reserve data from the EIA (EIA, 2012b). Upper bounds on crude oil production or import are set in the years 2005 and 2010. Beyond those years the supply from a specific step on the curve is allowed to grow or decline based on historical production and imports as reported by EIA.

Domestic oil uses the naming convention "MINOILD" followed by the step number for the specific step on the curve. For imported oil, the naming convention is given in Table 3.3.

Table 3.3: Oil Naming Conventions

Resource	Type	Description		PADD	Step
IMP	OIL	HH	High sulfur content, High gravity	1-5	1-5
		HL	High sulfur content, Low gravity		
		HV	High sulfur content, very high gravity		
		LL	Low sulfur content, Low gravity		
		MH	Medium sulfur content, High gravity		

Oil Transport
During a MARKAL run, domestic oil is collected as needed from the various supply steps and sent through a collector technology where transportation costs are applied. After that technology, oil is either delivered to the refinery technology within the region or traded between regions through trade technologies. All trading between regions carries an additional cost.

Imported Refined Products
There are thirteen imported refined products represented in the EPAUS9r. These products are listed in Table 3.4.

Table 3.4: Refined Fuels

MARKAL name	Description
ASP	Asphalt
DSH	Distillate - Heating Oil No. 2
DSL	Distillate - Low Sulfur Highway Diesel (500 ppm)
DSU	Distillate - Ultra-low Sulfur Highway Diesel (15 ppm)
GSR	Reformulated Gasoline
GSC	Conventional Gasoline
JTF	Jet Fuel
KER	Kerosene
LPG	Liquid Petroleum gas
MTH	Methanol
PFS	Petrochemical Feedstocks
RFH	High Sulfur Residual Fuel Oil
RFL	Low Sulfur Residual Fuel Oil

Imported refined products have a separate supply curve for each PADD, for a total of 65 unique curves located in Region 0. There are five steps for each of the supply curves with the exception of asphalt, which only has one step. The curves are characterized using four parameters: cost (**COST**), upper bound (**BOUND(BD)Or**), annual supply growth rate (**GROWTHr**), and annual supply decrease rate (**DECAYr**). The costs and upper bounds for step 3 are based on the AEO reference case data for price and expected import level. The costs and bounds for the other steps are calculated based on step 3 using price and quantity elasticities from the NEMS Natural Gas Transmission and Distribution module. Upper bounds on imports are set in the years 2005 through 2020. Beyond those years the supply from a specific step on the curve is allowed to grow or decline based on historical imports as reported by EIA.

Like imported oil, the imported refined products are apportioned to the regions in which the PADD for each supply curve resides. Once the imported refined products are in their destination regions, these refined products are then supplied to the different end-use sectors (industrial, commercial, and residential, for example) using transportation technologies in the RES. Delivery charges are applied to these technologies.

Refineries

The refinery representation in the database consists of three refinery technologies: existing, new, and high limit. Existing refineries and their output (designated with an "E" at the end of every name) are characterized based on AEO data for current refinery capacities and yields. New refinery capacity (designated with an "N") can be built in some of the regions starting in 2015 and have yields that are similar to the existing refineries. Both existing and new refineries can output a dummy liquid intermediate (called DLG) that feeds into a high limit refinery (designated with an "L") which produces higher proportions of gasoline and diesel. The high limit refineries have a lower cost than new refineries and are not meant to represent a stand-alone refinery. Instead the high limit refinery represents the ability to modify the process of an existing refinery to obtain different fuel yields. The existing and new refineries can produce up to 20% of DLG. This cascaded implementation of the refinery processes permits more flexibility in fuel production.

There are four key inputs into the refineries: crude oil, natural gas, natural gas plant liquids, and electricity. Crude oil and natural gas plant liquids serve as feedstock inputs, while natural gas and electricity are used to meet the refinery energy consumption.

Twelve fuels listed in Table 3.5 are produced by the refineries. The refineries can produce up to a maximum yield, designated in the database, for each fuel. The sum of the maximum yields for the twelve fuels is always greater than 1. A limiting parameter (**LIMIT)** is used to set the total sum of all fuel produced by the refinery per unit of activity equal to 1. This difference between the sum of the individual yields and the maximum total yield allows the refineries to vary the output to meet demands. In this way, the blend and output of the refinery can be optimized within a specific range.

Table 3.5 Refinery Fuel Outputs

MARKAL name	Description
ASP	Asphalt
DSH	Distillate - Heating Oil No. 2
DSU	Distillate - Ultra-low Sulfur Highway Diesel (15 ppm)
GSR	Reformulated Gasoline
JTF	Jet Fuel
KER	Kerosene
LPG	Liquid Petroleum gas
PFS	Petrochemical Feedstocks
PTC	Petroleum Coke
RFH	High Sulfur Residual Fuel Oil
RFL	Low Sulfur Residual Fuel Oil
DLG	Dummy Liquid Fuel

Each region, with the exception of R1, has its own set of refinery technologies that produces products used both within the region and by other regions. Trade between regions can take place either by pipeline, river barges, or ocean vessels. Each of these trade links are represented in the RES by trade technologies with trading costs attached to them.

3.7.3 Resource Supply – Coal

Forty-one domestically mined coal resources supply curves are represented in the EPAUS9r, broken out by region of origin, coal type, sulfur content, and mine type. Fourteen coal regions, five coal types, three sulfur content ranks, and two types of mines are described. The naming convention for each type of coal is based on these breakouts and is described in Table 3.6.

Table 3.6: Coal Naming Convention

	description	Region of Origin	description	Coal Type	description	Sulfur Content	description	Mine Type	description
C	Coal	**NA**	Northern Appalachia	**P**	Premium	**H**	High	**U**	Underground
		CA	Central Appalachia	**B**	Bituminous	**M**	Medium	**S**	Surface
		SA	Southern Appalachia	**L**	Lignite	**L**	Low		
		EI	East Interior	**S**	Sub-bituminous				
		WI	West Interior	**G**	GOB				
		GL	Gulf Lignite						
		DL	Dakota Lignite						
		WM	Western Montana						
		WN	Wyoming Northern PRB						
		SW	Wyoming Southern PRB						
		WW	Western Wyoming						
		RM	Rocky Mountains						
		ZN	Southwest						
		PC	Northwest						

Each supply curve step name begins with the three letters “MIN,” identifying the supply as domestically mined, followed by the coal naming convention given above and the step. The supply curves are represented in Region 0 and then exported into different regions using export and import technologies. Historical AEO transportation data is used to apply the costs for sending specific coal types to different regions. Not all types of coal are available in every region, nor are all types of coal traded between regions.

Coal Supply Curve
Each of the supply curves has eleven steps. The curves are characterized using five parameters: cost (**COST**), upper bound (**BOUND(BD)Or**), cumulative available resource (**CUM**), annual supply growth rate (**GROWTHr**), and annual supply decrease rate (**DECAYr**). The costs and upper bounds to 2035 are based on the AEO reference case data for coal supply curves. Beyond 2035, the costs and bounds grow or decrease in proportion to the years 2030 and 2035. The cumulative resource amount is calculated based on the upper bounds of the supply curve at each step.

Coal Transport
Coal is delivered to the end-use sectors of the economy (industrial, commercial, electricity, for example) in each region via transportation technologies.

Coke Imports
Imported coke is represented by a nine-step supply curve in Region 0. Step costs and cumulative step values are given based on AEO reference case data. Imported coke can be exported into any of the regions as needed and is delivered to the industrial sector.

Coal to Liquids and Natural Gas
Several process technologies are available in the database that transform coal supply into liquids or natural gas. The coal to liquids technology outputs diesel fuel and petrochemical feedstocks. It is first available to the model in 2015. A more efficient and less expensive technology becomes available in 2030. The coal to natural gas technology outputs synthetic natural gas as well as petrochemical feedstocks. Region 4 represents a gasification plant with residual capacity that is already up and running in North Dakota. Other regions have the ability to build a coal to natural gas plant starting in 2015. Like the coal to liquids, a more efficient and less expensive technology becomes available in 2030.

3.7.4 Resource Supply – Biomass and Biofuels

The EPAUS9r database characterizes a number of biomass supply chains covering biomass for use in electricity production, for use in the industrial sector, and for use in the production of ethanol for transportation. In each region, different biomass feedstock supplies are made available to the model, with transportation technologies needed to move the biomass and conversion technologies for ethanol production.

Biomass

Data for biomass supply were taken from the *Billion Ton Update* (DOE, 2011a) which includes a number of feedstock supply estimates organized by the following major groupings: (1) forest biomass and wood waste resources, (2) agricultural biomass and waste resources, and (3) biomass energy crops. Within each of those groupings, there are a number of biomass feedstock types. For example, energy crops can be divided into perennial grasses, woody crops and annual energy crops. Table 3.7 below shows the mapping between the Billion Ton Update Categories and the biomass supply curves incorporated in the nine-region MARKAL database.

Table 3.7: Biomass Supply Comparison

Billion Ton Update	EPAUS9r Resources
FOREST BIOMASS AND WOOD WASTE RESOURCES	
Forest Residues • Other removal residue • Conventional wood • Composite operations (with Federal Lands) • Other Forestland Treatment Thinnings (with Federal Lands)	**Forest Residues (FSR)** .
Mill Residues: • Unused secondary • Unused primary	**Primary Mill Residues (PMR)**
Urban Wood Waste: • Construction and demolition • Municipal solid waste	**Urban Wood Waste (UWW)**
AGRICULTURAL BIOMASS AND WASTE RESOURCES	
Primary Agricultural Residues: • Corn stover	**Stover (STV)**
• Barley straw • Oat straw • Sorghum stubble • Wheat straw	**Agricultural Residues (AGR)**

Secondary Agricultural Residues and Wastes: • Cotton gin trash • Cotton residue • Manure • Rice hulls • Sugarcane trash • Orchard and vineyard prunings • Rice straw • Wheat dust	**Not currently used in EPAUS9r.**
DEDICATED ENERGY CROPS	
Annual energy crops • High-yield sorghum	**Energy Crops: Annual (ECA)**
Perennial grasses • Switchgrass • Giant Miscanthus • Sugarcane	**Energy Crops: Grasses (ECG)**
Coppice and non-coppice woody crops • Poplar • Willow • Eucalyptus • Southern Pines	**Energy Crops: Woody (ECW)**

Agricultural residues reflect the quantity of “straw and stubble” collected from agricultural lands, including: wheat straw, barley straw, oats straw and sorghum stubble. Quantities of straw and stubble for specific crops are small relative to corn stover, and are therefore aggregated to a single supply curve. Forest residues include a variety of forest biomass resources, including residues from logging and thinning and other removal residues. For these supply curves, all lands, including federal lands, are included. Mill residues are either used or unused. Used mill residues are reflected as a single price point, and are available only to the mills themselves in the model. Urban wood waste includes two categories of wood waste: construction and demolition (C&D) waste, and wood from municipal solid waste (MSW). Three types of perennial grasses (switchgrass, Giant Miscanthus, and sugarcane) are included in the supply curves for Energy Crops – Grasses (ECG), and three types of woody energy crops (poplar, willow, eucalyptus, southern pines) are included in the supply curves for Energy Crops – Woody (ECW).

Each of the supply curves has a number of steps, ranging from five to twenty, that give the cost and upper bound for the given feedstock. Forest residues have 20 supply steps -- substantially more than the other biomass categories. The forest residue prices reflect forest “roadside prices” that a buyer would pay, and therefore do not include transportation or preprocessing costs. All of the biomass feedstocks supply curves take into account the cost and energy associated with the production and collection of biomass (and therefore costs are reflective of “farm gate” or “roadside” prices. The one exception is the inclusion of a factor accounting for some feedstock degradation and loss for stover and other agricultural residues (with a slightly higher factor for INP(ENT)p than OUT(ENC)p).

Feedstock transportation includes the diesel use for the truck transport of biomass. A variable operating and maintenance cost represents the non-fuel costs associated with the transport of cellulosic feedstocks in particular.

For electricity production, feedstocks are converted from million tons (Mt) to PJ based on their energy content. However, there are two different collectors: biomass to integrated gasification and combined cycle (IGCC) and biomass to combustion. The reason for the separation is that the emissions for the CO_2 from biomass feedstock going to combustion are accounted for on the input fuel, whereas for IGCC, the emissions are accounted for using a separate emissions accounting technology.

Electric sector biomass-related CO_2 and SO_2 emissions associated with combustion in the electric sector are tracked, but it should be noted that the CO_2 emissions are tracked as a separate CO_2 biomass source for the electric sector (e.g., CO2BE) but are not included in the total CO_2 accounting and are thus assumed to be carbon neutral.

Biofuels
The EPAUS9r characterizes biochemical ethanol production processes from both cellulosic feedstocks and corn feedstocks and thermo-chemical production processes for ethanol from cellulosic feedstocks.

For the corn-based biochemical processes, there are four variations of ethanol production: existing wet mills, existing dry mills, new dry mills, and new dry mills with combined heat and power. All of the corn-based ethanol production technologies utilize a number of fossil inputs (including electricity, natural gas, gasoline, and coal for the wet mills), and output corn-based ethanol. These technologies also produce a number of co-products ranging from high-fructose corn syrup to dried distiller’s grain. These non-energy co-products have been combined and included via a discount (**DELIV(ENT)**) on the corn-ethanol price. There is also a subsidy for corn-based ethanol applied for the first two time period (2005, 2010). This subsidy is set to zero for the rest of the time periods under the assumption that it will not be reintroduced. The majority of current U.S. ethanol production is dry mill corn-grain ethanol. Although most of the growth in ethanol production is dry mill, the residual capacity includes a number of wet mill facilities.

Cellulosic-based ethanol production via the biochemical platform is set up to use up to five different feedstocks, although for the purposes of the base model run, only stover and other agricultural residues are used. Additional feedstocks for biochemical ethanol can be added for scenario runs.

The thermochemical production of ethanol and a gasoline-blendstock is set up to pull from several different biomass feedstock sources, primarily, woody biomass. For each of these technologies, there is an investment cost (**INVCOST**), fixed and variable O&M (**FIXOM** and **VAROM**), two inputs (a biomass feedstock and the gasoline denaturant), and two outputs (ethanol and mixed higher alcohols that are blended into gasoline). A hurdle rate (**DISCRATE**) reflects the high level of investment uncertainty regarding the technology itself, as well as the uncertainty regarding the availability and price of the biomass feedstock (note that there is no hurdle rate associated with the biomass feedstocks production and logistics).

Ethanol Regional Trading
The model structure for the inter-regional trading, transport and blending of fuels includes individual transport modes (truck, barge, and rail) that move the ethanol from one region to another. Within the importing regions, there are additional technologies that designate where that ethanol was imported via barge, truck or rail. For each combination of mode, there are also energy inputs, variable O&M costs (**VAROM**), and upper bounds (**BOUND(BD)O**) on the capacity for transport. Currently the transportation bounds are set to an upper limit for rail and barge, with much greater flexibility to expand transportation by trucking. However, with corn-based and corn-stover based ethanol being the key feedstocks for much of the ethanol production, trucking is limited to go from Regions 3 and 4 to the other Regions.

Ethanol Blending
The model captures the blending of denatured ethanol and gasoline to an E10 blend and an E85 blend, including the costs associated with conversion of dispensers and storage tanks to handle E85 blends, as well as a blending of biodiesel into a B20 blend.

Biofuels Constraints
The majority of the biofuels constraints are for specifying lower, upper or fixed bounds on the production of particular fuels, such as corn-based ethanol or biodiesel, or categories of fuels, such as advanced biofuels or all exported biodiesel. These constraints are global, cross-region constraints, which means that the sum of the activity in all nine-regions has to meet the constraint. Some constraints are included as placeholders, labeled as non-binding constraints, which can be used in scenarios analyses. There are two share constraints: the share of new corn-based ethanol production that can come from combined heat and power (CHP) facilities, and the share of E85 in the total gasoline/E10 pool. The E85 share constraint is applied to the blending technology that represents gasoline station retrofits to dispense E85, and restricts the total dispensing of E85 to 1/3 of the total gasoline/E10 pool.

Biodiesel
Biodiesel production for use in transportation is also available in the model. Biodiesel is defined as fatty acid methyl esters (FAME) derived from soybean and waste oil. This supply chain includes the oil pre-processing steps (soybean crushing), the actual biodiesel production process, and credits for the co-products (e.g., glycerin), although that price credit drops substantially due to the glycerin glut and assumes no upgrading to refined glycerin.

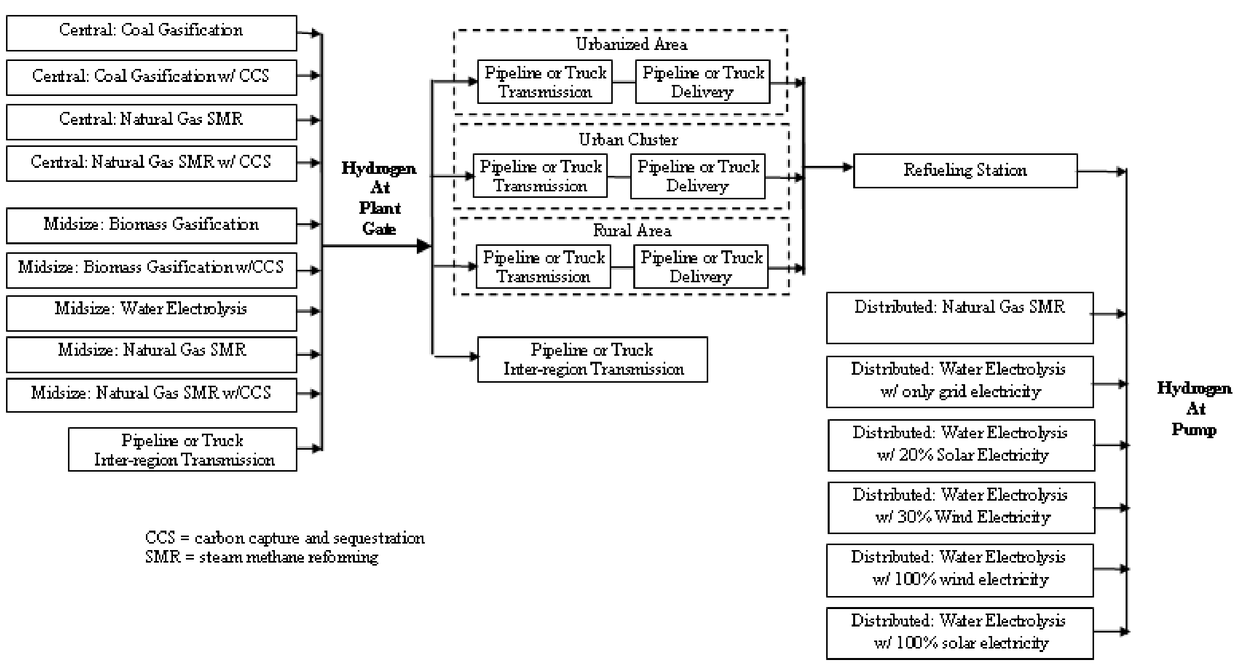
3.7.5 Resource Supply – Municipal Solid Waste

The Municipal Solid Waste (MSW) resource supply is represented in the database by a three step supply curve in each of the nine-regions. Supply upper bounds for MSW come from the 2006 report *The State of Garbage* (Simmons et al.). These bounds are given in Mt, which are then converted to PJ using biomass energy conversion factors taken from the U.S. Department of Agriculture (USDA). Cost data are derived from average garbage collection costs for U.S. cities taken from the EPA Municipal Solid Waste Decision Support Tool (MSW-DST) (Kaplan et al.). MSW supply is either turned into electricity by burning the waste or from the decomposition of the waste over time into landfill gas.

3.7.6 Resource Supply – Hydrogen

Hydrogen, available in the EPAUS9r for use in the transportation sector, is produced in the model by a variety of different technologies: coal gasification, natural gas steam methane reforming, biomass gasification, or electrolysis. The model can also bring in imported hydrogen in liquid form by truck and by gas pipeline. Much of the data for hydrogen production come from *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs* (NRC, 2004). Figure 3.5 illustrates the RES for hydrogen as implemented in each of the nine-regions. The rightmost side of the RES, Hydrogen at Pump, represents the hydrogen as fuel delivered into vehicle tanks. Hydrogen at Pump represents hydrogen fuel either delivered to refueling stations via pipeline or truck, or produced on site by any of the six distributed production technologies. While distributed production technologies combine production and refueling capabilities, The Refueling Station must receive hydrogen via delivery and transmission technologies from centralized production technologies.

Figure 3.5: The Hydrogen Supply Representation in the EPAUS9R



The transportation costs for hydrogen from centralized production technologies to refueling stations are characterized differently according to the type of area where the refueling station is located: Urbanized Area (UA), Urban Cluster (UC) and Rural Area (RA). Generally speaking, a UA refers to a densely settled territory of 50,000 or more people, a UC to at least 2,500 people but fewer than 50,000 people, and any area outside UA or UC is considered a RR.

Central and Midsize Production
Both Central and Midsize technologies are centralized production facilities located away from Refueling Stations, and are therefore connected to the hydrogen distribution infrastructure. The term Central represents a generic 1,200 ton per day hydrogen production facility, while Midsize represents a smaller 24 ton per day plant. Both Central and Midsize plants are dedicated to hydrogen production with no electricity co-generation. All technologies become available in 2015.

CO_2 capture is available for centralized production technologies including natural gas steam methane reform, coal gasification, and biomass gasification systems. Criteria pollutant emissions of these technologies with CCS are assumed to be the same as the corresponding technologies without the CCS option, except for SO_2 emissions, which are 50% lower in those technologies with the CCS option; the amount of CO_2 sequestered is equal to the difference in CO_2 emissions between a CCS technology and its conventional equivalent.

Distributed Production
A distributed production technology is an onsite facility that not only produces hydrogen but also dispenses hydrogen directly to vehicles. Therefore, a distributed production technology could be considered a technological combination of small-scale production and refueling technologies. The distributed production technology in the model represents a 480 kg per day based hydrogen production capacity.

Intra-region Distribution
Intra-region distribution technologies transport Hydrogen at Plant Gate from Central or Midsize plants to Refueling Station, and are modeled separately for UA, UC and RR, with the layouts based on the H_2A Delivery Analysis model (Mintz et al.).

For UA, Hydrogen at Plant Gate is transported by pipeline or truck transmission lines and arrives at the "city gate" of the UA as Hydrogen after Transmission. Hydrogen after Transmission is then transported by pipeline or truck delivery technologies and arrives at Refueling Station as Hydrogen Delivered. Three combinations of intra-region distribution technologies are allowed: pipeline transmission followed by pipeline delivery, pipeline transmission followed by truck delivery, and truck transmission followed by truck delivery.

The UC intra-region distribution is similar. Although it is reasonable for a transmission route to be dedicated to a single UA, dedicating a transmission route to a single UC would result in an unrealistically high cost estimate due to lower demand. As an approximation, the model combines ten UCs into a single urban unit that shares the same transmission route. Hydrogen at Plant Gate is transported by pipeline or truck transmission lines and arrives at the "city gate" of the aggregated cluster of UCs as Hydrogen after Transmission. Hydrogen after Transmission is then transported by pipeline or truck delivery technologies and arrives at Refueling Station as Hydrogen Delivered. Similarly, three combinations of intra-region distribution technologies are allowed: pipeline transmission followed by pipeline delivery, pipeline transmission followed by truck delivery, and truck transmission followed by truck delivery.

For RR, there is a four-segment highway layout approach. Pipelines or trucks transport and deliver Hydrogen at Plant Gate along each segment to Refueling Station technologies. The model allows two technology combinations: pipeline followed by pipeline, and truck followed by truck.

Inter-Region Transportation
The term Inter-Region Transportation includes both Export and Import technologies. The Export technology transports Hydrogen at Plant Gate in one census region to the region's border as Hydrogen Exported, which is then transported by the Import technology of an adjacent destination region and delivered as Hydrogen at Plant Gate in the destination region.

Vehicle Refueling Stations
Hydrogen from centralized production is dispensed to vehicles at Refueling Station technologies. Parameters are based on a hypothetical facility with a 2,740 kg per day hydrogen dispensing capacity.

Constraints Added to Address H_2 Transition Issues, Decentralized Hydrogen Production, and Production by Geographic Area Type
Due to the substantial transportation and distribution infrastructure barriers faced by centralized 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 built. These stations could serve remote, less populated areas where weak economies-of-scale are justified by high hydrogen delivery costs and low demand. To capture this expectation, the model contains constraints that require distributed (onsite) technologies to meet a given fraction of total per-period hydrogen demand. These minimum share constraints gradually relax and approach zero by 2030. The model also contains logical constraints on pipeline versus truck delivery within UA and UC area types.

3.7.7 Electric Sector

The Electric sector consists of conversion technologies that take in fuel resources and convert them to electricity for use in the end-use sectors. Power plant capacity is modeled as gigawatts (GW), and power plant costs are given in terms of dollars per GW. As electricity is produced, the output is converted to PJ of electricity through a conversion factor of 31.536 PJ/GW. The technologies represented range from fossil fuel conversion technologies to nuclear and renewable technologies. In addition to the regular emissions tracking (**ENV_ACT**), water consumption is characterized for all power plants using **ENV_ACT** in terms of million gallons per PJ of output electricity.

The naming convention for electric conversion technologies starts with ‘E’ for Electricity followed by three or four characters representing the fuel type and a number of characters used to represent the technology type. For all technologies with residual capacity, the last letter is “R.” The names of existing non-coal technologies are listed below in Table 3.8.

Table 3.8: Existing Electricity Conversion Technologies

MARKAL Technology Name	Description
EBIOSTMR	Wood/Biomass Steam
EDSLCCR	Diesel Oil Combined-Cycle
EDSLCTR	Diesel Oil Combustion Turbine
EHYDCONR	Hydroelectric, Conventional
EHYDREVR	Hydroelectric, Reversible
ELFGGTRR	Landfill gas to energy: Gas Turbines
ELFGICER	Landfill gas to energy: Engines
ELFGSTRR	Landfill gas to energy: Steam Turbines
EMSWSTMR	Municipal Solid Waste Steam
ENGACCRD	Natural Gas Combined-Cycle; Dry Cooling
ENGACCRO	Natural Gas Combined-Cycle; Open Loop Cooling
ENGACCRR	Natural Gas Combined-Cycle; Recirculating Cooling
ENGACTR	Natural Gas Combustion Turbine
ENGASTMRO	Natural Gas Steam; Open Loop Cooling
ENGASTMRR	Natural Gas Steam; Recirculating Cooling
ERFLSTMR	Oil Steam (Resid Fuel Oil LS)
ESOLPVR	Solar Photovoltaic
EURNALWRO	Pre-Existing Nuclear LWRs; Open Loop Cooling
EURNALWRR	Pre-Existing Nuclear LWRs; Recirculating Cooling
EWNDR	Wind

The existing technologies are characterized by residual capacity (**RESID**), fixed O&M (**FIXOM**), variable O&M (**VAROM**), plant lifetime (**LIFE**), availability (**AF** or **AF(Z)(Y)**), and efficiency (**INP(ENT)c**).

Coal Plant Retrofits
Residual capacity and costs for new installation for a number of air pollution control retrofits available to existing coal powered plants are available in the database. For NO_x reductions the model can choose between Low NO_x Burner (LNB), Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction (SNCR), or a combination set-up. For SO_2 reductions the model has can build flue gas desulfurization (FGD). PM_{10} retrofits include fabric filters (FFR), cyclones (CYC), ESP, and ESP upgrades.

New Electricity Conversion Technologies

Table 3.9 lists the new electric power production conversion technology options. In addition to the parameters specified for existing technologies, new technologies have an investment cost (**INVCOST**) for new construction. With the exception of the availability factors and growth constraints for renewables, the specifications for new generating technologies are the same across the nine MARKAL regions (solar thermal generation is available only in Regions 4, 7, 8, and 9).

The input for the nuclear technologies is **INP(MAT)c** instead of **INP(ENT)c**. In the EPAUS9R database, nuclear power plants take in metric tons of enriched uranium and produce electricity in PJ. Whereas all other conversion technologies have a specified efficiency in terms of **INP(ENT)c** in (PJ/PJ), nuclear conversion efficiency is specified in terms of **INP(MAT)c** in (tons U / PJ ELC). Investment costs represent the cost in the first year the technology is available.

Table 3.9: New Electricity Conversion Technologies

MARKAL Technology Name	Description
EBIOIGCC	Biomass Integrated Gasification Combined-Cycle
ECOALIGCC	Integrated Coal Gasif. Combined Cycle
ECOALIGCCS	Integrated Coal Gasif. Combined Cycle -- CO2 Capt.
ECOALSTM	Pulverized Coal Steam - 2010
EGEOBCFS	Geothermal - Binary Cycle and Flashed Steam
EGEOR	Geothermal, Residual
ELFGGTR	Landfill gas to energy: Gas Turbines
ELFGICE	Landfill gas to energy: Engines
ELFGSTR	Landfill gas to energy: Steam Turbines
ENGACC05	Natural Gas - Combined-Cycle (Turbine)
ENGAACC	Natural Gas - Advanced Combined-Cycle (Turbine)
ENGAACT	Natural Gas - Advanced Combustion Turbine
ENGACCCCS	Natural Gas Combined Cycle -- CO2 Capture
ENGACT05	Natural Gas - Combustion Turbine
ESOLPVCEN	Solar PV Centralized Generation
ESOLSTCEN	Solar Thermal Centralized Generation
ESOLPVCOM	Solar PV Distributed Commercial Generation
ESOLPVRES	Solar PV Distributed Residential Generation
EURNALWR15	Nuclear LWRs, Available in 2015
EWNDCL4A	Wind Generation Class 4 Cost Category A
EWNDCL4B	Wind Generation Class 4 Cost Category B
EWNDCL4C	Wind Generation Class 4 Cost Category C
EWNDCL4D	Wind Generation Class 4 Cost Category D
EWNDCL4E	Wind Generation Class 4 Cost Category E
EWNDCL5A	Wind Generation Class 5 Cost Category A

EWNDCL5B	Wind Generation Class 5 Cost Category B
EWNDCL5C	Wind Generation Class 5 Cost Category C
EWNDCL5D	Wind Generation Class 5 Cost Category D
EWNDCL5E	Wind Generation Class 5 Cost Category E
EWNDCL6A	Wind Generation Class 6 Cost Category A
EWNDCL6B	Wind Generation Class 6 Cost Category B
EWNDCL6C	Wind Generation Class 6 Cost Category C
EWNDCL6D	Wind Generation Class 6 Cost Category D
EWNDCL6E	Wind Generation Class 6 Cost Category E

New Solar and Wind

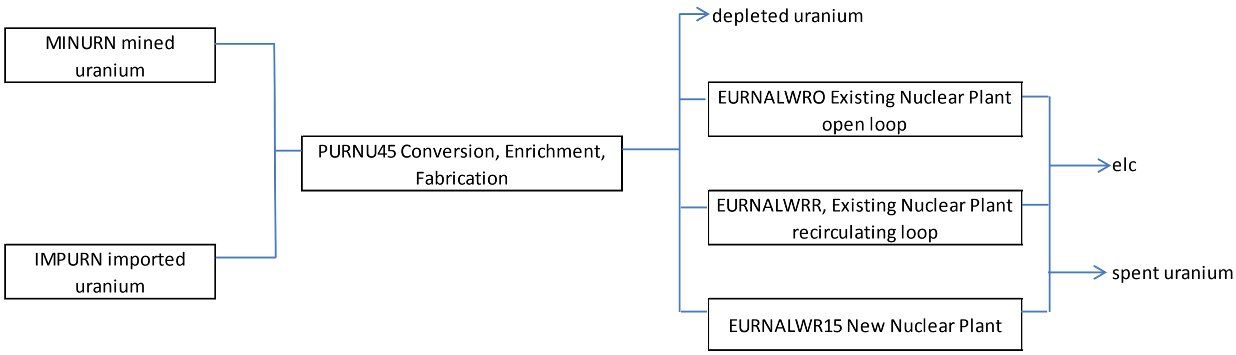
The economics of wind and solar depend strongly on the quality of the available resources, which vary by region. Regionally-specific availability factors (**AF**) differentiate the cost-effectiveness of wind and solar across regions. Two broad solar technology types are modeled: solar photovoltaic (PV) and concentrating solar thermal (ST). Three types of solar PV technology are modeled: central electricity generation plants, distributed generation for residential application and distributed generation for commercial application. The technology representations for commercial and residential PV are found in the commercial and residential end-use sector workbooks. One concentrating central solar thermal technology is modeled.

Three wind technology types are available based on the class of wind resource (Class 4-6) and five cost categories (A-E). The cost categories are based on the ease of access to wind resources for each wind class. The difference in capital cost from one category to another takes into account the cost of transmission interconnection. To constrain the total amount of wind development, total installed wind capacity (summed across wind classes) was constrained by region. In addition, inter-regional constraints on maximum installed wind capacity by cost category and wind class were applied at the national level using the NEMS input data from the AEO.

Nuclear Technology

The nuclear conversion technology RES consists of mined and imported uranium which feed materials (instead of energy carriers) into process technologies that enrich the uranium. These processes create the materials needed for the reactors. The reactors then output electricity and spent materials to be stockpiled. The RES is pictured in Figure 3.6.

Figure 3.6: Nuclear RES



A three step supply curve is available for extraction of uranium and a two step supply curve is available for imported uranium in R0. The uranium goes through a process technology for conversion, enrichment, and fabrication of uranium to U-235. At this point processed uranium is sent to the reactors via export technologies out of R0 and import technologies into each region. Mined raw uranium does not have an implicit energy content (like coal) because it depends on the ultimate level of enrichment. Different nuclear technologies require 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.

Carbon Capture and Sequestration (CCS)

CCS, if successfully implemented on a large scale, would allow the continued use of fossil fuels (especially coal and natural gas) for electric power generation with low atmospheric emissions of CO_2. The EPAUS9r CCS technology representation focuses on CO_2 capture, while incorporating CO_2 sequestration (underground injection) as a single cost term. This emphasis is in keeping with current thinking that capture would account for the largest share of CCS-related costs (IPCC, 2005) as well as the fact that the feasibility and economics of sequestration would likely be driven by policy and geologic factors that lie outside the domain of an energy systems model like MARKAL (Wilson et al.).

CO_2 Capture in EPAUS9r

CO_2 capture from electric power plants may take place along one of two generic technology pathways:

<u>Post-Combustion Capture</u>: Equivalent to traditional “smoke stack” controls for SO_2 and NO_x emissions, this pathway involves separation of CO_2 from the remaining flue gases. Applicable to both coal-steam and natural gas combustion turbines, the post-combustion approach is currently the most mature means of retrofitting existing power generation units (short of a complete repowering).

Pre-Combustion Capture: In this approach the carbon is separated from the fuel stream prior to combustion. The approach to separation most likely to shape the design of new power plants with CO_2 control, pre-combustion capture is a mature process that the hydrogen, synthetic fuel, and chemical industries use routinely. The process begins with either steam reforming or partial oxidation of natural gas, or gasification of coal, to produce hydrogen and CO (other byproducts need to be removed). A water gas shift reaction then produces additional hydrogen while converting CO into a high pressure CO_2 stream. The higher pressure simplifies the CO_2 capture process (which is typically accomplished via physical absorption) and reduces its energy requirements, improving overall system efficiency. The hydrogen is available for use in a combined turbine and steam cycle power generation unit. Coal-based IGCC plants with CO_2 capture are the most frequently mentioned pre-combustion CCS technology in the literature (IPCC, 2005, MIT, 2007).

EPAUS9r represents each of these CCS technology pathways as part of its electric sector module. (Note that the model only includes new post-combustion amine capture as a retrofit option; new coal plants with amine-based CO_2 capture are not likely to be competitive with IGCC or oxyfuel alternatives.) In each representation, the additional power needed to run the CCS technologies is represented as an energy penalty. This shows up in the model as a decrease in the efficiencies of the technologies as compared to conventional power plants without CCS.

CO_2 capture effects parameters related to two sets of emissions: economy-wide CO_2; CO2E, which is CO_2 from the electric sector; and CO2S, which tracks the amount of CO_2 sequestered. These values depend on two quantities: assumed capture efficiency and the underlying conversion technology emissions rate. Relative to their non-CCS counterparts, new CCS generating plants and retrofits reduce CO_2 and CO2E (the negative emission rates, in appropriate units) by an amount equal to CO2S. These values account for the fact that the EPAUS9r electric sector models emissions as a process technology on the fuel chain by factoring in the underlying conversion plant efficiency; i.e., as described earlier, emissions are in terms of energy input, while emissions rates tied directly to conversion plants—new generating units—are expressed in terms of electricity output.

CO_2 Capture Retrofits

EPAUS9r includes CO_2 capture retrofit options for all new coal steam technologies, residual (existing) coal plants, as well as new IGCC and new NGCC capacity. These retrofits sit as process technologies on the fuel chain upstream from their corresponding generating (conversion) technologies. As required by amine-based CO_2 scrubbers, the residual coal retrofits are in line with the flue gas desulfurization (FGD) retrofits (see below), requiring installation of both if CCS is pursued (CCS pass-through's allow FGD installation independent of CCS).

As with the new CCS plants, the retrofit power requirements are interpreted here as an energy penalty (i.e., a base plant output de-rating). The inverse of the retrofit efficiency (**INP(ENT)p**) is the increase in input energy required per unit of retrofit energy output. For a given retrofit energy penalty, this increase in input energy is related to the assumed energy penalty through the following relationship:

Input energy increase = 1 / (1 + energy penalty)

The efficiency for new conversion technologies with CCS, i.e., the inverse of the MARKAL **INP(ENT)c**, includes the CO_2 capture energy requirements. Hence, these conversion technologies, as opposed to the retrofit process technologies, do not include an explicit energy penalty.

CO_2 Sequestration in EPAUS9r

In keeping with this aggregate technology representation and the analytical focus on supply-side CO_2 abatement options, EPAUS9r uses a single figure to represent the cost of CO_2 transport, injection, and long-term monitoring. Geological sequestration enters EPAUS9r as the **ENV_COST** parameter on CO2S. EPAUS9r controls CCS market penetration through region-specific upper bounds on CO2S (**ENV_BOUND(UP)**), the aggregate amount of CO_2 sequestered per model time period.

Electricity Trade

Electricity trade limits in the EPAUS9r represent the non-simultaneous transfer capability of the transmission network to transfer electricity from one area to another for a single demand and generation pattern. Trade in electricity is broken into domestic inter-regional trade, where currently existing, and international transfers between the Canada and Mexico and the United States. The Canadian transfers are identified by province. For the international transfers there is a simple series of three supply steps available to identify a price for the imported electricity.

As the EPAUS9r model simulates the growth in the energy market on a regional basis, the model assumes the placement of the new generating facilities within each region with the interconnection of these facilities to the existing transmission grid. It is only appropriate to assume that these facilities will be integrated into the grid with an eye towards increasing regional reliability. These facilities could in fact by themselves contribute to increasing the transfer capability between two neighboring regions.

CHP Electricity Conversion Technologies

Several combined heat and power (CHP) systems are available that are considered a utility because they produce and sell electricity. These include boiler steam turbines, combustion turbines, microturbines, fuel cells, and reciprocating engines that use biomass, coal, natural gas, oil, or waste.

Electric Sector Constraints

Technology-specific constraints are implemented in the electric sector in the early years of the model time horizon, out to 2020, to help the model to follow historical and predicted electric production capacity.

Renewable Portfolio Standards (RPS)
Thirty-eight states now have defined targets for a percentage of total electricity supply to be met by *designated* renewable technologies. No two of these standards are the same and many of the states have multiple tiers to their standards. Given these considerations, constraints were developed for the EPAUS9r that try to replicate the state standards at the regional level. Data was drawn from DOE's Database of State Incentives for Renewables and Efficiency (DSIRE) (NCSU 2010). Up to three tiers per region were established to incorporate the state level breakouts and filters were developed in the model to specify which renewable technologies fell into each tier. RPS constraints start in the year 2010 and go out until 2055. For most states, once the established standard is met (for example, many states have RPS goals by 2020), the constraint level remains the same for the rest of the model time horizon.

3.7.8 Residential Sector

The residential sector representation in the EPAUS9r covers energy service demands for space heating, space cooling, lighting, water heating, refrigeration, freezing, and other household uses. These demands make up about 16% of the total energy used in the demand sectors of the database. The first six demands can be met in a model run by choosing from a number of detailed technologies. For example, space cooling demand can be met by central air conditioning, room air conditioning, electric heat pump, or geothermal heat pump. These six demands represent 80% of the energy use in the residential sector in 2010. The other 20% of energy demand, which come from appliances such as personal computers, TVs, clothes dryers, ovens, and dishwashers, are met with "Residential Other" technologies that use electricity, natural gas, or LPG. These "other" technologies do not have efficiency improvements over time.

In the reference run total energy consumption in the residential sector grows from 14,311 PJ in 2005 to 16,006 PJ in 2055, an average 1.13% increase per 5-year time period. The total residential energy use by region is shown in Figure 3.7. Much of the increase in energy use in Regions 5, 7, and 9 is due to large population increases in those regions.

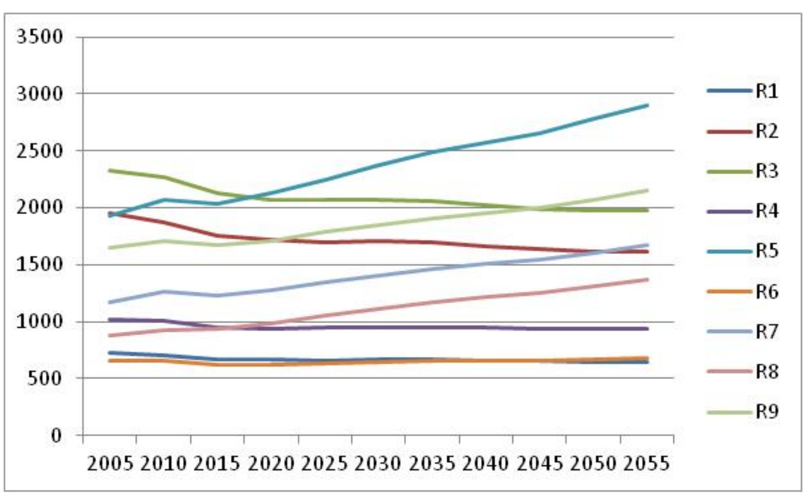


Figure 3.7: Total Residential Energy Use by Region in PJ

Residential Energy Demands

The residential sector is characterized by nine end-use energy demands. The MARKAL names and units are listed in Table 3.10.

Table 3.10: Residential Demands

Residential Demands		
Demand	**Units**	**Descriptor**
RSC	PJ/yr	Space Cooling
RSH	PJ/yr	Space Heating
RWH	PPJ	Water Heating
RLT	billion lumens/yr	Lighting
RRF	million units	Refrigerators
RFZ	million units	Freezers
ROE	PJ/yr	Other - Electricity
ROG	PJ/yr	Other - Natural Gas
ROL	PJ/yr	Other - LPG

The percent of total residential energy demand met by end-use type in 2010 and in 2055 is shown in Figure 3.8.

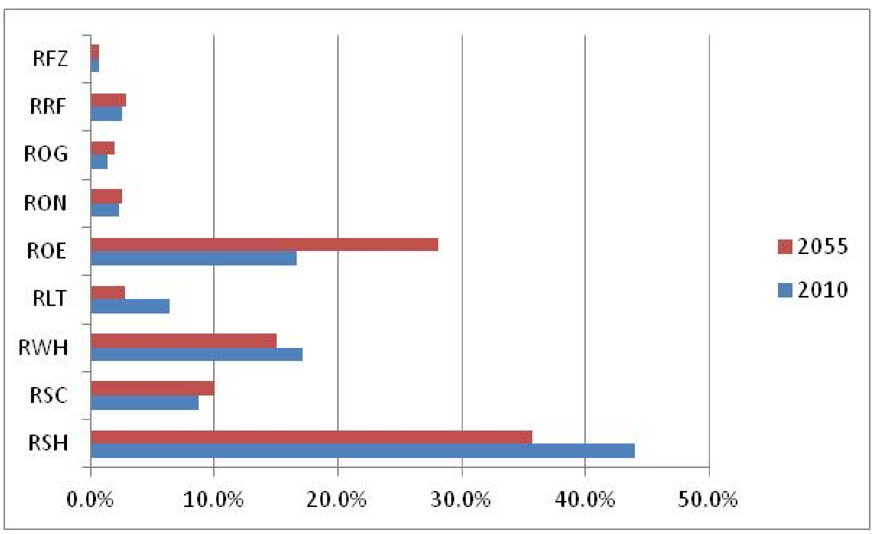


Figure 3.8: Residential Energy Demand by End-Use Type

Demands are first calculated at the national level using the data for energy consumption by end-use demand and fuel and the average stock equipment efficiency from the AEO reference case. Regional demands are then determined using calculations based on either projected population or projected number of households and coefficients calculated for square footage of heated or cooled space, average heating degree days (HDD) and cooling degree days (CDD), or number of units from AEO equipment stock data. The calculations for the individual demands are given below:

RSC: cooling coefficient * square footage of air conditioned space * CDD
RSH: heating coefficient * square footage of heated space * HDD
RWH: national water heating * regional percent of households
RLT: national lighting demand * regional percent of households
RRF: number of households * refrigerators per household
RFZ: number of households * freezers per household
ROE: national other electric * regional percent of households
ROG: national other natural gas * regional percent of households
ROL: national other LPG * regional percent of households

National heating and cooling coefficients go down over time based on AEO assumptions that building shell improvements reduce the energy demands for new and existing buildings. The coefficients are calculated using AEO heating and cooling demands over time and regional values for CDD and HDD, population, household air conditioning use, and household square footage. The CDD and HDD values were taken from the National Climate Data Center Historical Climatological Series (NCDC, 2009).

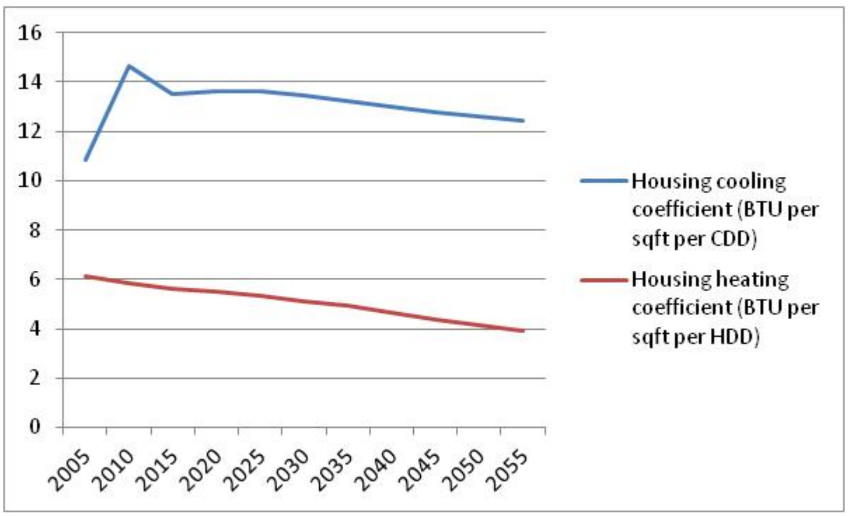


Figure 3.9: Residential CDD coefficient and HDD coefficient

Residential Technology Choice:
Twenty-nine different technology and fuel combinations listed in Table 3.11 meet the six main end use demands. Within each of these technology and fuel combinations there are a number of different available technologies based on vintage year and efficiency.

Table 3.11: Residential Technology and Fuel Combinations

End Use Demand	Technology Type	Fuel				
Space Heating	Radiant	Electric	Natural Gas	Distillate		
	Heat Pump	Electric	Natural Gas	Geothermal		
	Furnace		Natural Gas	Distillate	Kerosene	LPG
	Wood					
Space Cooling	Room AC	Electric				
	Central AC	Electric				
	Heat Pump	Electric	Natural Gas	Geothermal		
Water Heating		Electric	Natural Gas	Distillate	LPG	Solar
Refrigeration		Electric				
Freezing		Electric				
Lighting	Incandescent	Electric				
	CFL	Electric				
	LED	Electric				
	Halogen	Electric				
	Linear Fluorescent	Electric				
	Reflector	Electric				

Technology costs and efficiencies for space cooling, space heating, water heating, refrigeration, and freezers are taken from the AEO Residential Technology Equipment Type Description File (AEO, 2011). Lighting costs and efficiencies were taken from a report prepared for the EIA on residential and commercial building technologies (EIA, 2007).

Fuel shares are given for space cooling, space heating, and water heating starting in 2010 based on the fuel use in 2005. From 2015 to 2055, the given shares for electricity and natural gas are relaxed 3% per time period. Diesel, LPG, and kerosene fuel shares are relaxed 5% per time period out to 2055. Technology shares are given for space heating, space cooling, water heating, and lighting starting in 2010. For space heating, shares are given for furnaces and radiant heat. For space cooling, shares are given for heat pumps, central air conditioners, and room air conditioners. For water heating, shares are given for instantaneous water heaters. As with electricity and natural gas fuel shares, the shares for all of these technologies are relaxed 3% per time period. For the lighting technologies, incandescent lighting shares are reduced 50% by 2020 in keeping with the Energy Independence and Security Act (EISA) of 2007 and drop off to only 5% of the technologies used in 2055. Compact fluorescent and LED lighting technologies increase in shares by a minimum of 20% by 2055. Halogen and linear fluorescent lighting technologies are relaxed 3% per time period.

Residual technologies and new vintages of technologies that use electricity or natural gas and that are already saturated in the market carry a hurdle rate of 18%. Higher hurdle rates are assigned to technologies as follows:

28%	Compact fluorescent lights
45%	LED and linear fluorescent lights
45%	Technologies that use diesel, kerosene, or LPG
45%	Instantaneous and solar water heaters
45%	Electric heat pumps for space heating and cooling
60%	Geothermal heat pumps for space heating and cooling
60%	Room/window air conditioners

Residential Emissions Accounting:
All fuels coming into the residential sector pass through a "dummy" process technology which tracks emissions from a particular fuel type. The technology names start with an "SERES" to indicate emissions tracking for the residential sector, and ends with the three letter name for the fuel type. For every PJ of natural gas, diesel, kerosene, or LPG that flows through these dummy technologies to a specific residential technology, such as a natural gas water heater, the emissions from that fuel are counted. No costs are associated with these technologies. Emissions for electricity production are handled in the electric sector. Electricity passes through its own "dummy" technology called "SCRESELC" to get to the residential sector.

3.7.9 Commercial Sector

The commercial sector representation in the EPAUS9r database covers energy service demands for space heating, space cooling, lighting, water heating, refrigeration, cooking, ventilation, office equipment, and other commercial uses. These demands make up about 13.5% of the total energy used in the demand sectors of the database. The first seven demands can be met in a model run by choosing from a number of detailed technologies. For example, water heating demand can be met by electric, natural gas, or solar water heaters or an electric heat pump. These seven demands represent 64% of the energy use in the commercial sector in 2010 in the AEO. The other 36% of energy demand comes from other equipment such as office computers and printers, automated teller machines, telecommunications equipment, medical equipment, and emergency generators. These demands are met with "Commercial Miscellaneous" and "Commercial Office Equipment" technologies that use electricity, natural gas, diesel, fuel oil, or LPG. In the base representation, these "other" technologies do not have efficiency improvements over time.

In the reference run, total energy consumption in the commercial sector grows from 9,420 PJ in 2005 to 13,172 PJ in 2055, an average 3.42% increase per 5-year time period. The total commercial energy use by Region is shown in Figure 3.10.

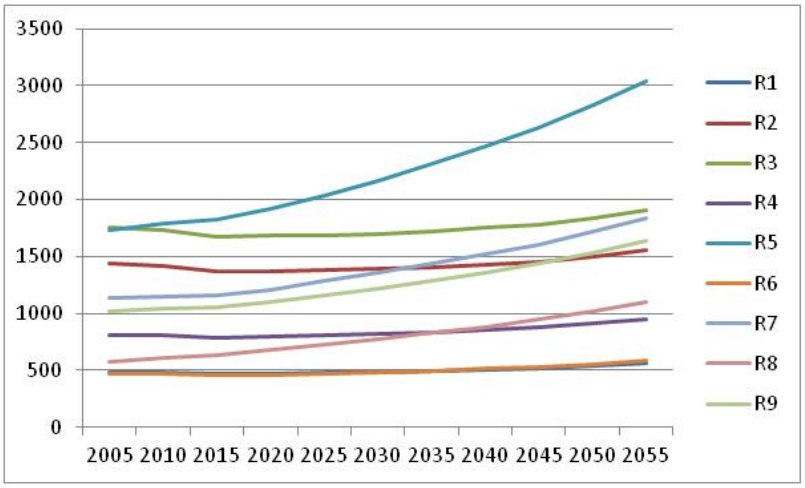


Figure 3.10: Commercial Energy Use by Region in pJ

Commercial Energy Demands

The commercial sector is characterized by thirteen end-use energy demands. The MARKAL names and units are listed in Table 3.12.

Table 3.12: Commercial Demands

Commercial Demands		
Demand	**Units**	**Descriptor**
CSH	PJ/yr	Space Heating
CSC	PJ/yr	Space Cooling
CWH	PJ/yr	Water Heating
COF	PJ/yr	Office Equipment
CCK	PJ/yr	Cooking
CLT	billion lumens/yr	Lighting
CMD	PJ/yr	Misc - DSL
CME	PJ/yr	Misc - ELC
CMN	PJ/yr	Misc - NG
CML	PJ/yr	Misc - LPG
CMR	PJ/yr	Misc - RFL
CRF	PJ/yr	Refrigeration
CVT	tcfm-hr	Ventilation

The percent of total commercial energy demand met by end-use type in 2010 and in 2055 is shown in Figure 3.11.

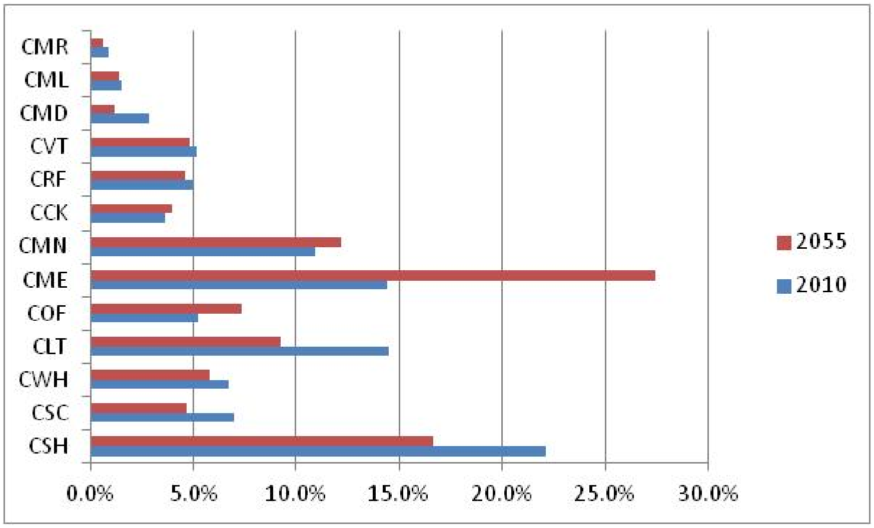


Figure 3.11: Commercial Energy Demand by End-Use Type

Demands are calculated by determining the energy intensity per square foot for each end-use demand from the average stock equipment efficiency in the AEO reference case and multiplying those intensities by the regional square footage. Heating and cooling demands are determined using calculations based on either projected population or projected number of households and coefficients calculated for square footage of heated or cooled space, average HDDs and cooling degree days CDDs from AEO equipment stock data. The calculations for the individual demands are given below:

CSC: cooling coefficient * square footage of air conditioned space * CDD
CSH: heating coefficient * square footage of heated space * HDD
CWH: water heating intensity * regional square footage
CLT: lighting intensity * regional square footage
CRF: refrigeration intensity * regional square footage
CVT: ventilation intensity * regional square footage
CCK: cooking intensity * regional square footage
COF: national demand for office equipment per square foot * regional square footage
CME: national demand for "other" electricity per square foot * regional square footage
CMN: national demand for "other" natural gas per square foot * regional square footage
CMD: national demand for "other" diesel per square foot * regional square footage
CML: national demand for "other" LPG per square foot * regional square footage
CMR: national demand for "other" residual fuel per square foot * regional square footage

National heating and cooling coefficients go down over time based on AEO assumptions that building shell improvements reduce the energy demands for new and existing buildings. Figure 3.12 shows the change in CDD and HDD coefficient values over time. The coefficients are calculated using AEO heating and cooling demands over time and regional values for CDD and HDD, population, household air conditioning use, and household square footage.

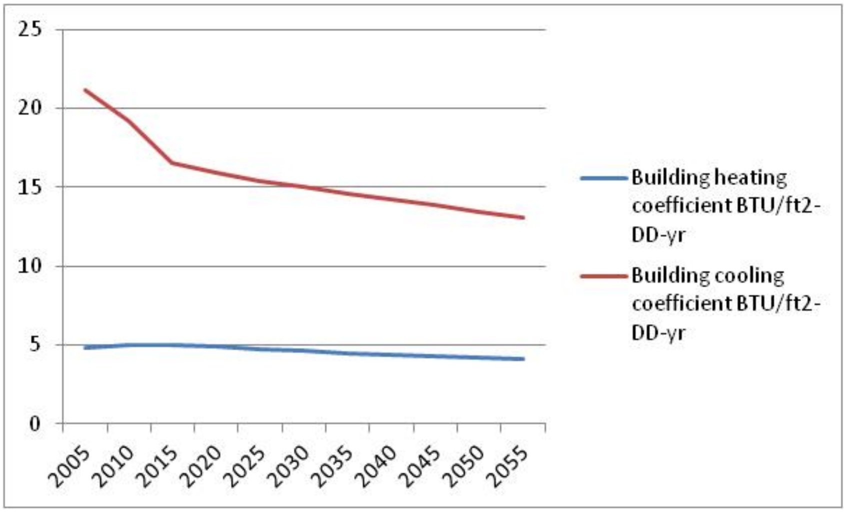


Figure 3.12 Commercial CDD coefficient and HDD coefficient

Commercial Technology Choice:
Forty-three different technology and fuel combinations are available to meet the seven main end use demands are listed in Table 3.13. Within each of these technology and fuel combinations there are a number of different technology representations based on vintage year and efficiency.

Table 3.13: Commercial Technology and Fuel Combinations

End Use Demand	**Technology Type**	**Fuel**			
Space Heating	Heat Pump	Air Source	Natural Gas	Ground Source	
	Boiler	Electric	Natural Gas	Diesel	
	Furnace		Natural Gas	Diesel	
Space Cooling	Heat Pump	Air Source	Natural Gas	Ground Source	
	Centrifugal Chiller	Electric	Natural Gas		
	Reciprocating Chiller	Electric			
	Scroll Chiller	Electric			
	Screw Chiller	Electric			
	Rooftop A/C	Electric	Natural Gas		
	Window/Wall A/C	Electric			
	Central A/C	Electric			
Water Heating		Electric	Natural Gas	Diesel	Solar
Ventilation	CAV	Electric			
	VAV	Electric			
Cooking		Electric	Natural Gas		
Refrigeration	Central	Electric			
	Walk-in Refrigerator	Electric			
	Walk-in Freezer	Electric			

	Reach-in Refrigerator	Electric			
	Reach-in Freezer	Electric			
	Ice Machine	Electric			
	Beverage Machine	Electric			
	Vending Machine	Electric			
Lighting	Incandescent	Electric			
	CFL	Electric			
	LED	Electric			
	Halogen	Electric			
	Linear fluorescent	Electric			
	Mercury Vapor	Electric			
	Metal Halide	Electric			

Technology costs and efficiencies for space cooling, space heating, water heating, lighting, refrigeration, and freezers are taken from the AEO Commercial Technology Equipment Type Description File (AEO, 2011a).

Fuel shares are given for space cooling, space heating, cooking, and water heating starting in 2010 based on fuel use in 2005. From 2015 to 2055, the given shares for electricity and natural gas are relaxed 3% per time period. Diesel, LPG, and kerosene fuel shares are relaxed over 5% per time period out to 2055. Technology shares are given for space heating, space cooling, water heating, lighting, ventilation, and refrigeration. For space heating, shares are given for furnaces, boilers, and other electric technologies. For space cooling, shares are given for rooftop, central, and wall/window air conditioners, air-source and ground-source heat pumps, and chillers. For water heating, shares are given for solar systems and heat pumps. As with electricity and natural gas fuel shares, the technology shares are relaxed 3% per time period. Incandescent lighting shares are reduced 60% by 2020 in keeping with the 2007 EISA and drop off to only 5% of the technologies used in 2055. All other lighting technologies are relaxed 3% per time period. Ventilation and refrigeration technology splits are held constant throughout the model time horizon.

Commercial technologies and new vintages of technologies that use electricity or natural gas and that are already saturated in the market carry a hurdle rate of 18%. Higher hurdle rates are assigned to technologies as follows:

24%	All high efficiency technologies (except otherwise noted).
24%	Ground source heat pumps, standard efficiency
45%	Ground source heat pumps, high efficiency
45%	Solar water heaters
60%	All high efficiency natural gas technologies
75%	Diesel technologies
125%	Diesel boilers

Commercial Emissions Accounting:
All fuels coming into the commercial sector pass through a "dummy" process technology which tracks emissions from a particular fuel type. The technology names start with an "SECOM" to indicate emissions tracking for the residential sector, and ends with the three letter name for the fuel type. For every PJ of natural gas, diesel, kerosene, or LPG that flows through these dummy technologies to a specific residential technology, such as a natural gas water heater, the emissions from that fuel are counted. No costs are associated with these technologies. Emissions for electricity production are handled in the electric sector. Electricity passes through its own "dummy" technology called "SCCOMELC" to get to the commercial sector.

3.7.10 Industrial Sector

The industrial sector representation in the EPAUS9r database covers energy demands for six main industrial sub-sectors: food, paper, chemicals, nonmetallic mineral products, primary metals, and transportation equipment. Two additional smaller demands are represented: other manufacturing, including wood and plastics, and non-manufacturing, including agriculture and construction. These demands make up about 32.5% of the total energy used in the demand sectors of the database. The six main industrial subsectors account for 60% of energy demand in the industrial sector. Another 10% is covered by the other manufacturing and non-manufacturing demands. Much of the remaining 30%, which includes petroleum and coal products, is covered in other parts of the database including the refinery sector and the various resource supply sectors.

In the reference run total energy consumption in the residential sector grows from 42,250 PJ in 2005 to 57,979 PJ in 2055, an average 3.25% increase per 5-year time period. The total industrial energy use by region is shown in Figure 3.13.

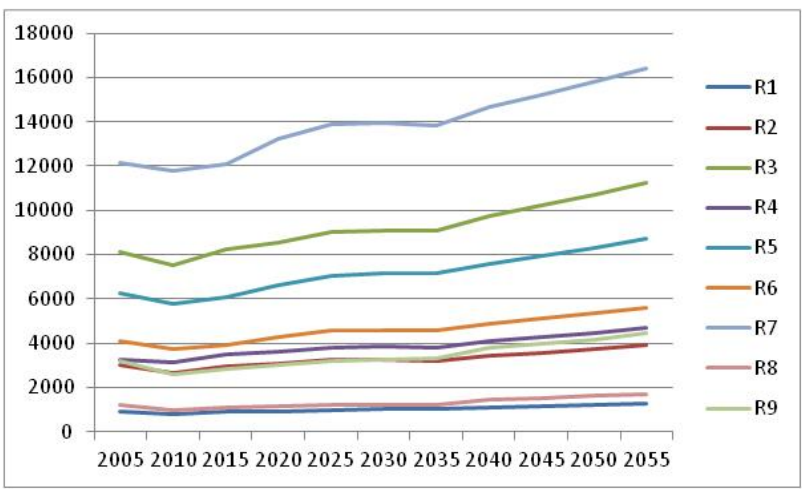


Figure 3.13: Industrial Energy Use by Region in PJ

Industrial Energy Demands
The industrial sector is characterized by eight end-use energy demands. The MARKAL names and units are listed in Table 3.14.

Table 3.14: Industrial Demands

Industrial Demands		
Demands	**Units**	**Description**
IC	PJ/yr	Chemicals
IF	PJ/yr	Food
IM	PJ/yr	Primary Metals
IN	PJ/yr	Non-metallic Minerals
IP	PJ/yr	Paper
IT	PJ/yr	Transportation Equipment
IO	PJ/yr	Other Manufacturing
IXNONM	PJ/yr	Non-manufacturing

The percent of total industrial energy demand met by sub-sector in 2010 and in 2055 is shown in Figure 3.14.

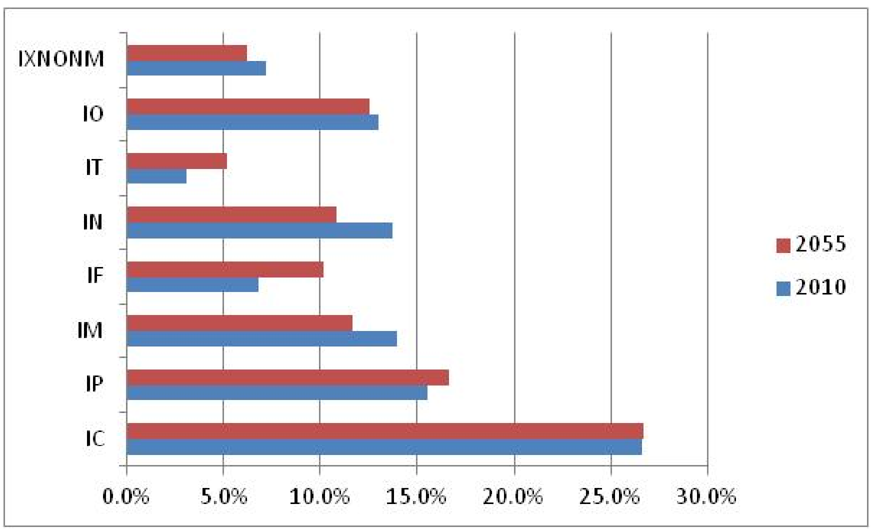


Figure 3.14: Industrial Energy Demand by Sub-Sector

National demands are calculated for each sub-sector using AEO reference case data for the value of shipments in dollars and the total energy consumption per dollar shipment. The energy consumption per dollar shipment is held constant at the 2009 value for all years. Energy efficiency improvements, which cause the AEO reference case values for energy consumption per dollar shipment to decrease over time, are ignored in the demand calculations. Instead, energy efficiency improvements are handled in the process technologies used to meet the demands. National level demands are then regionalized using EIA Manufacturing Energy Consumption Survey (MECS) (EIA, 2006) data for fuel consumption by sub-sector by region. With these data, the percent of each sub-sector demand met by each Region in 2006 was calculated. These percentages were then applied to the total sub-sector demand at a national level to obtain regional demands. The sub-sector breakdowns by region in 2006 are assumed to remain consistent throughout the model time horizon.

Industrial Technology Choice:
The industrial sector is modeled a little differently than the other end-use sectors. The industrial sector has a three layer structure consisting of a demand layer, an end-use demand technology layer, and a process technology layer.

Every demand has one end-use demand technology used to represent the sum total of the energy needs of the different process technologies. These technologies are named in MARKAL with the first two letters equal to the demand name, followed by "TECHEXT," an abbreviation for "existing technologies." For example, the demand technology for the food sub-sector is IFTECHEXT.

Each of the demand technologies is characterized by input energy carriers from up to eight different process technologies. Each of those energy carriers is given an input value equal to the percent of total fuel use in that sub-sector by the process technology it represents. Table 3.15 shows the energy carriers and their MARKAL naming conventions.

Table 3.15: Industrial Energy Carriers

Energy Carriers to End-Use Demand Technologies		
First two letters represent the demand	**Final letters represent the technology**	**Description**
IC, IF, IM, IN, IP, IT, or IO	STM	Steam
	BOL	Boilers
	PRH	Process Heat
	MDR	Machine Drives
	FAC	Facility
	EC	Electrochemical
	FEED	Feedstock
	HEAT	Other Heat

Process technologies are represented that output the different demand energy carriers. For example, non-metallic mineral sector machine drive needs can be met by diesel, electric, natural gas, or coal powered drives. The model chooses which process technologies to use based on fuel type, costs, efficiencies, and constraints.

Investment and fixed O&M costs are given for boilers, machine drives, electrochemical, and process heat technologies. Feedstock, facilities, steam, and other heat technologies do not have any costs associated with them. Changes in technology efficiency are calculated using the change in energy consumption per dollar shipment values over time from the AEO reference case run and are characterized in MARKAL using the input energy parameter.

Constraints are placed on process technologies to control the fuel shares used by each sub-sector. The constraints are based on the percentage a specific energy carrier accounts for the total energy use of a technology based on MECS. When MECS data are not available, AEO data are used. Constraints apply over all regions unless the technology does not exist in a particular region. Because of the end-use driven nature of the industrial sector, energy carriers and process technologies are tightly constrained. Fuel shares add up to 100% in 2010. From 2015 through 2050, some shares are reduced to allow for fuel switching, with natural gas and coal lower constraints being reduced 10% to 32% over the course of the model time horizon.

Industrial Emissions Accounting:
Industrial emissions are accounted for in the process technologies and parameterized as quantity of emission per PJ of fuel used in a given technology. Only emissions factors associated with fuel combustion are tracked. Therefore, no emissions are associated with feedstocks. Emissions from electricity generation are tracked in the electric sector at the power production plant.

Industrial Pulp and Paper Black Liquor Production
Within the industrial sector, the paper sub-sector creates a bi-product called black liquor. This black liquor can be gasified to create electricity and steam. The supply of black liquor, called MININDBL, is characterized in the database with a black liquor supply curve for each region. No costs are associated with the by-product, but there is an upper bound. The gasification process technology is called IPBLGCC. Black liquor and mill residue can also be used to power a boiler. This process technology is called IPBORBIO00. Both processes are characterized by investment and fixed O&M costs, efficiencies, and availability factors.

3.7.11 Transportation Sector

The transportation sector in the EPAUS9r database covers energy service demands for the following sub-categories: light duty vehicles, heavy duty vehicles, and off-highway vehicles. These demands make up about 38% of the total energy used in the demand sectors of the database.

Light Duty Vehicles (TL)

The light duty vehicle sub-sector, which accounts for about 55% of the total transportation demand, represents fuel use for personal vehicle miles traveled. The vehicle technologies available to the model range in fuel type and efficiency. In addition, there are seven different class sizes: mini-compact, compact, full size, minivan, pick-up truck, small SUV, and large SUV.

In the reference run, energy consumption for the fleet of personal vehicles decreases at an average of 2.4% per time period from 2005 to 2030 resulting from increasingly stringent Corporate Average Fleet Efficiency (CAFÉ) targets. From 2035, however, increases in vehicle miles traveled more than offsets the efficiency targets, and energy demands increased at an average of 2.0% per time period out to 2055. The total personal vehicle energy use by region is shown in Figure 3.15.

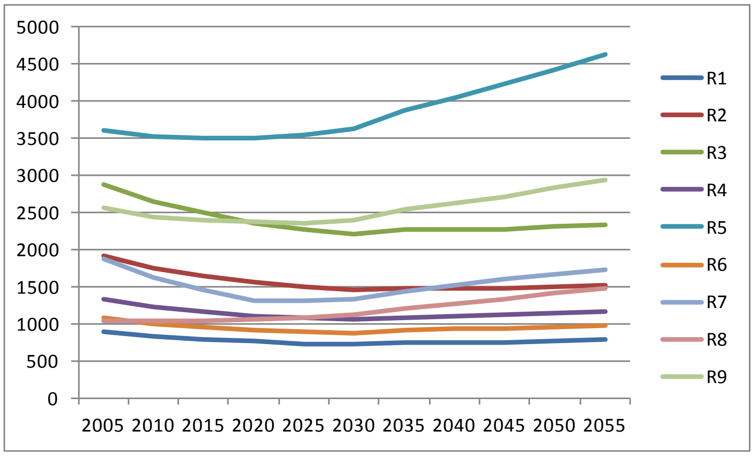


Figure 3.15: Light-duty Vehicle Energy Use by Region in PJ

Light Duty Vehicle Demands
There is one demand for the light duty vehicles, given the name TL. The demand is given in billion vehicle miles traveled.

Demands are calculated using the national vehicle miles traveled (VMT) reported in the AEO. Using population data, VMT per person can be calculated. The data are then regionalized using the Transportation Energy Consumption Survey regional percentage of vehicle miles traveled (EIA, 2001). An important assumption made in the database is that beyond 2035, the VMT per person is held constant.

Light Duty Vehicle Technology Choice:
Nineteen different fuel and technology combinations are available in one or more of the seven car classes, listed in Table 3.16.

Table 3.16: Light Duty Vehicle Fuel and Technology Combinations

		Car Class						
		Mini-Compact	**Compact**	**Full-size**	**Minivan**	**Pickup**	**Small SUV**	**Large SUV**
Gasoline	Conventional	X	X	X	X	X	X	X
	Advanced	X	X	X	X	X	X	X
	Hybrid		X	X	X	X	X	X
	Plug-in Hybrid (20 miles per charge)		X	X	X	X	X	X
	Plug-in Hybrid (40 miles per		X	X	X	X	X	X

	charge)							
Diesel	Conventional		X	X	X	X	X	X
	Hybrid		X	X	X		X	X
E85	Flexfuel		X	X	X	X	X	X
	Advanced		X	X	X	X	X	X
	Hybrid		X	X	X	X	X	X
	Plug-in Hybrid (20 miles per charge)		X	X	X	X	X	X
	Plug-in Hybrid (40 miles per charge)		X	X	X	X	X	X
CNG	Conventional		X	X	X	X		
	Flexfuel		X	X	X	X		
LPG	Conventional				X	X		
	Flexfuel		X	X	X	X		
Hydrogen	Fuel Cell		X	X	X	X	X	X
Electric	100 mile range	X	X	X	X	X	X	X
	200 mile range	X	X	X	X	X	X	X

Technology costs and efficiencies are calculated by layering EPA Office of Transportation Air Quality's (OTAQ) vehicle assumptions for advanced technologies on AEO assumptions regarding conventional vehicle technologies. Data from 2040 through 2055 are held constant to the 2035 value. AEO adjustment factors are used to reduce efficiencies to account for real-world driving conditions and vehicle degradation over time. In the transportation sector, instead of having a new technology created for each change in investment cost and efficiency, there is one technology with changing investment costs over time and vintaged efficiencies.

Car class constraints are introduced into the database in the 2010 time period to mimic the current distribution of cars across the country. From 2010 to 2035 the class splits are adjusted, with a greater percentage of light-duty transportation demand being met by smaller, more efficient vehicles. From 2035 on, the splits remain the same. Figure 3.16 shows the distribution of car classes in 2010 and 2035.

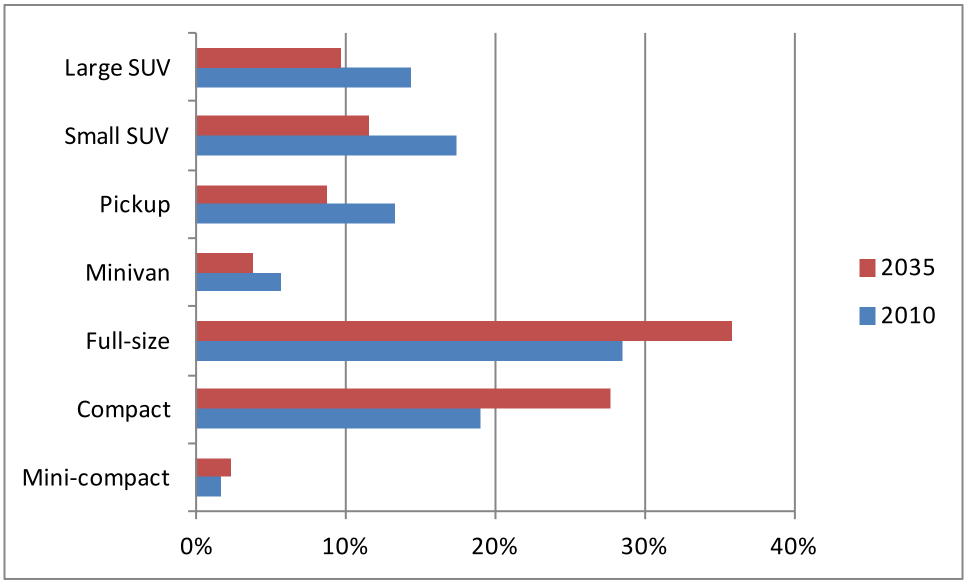


Figure 3.16: Distribution of Car Classes

In addition to class constraints, a number of other technology or fuel specific constraints are implemented in the database:

- 100 mile and 200 mile electric vehicles are limited to a maximum penetration equal to the number of consumers whose needs can be met with those ranges.
- Diesel-powered vehicles are given a regionally specific fixed amount of investment in each time period.
- Fuel cell vehicles, hybrid, hybrid electric, and advanced gasoline fueled vehicles are limited to a certain market penetration that increases over time. Most can penetrate the market 100% by 2025 if the model run finds the 100% market penetration to be the least cost solution.
- All technology types have a fixed investment constraint in 2010 that mimics the conditions in the actual market in 2010.
- A global constraint is implemented that forces a reduction in the total fuels going to light duty vehicles over time. This mimics the national CAFÉ standard that forces an improvement in the overall efficiency of light duty vehicles over time. No credit is given towards the standard for alternative fuel vehicles, and the constraint does not represent different efficiency targets for cars and trucks.

Conventional vehicles carry a hurdle rate of 40%. All other vehicles carry a hurdle rate of 44%.

Light Duty Vehicle Emissions Accounting:

Passenger vehicle emissions are tracked in two places. Carbon dioxide emissions are accounted for on the fuel collector coming into the transportation sector to allow for the differences in emissions when different blends of gasoline and biofuels are used. The remaining emissions are accounted for on the demand technology itself. The emission factors are derived from runs of the Motor Vehicle Emission Simulator (MOVES) (EPA, 2010) model. Emission factors for existing vehicles include consideration of pre-2005 vintages that leave the fleet, as well as degradation of vehicle emission controls over time. Emission factors for 2010 and later vintages represent lifetime average emissions and do not otherwise incorporate degradation.

Heavy Duty Vehicle Use

The heavy duty vehicle sector representation in the EPAUS9r database, which accounts for 43% of the total transportation demand, covers energy service demands for the following sub-categories: air, bus, commercial trucks, medium and heavy duty trucks, passenger and freight rail and shipping.

In the reference run total energy consumption in the heavy duty transportation sector grows from 9,427 PJ in 2005 to 12,964 PJ in 2055, an average 3.2% increase per 5-year time period. The breakdown by sub-sector is shown in Figure 3.17.

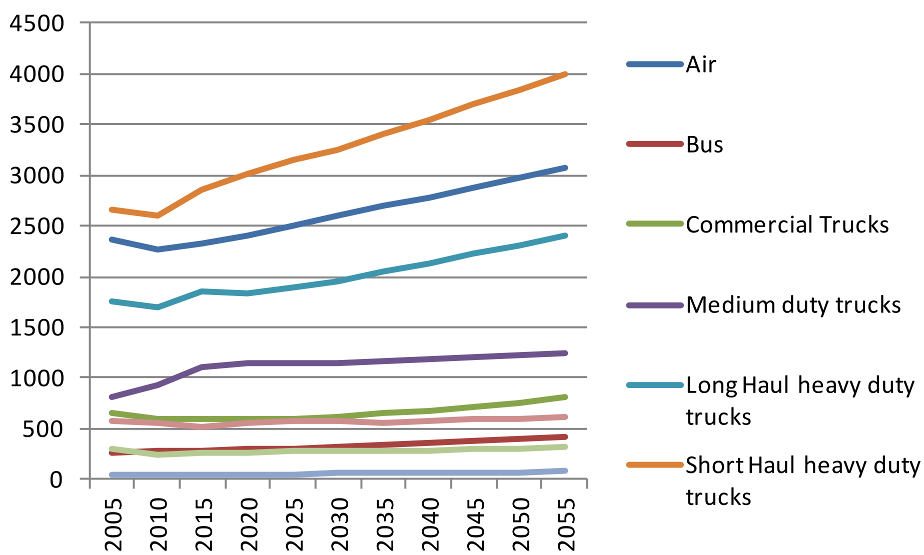


Figure 3.17: Heavy Duty Vehicle Energy Use by Type in PJ

Heavy Duty Transportation Energy Demands
The heavy duty transportation sector is characterized by nine end-use energy demands. The MARKAL names and units are listed in Table 3.17.

Table 3.17: Heavy Duty Transportation Demands

Heavy Duty Transportation Demands			
Name	**Description**	**Units**	**Unit Description**
TA	Domestic Air Transport	bn-pass-miles	billion passenger miles
TB	Bus	bn-vmt	billion vehicle miles traveled
TC	Commercial Trucks (Class 2b)	bn-vmt	billion vehicle miles traveled
TM	Medium Duty Trucks (Class 3-6)	bn-vmt	billion vehicle miles traveled

THL	Short Haul Heavy Duty Trucks (Class 7-8)	bn-vmt	billion vehicle miles traveled
THL	Long Haul Heavy Duty Trucks (Class 7-8)	bn-vmt	billion vehicle miles traveled
TRF	Freight Rail	bn-t-m	billion ton miles
TRP	Passenger Rail	bn-pass-miles	billion passenger miles
TS	Shipping (Marine)	bn-t-m	billion ton miles

Demands are calculated by using national level energy consumption from the AEO which are regionalized using data collected from a number of different sources.

Heavy Duty Transportation Technology Choice:
A number of different technology choices that vary in fuel use and efficiency improvements are available. Table 3.18 lists these choices. Within some of these combinations there are different vintage years available.

Table 3.18: Heavy Duty Vehicle Demand Types, Fuel, and Technology Combinations

End Use Demand	Fuel Type	Efficiency Improvements				
Air	Jet Fuel	Wing tip design	Improved Aerodynamics	Auxiliary Power Unit	Blended Wing Design	Geared Engine
	Gasoline					
Bus	Gasoline					
	Diesel	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Biodiesel (20%)	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	CNG	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Hydrogen Fuel Cell	Hybrid				
Commercial	Gasoline	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Diesel	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Biodiesel (20%)	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	CNG	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	E85	Improved Efficiency	Advanced Technology			
	LPG	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Hydrogen Fuel Cell					
Medium	Gasoline	Improved	Advanced	Advanced		

and Heavy Duty Short Haul		Efficiency	Technology	Hybrid		
	Diesel	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	Biodiesel (20%)	Improved Efficiency	Advanced Technology	Advanced Hybrid		
	CNG	Improved Efficiency		Advanced Hybrid		
	LPG	Improved Efficiency		Advanced Hybrid		
Heavy Duty Long Haul	Diesel	Improved Efficiency	Advanced Technology	Advanced Hybrid	Smartway	Smartway Hybrid
	Biodiesel (20%)	Improved Efficiency	Advanced Technology	Advanced Hybrid	Smartway	Smartway Hybrid
	LNG		Advanced Technology	Advanced Hybrid	Smartway	Smartway Hybrid
Passenger Rail - Commuter	Diesel					
	Electricity					
Passenger Rail - Subways and Streetcars	Electricity					
Passenger Rail - Intercity	Diesel					
Freight Rail	Diesel	Improved Efficiency	Auxiliary Power Unit			
	Biodiesel (20%)					
	LNG					
Shipping	Residual Oil	Fuel Injection	Bubble Lubrication			
	Diesel	Fuel Injection	Hybrid			

User defined constraints are given for fuel shares in each of the sub-sectors. These shares are set for the year 2010 based on historical data in the years leading up to 2010 in the AEO. After 2010, shares are relaxed to give the model freedom to switch to different fuels and/or different technologies. In most cases, constraints are relaxed 1-3% per period. For some fuels, AEO projects increased usage in the future (for example, CNG usage in buses). For these fuels, the share is constrained to match AEO in 2035.

The base efficiency technologies carry a hurdle rate of 18%. Higher hurdle rates are assigned to technologies as follows:

20%, 24%, 26%	Improved efficiency (modelers choice between the three)
24%	Hydrogen fuel cell technologies
28%	Advanced technology improvements

Off-Highway Diesel and Gasoline Use

Off-road diesel and gasoline used for construction, agriculture, industrial, commercial, and recreational purposes is tracked in the model using a simple system. Off-highway demand accounts for about 2% of the total transportation demand. There are two demands, one for diesel and one for gasoline, and two technologies that feed fuel into those demands. No costs are associated with the technologies, so essentially, the system is set-up to track the fuel use by off-road technologies and their corresponding emissions. Any reductions due to technology efficiency improvements are captured in the associated demands.

National demand for off-road fuel use at the start of the model time horizon is calculated using data from Oak Ridge National Laboratory (ORNL) *Off-Highway Transportation-Related Fuel Use* (Davis and Truett, 2004). Future year demands are calculated using a growth rate developed from AEO projections of agriculture, construction, and recreational transportation gasoline and diesel fuel use. National demands are then regionalized.

3.7.12 Air Quality Regulations and CAIR

Air quality regulations affecting the electric sector are represented in the EPAUS9r as both regional upper bounds (**ENV_BOUND)BD**) and global limits (**GEMLIMT**) on NO_x and SO_2 emissions. The purpose of the air quality regulation representation is to approximate limits on NO_x and SO_2 emissions from the electric sector that result from regulations that pre-date the Clean Air Interstate Rule (CAIR).

Emission limits for 2010 and 2015 were obtained from U.S. EPA Clean Air Market Division (CAMD) analysis of CAIR (EPA, 2004). The technical support document for that analysis provides state-level emissions of NO_x and SO_2 for both CAIR and non-CAIR modeling. We aggregate the non-CAIR state-level totals to the Census Division to obtain regional constraints. These constraints are then imposed upon the regional emissions. National emissions of both species from the electric sector are capped at 2015 levels through 2055.

CAIR emissions limits are represented in a similar manner, although CAMD's CAIR modeling results were used to develop state-level emission totals. The CAIR emissions limits also represent the effects of the Mercury Air Toxics Standards (MATS) toxics rule. To approximate the requirements of that rule, we obtained national totals for SO_2 and NO_x from CAMD's analysis of MATS (EPA, 2011) for 2015, 2020 and 2030. Constraint values for 2025 were interpolated.

We expect that CAIR, MATS, and Prevention of Significant Deterioration (PSD) rules will also impact the utilization of control technologies. Therefore, we represent the impacts of these rules by applying bounds (**BOUND(BD)O**) on the use of control technologies. For SO_2 controls, we assume that, after 2020, FGD will be used at all coal plants that utilize non-low-sulfur coal. Further, for those plants that do not use low-sulfur coal, but have FGD in place in 2020, FGD must continue to be used (e.g., controlled plants cannot "back off" their use of controls). For NO_x controls, we assume that all coal plants use some form of NO_x control from 2020 through the end of the time horizon. For particulate matter (PM) controls, upgrades beyond cyclones and electrostatic precipitators (ESP), whether ESP or fabric filters, are required for all coal units.

4. Database Quality Control Process

To ensure an accurate representation the EPAUS9r has been constructed and evaluated in the following ways:

- Data were chosen using the established quality guidelines outlined in the Quality Assurance Project Plan developed for this project.
- Data are fully documented and have been run through quality control checks to ensure accurate transmission of raw data into the MARKAL database
- The original database was subject to a full model peer review
- The results of a reference case EPANUS9r MARKAL run were assessed against the results of AEO for the year correlating to the most recent update of the database and found to be within stated ranges for measures of fuel use system-wide and within each sector.

The majority of the data were taken from NEMS (EIA, 2009) input data underlying the AEO. AEO data were selected because the AEO 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 EPAUS9r or better data were determined to exist. Where better data could be found, data were chosen and ranked using Table 4.1, given below. The rankings were determined based on the desire to use widely accepted, quality controlled and/or peer reviewed, data and to minimize the bias in information that is used in the database.

Table 4.1 Data Source Quality Rankings

Rank	Quality	Source
A	Highest	Federal and state agencies and laboratories
B	Second	Independent journal articles, academic studies, and manufacturer product literature
C	Third	NGO studies, trade journal articles, and conference proceedings: peer-reviewed
D	Fourth	Conference proceedings and other trade literature: non peer-reviewed
E	Lowest	Individual estimates

The goal in developing the database was that 90% of the data would be from sources in the top three tiers of data quality.

Another goal of the EPAUS9r is to ensure that the data are fully documented, are entered properly into the database with required units properly calculated, and are an accurate representation of the information provided in the reference source. ECAT 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.

A comprehensive peer review of the original EPA database was done to ensure that its performance is reasonable and that disaggregation to nine-regions has been well represented. The questions asked of the peer reviewers were as follows:

- Are the results plausible for a tested scenario?
- Are influences between sectors reasonable?
- Are influences and trades between regions reasonable?
- Are there critical regional constraints or ad ratios which are missing from the database?
- Are some constraints or bounds "over constraining" the model and limiting flexibility?
- Are there critical weaknesses in the database that significantly influence the results?

The peer reviews were exhaustively documented, and the peer reviewers found no major errors in the database. Peer review comments and any necessary changes were incorporated into the database.

Finally, before any release, a reference MARKAL run is performed and calibrated to ensure that the model is producing reasonable results and providing a plausible, consistent representation of the key features of the U.S. energy system. The results for the total system energy consumption and sectoral energy consumption are compared to the AEO. Broad trends (upward, downward, or changing over the time horizon) are also compared to see if the EPAUS9r results track with the AEO trends. Finally, the degree of quantitative match between the EPAUS9r results and AEO are compared. Constraints are added where there is an underlying feature of the energy system that an unconstrained MARKAL run does not represent.

Examples of these constraints include

- Transportation LDV class splits are implemented to keep the model run from choosing all small compact cars, and
- Some level of residential advanced lighting, such as Compact Fluorescent Lamps (CFL's), is forced in through constraints to overcome the models desire to always choose inexpensive incandescent lights.

5. Description of the National Database (EPANMD)

In addition to the EPAUS9r, which represents the U.S. energy system at the nine Census region level, ECAT has a corresponding aggregated national U.S. energy system representation called the EPANMD (EPA National MARKAL Database). The EPANMD contains one region (USEPA) which is a summation of the EPAUS9r's nine-regions. This section describes how parameters were developed for the EPANMD from EPAUS9r data.

Resource Supply Curves
In the EPAUS9r, crude oil (domestic and imported), imported refined products, and natural gas (domestic and imported) are characterized using a series of regional or PADD level stepped supply curves. In the EPANMD, these supply curves are weighted to become national curves. Since multiple regions are not present in the EPANMD, the trade technologies between regions for oil, gas, refined products, and coal are eliminated. Instead of allowing the products to be distributed to regions from PADDs, each product is collected by a dummy technology and then delivered to the end-use sectors. These dummy technologies are new technologies added to the EPANMD. Delivery charges are applied for delivery to sectors and refineries. The charges for each EPAUS9r region are averaged for a national level average value.

Biomass and Biofuels
Biomass feedstocks are produced by a supply curve that varies by region. For the EPANMD, the availability of feedstocks is summed while the costs are averaged for a national level supply curve. After biomass production, collection and transportation, delivered biomass is used either for biofuels production for use in the transportation sector, or sent to other sectors for other forms of energy production (electricity, heat, steam, etc.).

Biofuels are produced by eight technologies: six corn-based for ethanol production and two cellulosic ethanol production technologies. The input, output, and costs of these technologies are the same across the EPAUS9r regions and, therefore, remain the same for the EPANMD. Residual capacity for existing production technologies varies across regions, and is summed up for a national level RESID.

Municipal Solid Waste
Municipal solid waste (MSW) is used for electricity generation via direct combustion, utilization of landfill gas, combined heat and power (CHP), and gasification. MSW follows a similar path as biomass. Production is based on a supply curve and availability is apportioned by Region. In the EPANMD, the availability is nationalized by summing up the Regional values.

Refineries
In the EPAUS9r, the regional refineries produce petroleum products that will generally be used within the demand region, but each region can trade products with other regions. However, these trade technologies are eliminated in the EPANMD since multiple regions do not exist. In the EPANMD, three refinery technologies produce all the petroleum products for use within demand sectors. The start year for existing and high level refineries remain at 2000 and 2010 respectively. However, the start year for new conversion refineries, which varies across regions in the EPAUS9r, is averaged for a start year of 2015. Cost data for refineries are equal to the values for Region 7. Residual capacity and lower bounds on activity for existing refineries are added up across the regions for a national level value.

Electricity Generation

The EPANMD contains all of the electricity generating technologies present in the EPAUS9r. Primarily, parameters are either summed or averaged for national level values. Availability factors like LIFE, AF, AF(Z)(Y), and PEAK(CON), vary across regions and are averaged for national level values in the EPANMD. Cost parameters for existing technologies, including INVCOST, VAROM, and FIXOM, vary by region and are averaged for the EPANMD. For new technologies, these costs do not vary by region and remain at the same value for the EPANMD. Input and output parameters vary by region for existing technologies and are averaged for the national model. These parameters do not vary for new technologies by region and remain at the same level in the EPANMD. Residual capacity for existing technologies varies by region and is summed up for the national model. The fuel constraints, limiting the amount of electricity generated by each fuel (coal, natural gas, petroleum, and wind), varies by region in the EPAUS9r, and are averaged for a national level constraint value. In the EPAUS9r, global constraints are used to control the amount of electricity generated by each wind class. In the EPANMD, these constraints are converted to an upper bound on each specific wind technology.

Residential, Commercial, Transportation, and Industrial Sectors

End use demands are summed to a national level. Availability and utilization parameters, including CF, IBOND(BD), LIFE, and START vary by technology type, but are the same across regions in the EPAUS9r. Thus, these parameters remain the same in the EPANMD. Efficiency and cost parameters, including EFF and INVCOST and input/output parameters, including MA(ENT) and OUT(DM), do not vary across regions in the EPAUS9r, and therefore remain at the same values in the EPANMD. The residual capacity (RESID) for technology stock already existing at the beginning of the modeling horizon (2000) in the EPAUS9r is distributed based on regional demand. Therefore, for a national level RESID for each existing technology, the RESID was summed up across the regions. Weighted averages across the nine-regions are calculated for the fuel and technology constraints.

Emissions Data

Emission factors do not vary across the regions in the EPAUS9r, and thus remain at the same values for national emission factors.

References

Aden, et al., 2002 *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*. NREL/TP-510-32438.

AEO (Annual Energy Outlook). 2011. Residential Technology Equipment Description File. October 2011.

---. 2011a. Commercial Technology Equipment Description File (KTECH). October 2011. Provided by Erin Boedecker.

Argonne National Laboratory. 2007. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. Available at: http://greet.es.anl.gov/

Battye, W.; Boyer, K.; Pace, T.G. 2002. *Methods for improving global inventories of black carbon and organic carbon particulates.* (68-D-98-046). Prepared for Environmental Protection Agency.

Bond, T.C.; Streets, D.G.; Yarber, K.F.; Nelson, S.M.; Woo, J.-H.; Klimont, Z. A Technology-Based Global Inventory of Black and Organic Carbon Emissions from Combustion. *J. of Geophys. Res.* 2004, 109, D14203.

Bond, T.C.; Bhardwaj, E.; Dong, R.; Jogani, R.; Jung, S.; Roden, C.; Streets, D.G.; Trautmann, N. Historical Emissions of Black and Organic Carbon Aerosols from Energy-related Combustion, 1850-2000. *Global Biogeochemical Cycles.* 2007, v. 21, GB2018.

Bonskowski, Richard F. 2002. *U.S. Metallurgical Coal and Coke Supplies – Prices, Availability, and the Emerging Future Markets.* Iron and Steel Society Annual Conference. March 2002. Available at: http://www.eia.gov/neic/speeches/isspaper.pdf

Elobeid, A.; Carriquiry, M.; Fabiosa, J.; Mulik, K.; Hayes, D.; Babcock, B.; Dumortier, J.; Rosas, F. "Greenhouse Gas and Nitrogen Fertilizer Scenarios for U.S. Agriculture and Global Biofuels" June 2011 Working Paper: 11-WP 524 Available at: http://www.card.iastate.edu/publications/synopsis.aspx?id=116

Denholm, P. and W. Short. An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles. October 2006. (NREL?TP-620-40293) Available at: http://www.nrel.gov/docs/fy07osti/40293.pdf

DOC (Department of Commerce). 2012. Implicit Price Deflators for Gross Domestic Product. Available at: http://www.bea.gov/itable/error_NIPA.cfm

DOE (United States Department of Energy). 2008. *Documentation for Emissions of Greenhouse Gases in the United States 2006* (DOE/EIA-0638). October 2008. Available at: http://www.eia.gov/oiaf/1605/ggrpt/documentation/pdf/0638(2006).pdf

---. 2010. Transportation Energy Data Book. Available at: http://cta.ornl.gov/data/index.shtml

---. 2011a. *U.S. Billion-Ton Update*: *Biomass Supply for a Bioenergy and Bioproducts Industry* (ORNL/TM-2011/224). December 2011. Available at: http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf

Dutta, A., & Phillips, S. (2009). *Thermochemical ethanol via direct gasification and mixed alcohol synthesis of lignocellulosic biomass* (NREL/TP-510-45913). Golden, CO: National Renewable Energy Laboratory: http://www.nrel.gov/docs/fy09osti/45913.pdf.

Dutta, A., Talmadge, M., Hensley, J., Worley, M., Dudgeon, D., Barton, D., et al. (2011). *Process design and economics for conversion of lignocellulosic biomass to ethanol: thermochemical pathway by indirect gasification and mixed alcohol synthesis* (NREL/TP-5100-51400). Golden, CO: National Renewable Energy Laboratory: http://purl.fdlp.gov/GPO/gpo9356.

EIA (United States Energy Information Administration). 1999. *US Coal Reserves: 1997 Update.* (DOE/EIA-0529(97). February 1999. Available at: ftp://ftp.eia.doe.gov/coal/052997.pdf

---. 2001. Transportation Energy Consumption Survey. Available at: http://www.eia.gov/emeu/rtecs/

---. 2003. *Model Documentation Report: System for the Analysis of Global Energy Markets (SAGE).* August 2003. (DOE/EIA-M072). http://www.eia.gov/FTPROOT/modeldoc/m072(2003)2.pdf

---. 2004. State Energy Consumption, Price, and Expenditure Estimates (SEDS). Available at: http://www.eia.gov/beta/state/seds/

---. 2006. Manufacturing Energy Consumption Survey. Available at: http://www.eia.gov/emeu/mecs/

---. 2007. EIA-Technology Forecast Updates – Residential and Commercial Building Technologies – Reference Case Second Edition (Revised). September 2007. Prepared by Navigant Consulting. Available at: http://wpui.wisc.edu/news/EIA%20Posts/EIA%20Reference%20Case%2009-2007%20Second%20Edition%20Final.pdf

---. 2007a. Commercial Buildings Energy Consumption Survey. Available at: http://www.eia.gov/consumption/commercial/

---. 2009. *The National Energy Modeling System: An Overview 2009.* (DOE/EIA-0581). October 2009. Available at: http://www.eia.gov/oiaf/aeo/overview/pdf/0581(2009).pdf

---. 2009a. *Annual Energy Review 2008.* (DOE/EIA-0384). June 2009. Available at:

http://www.eia.gov/totalenergy/data/annual/archive/038408.pdf

---. 2009c. Reidential Energy Consumption Survey. Available at: http://www.eia.gov/consumption/residential/data/2009/

---. 2011. *Documentation of the Oil and Gas Supply Module* (DOE/EIA-M063). July 2011. Available at: http://www.eia.gov/FTPROOT/modeldoc/m063(2011).pdf

---. 2012a. *Natural Gas Transmission and Distribution Module of the National Energy Modeling System* (DOE/EIA-M062). February 2012. Available at: http://www.eia.gov/FTPROOT/modeldoc/m062(2011).pdf

---. 2012b. *U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Proved Reserves, 2010*. August 2012. Available at: http://www.eia.gov/naturalgas/crudeoilreserves/pdf/uscrudeoil.pdf

---. 2012c. *Annual Energy Outlook 2012 with Projections to 2035* (DOE/EIA-0383). June 2012. Available at: http://www.eia.gov/forecasts/archive/aeo12/pdf/0383(2012).pdf

---. 2013. *Coal Market Module of the National Energy Modeling System*. January 2013. Available at: http://www.eia.gov/forecasts/nemsdoc/coal/pdf/m060(2012).pdf

EPA (United States Environmental Protection Agency). 2004. *Air Quality Data Analysis Technical Support Document for the Proposed Interstate Air Quality Rule*. January 2004. Available at: http://www.epa.gov/cair/pdfs/tsd0006.pdf

EPA (United States Environmental Protection Agency). ---. 2004a. *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines*. 2004. (EPA420-R-04-007).

---. 2007. *Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes*, US EPA, Office of Policy, Economics and Innovation, pp.204.

---. 2010. *Moves (Motor Vehicle Emission Simulator)*. 2010. Available at: http://www.epa.gov/otaq/models/moves/index.htm#ghg

---. 2010b. *Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis*. (EPA-420-R-10-006).

---. 2011. *IPM Analysis of the Proposed Mercury and Air Toxics Standard*. 2011. Available at: http://www.epa.gov/airmarkt/progsregs/epa-ipm/proposed-toxics.html

Foster Associates. “Capital Costs for Gas Pipeline and Storage Project Expansions.” Report for EIA. May 1999.

CPBIS (Georgia Tech Center for Paper Business and Industry Studies). 2007. Mills Online Database. Available at: http://www.cpbis.gatech.edu/data/mills-online-new

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D., Aden, A., et al. (2011). *Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol* (NREL/TP-5100-47764). Golden, CO: National Renewable Energy Laboratory: http://www.nrel.gov/docs/fy11osti/47764.pdf.

IPCC (Intergovernmental Panel on Climate Change). 2005. Carbon Dioxide Capture and Storage. Metz, B., Davidson, O., de Coninck, H., Loos, M., and Meyer, L. (Eds.). NY: Cambridge University Press.

Kaplan, P. O.; DeCarolis, J.; Thorneloe, S., Is it better to burn or bury waste for clean electricity generation? *Environmental Science & Technology* **2009,** *43* (6), 1711-1717.

Kocoloski, M., Griffin, W.M. and H.S. Matthews (2010). Impacts of facility size and location decisions on ethanol production cost. *Energy Policy*, *39*(1), 47–56.

Larson, E.; Consonni, S,; Katofsky, R.; Kreutz, T. *Preliminary Economics of Black Liquor Gasification/Gas Turbine Cogeneration at Pulp and Paper Mills. Journal of Engineering for Gas Turbines and Power.* Volume 122, April 2000.

Larson, E.; Consonni, S,; Katofsky, R.; Iisa, K., Fredrick, J. *A Cost-Benefit Assessment of Gasification-based Biorefining in the Draft Pulp and Paper Industry*. Volume 1, Main Report, December 2006. DOE Contract Number: DE-FC26_04NT42260.

McAloon, A., F. Taylor, W. Yee, K. Ibsen and R. Wooley (2000). Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks. (NREL/TP-580-28893). Golden, CO: National Renewable Energy Laboratory: http://www.nrel.gov/docs/fy01osti/28893.pdf

Mintz, Marianne, Amgad Elgowainy and Jerry Gillette. "H2A Delivery Scenario Analysis Model Version 2.0 (HDSAM 2.0) User's Manual." September 2008.

MIT (Massachusetts Institute of Technology). 2007. The Future of Coal: Options for a Carbon-Constrained World. Cambridge, MA: Massachusetts Institute of Technology.

NCDC (National Climatic Data Center). 2010. *State, Regional and National Monthly Heating Degree Days, Historical Climatography Series No. 5.1 (HCS No 5.1).* Available at: http://www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html#51updates

North Carolina State University (NCSU). 2010. Database of State Incentives for Renewables and Efficiency. Available at: http://www.dsireusa.org/rpsdata/index.cfm

NRC (National Research Council). 2004. *The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs*. Washington, D.C.

ORNL (Oak Ridge National Laboratory). 2004. *Off-highway Transportation Related Fuel Use*. Washington, D.C.

---. 2004b. *Transportation Routing Analysis Geographic Information System (TRAGIS)*. Available at: http://www.ornl.gov/sci/gist/TRAGIS_2005.pdf

Perrin, R. K., Fretes, N. F., & Sesmero, J. P. (2009). Efficiency in Midwest US corn ethanol plants: A plant survey. *Energy Policy, 37*(4), 1309-1316.

Simmons, Phil, Scott M. Kaufman and Nickolas J. Themelis. "State of Garbage in America Recycling Data Analysis." BioCycle, October 2006. Vol. 47, No. 10, page 21.

USDA (U.S. Department of Agriculture). 2012. Agricultural Long-term Projections. Released February 2012. Available at: http://www.usda.gov/oce/commodity/ag_baseline.htm

Wilson, E.J., T.L. Johnson and D.W. Keith. 2003. "Regulating the ultimate sink: Managing the risks of geologic CO_2 sequestration." Environmental Science and Technology 37:3476-3483.

Wright, M.M., , J.A. Satrio, R.C. Brown, D.E. Daugaard, and D.D. Hsu (2010). *Techno-Economic Analysis of Biomass Fast Pyrolysis to Transportation Fuels* (NREL/TP-6A20-46586). Golden, CO: National Renewable Energy Laboratory: http://www.nrel.gov/docs/fy11osti/46586.pdf

Zhang, Y., M.A. Dube, D.D. McLean, M. Kates (2003a). "Biodiesel production from waste cooking oil: Part 1. Process design and technological assessment" *Bioresource Technology* (83)1.

Zhang, Y., M.A. Dube, D.D. McLean, M. Kates (2003b). "Biodiesel production from waste cooking oil: Part 2. Economic assessment and sensitivity analysis" *Bioresource Technology* (83)1.

Appendices

A: MARKAL Parameter Descriptions

AF(Z)(Y): Availability of relevant conversion technologies in the specified season (Z) and time-of-day division (Y) allowing for variation in availability according to time division. This parameter is used primarily for renewable technologies, such as hydroelectric where water levels may vary by season. AF(Z)(Y) is specified as a decimal fraction of the time available during each of the six time divisions.

AF: Total annual availability of a process or conversion technology in each period. This parameter is presented as a decimal fraction of the total number of hours (8760 hours) per year and, as a result, is dimensionless. If availability by season and time-of-day (AF(Z)(Y)), or a fixed capacity utilization (CF(Z)(Y)) is specified, then AF is not required. The default value is 1.

AF: Total annual availability of a process technology in each period. This parameter is presented as a fraction of the total number of hours (8760 hours) per year, and as a result is dimensionless. The default is 1.

BAS(E)LOAD: Baseload capacity of the electricity generation system as a fraction of the total night production of electricity (measured in terms of the generation capacity) in each specified period. In MARKAL baseload power plants are forced to operate at the same levels day and night within a season, that is, if used they tend not to be turned off and on. This parameter is expressed as a decimal fraction, and is generally close to 1.

BOUND(BD): A limit (lower, upper, or fixed) on the installed capacity of a technology in a specified period. The value of this parameter is usually set as the average of the annual installed capacity of a technology in a specified period. BOUND(BD) can be used to anchor the model to historical data or where future capacity of a technology may be limited in a period.

BOUND(BD)O: Limit on the activity of a given technology during a time period. An upper, lower, or fixed bound may be applied to a technology's total output (i.e., the sum of all outputs).

BOUND(BD)Or: If a resource is limited during a period as a result of technical or economic characteristics, this parameter can provide a lower (LO), upper (UP), or fixed (FX) limit. An example of a technical reason would be the limit on the amount of oil that can be produced during any given year from a petroleum reservoir. An economic limit would indicate that, at the price reflected in the COST parameter, only the stated amount could be produced; more, if available, would be at a higher COST. BOUND(BD)Or is measured as the production actually available for injection into the system, e.g., natural gas used in production or maintenance of a lease would be excluded from the values applied for this parameter.

CAPUNIT: Conversion factor between units of activity and units of production capacity. For process technologies, this parameter is defined as PJ (annual activity) per PJ per annum (unit of capacity). For process technologies, this parameter defaults to 1 (PJ/PJa). For demand technologies, this parameter will vary depending on the basis (e.g., light duty vehicles are presented in vehicle miles traveled, while commercial HVAC is presented in PJ). For conversion technologies, this parameter is defined as PJ (annual activity) per GW (unit of capacity). For conversion technologies, this parameter defaults to 31.536 PJ/GW.

CF: Average annual utilization of the installed capacity of a demand technology in a specified period. Because MARKAL works with average annual device output, but investment in devices is usually based upon rated maximum output, CF serves to "pump up" the cost of a new investment to the capacity needed to service the highest demand. For example, an air conditioner is purchased with a rating that will cool an entire house adequately on the hottest days, but normally runs at a much lower utilization level. So a CF = 0.35 would indicate that average use is only 35% of the maximum rated cooling capacity and would result in 1/0.35 units overcapacity installed. This parameter is expressed as a decimal fraction and defaults to 1 (i.e., 100% utilization during the year) when created.

COST: Annual cost of energy from a source in a specified period. Sources can include domestic extraction/mining (MIN), imports (IMP), exports (EXP), renewables (RNW), or stockpiles (STK). Cost excludes any costs associated with delivery of the carrier from the source to the user. Further, costs are generally valued at the point that an energy carrier enters the energy system. For example, coal mined domestically would be valued at the mine-mouth, and domestically produced natural gas would be valued at the wellhead. Because exports represent a cost reduction to the system, the level of exports usually requires that an upper limit be applied.

CUM: Total availability of an energy carrier from a resource supply curve step over the entire forecast horizon. An example would be the total proven reserves from a particular group of reservoirs. Whereas BOUND(BD)Or limits the annual production level (e.g., pumping rate), the CUM indicates the total that can be extracted over time.

DELIV(ENT): Annual delivery and handling costs of an energy carrier from source to a specified technology in a specific period.

DEMAND: Annual demand for an energy service. This parameter is expressed in the units of the demand service. In the EPAUS9r model, demands may be expressed in various units, including energy units (PJ) as well as such measures as vehicle miles traveled (VMT).

DISCOUNT: Long term annual discount rate for the economy as a whole. This parameter is expressed as a decimal fraction and currently, in the U.S. model, this parameter is valued at 5%.

DISCRATE: Technology-specific discount rate. This differential discount rate, often referred to as a "hurdle" rate, can be used to represent the impediments that a technology may face when competing in the market strictly on economic terms. These impediments might be a function of preference (e.g., SUVs vs. compact cars), behavior (e.g., builders put in electric hot water heaters owing to lower initial cost), or high required rates of return and/or lack of understanding (e.g., the extra upfront $ for compact fluorescent light bulbs or high efficiency refrigerators are not perceived to be justified by the eventual down-the-road energy cost savings). These impediments to the market can be represented to MARKAL as higher discount rates for such technologies. The value is a percent.

(E)RESERV: Amount of installed electricity generating capacity above the average load of the season and time-of-day division of peak demand. This parameter is calculated by dividing the reserve capacity (i.e., sum of scheduled outages, forced outages, and load required to meet the peak requirement) by the average load of the season/time-of-day peak load, and is expressed as a decimal fraction. This number is usually higher than the traditional utility reserve margin as it is the level above the *average* peak period load, not the peak itself.

EFF: Technical efficiency of a demand technology in a specified period. Efficiency is measured as the number of units of end-use demand satisfied per unit of input energy carrier consumed. EFF is a decimal fraction, and usually, with existing technologies, it does not vary over the life. In the case of some demand technologies, such as commercial HVAC, this measure is PJ in per PJ out. For other technologies such as light duty vehicles, this measure is PJ in/ number of vehicle miles traveled. The majority of demand technologies will have efficiencies of less than one. However, such technologies as heat pumps may have efficiencies greater than one. For some technologies, such as lighting, where outputs are not easily measured in PJ, the efficiency of some standard technology has been set to 1, and efficiencies for other technologies and demand levels have been calibrated accordingly.

ELF: Fraction of the electricity consumed by technologies in an end-use demand category that is to be included in the electricity peaking constraint. This parameter should be specified if a demand category has one or more demand technologies using electricity. A value of less than 1 would be provided only to indicate that not all the demand will coincide with the peak moment (e.g., as a result of off-peak electric pricing to industry). Default is 1 indicating that all the electricity consumed should be charged in the peaking constraint. The value is a dimensionless fraction.

ENV_ACT: Emission coefficient per unit of activity. This parameter specifies the quantity of an environmental emission or other variable that is associated with the actual operation of a conversion or process technology or demand device. Most emissions associated with the burning of a fuel (e.g., at a power plant or vehicle) are represented using this parameter. The parameter specifies the amount of pollutant emitted per unit of technology activity. The units are a function of the activity unit of the technology (usually PJ) and the unit of the environmental variable (in the U.S. model, million tons for CO_2 and thousand tons for the other pollutants.)

ENV_COST: The cost ("tax") added to the objective function associated with each unit emissions.

ENV_MAXEM: Annual maximum (net) quantity of an emission or other environmental variable that can be released (or used) in a given period. This parameter is used to model such environmental regulations as limitations on emissions of SO_2 or NO_x under CAIR. The units are those of the environmental variable.

ENV_SEP: Emission coefficient per unit of resource activity. This approach links emissions or other environmental variables to a unit of resource activity (e.g., tons of CH_4 released in the production of a PJ of coal). Resource activities include coal mining, natural gas and oil production, and similar extractive activities. The units are a function of the activity unit of the technology (PJ) and the unit of the environmental variable

FIXOM: Annual fixed O&M costs associated with the installed capacity of a demand technology. Costs associated with this parameter are assessed without regard for the annual capacity utilization rate of a technology. The same FIXOM is charged whether the process actually operates or not. Examples of fixed O&M include fixed labor costs, rental of a building, property taxes, and similar costs.

FR(Z)(Y): For each demand sector that can be serviced by demand devices consuming electricity or heat, FR(Z)(Y) indicates the fraction of annual consumption occurring in each season and time-of-day subdivision that best describes the end-use demand load through the typical year. This parameter is required where the load is non-uniform, e.g., space heating and space cooling. If the demand is not required in a time slice, then the associated FR(Z)(Y) should be omitted or specified as 0. The sum over all demands for each season/time-of-day time slice determines the amount of electricity and heat that must be generated by the conversion plants in that time slice, as well as the peaking and baseload requirements. If this parameter is not specified, MARKAL defaults to the seasonal/time-of-day energy distribution specified across the entire system by the global parameter QHR(Z)(Y). The FR(Z)(Y) should sum to 1.

GROWTH: Maximum rate of growth of the capacity of a technology from period to period. This parameter is expressed as the sum of 1 and the annual growth rate. For example, a growth rate of 15% over a period would be expressed as 1.15 in the designated period. If a technology has a 5% annual growth rate, then the period growth rate for a five-year period = $1.05^{\wedge 5}$ = 1.276.

GROWTH_TID: Incremental quantity of a technology's capacity that is permitted over and above the GROWTH constraint. This parameter provides flexibility in allowing investment in new capacity. In addition, if technology capacity could be zero in the first time period that GROWTH is applied, a GROWTH_TID with the anticipated initial maximum period penetration level must be provided in order to "seed" the growth constraint. The GROWTH_TID should be set to the initial level of new capacity expected to be possible when the technology first becomes available.

IBOND(BD): Limit on the investment in capacity for a technology during a specified period. Investment in MARKAL is assumed to occur at the beginning of a period. This parameter will therefore impact investment for an entire period. This constraint may have an upper, lower, or fixed bound. IBOND(BD) is specified in the units for capacity.

INP(ENT)c: Amount of an energy carrier(s) that is input to a conversion technology in a specified period. Each energy carrier requires a separate INP(ENT)c entry and can be interpreted as the number of PJs of an input energy carrier per unit of electricity produced. Another way of thinking of it is that INP(ENT)c is expressed as the inverse of the efficiency (1/eff) of the power plant. For renewables and other non-fossil fuels (e.g., nuclear), the standard practice is to use the average efficiency from fossil technologies to compute the required "fossil fuel equivalent." The model uses this value when reporting consumption of primary energy (as fossil equivalent).

INP(ENT)p: Amount of an energy carrier(s) that is input to a process technology during a specified period. Each energy carrier requires a separate INP(ENT)p entry, which can be interpreted as the number of PJs of that input carrier required per unit of activity (output) from the process. In the EPAUS9r, processes are usually normalized to the sum of the output carriers; i.e., the outputs should sum to one. However, in a number of limited cases, inputs are normalized to a subset of inputs (e.g., some of the technologies depicted in the industrial sector). The ratio of the sum of output energy carriers to the sum of input energy carriers represents the technical efficiency of the process technology activity. Because INP(ENT)p relates outputs to inputs, its units are dependent upon the units of the outputs and inputs.

INVCOST: Total cost of investment for one incremental unit of new capacity in a specified period. The unit of capacity becomes available for production at the beginning of the specified period, and the investment cost is assumed to be charged at the beginning of that period.

LIFE: Technical life or period of potential operation of a technology. Note that the technical and economic lifetimes are assumed to be the same in MARKAL. This parameter is expressed in number of years.

LIMIT: Sets a maximum total output per unit of input for a process having flexible (that is, model-chosen) outputs, as opposed to the normal fixed proportions. When LIMIT is specified, the OUT(ENC)p then represents the maximum share of each energy carrier that can be produced per PJ of input. Thus the OUT(ENC)p in this case may sum to > 1, though the overall level in the solution will adhere to the LIMIT in accordance to the input levels.

MA(ENT): Fraction of each energy carrier that is input to a demand technology in a given period. For multiple energy carrier inputs, this parameter is expressed as a fraction of the total inputs to a demand technology. In most cases, when a single energy carrier feeds a demand device, MA(ENT) equals 1.

OUT(DM): Fraction of the output per activity of a demand technology that contributes to servicing an end-use demand in a specified period. If more than one end use is satisfied, the sum of this parameter must equal 1. This parameter can be used for such demand technologies as heat pumps that satisfy both heating and cooling demand or heating systems that also produce hot water.

OUT(ENC)p: Amount of an energy carrier produced by a process technology per unit activity. Each energy carrier output from a technology requires a separate OUT(ENC)p entry. As with input energy carriers, output carriers are described as so many PJ output per PJ input.

OUT(ENT)r: Specifies the energy carrier entering the energy system due to a resource activity (e.g., natural gas from a well or coal from a strip-mine.). The value of this parameter should be set to 1, the default.

PEAK(CON): Fraction of the total capacity of a conversion technology in a specified period that can be counted on to be available to meet peak demand and reserve margin requirements, based upon its availability, reliability, and other considerations. Base-loaded technologies will have values close to 1, while other technologies, such as renewables, may have values less than 0.5.

QHR(Z)(Y): Division of the year into season and time-of-day fractions that describe the duration of the seasons and time-of-day associated with a typical year. These values are used as the default when constructing the load curve for electricity and heat.

RESID: Capacity of a technology installed prior to the start of the modeling horizon, or capacity in place today. The investment cost for previously installed capacity is assumed to be sunk, and the model is thus encouraged to use existing capacity before new capacity is added. This parameter is defined in the same units as other capacity measures, and in the U.S. model demand device capacities are expressed in PJa, billions of vehicle miles traveled per annum, etc.

START: First period of availability of a technology within the modeling horizon. For technologies already in existence at the beginning of the modeling horizon, START should be set to the first period, which is the default.

TE(ENT): Average transmission and distribution efficiency of a specified energy carrier in a given period. This parameter is applicable to all energy carriers and, for the majority of energy carriers, is set to 1 (i.e., 100% efficiency). The default value is 1. Electricity generally has a value of less than 1, and in the EPAUS9r has a value of 0.9350.

TRNEFF(Z)(Y): Specifies the average transmission efficiency of low temperature heat from a coupled-production (CPD) technology during each season/time-of-day. The value is a dimensionless fraction.

VAROM: Annual variable O&M costs of a technology. These costs are assessed as each unit of activity occurs and are to be normalized in the same manner as the process itself (usually to output). VAROM does not include fuel costs or the costs associated with fuel handling and delivery.

B: Sector Workbook Description – Oil Resource Supply

Workbook Name:	EPAUS9r_12_Oil_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the domestic and imported oil resources and the imported refined products in the EPAUS9r MARKAL database.

Data Sources
The supply characteristics were taken from the AEO reference case (EIA, 2012c) and the NEMS Oil and Gas Supply Module (EIA, 2011) output data. Emissions factor data were derived from the GREET model, version 1.8 (Argonne, 2007).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Emission factors are expressed in ktonnes per PJ with the exception of CO_2, which is expressed in Mtonnes per PJ.

Workbook Description
The following section gives a description of each of the 25 worksheets found in the oil resource supply workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all energy carriers used for oil supply. The following naming conventions are used (where R represents region number, P represents the PADD number, and FFF represents the 3-letter distinction for fuel type):

OILDR	Domestic Crude Oil
OILIPP	Imported Crude Oil, all types
OILHHP	Imported Oil, high sulfur, heavy gravity
OILHLP	Imported Oil, high sulfur, low gravity
OILHVP	Imported Oil, high sulfur, very heavy gravity
OILLLP	Imported Oil, low sulfur, low gravity
OILMHP	Imported Oil, medium sulfur, heavy gravity
FFFPP	Imported Refined Products

Technologies*
Lists the technology names, units, and set memberships for all supply curve steps, import and export technologies, and transportation technologies for domestic and imported oil and imported refined products. The following naming conventions are used (where X represents the step

number, YY represents the sulfur type and specific gravity, XX represents the PADD and step number, and FFF represents the fuel type):

MINOILDX	Domestic Crude Oil Supply Step
IMPOILYYXX	Imported Crude Oil Supply Step
IMPZZZPXX	Imported Refined Product Supply

TechData_R0*
Contains the costs (COST), supply limits (BOUND(BD)Or), and cumulative supply amounts (CUM) for each of the supply steps for domestic oil and imported refined products. The data are drawn from the worksheets described below. In addition, each supply step has a maximum annual growth rate in activity from 2.5% to 5% (GROWTHr) and a limit rate at which supply activity can be reduced by 5% annually (DECAYr). Once oil is "purchased" from the supply curve it passes through respective collectors (SCMINOILD) where emissions associated with extraction are applied. These emission factors are pulled from the **Emissions** worksheet.

TechData_ExIm*
Contains the trading links needed to move oil between regions. Export (names begin with EXP) and import (names begin with IMP) trade technologies are used to export oil out of one region and import it into another region. The parameter BI_TRD(ENT) is equal to 1 when a region can receive a particular source.

TechData_DelOIL*
Contains the bound on capacity (BOUND) and costs (VAROM) for the crude oil and imported refined product transportation technologies including transport between regions and transport to end-use sectors.

TechData_Limits*
Contains the investment costs and flow bounds for pipeline delivery of crude oil and imported refined products.

Constraints*
There are no user-defined constraints in the Oil workbook.

ConstrData*
There are no user-defined constraints in the Oil workbook.

Domestic Crude Production Trends
Contains data and charts that graph the historical annual production of crude oil in each of the PADDs in the U.S. Data are used to estimate GROWTH and DECAY values for domestic crude supply. These data can be found on the EIA's website at the following link: http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm

Domestic Crude Oil CUM
Contains the raw data and calculations for determining the cumulative (CUM) amount of crude oil reserves in each of the nine-regions. The data are pulled from the EIA proved reserves data

(EIA, 2012b). Raw data are converted from million barrels to PJ and multiplied by a factor used to estimate how the reserves will change over time.

Domestic Crude Oil Prices
Contains the raw data used to calculate crude oil production prices. Data are taken from two AEO reference case tables: "Lower 48 Crude Oil Production and Wellhead Prices by Supply Region," and "Oil and Gas Supply." Data are regionalized and converted to MARKAL units. A growth factor is calculated and used to extend the prices out beyond 2035.

Domestic Crude Oil Prod
Contains the raw data used to calculate crude oil production by state for the years 2002 through 2011. These data can be found at http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm. Average production levels for 2005 and 2010 are calculated by region. Those average values are then converted to MARKAL units and set as the production bound (BOUND(BD)Or) for Step 3 in the regional supply curves. Steps 1, 2, 4, and 5 are then calculated from Step 3 using supply curve elasticities taken from AEO.

Imported Prod Trend
Contains data and charts that graph the historical annual production of imported crude oil and of refined products in each of the PADDs in the U.S. Data are used to estimate GROWTH and DECAY values for domestic crude supply. These data can be found on the EIA's website at the following link: http://www.eia.gov/dnav/pet/pet_move_wkly_dc_NUS-Z00_mbblpd_4.htm

Imp Refined
Contains calculations used to convert the imported refined supply curve data aggregated in the worksheet **Agg prdcrv** to MARKAL units of million dollars per pJ. In addition, standard naming conventions are applied to each step of the supply curve.

Agg prdcrv
Aggregates the imported refined products supply curve data found in the worksheet, **AEO 2012 prdcrv.**

AEO prdcrv
Contains the raw data for the AEO imported refined products supply quantities and prices provided by NEMS.

Imp Crude
Contains the calculations used to convert crude supply curve data from the worksheet **Agg crdcrv** to MARKAL units of million dollars per pJ. In addition, standard naming conventions are applied to each step of the supply curve.

Agg crdcrv
Aggregates the crude oil supply curve data found in the worksheet, **AEO crdcrv**.

AEO crdcrv
Contains raw data for imported crude oil supply quantities and prices provided by NEMS.

Imported Price Trends
Contains the raw data for refined petroleum product prices found in the AEO reference case table: "Petroleum Product Prices.'

DelivOIL
Contains the raw data and calculations for the delivery prices of crude oil to the refineries and the delivery prices of imported refined oil products to the end-use sectors. Raw data tables come from the NEMS Petroleum Market Module and include Table 1D: "Refinery Gate Prices" and Table 8: "End Use Prices."

OILTrade
Contains raw data from the AEO's Oil and Refining Markets division showing the total capacity of refined products moved from one region to another through pipelines in the U.S. These data are used to determine pipeline capacities.

Emissions
Contains emission factors associated with natural gas and oil extraction, processing and distribution. These factors do not differentiate between conventional and unconventional resources.

Types
Contains a series of tables matching fuel types and regions with MARKAL designations for those same fuel types and regions.

Conversion Factors
Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) and the Annual Energy Review Table A1: "Approximate Heat Content of Petroleum Products."

C: Sector Workbook Description – Natural Gas Resource Supply

Workbook Name:	EPAUS9r_12_NatGas_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the domestic and imported natural gas resources in the EPAUS9r MARKAL database.

Data Sources
The supply characteristics were taken from the AEO reference case (EIA, 2012a) and the NEMS Oil and Gas Supply Module (EIA, 2011) output data. Emissions factor data were derived from the GREET model, version 1.8 (Argonne, 2007).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Emission factors are expressed in ktonnes per PJ with the exception of CO_2, which is expressed in Mtonnes per PJ.

Workbook Description
The following section gives a description of each of the 19 worksheets in the natural gas resource supply workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all energy carriers used for natural gas supply. The following naming conventions are used:

NGA	Natural Gas
NGAD	Domestic Natural Gas
NGAC	Imported Canadian Natural Gas
NGAL	Imported Liquified Natural Gass
NGAM	Natural Gas Net Exports to Mexico
NGL	Natural Gas Liquids

Technologies*
Lists the technology names, units, and set memberships for all supply curve steps, import and export technologies, and transportation technologies for domestic and imported natural gas supplies. The following naming conventions are used (where X represents the step number):

MINNGADX	Domestic Natural Gas Supply Step
IMNPNALX	Imported NatGas Liquids Supply Step
IMPNGACX	Imported Canadian NatGas Supply Step

TechData_R0*
Contains the costs (COST), supply limits (BOUND(BD)Or), and cumulative supply amounts (CUM) for each of the supply steps for natural gas. The data are drawn from the worksheets described below. In addition, each supply step has a maximum annual growth rate in activity from 2.5% to 30% (GROWTHr) and a limit rate at which supply activity can be reduced 5% annually (DECAYr). Domestic natural gas supply passes through respective collectors (SCMINNGAD) where emissions associated with extraction are applied. These emission factors are pulled from the Emissions worksheet.

TechData_ExIm*
Contains the trading links needed to move natural gas between regions. Export (names being with EXP) and import (names begin with IMP) trade technologies are used to export gas out of one region and import gas into another region. The parameter BI_TRD(ENT) is equal to 1 when a region can receive a particular source.

TechData_DelNGA*
Contains the bound on capacity (BOUND) and costs (VAROM parameter) for the natural gas transportation technologies including transport between regions and transport to end-use sectors.

TechData_Limits*
Contains the investment costs and flow bounds for pipeline delivery of natural gas.

Constraints*
There are no user-defined constraints in the NatGas workbook.

ConstrData*
There are no user-defined constraints in the NatGas workbook.

Types
Contains a series of tables matching fuel types and regions with MARKAL designations for those same fuel types and regions.

Domestic NG CUM
Contains the raw data and calculations for determining the cumulative (CUM) amount of natural gas reserves in each of the nine-regions. The data are pulled from EIA proved reserves data (EIA, 2012b). Raw data are converted from billion cubic feet to petajoules and multiplied by a factor used to estimate how the reserves will change over time.

Domestic NG Production
Contains the raw data used to calculate natural gas production by state for the years 2002 through 2010. These data can be found at http://www.eia.gov/dnav/ng/ng_prod_sum_dcu_NUS_m.htm. Average production levels for 2005 and 2010 are calculated by region. Those average values are converted to MARKAL units and set as the production bound for Step 3 in the regional supply curves. Steps 1, 2, 4, 5 and 6 are then calculated from Step 3 using supply curve elasticities taken from AEO.

Domestic NG Prices
Contains the raw data for natural gas production prices. Data are taken from two AEO reference case tables: “Lower 48 Natural Gas Production and Wellhead Prices by Supply Region,” and “Oil and Gas Supply.” Data are regionalized and converted to MARKAL units. A growth factor is calculated and used to extend the prices out beyond 2035.

NGATrade
Contains the raw data for regional natural gas imports. Data taken from AEO Table: “Primary Natural Gas Flows Entering NGTDM Region from Neighboring Regions” provides the raw data for regional pipeline natural gas imports from Canada. Table 76: “Natural Gas Imports and Exports” provides the raw data for regional liquified natural gas imports.

AEO NG Imports
Contains the raw data and calculations for the imported natural gas supply curves, both pipeline gas from Canada and LNG. Raw data comes from the AEO reference case table: “Natural Gas Imports and Exports.” Average import levels for 2005 and 2010 are calculated and converted to MARKAL units and then set as the production bound (BOUND(BD)Or) for Step 3 in the imported supply curves. Steps 1, 2, 4, 5 and 6 are then calculated from Step 3 using supply curve elasticities taken from AEO.

DelivNGA
Contains the raw data and calculations for regional delivery costs to transport natural gas from production to the end-use sectors. End-use sector prices come from the AEO Table: “Natural Gas Delivered Prices by End-Use Sector and Census Division.” MARKAL delivery costs (VAROM) are calculated by subtracting the wellhead gas prices, found on worksheet **NGADom**, from these end-use sector delivered prices.

NGACap
Contains the raw data and calculations for the upper bound on capacity for existing natural gas pipelines. Raw data are taken from two AEO tables: “Natural Gas Pipeline Capacity by NGTDM Region” and “Primary Natural Gas Capacity Entering NGTDM Region from Neighboring Regions.”

NGExpansion
Contains the raw data and calculations for the cost of natural gas pipeline expansion in each region. The raw data are taken from a report done for EIA on costs for pipeline expansion projects (Foster Associates).

Emissions
Contains emission factors associated with natural gas and oil extraction, processing and distribution. These factors do not differentiate between conventional and unconventional resources.

Conv

Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) and the Annual Energy Review Table A1: "Approximate Heat Content of Petroleum Products."

D: Sector Workbook Description – Coal

Workbook Name: EPAUS9r_12_Coal_v1.0.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Document describes the sources of the data and the calculations used to characterize the domestic coal resources in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics were taken from the AEO reference case and NEMS Coal Market Module (EIA, 2013) output data. Emission factors were derived from the GREET model, version 1.8 (Argonne, 2007).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Emission factors for CO_2 are in units of MTonnes/PJ. Units for all other pollutants and for CO_2 attributed specifically to this sector, are in units of kTonnes/PJ.

Workbook Description
The following section gives a description of each of the 22 worksheets in the coal resource supply workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all coal energy carriers. Coal types follow the naming convention given below:
First letter = C (Coal)
Next 2 letters = Coal Region
Final 3 letters = Coal Type

Coal region and coal type descriptions can be found on the worksheet **AEO CMM_BASE_YR_SUPPLY_CURVE**.

Technologies*
Lists the technology names, units, and set memberships for coal supply curve steps, import technologies, export technologies, and coal transportation technologies.

Each supply curve step follows the naming convention given below:
First 3 letters = MIN
Next 2 letters = Coal Region
Next 3 letters = Coal Type
Final letter = Step on the curve (from A to K)

Import and Export technologies follow the naming convention given below:
First 3 letters = IMP (import) or EXP (export)
4th letter = C (coal)
Next 2 letters = Coal Region
Next 3 letters = Coal Type
Final letter = Region

Transportation technologies follow the naming convention given below:
First letter = X (denotes a transportation technology)
2nd letter = C (coal)
Next 2 letters = Coal Region
Next 3 letters = Coal Type
Final 3 letters = End-use demand distinction (i.e. RES for residential)

TechData_R0*
Contains the costs (COST), supply limits (BOUND(BD)Or), and cumulative supply amounts (CUM) for each of the eleven steps in each of the 41 supply curves. The data are drawn from the worksheets described below. In addition, each supply curve step is allowed a maximum annual growth rate in activity of 5% (GROWTHr) and a limit rate at which activity can be reduced 3% annually (DECAYr).

TechData_ExIm*
Contains technology links that transport coal from the dummy supply region (R0) to one of the nine census regions. The parameter BI_TRD(ENT) is equal to 1 when a region can receive a particular coal source.

TechData_Trans*
Contains the costs (VAROM) for coal transportation technologies. Data comes from the **Trans-rates** worksheet.

Emissions
Contains emissions associated with coal mining and cleaning. Coalbed methane emissions are included for surface and underground mines in various coal supply regions. These factors are not currently used within MARKAL. More information about these factors is available upon request.

Data-curves conversions
Converts the supply curve step quantities and prices from the worksheet **Agg 5 YR** into MARKAL units of PJ and 2005 U.S. dollars per PJ.

Agg 5 YR
Sorts the average data from the **5 YR AVG** worksheet by supply curve and adds naming conventions.

5 YR AVG
Sorts the supply curve data from the **AEO Supply Curves Raw** worksheet by coal region and coal type and calculates 5-year averages for the Step Quantity and Step Price.

AEO Supply Curves Raw
Contains the raw data for the coal supply curves from the AEO reference case.

Types
Expands the **CMM_BASE_YR_SUPPLY_CURVE** worksheet, adding naming conventions, cumulative productions, weighted sulfur and mercury totals, and reserves.

AEO CMM_BASE_YR_SUPPLY_CURVE
Contains the raw coal supply data from the AEO *CMM_BASE_YR_SUPPLY_CURVE* output file. This file gives the base year production and prices for each of the 40 coal supply curves.

Data-reserves
Contains raw data from the EIA coal reserves data (EIA, 1999) which gives estimated recoverable reserves by heat and sulfur content.

Coke Imports
Contains the calculations used to develop a supply curve for imported coke. The step quantities and step prices for the years 2000 and 2005 are taken from historical data of coke imports and exports found in a EIA report on metallurgical coal and coke supplies (Bonskowsi, 2002) and the Annual Energy Review (EIA, 2009a). For years out beyond the historical data, the step quantities are calculated by applying a quantity growth factor calculated from the AEO net imports data found in Table 15: “Coal Supply, Disposition, and Prices.” The step prices of the out years are calculated by applying an average coal import price to export price factor to the export price in the out years.

Trade-rules
Contains a manually generated table of supply rules which holds a “Y” if there is trading out of or in to a region of a particular coal type and a “N” if there is no trading between that coal type and a particular region.

Rate esc
Contains the raw data from the AEO *CMM_TRAN_RATE_ESC_COMP* output file, which gives the projections for the change in transportation rates out to the year 2055 for the eastern and western portion of the U.S. An average is calculated for the east and the west which is applied to the projections for the VAROM in the **TechData_Trans** worksheet.

Trans-rates
Takes the data from the AEO *CMM_ORIGIN_DEST_RATES* raw data file and calculates the cost in 2005 million dollars per PJ. In addition, transportation technology names are assigned to represent each node in the coal transportation system (i.e. “XCCABLSRES” represents the transportation of Central Appalachian low sulfur, surface bituminous coal to the residential sector).

AEO CMM_ORIGIN_DEST_RATES
Contains the raw data from the AEO *CMM_ORIGIN_DEST_RATES* output file. This file gives the costs of different coal types from one region to a particular sector in another region.

Data Production
Contains raw data from the AEO *CMM_ANN_COAL_PRODUCTION* output file that gives coal production by year (2011 through 2046) for each coal supply curve. A total production across the time frame is calculated and used in other worksheets to calculate the cumulative (CUM) available coal for each supply curve.

Defs
Contains AEO tables that define index numbers used in producing the coal supply curves.

Conversion Factors
Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012).

E: Sector Workbook Description – Unconventional Fuels

Workbook Name:	EPAUS9r_12_UNCNV_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the coal to liquids and coal to natural gas process technologies in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics were taken from the data gathered by the Southern Research Institute (SRI) under contract from the EPA. Detailed references are provided on the **References** worksheet.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Emission factors are expressed in ktonnes per PJ with the exception of CO_2, which is expressed in Mtonnes per PJ.

Workbook Description
The following section gives a description of each of the 19 worksheets found in the unconventional fuels workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all process energy carriers and emissions. Energy carrier names include:

DSU_CTL	Ultra Low Sulfur Diesel from FT Diesel Process
PFS_CTL	Petrochemical Feedstocks from FT Diesel Process
STM_CTL	Steam from FT Diesel Process
SNG_CTG	Natural Gas from Coal the Gas Process
PFS_CTG	Petrochemical Feedstocks from Coal to Gas Process

Technologies*
Lists the technology names, units, and set memberships for the coal to liquids and coal to natural gas process technologies and collector technologies for the process outputs. Each process technology follows the naming convention given below:

First letter	=	P (process)
Next 3 letters	=	COA (coal)
Next 3 letters	=	Output (DSU for diesel, SNG for synthetic natural gas)
Final 2 letters	=	Vintage year (if necessary)

Collector technologies follow the naming convention given below:

First 2 letters =	SC (collector)
Next 3 letters =	Output (PFS for petrochemical feedstocks, DSU for diesel, SNG for natural gas)
Next 2-3 letters=	Technology Type (FT for Fisher Tropsch, FTN for FT with NG)
Final 2 letters =	Vintage year (R for residual, 30 for new)

Constraints*
Lists the names, units, and set memberships for the coal to liquids and coal to natural gas user constraints.

TechData*
Contains the data for coal to liquids and coal to synthetic natural gas processes. The data are drawn from worksheets **4A2**, **4A3**, and **4B3** and converted to MARKAL ready units.

ConstrData*
Contains user defined constraints limiting the amount of coal to liquids and coal to natural gas that can be produced in a MARKAL model run. Coal to liquids production is based on AEO results. Coal to synthetic natural gas production is held constant at 2005 levels until 2040, when it is able to as much as double in production.

Coal to Liquids
Summarizes the collected coal to liquids data and chooses the best representation of the process for use in MARKAL.

Coal to SNG
Summarizes the collected coal to synthetic natural gas data and chooses the best representation of the process for use in MARKAL.

4A1
Contains raw data for the production, efficiency, inputs, outputs, and emissions of the Gilberton Coal-to-Clean Fuels and Power Project.

4A2
Contains raw data and calculations for the cost, efficiency, inputs, outputs, and emissions for the production of Fischer-Tropsch fuels and other conventional byproducts using Wyoming coal.

4A3
Contains raw calculations for the cost, efficiency, inputs, outputs, and emissions of the Gilberton Coal-to-Clean Fuels and Power Project.

4B1
Contains coal to synthetic gas raw production data for the Orlando Gasification Project at Stanton Energy Center.

4B2
Contains raw production data for the Dakota Gasification Company coal to synthetic gas process.

4B3
Contains a spreadsheet developed by SRI showing calculations for the costs, efficiencies, outputs, emissions, and capacities of coal to synthetic plants.

4C1
Contains a spreadsheet developed by SRI showing raw data and calculations for the costs, efficiencies, and capacities of transport reactor integrated gasification plants, first and nth of its kind.

AEO2010 Tables and Calibration
Contains raw data from the AEO Table 2: "Energy Consumption by Sector and Source and Table 11: Liquid Fuels Supply and Disposition." Data from these tables are used to determine the global constraint for coal to liquids in the model.

Conversions
Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) chart used to convert AEO prices to the year 2005.

Tech Authors
Lists the contact information for the researchers from both EPA and SRI who worked on this workbook.

References
Provides a detailed list of data references, including the full citation, source comments, and general data assumptions.

Definitions
Provides a list of definitions for various terms used throughout the workbook.

F: Sector Workbook Description – Refineries

Workbook Name:	EPAUS9r_12_REF_v1.1.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the refinery process technologies in the EPAUS9r MARKAL database.

Data Sources

The technology characteristics were taken from the AEO reference case. Additional data used to calculate costs were taken from research done for EPA by Research Triangle Institute (RTI). Emission factors are derived from the GREET model, version 1.8 (Argonne, 2007). In addition, speciation factors for black carbon and organic carbon are derived from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

Units

All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Emission factors are in kTonnes per PJ, with the exception of CO_2, which is expressed in MTonnes per PJ.

Workbook Description

The following section gives a description of each of the 18 worksheets found in the refinery workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*

Lists the commodity names, units, and set memberships for all refinery input and output fuels (energy carriers). The refinery fuel outputs are named using a three letter representation of the fuel name as given below followed by an "E," "N," or "L" to distinguish which refinery type the fuel was produced by.

LPG	Liquid Petroleum Gas
GSC	Gasoline – Conventional
GSR	Gasoline – Reformulated
JTF	Jet Fuel
DSH	Distillate Heating Oil No. 2
RFL	Low Sulfur Residual Fuel Oil
RFH	High Sulfur Residual Fuel Oil
KER	Kerosene
PFS	Petrochemical Feedstocks
ASP	Asphalt
DSL	Low Sulfur Highway Diesel (500 ppm)
DSU	Ultra-low Sulfur Highway Diesel (15 ppm)

PTC	Petroleum Coke
DLG	Dummy Liquid Fuel

Constraints*
Lists the constraint names for all refinery constraints.

Technologies*
Lists the technology names, units, and set memberships for all refinery and refinery fuel output collector technologies. The refinery names start with a "P" to indicate a process technology, followed by "REF" for refinery, and then "E" (existing), "N" (new), or "L" (limit) to distinguish the type.

The fuel output collector technologies start with "SC" for collector, followed by the three letter representation of the fuel name as given in the Table above, and then an "E," "N," or "L" to distinguish which refinery type the fuel was produced by.

ConstrData*
Contains the data for fuel shares for asphalt, petroleum feedstocks, petroleum coke, and LPG fuels. The constraints force the refineries to produce a minimum amount of these fuels. The values can range from fifty to seventy-five percent of the historical levels of output that have been reported by the EIA.

TechData*
Contains the inputs, outputs, and costs for refineries by region. The data are drawn from the worksheets described below. There are three refinery types in each region: existing refineries, new refineries (with associated capital costs), and new limit refineries. The new limit refineries can take up to twenty percent of the output of a refinery and produce higher percentages of gasoline and diesel fuels.

TechData-Emis*
Contains emission factors associated with refining.

RESID
Contains calculations for the regional residual capacity (RESID) of existing refineries in 2005.

Capacity
Contains calculations for the residual refinery capacity by PADD. Total capacity in million barrels per day is taken from the AEO reference case table "Domestic Refinery Distillation Base Capacity, Expansion, and Utilization." From these totals, the capacity used is calculated using the average utilization over 2010 - 2012 found on the **Utilization** worksheet. Process loss and refinery outputs not used in MARKAL are subtracted from the capacity utilized to come up with a final residual capacity amount. Data for the process loss and refinery outputs is found in the **Yields** worksheet. Finally, based on these residual capacity amounts, the percent of crude oil per output is calculated as input to the refinery in MARKAL.

PADD Products
Takes the yield data by fuel and by PADD from the **Yields** worksheet. Factors are applied to give MARKAL a range of fuel output to work from. Gasoline and diesel have higher output values than the other refinery products.

Yields
Contains raw data from EIA for the refinery and blender percent yields by fuel type and by PADD. Average values for 2005 and 2010 are calculated. Only the fuels that are tracked in the database are outputs.

Utilization
Contains raw data from EIA for the refinery inputs and utilization by PADD. Data are used to calculate the average yearly percent refinery utilization.

DSH Percent
Contains raw data from EIA for the weekly refinery and blender net production by PADD. These data are used to calculate the percentage of refinery yield of distillate fuel oil that is greater than 500 ppm sulfur (DSH in MARKAL).

Inputs ELC NG
Contains raw data from the AEO 2010 Table 34: "Refinery Industry Energy Consumption," including refinery energy fuel inputs. This information is used to calculate the input (INP(ENT)p) of electricity and natural gas per unit of refinery output.

RTI Costs
New refinery cost data from the "Task_5_Refinery_investment_costs," prepared by RTI International.

Conv
Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012). chart used to convert AEO prices to the year 2005.

EmisGREET
Includes refinery related emissions that were extracted from GREET and converted to MARKAL units.

EmisBC
Includes estimates of the fraction of PM2.5 that can be classified as black carbon. The fractions can differ by source category,

EmisOC
Includes estimates of the fraction of PM2.5 that can be classified as organic carbon. The fractions can differ by source category.

G: Sector Workbook Description – Biomass

Workbook Name:	EPAUS9r_12_BIOMASS_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize biomass resources in the EPAUS9r MARKAL database.

Data Sources

For the feedstock supply curves are derived from the *Billion Ton Update* (DOE, 2011a). Prices and quantities for a number of supply steps were derived from this report and data were downloaded from the website: https://bioenergykdf.net/content/billiontonupdate.

Units

All costs are expressed in millions of 2005 dollars. Biomass feedstock is generally expressed as million short tons (Mt). For some end-use sectors, such as the electric sector and industrial sector, the feedstock supplies are converted to PJ based on the energy content of the feedstock.

Workbook Description

The following section gives a description of each of the 32 worksheets in the biomass workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Conversions

Contains basic unit conversion data.

Commodities*

The naming for the biomass commodities follows their supply chain from production in the field to the conversion technologies that convert the biomass into liquid fuels, heat or power. Biomass feedstocks as produced at the farm, forest, etc. begin with a B. As the biomass moves down the supply chain emissions are accounted for (noted by EA) and any additional collection costs or energy use is added (noted by C). Delivered biomass after transport is simply indicated by its three letter name (STV for corn stover or AGR for agricultural residues), and when they are converted from Mt to PJ, there is a _PJ appended. Biomass that is delivered to specific sectors is indicated by a prefix (INDBIO or ELC). Emissions commodities and some fossil energy commodities are also included. Biomass commodities use the solid synthetics set membership, with only the initial commodities (e.g., BCRN, BFSR) designated as renewables. These solid synthetics should not be changed to renewable commodities, as this can lead to errors in the modeling (i.e., upper bounds from initial supply curves will not necessarily be met).

Technologies*

The naming for the biomass technologies follows the same structure as the commodities: biomass production, emissions accounting, collection, transportation, and designation to specific sectors. The critical technologies are the "biomass production" technologies, which begin with RNW. These technologies are essentially the supply curves for each of the biomass categories. For some biomass, corn and soybean oil, there may simply be one price point and upper bound. However, for all other cellulosic feedstocks, there are between 4 and 20 incremental price steps that form the supply curves. These supply curves form the bulk of the biomass workbook, and are the key component to this sector.

TechData_AgFeedstock*

Includes the agricultural-based biomass feedstocks that have supply curves derived from the Iowa State University's FAPRI-CARD model (using a modified version of the FAPRI-CARD baseline, see Elobeid 2011 for background on the model structure) or from USDA Agricultural Long-term Projections for corn (USDA, 2012. Table 18) and soybean and soybean products (USDA, 2012. Table 23) These feedstocks include corn grain, soybean oil, and corn stover. The corn grain and soybean oil include a single price (COST) and quantity (BOUND(UP)Or), according to the CARD model run that is included or the USDA projection. Corn stover is also projected in the CARD model, and can be run. However, as a default, these projections are not used, and the Billion Ton Update supply curves (on another worksheet) are used instead.

Conversion Process for Billion Ton Update Data

A general overview of how the Billion Ton Update data (DOE, 2011a) are utilized in MARKAL follows.

Although there are a number of different cellulosic feedstocks, the process for converting the raw data from the Billion Ton Update to the **TechData** worksheet follow the same basic steps.

1. The quantities reported when the raw data are downloaded from the Bioenergy KDF website (https://bioenergykdf.net/content/billiontonupdate) are cumulative amount of biomass (tons) by year (2012, 2015, 2020, 2025 and 2030), price ($10/ton, $20/ton…$200/ton) and location (county or state).
2. Where multiple biomass feedstocks were aggregated into one category, those feedstocks quantities were summed for each year, price, and state/county.
3. State level data were then aggregated to the nine-regions.
4. Cumulative amounts were converted into incremental quantities for each time step.
5. Quantities were then converted from tons to million tons (note that these are short tons).

In step 4, for some of the feedstocks based on agricultural lands, higher price steps could result in a lower supply (or negative price step). This result is somewhat counterintuitive, but is due to the fact that the Billion Ton Update also represents land use change – shift from one crop to another crop depending on the price. Therefore, at a higher price step for biomass feedstocks, there may be land use changing from one feedstock category to another, e.g., conversion of land from wheat or corn to energy crops. In the cases where this change occurs, the incremental step was set to zero, resulting in a trivial difference in total feedstock supply, typically on the order of 0.1% - 0.3%.

TechData_Stover(Bton)*

Stover supply curves reflect the quantity of stover that can be collected profitably, and takes into consideration factors such as crop yields, tillage, and upper limits on removal due to factors such as erosion. Stover supplies have five price steps from $40-$60 per ton of collected stover and are available for all regions except Region 2. These prices reflect farm gate prices.

TechData_AgRes(Bton)*
Agricultural residues reflect the quantity of "straw and stubble" collected from agricultural lands, including: wheat straw, barley straw, oats straw and sorghum stubble. Quantities of straw and stubble for specific crops are small relative to corn stover, and are therefore aggregated to a single supply curve. Similar to stover, these agricultural residues have five price steps from $40-$60 per ton of collected residues and are available for all regions except Region 2.

TechData_ForestRes(Bton)*
Forest residues include a variety of forest biomass resources, including residues from logging and thinning and other removal residues. For these supply curves, all lands, including Federal lands are included. Removing the Federal lands from the analysis reduces the total potential forest biomass available by about 1-9 million tons, with the larger differences at the higher price steps. In the future, we may include differentiated supplies with and without Federal lands. Note that thinning on federal lands do not currently qualify as renewable feedstocks under the Renewable Standards Program. However, they are currently aggregated together.

Forest residues have 20 supply steps – from $10 to $200 per ton -- substantially more than the other biomass categories. Prices reflect forest "roadside prices" that a buyer would pay, and therefore do not include transportation or preprocessing costs. However, our default for the base EPAUS9r database is to include only up to $70 per ton. We limit the feedstock supplies to this price step because according to the description in the Billion Ton Update report, estimates for conventional pulpwood to energy at prices above $80 per ton fall outside the model parameters. Given the higher level of uncertainty for these higher price steps, we have excluded them from the TechData sheet. However, the values are available from the **BtonU-base** worksheet and can be used in scenario analysis, with the caveat that extrapolating to these higher price steps has a great deal of uncertainty.

TechData_MillResUU(Bton)*
The Billion Ton Update also included Mill Residues, but is careful to distinguish used from unused mill residues. For the unused mill residues, four price steps range from $10-$40 per ton and are available for all regions except Region 2. These prices reflect the price at which it is assumed that they residues can be purchased at the mill and are comparable to the disposal cost. Although there are four price steps, all of the residues can actually be purchased at $20 or less. Therefore only the first two price steps are actually used.

TechData_MillResUsed(Bton)*
Again, the unused mill residues were the focus of the Billion Ton Update. However, we are also interested in the approximately 32 million dry tons of used mill residues that are currently used, mostly for energy. These supply curves are reflected as a single price point but are available only to the mills themselves in the model. The extrapolations of the used mill residues are also included on the worksheet **BtonU-base**.

TechData_UrbanWood(Bton)*
Urban wood waste (UWW) includes two categories of wood waste: C&D waste and wood from MSW. UWW has ten price steps, ranging from $10-$100 per collected ton, and is available for all regions. Only the first five steps are used, as all UWW is available at less than $50/ton.

TechData_ECG(Bton)*
Three types of perennial grasses (switchgrass, Giant Miscanthus, and sugarcane) are included in the supply curves for Energy Crops – Grasses (ECG). Perennial grasses have five price steps from $40-$60 per ton of collected residues and are available for all regions except Region 2. The prices and quantities are for the "baseline" assumptions from the Billion Ton Update. Note that there are also high-yield scenarios (for 2%, 3% and 4% yield growth). These additional options may be incorporated in future workbooks, but are currently not available.

TechData_ECW(Bton)*
Three types of woody energy crops (poplar, willow, eucalyptus, southern pines) are included in the supply curves for Energy Crops – Woody (ECW). Woody crops have five price steps from $40-$60 per ton of collected residues and are available for all regions except Region 8. The prices and quantities are for the "baseline" assumptions from the Billion Ton Update. Note that there are also high-yield scenarios (for 2%, 3% and 4% yield growth). These additional options may be incorporated in future workbooks, but are currently not available.

TechData_ECA(Bton)*
The last of the energy crops is energy sorghum, or a high-yield sorghum, considered an energy crop in the Billion Ton Update. Energy sorghum is an annual crop but was included in the Billion Ton Update due to its ability to grow across a wide range of sites. The supply curves are included as a **TechData** sheet, but it has not been linked to any potential end uses. However, energy sorghum is available as a feedstock for consideration under alternative scenarios. The production potential of energy sorghum is relatively small (on the order of 5-20 Mt per year) compared to the larger feedstock categories.

TechData_ProdCollect*
The technologies in this workbook represent the production and collection of biomass feedstocks. In general, these are simply "pass through" technologies, but provide a placeholder if additional analyses regarding changes in production and collection costs and/or energy use are desired. However, because all of the biomass feedstocks supply curves already take into account the cost and energy associated with the production and collection of biomass (and therefore costs are reflective of "farm gate" or "roadside" prices), additional costs and energy use here could be double counting. The one exception is the inclusion of a factor accounting for some feedstock degradation and loss for stover and other agricultural residues (with a slightly higher factor for INP(ENT)p than OUT(ENC)p.

TechData_Transport*
Contains both the transportation of feedstock, as well as sector specific "collector technologies" that take multiple biomass feedstocks, and send them to individual end use sectors. Feedstock transportation includes the diesel use for the truck transport of biomass (INP(ENT)p which is PJ

of diesel for every Mt or PJ of biomass transported). There is also a VAROM that represents the non-fuel costs associated with the transport of cellulosic feedstocks in particular.

For electricity production, feedstocks are converted from Mt to PJ based on their energy content. However, there are two different collectors: biomass to integrated gasification and combined cycle (IGCC) and combustion. The reason for the separation is that the emissions for the CO_2 and CO_2 from biomass feedstock going to combustion is accounted for on the input fuel (biomass), whereas for IGCC, the emissions are accounted for using a separate emissions accounting technology (SEELCBIGCC).

TechData_Emissions*
Includes tracking of electric sector biomass-related CO_2 and SO_2 emissions associated with combustion in the electric sector. There is also a placeholder for looking at CO2 update from biomass but is not included in the base CO_2 emissions accounting for biomass. Note that the CO_2 emissions are tracked as a separate CO_2 biomass source for the electric sector (e.g., CO2BE) as but are not included in the total CO_2 accounting and are thus assumed to be carbon neutral.

BtonU-base
Contains all of the feedstock supply curves from the Billion Ton Update . As described earlier, the data from the Billion Ton Update has been aggregated from state-level to the nine-regions and converted from cumulative to incremental quantities for each price step and from tons to million tons. The maximum quantity available for all price steps and all regions are summed after the last row of each set of supply curves. These quantities have been cross-checked against the tables in the report itself to ensure that all aggregation was correct.

OldStover(CARD+Removal)
Includes the earlier corn stover supply forms used in the 2008 version of the EPAUS9r database. Because there are some stover related parameters that are included in this sheet, such as the average losses during feedstock storage and transportation, this sheet has been retained.

Stover(CARD), Corn(CARD) and Soybean(CARD)
These worksheets take the state and regional level data from the **CARD_DATA_Sheet** and convert it into the cost and bounds for corn grain, corn stover and soybean oil in the **TechData_AgFeedstock** worksheet. Data that are linked directly to the **CARD_DATA_Sheet** are highlighted in yellow, and data that are then linked to the **TechData** sheet are highlighted in blue. For the quantities (Mt) available in each EPAUS9r region, we start with total corn production (million bushels) based on the CARD regions. CARD does not provide total corn production at the state level, so corn production is disaggregated to states based on CARD planted acreage, and then re-aggregated from the state to the nine-region level. There are also three options for how much corn may be utilized for ethanol production. The default is 50% of total corn production. Other options are to link to the CARD projections for corn used for ethanol (between 30-38% of total corn production) or allow the model to use as much of the corn crop as it chooses based on the price (although even 50% must be taken with majors caveats). Prices are also given by CARD using their regional definitions. Therefore, prices are again disaggregated from the CARD regions to states, then aggregated up again to a price using a weighted (by total production in each state) average. The process is similar for soybean oil,

although it also takes the additional step at incorporating the share of total soybean production to crush for oil, and the share of that soybean oil to FAME biodiesel.

Corn(USDA), Soybean(USDA)
To have another set of corn grain and soybean oil prices and quantities to run alternative scenarios, we have also included agricultural baseline projects from the USDA (http://www.usda.gov/oce/commodity/ag_baseline.htm). These supply curves are simple prices and quantities, and again, have defaults of 50%, which can be adjusted by users to account for the share of crops that can be used toward fuel production. Soybean oil curves are in the process of being included.

CARD_DATA_Sheet
This sheet includes the data from the FAPRI-CARD agricultural market model. These are the raw data that include all agricultural commodity market projections out to 2025. Only a subset of These data are used and is converted into MARKAL parameters in the earlier CARD worksheets.

Collect-Trans
Fuel use (diesel) for transportation of biomass feedstocks is calculated using default values from the GREET model (Argonne, 2007). Fuel use is expressed as PJ for every Mt of biomass transported, and takes into account one-way and roundtrip distances for transport (miles), payload (tons/vehicle) by vehicle type (medium or heavy duty truck), and vehicle efficiency (gal/mi). These assumptions (trip distance) can be modified from these default values. These are static values and do not take into account vehicle efficiency improvements that would be reflected in the heavy duty sector of the MARKAL model. Transportation costs are also modeled as a combination of fixed and variables costs for trucking based on reported data (Kocoloski et al.)

Feedstock Emissions
Calculates the carbon and sulfur emissions associated with combustion in the electric sector based on the carbon and sulfur content (by weight, derived from references with ultimate analysis of the chemical composition of various feedstocks) for each category of biomass feedstock. Original journal articles referenced are included in the table along with the full reference listed at the bottom of the worksheet. The carbon content is also used to derive an optional carbon dioxide uptake factor as well for the growing of the biomass, which can be used on the **TechData_Emissions** worksheet.

H: Sector Workbook Description – Biofuels

Workbook Name: EPAUS9r_12_BIOFUEL_v1.0.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Document describes the sources of the data and the calculations used to characterize biofuel production in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics for the majority of the biofuel production technologies are based on techno-economic assessments from the National Renewable Energy Laboratory (NREL). Data regarding fuel transportation and blending come from a number of sources, including DOE reports and peer-reviewed journal articles. The renewable fuel volumes from the EPA Renewable Fuel Standard Program are also included as reference and for potential use as constraints, as are EIA data from the Annual Energy Review for historic (2005, 2010 volumes). Additional data sources are specified in the worksheets themselves next to the raw data that were utilized.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ or MTons (million short tons) in the case of biomass resource inputs. Most emission factors are in units of kTonnes per PJ of biofuel that is transported within a region or from one region to another, with the exception of CO_2 emissions, which are in units of MTonnes per PJ.

Workbook Description
The following section gives a description of each of the 30 worksheets in the biofuels workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Conversions
Provides basic unit and price conversions.

Commodities*
Declares the energy carriers that are included in the biofuels workbook, including all biofuel energy carriers and associated fossil fuel inputs and biomass inputs.

Technologies*
Declares the technologies for biofuel production processes, application of subsidies and credits, inter-regional trading and transportation of biofuels, blending, application of credits for non-energy co-products, and international imports/exports of ethanol and biodiesel.

Constraints*
Declares the constraints that can be applied to model upper, lower or fixed bounds for specific biofuel categories, such as corn-based ethanol or total advanced biofuels. There are global, cross-region constraints that apply upper or lower limits to the aggregated national volumes of bio-based fuels that are produced or consumed.

TechData_BiochemEth*
Ethanol produced via biochemical processes (as opposed to thermochemical) is included in this sheet. This includes four variations of corn-based ethanol production: existing wet mills, existing dry mills, new dry mills, and new dry mills with combined heat and power. The first two represent the existing ethanol production capacity as of 2005 via the RESID. All of the corn-based ethanol production technologies utilize a number of fossil inputs (including electricity, natural gas, gasoline, and coal for the wet mills), and output corn-based ethanol. These technologies also produce a number of co-products ranging from high-fructose corn syrup to dried distiller's grain. Those co-products were tracked separated as material flows in earlier versions of the model. However, for simplicity tracking the energy carrier flows, these non-energy co-products have been combined and included via a discount (DELIV(ENT)) on the corn-ethanol energy carriers (the raw data links back to the "co-products" worksheet). There is also a subsidy for corn-based ethanol applied for the first two time periods (2005, 2010), and the subsidy is zero for the rest of the time horizon (to 2055), with the assumption that this subsidy will not be reintroduced.

This sheet also includes cellulosic-based ethanol production via the biochemical platform. This technology is set up to use up to five different feedstocks, although for the purposes of the base model run, only stover and other agricultural residues are used. Additional feedstocks for biochemical ethanol can be added for scenario runs. Biochemical cellulosic ethanol (CELETHB) then has the subsidy applied (with the parameter DELIV(ENT)) and the subsidy is assumed to extend throughout the modeling horizon.

Note that some of the technologies have improvements in product yield (declining INP(ENT) over time) in terms of Mt biomass required for per 1 PJ ethanol produced. Some technologies also have energy efficiency improvements. For example, the energy efficiency of existing corn-based ethanol is assumed to improve to begin to approximate the efficiency of new corn-based dry mills without CHP. The model can also chose to apply CHP. However, the share of CHP is constrained to less than 30% of the total corn ethanol production (see **ConstrData**). The share of CHP can be changed for scenarios analyzing high or lower potential for adoption of CHP.

CornEthProdDry
The majority of current U.S. ethanol production is dry mill corn-grain ethanol. Includes the raw data from a number of peer-reviewed publications and government reports that provide information regarding efficiency and costs that use process engineering economic studies, survey based approaches, or spreadsheet models. The primary source for much of the data are a survey article (Perrin, 2009). Data on CHP come from the **CornEthProdWet** worksheet, discussed below.

CornEthProdWet
Contains data related to ethanol production from wet mills. Much of the data are relevant only to existing wet mill capacity, given that new ethanol capacity in the U.S. has been new dry mills. Therefore, the residual capacity includes a number of wet mill facilities. Includes data from the USDA Ethanol Cost-of-Production Survey as referenced in the worksheet. As noted above, information regarding the CHP option for dry mills also links back to Worksheet.

CellEthProdBio
Includes the detailed raw data that were used for characterizing the biochemical platform for cellulosic ethanol production. Three related reports (McAloon, 2000; Aden, 2002; Humbird, 2011) were examined and relevant numbers are included for comparison. The Humbird 2011 report provided the final numbers for the technology included in the sheet **TechData_BiochemEth**.

EthRESID
The state-level existing dry and wet mill ethanol capacity for 2005 was derived from several tables in the Renewable Fuel Standard Program Regulatory Impact Analysis (EPA, 2010b) and aggregated up to the nine-regions.

EthRESID-old
Contains data used in earlier versions of the EPAUS9r database. The worksheet is retained because of the state-level capacity data for 2005 by company, city and state that were derived from publicly available data maintained by the Renewable Fuel Association. These production data were also used to support GIS analysis that went into the distances by mode for ethanol transportation from the ethanol plants to blending/end users, for the calculation of ethanol transportation costs. These transportation routes/distances were derived using the TRAGIS model (ORNL, 2004b), which was developed and maintained by Oak Ridge National Laboratory.

TechData_Biodiesel*
Biodiesel within worksheet is defined as FAME derived from soybean and waste oil. Includes the oil pre-processing steps (soybean crushing), the actual biodiesel production process, and credits for the co-products (glycerin), although that price credit drops substantially due to the excess of glycerin on the market and assumes no upgrading to refined glycerin.

Biodiesel
The raw data for the characterization for the biodiesel production process come from two articles (Zhang, et al 2003a, 2003b). This characterization of the biodiesel production process also includes an assessment of waste oil based on population and a related urban waste resources assessment cited in the worksheet.

TechData_Thermochem*
This sheet contains the data for the thermochemical production of ethanol and a gasoline-blendstock from several different biomass feedstock sources, primarily, woody biomass. For each of these technologies, there is an investment cost, fixed and variable O&M, two inputs (a biomass feedstock and the denaturant), and two outputs (ethanol and mixed higher alcohols that

are blended into gasoline). There is also a hurdle rate to reflect the high level of investment uncertainty regarding the technology itself, but also the uncertainty regarding the availability and price of the biomass feedstock (note that there is no hurdle rate associated with the biomass feedstocks production and logistics). This sheet also includes a number of collectors (including XCELGSL and XCELDSL) that apply a subsidy for cellulosic biofuels, before those biofuels are sent as a "drop-in" fuel to the gasoline and diesel supply. The raw data for this sheet come from **CellETHTC**.

Thermochem(TBD)
This sheet is a **TechData** sheet intended for use in scenarios and is not included in the baseline. This sheet provides a number of additional thermochemical pathways for the production of renewable gasoline and diesel and additional co-products such as LPG. These pathways are considered more uncertain technologies, but are of potential interest and use in exploring additional scenarios regarding biofuel production pathways. If the user decides to do model runs with these technologies as an option, the sheet name would need to be changed to **TechData_Thermochem(2)**, and all technologies and cells above the parameter would need to have the * removed. The raw data for this sheet comes from **CellGSLTC** and **CellGSLPYR**.

CellEthTC
The primary thermochemical biofuel technology was modeled as woody biomass to ethanol (Dutta et al., 2011). Provides details regarding the raw data and detailed information regarding the fuel and product yields, capacity, capital and operating costs. The worksheet also includes references and comparisons to earlier reports with similar techno-economics analysis (Phillips, 2007) and also shows the unit conversions to MARKAL units and conversion to 2005 dollars.

CellGSLTC
Worksheet and the following worksheet highlight two additional thermochemical biofuel options that can be included in scenario analysis. This sheet summarizes a wood to gasoline via the Methanol to Gasoline (MTG) intermediate process (Phillips et al., 2011). The Provides details regarding the raw data and detailed information regarding the fuel and product yields, capacity, capital and operating costs and also shows the unit conversions to MARKAL units and conversion to 2005 dollars.

CellGSLPYR
Includes the characterization of a fast pyrolysis to gasoline pathway (Wright et al., 2010). Again, pyrolysis is an additional thermochemical biofuel option that can be included in scenario analyses. This technology is translated into two potential options for linking to the **TechData** sheet, on-site hydrogen production and hydrogen purchase (included as a cost, not an actual H_2 input).

TechData_FuelTransport*
This sheet establishes the structure for the inter-regional trading, transport and blending of fuels. The underlying structure is such that there is a full origin-destination matrix that connects all regions to all regions for the transportation of ethanol. However, when the ethanol is moved by individual transport modes (truck, barge, rail) there are limitations on the capacity to move between regions. In the basic set up, each region is able to export to the other regions via

EXPETH# for the exporting regions IMPETHR## for the importing regions, where the # indicates the regions. Within the importing regions, there are additional technologies that designate whether that ethanol was imported via barge, truck or rail. For each combination of mode, there are also energy inputs, variable O&M costs, and upper bounds on the capacity for transport. Currently the transportation bounds are set to an upper limit for rail and barge, with much greater flexibility to expand transportation by trucking. However, with corn-based and corn-stover based ethanol being the key feedstocks for much of the ethanol production, trucking is limited to go from Regions 3 and 4 to the other Regions. This can be modified for scenario analyses.

Worksheet also captures the blending of denatured ethanol and gasoline to an E85 blend, including the costs associated with conversion of dispensers and storage tanks to handle E85 blends, as well as a blending of biodiesel into a B20 blend. Technologies for the international exports and imports of both ethanol and biodiesel are also captured here, and are derived from the FAPRI-CARD agricultural model. Because there are no supply curves (only a single price and quantity point are available), these volumes are fixed in the **ConstrData** sheet. These prices are the cost to import (with fixed amounts of imports), as well as the credit to export (again, with fixed amounts of exports).

TechData_Emissions*
This **TechData** sheet includes emissions of CO_2, NO_x and SO_2 associated with the transportation of biofuels, specifically ethanol.

ConstrData*
The majority of the constraints are for specifying lower, upper or fixed bounds on the production of particular fuels, such as corn-based ethanol or biodiesel, or categories of fuels, that either go through a collector (such as CELETH) or are specified by a technology filter in the database, such as advanced biofuels (BIOF_ADV2) or all exported biodiesel (BDL_IMP). These constraints are global, cross-region constraints, meaning the sum of the activity in all 9 regions has to meet the "GLOBAL" constraint which is specified as the cross-regional right hand side of the equation. Some constraints are included as "NON" or non-binding constraints, but can be used in scenario analyses. There are two share constraints: the share of new corn-based ethanol production that can come from CHP facilities, and the share of E85 in the total gasoline/E10 pool. E85 share constraint is applied to the blending technology (XBLNDE85) that represents gasoline station retrofits to dispense E85, and restricts the total dispensing of E85 to 1/3 of the total gasoline/E10 pool. Both constrains can be changed.

RFS2 Volumes
Includes the original volume standards for the EPA's Renewable Fuel Standard program (RFS2), as well as historical renewable fuel production data from the EIA's Annual Energy Reviews that are used to set the 2005 RESID and 2010 production volumes.

Co-Products
Includes non-energy co-products from both wet and dry mill production and biodiesel production to capture the economic value of producing these products. These non-energy co-products are calculated based on data from the FAPRI-CARD agricultural market model, and translate the price per unit of co-product ($/ton or $/lb) and co-product yield (Mt co-product per PJ fuel produced) into a cost credit (M$/PJ fuel produced). For each fuel product, dry mill ethanol, wet mill ethanol or biodiesel, the multiple feedstock credits are then summed and added as a negative delivery cost (DELIV(ENT)) in the corresponding **TechData** sheet.

Int'l Exp+Imp
Summarizes the raw data from the CARD model for the imports and exports of ethanol and biodiesel. Because these are point estimates for prices and quantities, and not supply curves, these are included as fixed constraints on the **ConstrData** worksheet. Their inclusion is to account for potential imports and exports of biofuels, and is primarily intended for use when run iteratively with the CARD model.

EthTrans2
Contains data from a number of different sources, including an in-house geospatial analysis. At the core are the origin-destination matrices that provide the travel distances by mode (rail, barge, truck) from each region to each region. These distances were obtained using the TRAGIS model (ORNL, 2004b), which provided the approximate routing distance by rail, barge and truck for each region to region combination. Barge and rail capacity was considered to be constrained to existing limits, using the capacity limits from the PMM documentation. However, capacity is allowed to grow for all trucking transport from Regions 3 and 4 to the other Regions, given that with corn based ethanol and biofuels from other Midwest feedstock, such as corn stover, the majority of interregional transport will come from these regions. Other regions can produce and use biofuels but there are more constraints on their ability to export to other regions. Those assumptions can be changed for scenarios analysis by changing the upper bound for specific region-region pairs. Transportation costs were updated from: Kocoloski et al., (2010). Based on the transportation distances for truck from Kockoloski et al, a $/ton-mi is then translated into a VAROM for transportation. These distances and vehicles efficiencies and capacities are also used to calculate the fuel use (diesel) for the transportation of ethanol – interregionally and locally.

EthTrans
Contains data from the EIA. Specifically, from the PMM Documentation: Table I4. 2012 New Ethanol Shipments and Freight Costs by Census Divisions. That this is an older version, and is primarily for reference. All of the cost numbers have been updated in the **EthTrans2** worksheet, but some of the capacities – for rail and barge, specifically – still link back to these data.

Emissions-Trans
Includes emissions factors for the transportation sector for calculation of emissions associated with the transporting ethanol.

Blend
Provides the data for different ethanol blend levels, including denatured ethanol, E10, and E85. The infrastructure costs for upgrading retail stations to provide E85 in dispensers are also included.

Credits
Federal credits for ethanol blending include the Volumetric Ethanol Excise Tax Credit (VEETC), also known as the 'blenders credit' and cellulosic ethanol income tax credit for cellulosic alcohol and other cellulosic biofuels as specified in the Food, Conservation and Energy Act (FCEA) of 2008 (H.R. 2419). The corn ethanol and biodiesel credits expired December 31, 2011. The expiration of credits is reflected starting in model year 2015. Cellulosic ethanol credits are assumed to remain in place to 2055.

CARD CellETH Yields
Includes projections of changes in yields (gallons of ethanol per ton of biomass) for cellulosic ethanol production from the FAPRI-CARD model.

Soybean00
Provides basic state level data on soybean production and was used to derive 2005 RESID biodiesel capacity (linked to sheet **Biodiesel**) for each of the regions.

I: Sector Workbook Description – Municipal Solid Waste

Workbook Name:	EPAUS9r_12_MSW_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the conversion of MSW to electricity in the EPAUS9r MARKAL database.

Data Sources
The MSW resource supply curve data were taken from *The State of Garbage* (Simmons et al.). The emissions data are derived from the EPA's MSW-DST (Kaplan et al.).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ.

Workbook Description
The following section gives a description of each of the six worksheets in the MSW workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all fuels (energy carriers) associated with MSW, including supply, transportation, and emissions.

Technologies*
Lists the names, units, and set memberships for the resource supply curves, collection technologies, transportation to end-use sector technologies, and emissions tracking technologies for MSW.

TechData_MSW*
Contains the supply curve costs and bounds for MSW by region. In addition, the worksheet has emissions data for emission tracking technologies. The methodology to calculate the emissions is presented in the paper *Is It Better To Burn or Bury Waste for Clean Electricity Generation?* (Kaplan et al., 2009)

MSW
Contains the raw data and calculation for the cost and supply bounds for the MSW supply curves.

Pop
Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the Census 2000. Data can be found at www.census.gov/population/www/projections/projectionsagesex.htmal, *Table 6: Total*

population for regions, divisions, and states: 2000 to 2030. Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are also taken from EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. The data have been adjusted to include Alaska and Hawaii.

Conversion Factors

Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) chart used to convert AEO prices to the year 2005 and biomass energy conversions.

J: Sector Workbook Description – Electric Sector

Workbook Name:	EPAUS9r_12_ELC_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the electric sector in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics for electric power production technologies come from a number of different sources, with the primary one being the AEO reference case (EIA, 2012c). Additional sources are specified in the worksheets themselves next to the raw data that were utilized.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ or GW. Most emission factors are in units of kTonnes per PJ of fuel input with the exception of CO_2, which is expressed in MTonnes per PJ.

Workbook Description
The following section gives a description of each of the 47 worksheets in the electric sector workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all fuels (energy carriers) and emissions in the electric sector.

CommData*
Contains the reserve margin (15%) and the transmission efficiency (93.5%) for electricity.

CommData-CCS*
Contains the upper bound for sequestered CO_2 from CCS technologies. Values are based on electric sector expert judgement.

CCS Capacity Raw Data
Contains CCS storage capacity potential raw data for use in determining the upper bounds for CO2 sequestration.

Technologies*
Lists the technology names, units, and set memberships for all technologies in the electric sector.

TechData_DMY*
Contains a dummy electric supply technology with a high investment and variable O&M cost. This electricity supply will be used only by the model when there are no other sources for electricity, allowing the modeler to complete an otherwise infeasible model run and then go back and look for the cause of the use of a dummy fuel. Also includes a number of dummy technologies for use with the retirement constraints for residual coal steam technologies.

TechData_NewCap*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for new electric production technologies (not including CCS, wind, solar, and landfill gas).

New Cap Raw Data
Contains raw data for the costs and efficiencies of new electric generation technologies. The data comes from AEO Table: "Cost and Performance Characteristics of New Central Station Electricity Generating Technologies."

Geothermal Raw Data
Contains raw data for the costs and efficiencies of new geothermal technologies.

TechData_CCS*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for carbon capture and sequestration electric production technologies.

CCS Calcs
Contains the raw data and calculation for new CCS electric production technologies. The data are drawn from a number of sources including AEO and the MIT *Future of Coal* (MIT, 2007).

TechData_Uranium*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for mined uranium conversion and nuclear power plant technologies.

Nuclear Flowcharts
Describes the flow of nuclear power production from mined uranium through conversion of the uranium and the associated waste products. Parameter values are placed in each of the corresponding boxes in the flowchart.

Nuclear Raw Data
Contains raw data for nuclear power plant production. Data comes from a number of sources referenced in the worksheet.

TechData_Solar&Wind*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for wind and solar energy technologies.

Solar Raw Data
Contains raw data for wind power technologies taken from the AEO 2006 solar input files.

Wind Raw Data
Contains raw data for wind power technologies taken from the AEO 2006 wind input files.

TechData_LFG&MSW*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for landfill gas to energy technologies and municipal solid waste to energy technologies.

LFG Raw Data
Contains raw data for costs, efficiencies, and residual capacities for existing and new LFG technologies.

MSW Raw Data
Contains raw data for costs, efficiencies, and residual capacities for existing and new MSW technologies.

TechData_CHP*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for CHP technologies.

CHP raw data
Contains the raw data for combined heat and power technologies.

TechData_NonCoalResid*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for existing non-coal electric generation technologies (not including wind, solar, nuclear, CHP, and municipal solid waste).

Resid Raw Data
Contains old residual capacity mined directly from NEMS.

RESID Calcs
Contains the residual capacity calculations by region and by fuel type. Data for the calculations come from the **ExistingUnits2007** worksheet.

ExistingUnits2007
Contains the raw data, including region, fuel type and plant capacity, for all existing generating units in the United States in 2007. Data comes from Form EIA-860 data (Energy Information Administration's "Annual Electric Generator Report").

ExistingUnits2007 NG STM and CC
Contains the raw data from EIA-860 for natural gas steam and combined cycle plants only.

ExistingUnits2007 Nuclear
Contains the raw data from EIA-860 for nuclear plants only.

File Description
Describes the column headings and various codes contained in the **ExistingUnits2007** worksheet.

TechData_CoalResid*
Contains the costs, efficiencies, residual capacities, availability factors, and peak demand parameters for existing coal electric generation and selected air pollution control technologies (SO_2, NO_x, PM).

Resid Coal Boilers
Contains the raw data used to populate information in the **TechData_CoalResid** worksheet. Data in worksheet originate from the National Electric Energy Data System (NEEDS) v.4.10 database, and were expanded/refined by E.H. Pechan & Associates under EPA Contract No. EP-D-07-097.

Bin Table – Resid Coal
Contains calculations used to populate residual capacities and input requirements of the existing coal generation technologies in the **TechData_CoalResid** worksheet. Development of the regional qualifiers, required in the **Technologies** worksheet, is also performed in worksheet.

Bin Table – SOx
Contains calculations used to populate residual capacities of the SO_2 control technologies in the **TechData_CoalResid** worksheet. Data for the calculations comes from the **Resid Coal Boilers** worksheet.

Bin Table – NO_x
Contains calculations used to populate residual capacities of the NO_x control technologies in the **TechData_CoalResid** worksheet. Data for the calculations comes from the **Resid Coal Boilers** worksheet.

Bin Table – PM
Contains calculations used to populate residual capacities of the PM control technologies in the **TechData_CoalResid** worksheet. Data for the calculations comes from the **Resid Coal Boilers** worksheet.

PM Emissions
Contains the calculations used to populate environmental accounting parameter for PM_{10} emissions in the **TechData_CoalResid** worksheet. Data for the calculations comes from the **Resid Coal Boilers** worksheet.

PM Control Data
Contains the calculations used to derive investment and O&M costs for the PM control technologies in the **TechData_CoalResid** worksheet. Data for the calculations comes from the Integrated Environmental Control Model (IECM) Version 6.2.4, E.H. Pechan & Associates, and the **Resid Coal Boilers** worksheet.

Retrofit Resid Raw Data
Contains the calculations used to derive investment and O&M costs, as well as environmental accounting parameter values for the SO_2 and NO_x control technologies in the **TechData_CoalResid** worksheet. Data in Worksheet were generated with the EPA CUECost spreadsheet model.

Constraints*
Lists the share constraint names for all user defined constraints.

ConstrData*
Contains the constraint data for regional fuel shares, technology shares, and RPS standards. Fuel share constraints are taken from the **Raw Regional Projected Shares** worksheet. Lower values for wind technology in each region and upper bounds on each class of wind technology are taken from the **Wind Raw Data** worksheet. Nuclear, solar, MSW, and gas turbine constraints are based on electric sector expert judgement.

ConstrData-CoalRetire*
Contains the constraint data used to keep retired coal capacity from coming back on-line. This keeps coal plants in the model from starting and stopping throughout the time horizon.

ConstrData-RPS*
Contains the constraint data for regional tiered RPS constraints. The data is pulled from the **Regional RPS Calcs** worksheet.

Regional RPS Calcs
Aggregates the data from the **State RPS Data** worksheet into regions and calculates a regional RPS for each tier.

State RPS Data
Contains state RPS raw data from the DSIRE website (NCSU 2010). The data includes accepted technologies and RPS goals.

Raw Regional Projected Shares
Contains the fuel use percentages by region used on the **Constraints** worksheet. Percentages are calculated from the data on the **AEO Regional Fuel** worksheet.

AEO Regional Fuel
Contains raw data from the AEO Supplemental tables for Regional Data, Tables 1-8, "Energy Consumption by Sector by Source". The data for the fuel use in the electric sector is pulled from

these tables. These data are used to determine fuel splits for the first three time periods after 2005 in the model.

TechData_EmisCoal*
Contains pre-control emission factors for existing and new pulverized coal-fired electric generation units (EGUs), as well as factors for IGCC units. All factors are in kTonnes per PJ of coal input, with the exception of CO_2, which is in MTonnes per PJ of coal input. PM2.5 emissions are assumed to be 85% of PM10 emissions. All other factors on this workbook originate from the GREET model (Argonne, 2007)) or were derived using $PM_{2.5}$ speciation estimates from the **RTI-BC** and **RTI-OC** worksheets.

TechData_EmisOther*
Includes emission factors for non-coal sources within the electric sector. Emission factors are derived from the GREET model or were calculated using $PM_{2.5}$ speciation estimates from the **RTI-BC** and **RTI-OC** worksheets. Fuel oil and diesel controls on NO_x and PM are assumed to reduce 75% of uncontrolled emissions. The fractions of PM_{10} that are $PM_{2.5}$, black carbon (BC) and organic carbon (OC) are assumed to be equivalent to those for natural gas turbines.

GREET2012-UtilityFactors
Summarizes available emission factors for utilites.

NewEmissionFactors
Displays the new MARKAL emission factors as original data (value, unit, and data source) for each pollutant-technology combination..

GREET-EF_TS
This table was extracted from the GREET model, version 1.8.c.0. Cells were added to convert factors from grams/MMBT to kTonnes/PJ.

RTI-BC
Contains factors that represent the fraction of $PM_{2.5}$ that is BC for various fuels and source categories. The factors were derived from the literature. More detailed information about the source of these factors is available upon request.

RTI-OC
Contains factors that represent the fraction of $PM_{2.5}$ that is OC for various fuels and source categories. The factors were derived from the literature. More detailed information about the source of these factors is available upon request.

GREET_Summary
This table was extracted from the GREET model, version 1.8.c.0. The data shown here are equivalent to those in the GREET-EF_TS tab, but have been reformatted to facilitate use in other tabs. Also, SO_2 factors have been added.

GREET_FuelSpecs

Includes data from the GREET model, version 1.8.c.0. These values are used to calculate CO_2 and SO_2 emission factors for various fuels.

LFG_MSW-Emis
Includes emission factors for waste-to-energy and landfill gas combustion.

Water Data
Contains the water consumption and water withdrawal factors for electric generation technologies.

Conversions
Contains common conversion factors including the Implicit Price Deflator (DOC, 2010) chart used to convert AEO prices to the year 2005 and conversion technology heating values.

K: Sector Workbook Description – Residential Sector

Workbook Name:	EPAUS9r_12_RES_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the residential sector in the EPAUS9r MARKAL database.

Data Sources

The technology and end-use demand characteristics were taken from the AEO reference case. Additional data used to calculate demands were taken from RECS (EIA, 2009c). Lighting data were taken from a report provided to the EIA from Navigant Consulting (EIA, 2007). Regional HDD and CDD values were taken from NOAA's National Climate Data Center (NCDC) Historical Climatological Series – HCS 5.1. Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the 2000 Census. Emission factors were developed from several sources, including the Climate Registry (TCR), EPA's WebFIRE emission factor database, and the Easter Regional Technical Advisory Committee (ERTAC).

Units

All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of PJ with the exceptions of refrigeration and freezing, which are given in terms of million units, and lighting, which is given in terms of billion lumens per year. Emission factors are represented in units of ktonnes per PJ of fuel or energy input.

Workbook Description

The following section gives a description of each of the 27 worksheets in the residential workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*

Lists the commodity names, units, and set memberships for all fuels (energy carriers) and demands in the commercial sector. Fuels coming into the residential sector have passed through a collector technology that tracks the emissions from the fuels. The "EA" used in the fuel name stands for "Emissions Accounting." Fuels used include electricity (RESELC), diesel (RESDSLEA), kerosene (RESKEREA), LGP (RESLPGEA), natural gas (RESNGAEA), biomass for wood heating (RESBIOEA), and solar (SOL).

For the naming convention for the demand technologies, the first letter in the technology name reflects the technology category. In this case 'C' is used for 'Commercial'. The remaining letters represent the type of end-use demand. The demands in the database are:

RSC = Space Cooling equipment
RSH = Space Heating equipment
RWH = Water Heating equipment
RLT = Lighting equipment
RRF = Refrigeration equipment
RFZ = Freezing equipment
ROE = Miscellaneous Electric equipment
ROG = Miscellaneous Natural Gas equipment

Constraints*
Lists the constraint names for all user constraints in the residential sector.

Technologies*
Lists the technology names, units, and set memberships for all end-use and collector technologies in the commercial sector. The naming convention starts with the end-use demand, followed by the fuel type, the technology type, the efficiency level, and the model year. For example, "RSHEHPV110" refers to the 2010 model year of the lowest efficiency electric heat pump for residential space heating. The efficiency level goes from V1 for base model efficiency to V4 or V5 for the highest efficiency.

ConstrData*
Contains the data for fuel shares and technology shares by end-use demands. Values for 2010 were calculated in the **RECS RESID** worksheet for all end-uses except lighting. Electricity and natural gas fuel shares are relaxed 3% per time period out to 2055. Diesel, LPG, and kerosene fuel shares are relaxed over 5% per time period out to 2055 (for a total of 50%). Lighting technology shares were calculated in the **RLT Splits** worksheet. Incandescent lighting shares are reduced 50% by 2020 in keeping with the Energy Independence and Security Act (EISA) of 2007. Compact fluorescent and LED lighting technologies increase in shares by a minimum of 20% by 2055. Purchased electric and geothermal heat pumps provide both heating and cooling for residential homes, therefore a constraint is used to force any purchased technologies to be used for both end-uses.

CommData_Demand*
Contains the demand values by end-use and by region. The data are taken from the **RegionalDmds** worksheet which is explained below. The fraction of capacity entering electricity peak equations and the fractional demand by season and time of day (FR(Z)(Y)) are based on expert judgement.

TechData*
Contains the parameter values for all end-use technologies (with the exception of solar photovoltaics). The data for the technology investment cost, efficiency, and capacity factor are drawn from the AEO technology data aggregated in **RTEKTY Conv**. The data for the residual capacity are calculated in the **RESID CALC** worksheet. The values for the implied discount rate (or hurdle rate) for each technology are determined based on financial and non-financial factors that affect the choice of various residential technologies. The discount rates range from 0.18 to 0.45 with the lower rates being attached to standard technologies and the higher rates

being attached to higher efficiency technologies, new technologies such as LED lighting and technologies that use diesel fuel.

TechData_Emis*
Contains technology definitions for the collectors that are used to assign emissions to various fuels used within the residential sector. The emission factors are fuel specific and do not currently change as a function of time. Several species include an "R" added to the end, which is used in sectoral emissions accounting. The emissions factors that populate Worksheet are obtained from the following worksheets: EIACO2Coef, EmisBC, EmisOC, and EmisRes.

TechData_SESC*
Contains the parameter values for a collector technology carrying electricity to residential technologies.

TechData_ZZ*
Contains the parameter values for dummy technologies for each of the end-use demands. These technologies have a high variable O&M cost and will be used in a model run only when the model cannot meet its demand with available technologies. The use of any of these technologies indicates an infeasibility in the model.

Sol_PV*
Contains the parameters for residential solar photovoltaics. The investment costs, fixed O&M costs, and seasonally adjusted technology availability factors are taken from the electric sector workbook and are based on values from the AEO2006 Solar Input data. Fixed bounds are implemented forcing the use of solar photovoltaics based on the AEO projections. Nationally projected use, found in the **AEO12 Renew** worksheet, is evenly distributed across the nine-regions.

AEO12 Renew
Contains raw data from the AEO main reference case table: "Renewable Energy Consumption by Sector and Source."

RESID CALC
Contains calculations for the regional residual capacity (RESID) of existing technologies in 2005. RESID is calculated by multiplying the market share (taken from **RECS RESID**) for each end-use technology times the total demand for that end-use and dividing by the capacity factor (CF) for that technology.

RECS RESID
Regional market shares by technology are calculated from the EIA 2005 RECS detailed tables for space heating, air conditioning, and water heating. Fuel and aggregated technology shares are also calculated for use as model constraints.

RLT Splits
Data from the Navigant Consulting (EIA, 2007) are used to determine the 2005 market shares for lighting technologies.

RTEKTY Conv
Contains an aggregated listing of the end-use technologies from the **AEO RTEKTY** file and from **Res Lighting** with their data characterizations. The technologies are given MARKAL-specific names and descriptions using standard MARKAL naming conventions and the technology efficiency and capital cost are converted to MARKAL units. Technology capacity factors are determined from expert elicitation.

Res Lighting
This residential lighting raw data come from an EIA report prepared by Navigant Consulting (EIA, 2007).

RTEKTY12 agg
Worksheet takes the technology data from the **RTEKTY12** worksheet for Region 2. Decisions are then made about which technologies to represent in MARKAL. Where certain technologies do not exist in Region 2, Region 5 data are used.

RTEKTY12
Contains raw data from the AEO Residential Technology Equipment Type Description File (RTEKTY). Each record gives specifications for a specific model year of a specific end-use technology.

RegionalDmds
Demand values calculated in **ResDemand** are re-organized into regions.

ResDemand
End-use demands are calculated for each region by taking the national demands calculated in **USDemand** by regional data calculated in **ResCalc** as follows:

Regional Cooling Demand = cooling coefficient * square footage of AC space * CDD
Regional Heating Demand = heating coefficient * square footage of heated space * HDD
Regional Refrigeration Demand = number of households * refrigerators per household
Regional Freezer Demand = number of households * freezers per household
Regional Lighting Demand = national lighting demand * regional percent of households
Regional Misc Electric Demand = national misc electric * regional percent of households
Regional Misc NG Demand = national misc NG * regional percent of households
Regional Water Heating Demand = national water heating * regional percent of households

ResCalc
Contains a number of preliminary calculations used to determine the end-use demands found in workbooks **USDemand** and **ResDemand**.

The grey and green shaded areas hold the data and calculations for regional household heating degree day (HDD) and cooling degree day (CDD) coefficients. Regional HDD and CDD values for the 10 year average from 1998-2008 were take from the NCDC Historical Climatological Series – HCS 5.1. Years recorded and used for our calculations end in June 2009. These data can be found at www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html#51updates. National

CDD and HDD adjustment factors were calculated by time period by doing a weighted average based on regional population data. These adjustment factors, along with the national demands, average household square footage, and CDDs and HDDs were used to calculate the national housing cooling and heating coefficients by time period.

The blue shaded area in the workbook holds the calculations for the percentage of households with cooling technologies, refrigerators, and freezers. Air conditioning usage was taken from DOE's 2005 Residential Energy Consumption Survey (RECS). Regional refrigerator and freezer distributions were calculated based on data from the 2005 Annual Energy Review.

USDemand

National energy demands for space cooling, space heating, and water heating (given in PJ) are calculated using the data for energy consumption by end-use demand and fuel and the average stock equipment efficiency from the AEO reference case. National energy demands for refrigerators and freezers (given in million units) are calculated from the AEO equipment stock data found in the table: "Residential Sector Equipment Stock and Efficiency." National energy demands for miscellaneous electric and natural gas demands are taken from the AEO delivered energy data found in the table: "Residential Sector Key Indicators and Consumption." National lighting demands (given in billion lumens per year) are calculated by multiplying the lighting energy use data found in the AEO by a billion lumens per PJ conversion factor, and then applying that conversion factor by regional square footage per household.

AEOHW

Water heater data from AEO are used to calculate a factor for the average number of PJ of demand met by a water heater unit. This information is used to convert AEO costs per water heater unit into cost per PJ of demand met on the **RTEKTY Conv** worksheet.

Pop

Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the 2000 Census. Data can be found at www.census.gov/population/www/projections/projectionsagesex.html, Table 6: "Total population for regions, divisions, and states: 2000 to 2030." Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are also taken from EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. These data have been adjusted to include Alaska and Hawaii.

Conversion Factors

Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) chart used to convert AEO prices to the year 2005.

EmisCO2Coef

Contains CO_2 coefficients for various fuels, as reported by the DOE (DOE. 2008).

EmisBC
Includes estimates of the fraction of PM2.5 that can be classified as BC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

EmisOC
Includes estimates of the fraction of PM2.5 that can be classified as OC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

EmisRes
Includes commercial emission factors. These factors were derived from a number of sources, including the Climate Registry and the EPA WebFIRE emission factor database. More information about the derivation of the emission factors is available upon request.

L: Sector Workbook Description – Commercial Sector

Workbook Name: EPAUS9r_12_COM_v1.0.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Document describes the sources of the data and the calculations used to characterize the commercial sector in the EPAUS9r MARKAL database.

Data Sources
The technology and end-use demand characteristics were taken from the AEO reference case. Additional data used to calculate demands were taken from the CBECS database (EIA, 2007a). Regional HDD and CDD values were taken from the NCDC Historical Climatological Series – HCS 5.1. Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the 2000 Census. Emission factors were developed from several sources, including the Climate Registry (TCR), the EPA WebFIRE emission factor database, and the Easter Regional Technical Advisory Committee (ERTAC).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of PJ with the exceptions of ventilation, given in terms of thousand cubic feet per minute, and lighting, given in terms of billion lumens per year. Emission factors are represented in units of ktonnes per PJ of fuel or energy input.

Workbook Description
The following section gives a description of each of the 25 worksheets in the commercial workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all fuels (energy carriers) and demands in the commercial sector. Fuels coming into the commercial sector have passed through a collector technology that tracks the emissions from the fuels. The "EA" used in the fuel name stands for "Emissions Accounting." Fuels used include electricity (COMELC), diesel (COMDSLEA), kerosene (COMKEREA), LGP (COMLPGEA), natural gas (COMNGAEA), residual fuel oil (COMRFLEA), and solar (COMSOL).

For the naming convention for the demand technologies, the first letter in the technology name reflects the technology category. In this case 'C' is used for 'Commercial'. The remaining letters represent the type of end-use demand. The demands in the database are:

CSC = Space Cooling equipment
CCK = Cooking equipment
CSH = Space Heating equipment

CWH= Water Heating equipment
CLT = Lighting equipment
CRF = Refrigeration equipment
CVT = Ventilation equipment
COF = Office Equipment
CMD = Miscellaneous Diesel equipment
CME = Miscellaneous Electric equipment
CMN = Miscellaneous Natural Gas equipment
CML = Miscellaneous LPG equipment
CMR = Miscellaneous Residual Fuel Oil equipment

Constraints*
Lists the constraint names for all user constraints in the commercial sector.

Technologies*
Lists the technology names, units, and set memberships for all end-use and collector technologies in the commercial sector. The naming convention starts with the end-use demand, followed by the fuel type, the technology type, the efficiency level, and the model year. For example, "CSH.NG.FURNACE.ST.10" refers to the 2010 model year of a standard efficiency natural gas furnace for commercial space heating. The efficiency level is either: BS for base model efficiency, ST for standard efficiency, or HE for high efficiency. Some of the technology abbreviations used are given below:

Heating and Cooling
AHP = Air Source Heat Pump
GHP = Ground Source Heat Pump
ELO = Other Electric
CSC = Commercial Scroll Chiller
CSW = Commercial Screw Chiller
CRC = Commercial Reciprocating Chiller
CCC = Commercial Centrifugal Chiller
RAC = Rooftop Air Conditioning
WAC = Window Air Conditioning
CAC = Central Air Conditioning

Ventillation
CAV = Constant Air Volume
VAV = Variable Air Volume

Refrigeration
CEN = Supermarket Central Refrigeration
WIR = Walk-in Refrigerator
WIF = Walk-in Freezer
RIR = Reach-in Refrigerator
RIF = Reach-in Freezer
ICM = Ice Machine
BVM = Beverage Machine
RVM = Vending Machine

Lighting
INC = Incandescent
CFL = Compact Fluorescent
HAL = Halogen
LFL = Linear Fluorescent
LED = Light-emitting Diode
MH = Metal Halide
MV = Mercury Vapor
MAG = Magnetic
HPS = High Pressure Sodium

ConstrData*
Contains the data for fuel shares and technology shares by end-use demands. Values for 2010 were calculated from the AEO market shares found in the **Mkt Shares raw** worksheet. Shares are relaxed 3% per time period out to 2055.

CommData_Demand*
Contains the demand values by end-use and by region. The data are taken from **DMD ByRegion** worksheet which is explained below. The fraction of capacity entering electricity peak equations and the fractional demand by season and time of day (FR(Z)(Y)) are based on expert judgement.

TechData_COM*
Contains the parameter values for all end-use technologies (with the exception of solar photovoltaics). The data for the start year, technology lifetime, investment cost, efficiency, and fixed operating and maintenance cost are drawn from the AEO technology data aggregated in the **Aggregated Data** worksheet. The data for the residual capacity are calculated in the **RESID** worksheet. The values for the implied discount rate (or hurdle rate) for each technology are determined based on financial and non-financial factors that affect the choice of various commercial technologies. The discount rates range from 0.18 to 1.25 with the lower rates being attached to standard technologies and the higher rates being attached to higher efficiency technologies, new technologies such as ground source heat pumps, and technologies that use diesel fuel.

TechData_Emis*
Contains technology definitions for the collectors that are used to assign emissions to various fuels used within the commercial sector. The emission factors are fuel specific and do not currently change as a function of time. Several species include a "C" added to the end, which is used in sectoral emissions accounting. The emissions factors that populate Worksheet are obtained from the following worksheets: EIACO2Coef, EmisBC, EmisOC, and EmisCom.

TechData_SESC*
Contains the parameter values for two collector technologies: one carrying electricity to commercial technologies and one carrying solar to the photovoltaics.

TechData_ZZ*
Contains the parameter values for dummy technologies for each of the end-use demands. These technologies have a high variable O&M cost and will only be used in a model run when the model cannot meet its demand with available technologies. The use of any of these technologies indicates an infeasibility in the model.

Sol_PV*
Contains the parameters for commercial solar photovoltaics. The investment costs, fixed O&M costs, and seasonally adjusted technology availability factors are taken from the electric sector workbook and are based on values from the AEO2006 Solar Input data. Fixed bounds are implemented forcing the use of solar photovoltaics based on the AEO 2010 projections. Nationally projected use, found in the **AEO12 Renew** worksheet, is evenly distributed across the nine-regions. After 2035, solar photovoltaics are projected to grow 30% per 5-year time period.

AEO10 Renew
Contains raw data from the AEO main reference case table: "Renewable Energy Consumption by Sector and Source."

RESID
Contains calculations for the residual capacity (RESID) of existing technologies in 2005. RESID is calculated by multiplying the market share for each end-use technology times the total demand for that end-use and dividing by the capacity factor (CF) for that technology.

Mkt Shares raw
Regional market shares by technology are taken from the AEO KTECH file and organized for use in the **Mkt Shares** worksheet. Market shares for refrigeration, ventilation, and lighting are given for the 11 building types instead of the nine-regions. Therefore, a national market share is calculated.

Agg CLT
Lighting data are aggregated into 29 technologies.

CLT raw data
Worksheet has the lighting specific data from the AEO KTECH file.

Aggregated Data
Contains an aggregated listing of the end-use technologies from the AEO KTECH file. Technologies grouped and shaded in grey are averaged into a single technology for the MARKAL database. The technologies going into the EPA database are then given MARKAL specific names and descriptions using standard MARKAL naming conventions.

AEO10 Com Tech
Contains raw data from the AEO Commercial Technology Characterization Database (KTECH file). Each record gives specifications for a specific model year of a specific end-use technology in a specific Census Division.

DMD ByRegion
Demand values calculated in the **ComDemand** worksheet are re-organized into regions.

ComDemand
End-use demands are calculated for each region using data from the **CMCalc** worksheet. For space heating and space cooling, demands are calculated by multiplying the demand coefficient by the regional commercial floorspace and the national HDD value. For all other end-uses, the demands are calculated by multiplying the demand intensity by the regional commercial floorspace. The national AEO demand is calculated using the delivered energy by end-use and the stock efficiency from the AEO. These values are compared and graphed to the summed regional demands as a reference.

CMCalc
Contains a number of preliminary calculations used to determine the end-use demands found in the worksheet **ComDemand**.

The grey shaded area of the worksheet holds the data and calculations for regional commercial square footage. National square footage per capita is determined by dividing AEO total commercial floorspace for each 5-year time period found in the table: "Commercial Sector Key Indicators and Consumption" by the national population projections. From those Figures, a national annual rate of change is calculated. The regional square footage per capita is calculated for 2005 by dividing the square footage data found in the CBECS Table A2: "Census Region, Number of Buildings and Floorspace for All Buildings" by the population for each region. Subsequent years are then calculated by applying the annual rate of change to the previous year's value. These regional square footage per capita are then multiplied by the regional population projections to give the regional square footage, which are used in the end-use demand calculations.

The green shaded area of the workbook holds the calculations for the percentage of buildings with cooling technologies. The 2003 regional percentages were taken from the CBECS tables C7, C8, C9: "Consumption and Gross Energy Intensity by Census Division for Sum of Major Fuels for Non-Mall Buildings." Subsequent years were then calculated using an assumed annual growth rate of 0.42%. This annual growth rate was calculated based on historical CBECS data.

The blue shaded area of the workbook holds the calculations for HDD and CDD and demand intensity. Regional HDD and CDD values were take from the NCDC Historical Climatological Series – HCS 5.1. Years recorded and used for our calculations end in June 2009. These data can be found at www.ncdc.noaa.gov/oa/documentlibrary/hcs/hcs.html#51updates. Building heating and cooling coefficients were calculated in the first two time periods by taking AEO national space heating and space cooling demands and dividing them by the national floorspace and the national HDD or CDD. Subsequent years were left equal to the year 2010. The demand intensity for the other end-use demand categories were calculated simply by taking the AEO national demands and dividing them by the national floorspace. For water heating and cooking, the demand intensity was calculated by taking the major fuel energy intensity by end-use demand from the CBECS Table E2A: "Major Fuel Consumption (Btu) Intensities by End Use for All Buildings."

Pop
Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the 2000 Census. Data can be found at www.census.gov/population/www/projections/projectionsagesex.htmal, Table 6: "Total population for regions, divisions, and states: 2000 to 2030." Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are also taken from EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. The data have been adjusted to include Alaska and Hawaii.

Conversion Factors
Contains a number of conversion factors including the Implicit Price Deflator (DOC, 2012) chart used to convert AEO prices to the year 2005.

EmisCO2Coef
Contains CO_2 coefficients for various fuels, as reported by the DOE (DOE. 2008).

EmisBC
Includes estimates of the fraction of PM2.5 that can be classified as BC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

EmisOC
Includes estimates of the fraction of PM2.5 that can be classified as OC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

EmisCom
Includes commercial emission factors. These factors were derived from a number of sources, including the Climate Registry and the EPA WebFIRE emission factor database. More information about the derivation of the emission factors is available upon request.

M: Sector Workbook Description – Industrial Sector

Workbook Name: EPAUS9r_10_IND_v1.3.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Document describes the sources of the data and the calculations used to characterize the industrial sector in the EPAUS9r MARKAL database. The also provides a brief description of each worksheet in the Industrial workbook. The industrial sector workbook characterizes and accounts for the energy consumption of many industries in the economy. In this documentation, following terminology will be used.

- An *industry sector* is a group of industries that produce similar end-products or uses similar raw materials. Examples include primary metals, chemicals, cement, food, etc.
- A *process* (plant design/configuration) is defined as the set of technologies that would make up the complete system (i.e. sets of equipment) to produce end-product/s in an industry.
- The energy used by the process will be categorized under *energy service categories* such as boilers/steam/cogen, process heat (direct/indirect heat, electrical heating etc.), machine drive, facility (or building), electrochemical, feedstock and other heat.
- A *technology* could be a piece of equipment (e.g. boiler) or set of equipments (e.g. a boiler with control equipments) in a process.

Data Sources

The largest source of end-use energy consumption data for the industrial sector comes from the MECS database (EIA, 2006). EIA State Energy Consumption, Price, and Expenditure Estimates (SEDS) data (EIA, 2004) were used along with the MECS data to estimate the MARKAL regional distribution of industrial energy use. Because these data set includes non-manufacturing energy consumption, these data were used to make non-manufacturing demand assumptions in the model. Additional data were taken from the AEO reference case. Some of the technology definitions and parameter determinations for the industrial sector were based on EIA System for Analysis of Global Energy markets (SAGE) model (EIA, 2003). Emissions data for energy carriers used in the industrial sector is taken from the GREET model version 1.8 (Argonne, 2007).

Units

All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of PJ. Emission factors for CO_2 are in units of MTonnes/PJ. Units for all other pollutants and for CO_2 attributed specifically to this sector are in units of kTonnes/PJ.

Workbook Descriptions

The following section gives a description of each of the 34 worksheets in the industrial workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

ReadMe
Includes tips for adding new process and demand technologies, CHP characterization and troubleshooting pointers.

Demand
Calculates the future energy demands based on AEO value of shipments pulled from the **AEOData** worksheet. These energy demands are used in the **CommData_Dmd** worksheets.

AEOData
Presents raw AEO data for value of shipment from each industry sector.

Commodities*
Declares the commodity names, units, and set memberships for all fuels (energy carriers), emissions, and demands in the industrial sector.
The energy carriers for industrial sector follow the naming convention below:

First 3 letters:	IND for industrial
Next letters:	indicates the fuel type used in all industrial sectors (e.g. COA for coal, DSL for diesel, etc.)
Next 3-5 letters:	indicate the particular fuel carrier (i.e. CNG for compressed natural gas, E85 for 85% ethanol, DSL for diesel, JTF for jet fuel, etc.)

The demands for industrial sector follow the naming convention below:

First letter:	I for Industrial
Second letter:	(When not IND) indicates the industry sector (i.e. C for chemicals, P for pulp & paper, M for metals. F for food, N for non-metallic manufacturing, T for transportation equipment, O for all other industries, and X for non-manufacturing)
Next 3-7 letters:	indicate the energy service demand category (i.e., STM for steam, PRH for process heat, MDR for machine drive, FAC for facility, FEED for feedstock, OHEAT for other heat)

Technologies*
Declares the technology names, units, and set memberships for all end-use demand and collector technologies for each industry in the industrial sector. For each industry sector, a variety of process technologies using a variety of fuel types is represented to fulfill energy service demands such as steam, process heat, machine drive, etc.

The process technologies for the industrial sector follow the naming convention below:

First letter:	I for Industrial
Second letter:	Indicates the industry sector (i.e. C for chemicals, P for pulp & paper, M for metals. F for food, N for non-metallic manufacturing, T for transportation equipment, O for all other industries, and X for non-manufacturing)

Next 2-3 letters:	indicate the energy service demand technologies (i.e., BOR for boiler, PRH for process heat, MDR for machine drive, ECM for electrochemical, FAC for facility, FST for feedstock, OH for other heat)
Next 3-5 letters:	indicate the type of fuel used in that category (i.e., COA for coal, DST for distilates, RFL for residual fuel oil, NGA for natural gas, ELC for electricity, etc.)
Last 2 letters:	01 for existing technologies; new technologies do not include any number suffix

Besides process technologies, industries may use CHP technologies. The naming conventions for these technologies are:

First letter:	I for Industrial
Next 1-2 letters:	Indicates the industry sector (i.e. CM for chemicals, PP for pulp & paper, M for metals. FD for food, NM for non-metallic manufacturing, TN for transportation equipment, and OT for all other industries)
Next letter	Indicates an existing (E) or new (N) technology
Next 3 letters:	indicate the CHP technology type (i.e., BST for boiler/steam turbine, CCT for combined cycle/combustion turbine, FCL for fuel cell, REG for reciprocating engine, MTT for microturbine)
Next 3 letters:	indicate the type of fuel used in that category (i.e., COA for coal, BIO for biofuels, OIL for oil, NGA for natural gas, WOD for wood)

In addition there is a technology which represents each industry sector as a whole. The naming convention for this technology is

First letter:	I for Industrial
Second letter:	Indicates the industry sector (i.e. C for chemicals, P for pulp & paper, M for metals. F for food, N for non-metallic manufacturing, T for transportation equipment, O for all other industries, and X for non-manufacturing)
Next 7 letters:	TECHEXT

In addition, two types of dummy technologies are utilized in the database. The first are dummy backstops for each demand technology. These avoid model infeasibility from inadequate energy carrier supply to a certain demand; if enough energy is not available to meet the demand the model will use “ZZDMY”. This aids the modeler in determining where problems exist within the specific energy chains.

The second are dummy fuel collectors. Because the MECS data, the SEDS data, and the fuels entering the industrial sector all have different names and characteristics, it is sometimes necessary to combine fuels into one generic energy source.

TechData_X&ZZ*

Contains the parameter values for all dummy backstop technologies.

CHP_resids
Contains raw data calculations for the technology characterization of the existing CHP units in each industry sector. Data are pulled from the **CHP-raw data** worksheet.

CHP-raw data
Includes the raw data on the individual existing CHP units taken from the CHP database. See CHPDATA_22108LCD.xls workbook for details. Worksheet also contains the AEO raw data on CHP usage for all industries.

TechData_CHP*
Includes technology parameter values to be input to MARKAL for both existing and new CHP in each industry sector, i.e., food, paper, chemical, other, primary metals, non-metals, and transportation equipment.

TechData_DMD*
Contains parameter values for all end-use demand technologies in the industrial sector as defined in the Technologies worksheet. Worksheet also includes the fractional distribution of each process category (boiler/steam, machine drive, process heat, electrochemical, other heat, feedstock, and facilities) which is required to meet a unit of demand for a given industry. (This is the xxTECHEXT technology) The parameter values are pulled from **Demand**, **RESID_TDATA**, **National_EndUse**, and **Steam** worksheets.

TechData_Emis*
Contains emission factors associated with industrial fuel combustion. These factors are pulled from the **Emissions**, **RTI-BC** and **RTI-OC** worksheets.

Emissions
Worksheet compiles relevant emissions from the **GREET1.8bEmis** worksheet into a format that can be readily used in the **TechData_Emis** worksheet.

GREET1.8bEmis
Includes industrial emission factors that were extracted from the GREET model, version 1.8, and converted to MARKAL units.

RTI-BC
Includes estimates of the fraction of PM2.5 that can be classified as BC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

RTI-OC
Includes estimates of the fraction of PM2.5 that can be classified as OC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

Steam
Worksheet allocates CHP steam residuals to the regional steam demands. The balance of the steam demands and other process heat demands are distributed across the steam and other process heat technologies, respectively, using national fuel ratios to establish residual capicity for these processes.

RESID_TDATA
Worksheet compiles the raw data from the **Steam** worksheet and does additional calculations to have residual values for all other existing technologies.

old_CensusDiv
Contains the original MECS data on fuel consumption. The original MECS data are presented for four-regions, i.e., northeast, southeast, northwest and southwest.

CensusDiv
Worksheet allocates the fuel consumption presented in the **old_CensusDiv** worksheet from MECS four-regions into MARKAL's nine census regions by using SEDS data Table S6 of estimated industrial energy use in 2004 by state. Because SEDS data includes non-manufacturing demand, a ratio of total energy use between MECS data and SEDS data was calculated to estimate the manufacturing-only energy use by state. Those state data could then be organized on a nine-region basis and compared directly with the census four-region data available from MECS. The fraction of nine-region energy use to four-region energy use was calculated by dividing the total manufacturing energy use in a particular nine-region by the total manufacturing energy use in the four-region (i.e., energy use in MARKAL Region 2 (New England) over energy use in the Northeast census division). For the paper sub-sector, regional distribution was calculated using the state-based mill data from the CPBIS database (CPBIS, 2007). Mills in both the nine-region and four-region areas were counted, and the same ratio for energy use was calculated.

Feedstock
Contains MECS data on feedstock type fuel consumption in industrial sector. Original data are presented in four census regions. In the spreadsheet the data are allocated into nine census regions using SEDS data as above.

CommData_Dmd_Food*
Contains parameter data for the total food sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Prmry Metals*
Contains parameter data for the total primary metals sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Chem*
Contains parameter data for the total chemicals sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Paper*
Contains parameter data for the total pulp and paper sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Non-Metal Minrls*
Contains parameter data for the total non-metallic manufacturing sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Tranprt Equip*
Contains parameter data for the total transportation equipment sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_Oth*
Contains parameter data for all the other industrial sectors end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

CommData_Dmd_NonMan*
Contains parameter data for the total non-metal manufacturing sector end-use demand. The data are pulled from **CensusDiv** and **Demand** worksheets.

Constraints*
Worksheet declares the share constraint names for all user constraints in the industrial sector.

ConstrData*
Contains the data for fuel share splits for each energy service demand in industrial sectors. Constraints in the industrial sector are added to all process technologies from the years 2010-2055. There are no constraints in the year 2005 because the RESID parameter acts as a constraint. Similar to the RESID parameter, constraints are based on the percentage a specific energy carrier accounts for the total energy use of a technology based on MECS data Table 5.2. When MECS data are not available, AEO data are used. Constraints apply over all regions unless the technology does not exist in a particular region. Constraints in the industrial sector are all lower bounds, meaning the technology has to use equal to the constraint value for a particular energy carrier, but above that the technology can chose another carrier if it provides a less-cost solution. Because of the end-use driven nature of the industrial sector, energy carriers and process technologies are tightly constrained. Some of the technologies are allowed fuel switching, and for these technologies associated fuel constraints are relaxed somewhat up to 2055.

Worksheet also contains national level constraints for CHP usage in each industry. CHP usage through time grows at the rates given by AEO which are pulled from the **CHP-raw data** worksheet.

UC_Shares
Worksheet calculates the fuel splits for each energy service end-use category in each sector. The values generated in this workbook are linked to the **ConstrData** worksheet to implement lower bounds on the fuel shares. Worksheet also contains the raw data for fuel switching which sets the

relaxation limits for the constraints. The fuel switching data comes from OPEI report (EPA, 2007).

National_EndUse1

Contains raw data from MECS on the fuels used by each industry at the national end use. The worksheet aggregates the MECS categories to MARKAL process categories and brings the CHP steam data and feedstock data from their worksheets.

N: Sector Workbook Description – Industrial Biofuels

Workbook Name: EPAUS9r_12_INDBIO_v1.0.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Document describes the sources of the data and the calculations used to characterize the pulp and paper process to convert biomass into process steam and black liquor production in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics were taken from the work of E.D. Larson et al. (Larson et al., 2000 and Larson et al., 2006). and the AEO. Detailed references are provided on the **BiomassCHPforIPS** worksheet.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ.

Workbook Description
The following section gives a description of each of the five worksheets in the industrial biofuels workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all process energy carriers.

Technologies*
Lists the technology names, units, and set memberships for pulp and paper black liquor production, black liquor gasifier, and biomass boiler.

TechData*
Contains the MARKAL ready data for pulp and paper black liquor production, black liquor gasifier, and biomass boiler.

BiomassCHPforIPSupdated
Contains the calculations for the residual capacity for the biomass boiler and the black liquor resource supply. Data are drawn from the EIA, Office of Energy Markets and End Use, Energy Consumption Division, Form EIA-846, "2002 Manufacturing Energy Consumption Survey."

BiomassCHPforIPS
Charts the raw data for the capital and operating costs of a black liquor cogeneration system. Data are drawn from the reports Larson et al.

O: Sector Workbook Description – Light Duty Transportation

Workbook Name:	EPAUS9r_12_TRN_LDV_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the transportation light duty vehicle sector in the EPAUS9r MARKAL database.

Data Sources
The technology characteristics for traditional light-duty vehicle technologies were taken from the AEO. Additional data used were taken from the Transportation Energy Consumption Survey (EIA, 2001) and the Transportation Energy Data Book (DOE, 2010). Data for advanced technologies were taken from inputs provided by National Renewable Energy Laboratory, ERG, and EPA's Office of Transportation Air Quality. Emissions data were developed using the MOVES model (EPA, 2010), although black carbon and organic carbon emission speciations were developed by RTI from a literature review. CO_2 emission factors were developed from EIA estimates.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of billion vehicle miles traveled (bn-vmt). Emissions are represented in grams per mile, which is equivalent to kTonnes/billion-vmt.

Workbook Description
The following section gives a description of each of the 35 worksheets in the light duty transportation workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that is automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all fuels (energy carriers), emissions, and demands in the transportation light-duty vehicle sector. The demand for this sector is given the name TL for "transportation light-duty." The energy carriers follow the following naming convention:

First 1-2 letters:	TR or TRN for Transportation
Next 3-5 letters:	point to the particular fuel carrier (i.e. CNG for compressed natural gas, ETH for ethanol, GSLR for reformulated gasoline, etc.)

Technologies*
Lists the technology names, units, and set memberships for all end-use and collector technologies in the commercial sector. The naming convention for the demand technologies starts with the end-use demand (TL), followed by the car class (E for existing, MC for minicompact, C for compact, F for full-size. M for minivan, P for pickup, SS for small SUV, and

LS for large SUV), the fuel type, and finally the first year of technology availability. For example, "TLPHEV15" refers to hybrid electric pickups with an initial availability in the year 2015.

Collector technologies start with an SC, followed by the input energy carrier name and then the output energy carrier name.

Constraints*
Lists the share and investment constraint names for all user constraints in the transportation light-duty vehicle sector.

CommData*
Contains the demand values for transportation light-duty vehicles by region. The data are taken from the **VMT By Region** worksheet which is explained below. The fraction of capacity entering electricity peak equations and the fractional demand by season and time of day (FR(Z)(Y)) are based on expert judgement.

TechData_All*
Contains the parameter values for all light-duty vehicle technologies drawn from the **ConsolidatedVehData** worksheet explained below. The discount rates range from 0.40 to 0.44: with the lower rate attached to conventional gasoline vehicles and the higher rate being attached to new technologies.

TechData_RES*
Contains the parameter values for existing light-duty vehicle technologies. Efficiency and O&M costs come from the **ConsolidatedVehData** worksheet and the residual capacity values come from the **ResidDataAndCalcs** worksheet.

TechData_ZZ*
Contains the parameter values for a dummy technology for the end-use demand. This technology has a high variable O&M cost and will be used only in a model run when the model cannot meet its demand with available technologies. The use of any of these technologies indicates an infeasibility in the model.

ConstrData*
Contains the constraint data for fuel shares, car class splits, technology shares, and CAFE standard by region. Approximated CAFE standards are pulled from the **CAFE10** worksheet.

TechData_ResidEmis*
Represents emissions from the existing stock of vehicles. These emission factors are obtained from the **EmisLDV** worksheet.

TechData_NewEmis*
Represents emissions from new vehicles, vintage 2010 and beyond. These emission factors are obtained from the **EmisLDV** worksheet.

EmisLDV
Represents light duty emission factors derived from runs of the MOVES model. Emission factors for existing vehicles include consideration of pre-2005 vintages that leave the fleet, as well as degredation of vehicle emission controls over time. Emission factors for 2010 and later vintages represent lifetime average emissions and do not otherwise incorporate degredation. The calculations that underlie these emission factors are available upon request.

EmisOC
Includes estimates of the fraction of PM2.5 that can be classified as OC. The fractions, which can differ by source category, originate from three studies: Battye et al., Bond et al., 2004, and Bond et al., 2007.

ERG_ElectricVeh
Contains vehicle cost and efficiency data for electric vehicle technologies. The data were provided by Rick Baker of ERG.

ConsolidatedVehData
Worksheet consolidate vehicle efficiency and cost from the **Costs**, **Efficiencies**, and **AdditionalVehs** worksheets into a single large table.

AdditionalVehs
Contains cost and efficiency data for vehicle technology-classification pairs not in the original AEO data, including E85 hybrids, PHEV20, E85 PHEV20, and E85 PHEV40. These tables consolidate efficiency and cost data on advanced vehicle technologies from OTAQ and AEO sources. Additional technologies are also added, including moderate ICE vehicles, running both on gasoline and E85, advanced ICE vehicles running on E85, PHEV20s running on gasoline and E85, and PHEV40s, running on E85. Many of these additional vehicles currently are commented out in the Answer upload sheets.

Costs
Contains the vehicle technology purchase cost estimates calculated by layering OTAQ vehicle assumptions for advanced technologies onto AEO assumptions regarding conventional vehicle technologies. Data from 2040 through 2055 are held constant to the 2035 value.

Efficiencies
Contains the vehicle technology efficiency estimates calculated by layering OTAQ's vehicle assumptions for advanced technologies on AEO assumptions regarding conventional vehicle technologies. Data from 2040 through 2055 are held constant to the 2035 value. AEO adjustment factors are used to reduce efficiencies to account for real-world driving conditions and vehicle degredation over time.

CAFE10
Includes calculations to derive the national energy-to-LDV constraints to reflect the CAFE standards. This is a preliminary implementation. No credit is given towards the standard for alternative fuel vehicles. Similarly, this constraint does not represent different efficiency targets for cars and trucks.

NREL_PHEV
Contains raw data estimating the fraction of plug-in hybrid electric vehicle operation under electric-power only. Data come from the National Renewable Energy Laboratory (Denholm and Short).

AEO10 T59
Contains the raw data for vehicle efficiency projections by technology and vehicle classification taken from the AEO table: "New Light-Duty Vehicle Fuel Economy."

AEO10 T60
Contains the raw data for vehicle cost projections by technology and vehicle classification taken from the AEO table: "New Light-Duty Vehicle Prices."

OTAQ Car
Contains data for light duty car technology cost and efficiency assumptions as used with SGM, provided by the EPA Office of Transportation and Air Quality. Plug-in hybrid electric vehicle assumptions for efficiency gain and gasoline utilization are taken from worksheet.

OTAQ Truck
Contains data for light duty truck technology cost and efficiency assumptions as used with SGM, provided by the EPA Office of Transportation and Air Quality. Plug-in hybrid electric vehicle assumptions for efficiency gain and gasoline utilization are taken from Worksheet.

AEO10 Salesdata
Contains the raw data and calculations for determining the car class splits in 2005 and 2025. Total new car and truck sales, in thousands, come from the AEO table: "Light-Duty Vehicle Sales by Technology Type." Percent of new vehicle shares by car class comes from the AEO table: "Summary of New Light-Duty Vehicle Class Attributes." Car class splits are calculated by multiplying the percent of new vehicle shares by car class by the total new sales, and then getting the fraction of the total by car class.

AEO10 T7
Contains raw data from the AEO table: "Transportation Sector Key Indicators and Delivered Energy Consumption."

ResidDataAndCalcs
Contains the calculations for regional residual capacity for existing light-duty vehicle types. Residual capacity in the year 2005 by technology and by region, given in billion vehicle miles traveled (VMT) per year, is calculated by multiplying the regional total VMT by the fraction of VMT that is either passenger cars or light trucks. The resulting value is then multiplied by the fraction of total VMT for each technology class (i.e. MiniCompact, Full, Minivan, etc.). Data for the calculations come from a number of sources. The 2005 regional total VMT are calculated in the **VMT By Region** worksheet. The fraction of VMT that is either passenger cars or light trucks is found on the **TED10** worksheet. The fraction of total VMT for each technology class is calculated in worksheet from data for millions of vehicles by type and fractional VMT taken from the Transportation Energy Consumption Survey table: "Light Duty BVMT by Technology,

2005." Residual capacity for the time periods after 2005 are calculated by multiplying the 2005 value by the estimated scrappage rates of 30% after 5-years, 59% after 10 years, 84% after 15-years, and 92% after 20 years.

TED10

Contains data from the Transportation Energy Data Book. Vehicle miles traveled for 2005 are taken from Table 4.1 "Summary Statistics for Passenger Cars" and Table 4.2 "Summary Statistics for Two-Axle, Four-Tire Trucks" and used for residual capacity splits for passenger cars and trucks on the **ResidDataAndCalcs** worksheet. Table 2.3 "Alternative Fuel and Oxygenate Consumption" and Table 6.4 "Number of Alternative Refuel Sites by State and Fuel Type" provide raw data for calculating the residual capacity for alternative fuel vehicles on the **ResidDataAndCalcs** worksheet.

AEO08 T50

Contains raw data from the AEO table: "Light-Duty Vehicle Miles Traveled by Technology Type." Data for 2005 vehicle miles traveled is used on the **ResidDataAndCalcs** worksheet to calculate residual capacity of the different technology types within passenger and light truck classes.

VMT By Region

Contains the raw data and calculations for determining the regional demand for light duty vehicle miles traveled. Raw data for the regional percentage of national vehicle miles traveled comes from the Transportation Energy Consumption Survey Table A1: "U.S. Number of Vehicles, Vehicle-Miles, Motor Fuel Consumption and Expenditures, 2001." These values are multiplied by the national VMT demand and then divided by the population to get the regional VMT per capita. These new regional splits are then multiplied by the regional population from the worksheet **Pop** to obtain the regional demands.

AEO10 DMD

Contains the raw data and calculations for determining the base light duty vehicle miles traveled per capita. Raw data for national vehicle miles traveled (VMT) comes from the AEO table: "Transportation Sector Key Indicators and Delivered Energy Consumption." The base VMT per person is determined by dividing the national VMT by the population from the **Pop** worksheet. Beyond 2035, the VMT per person is held constant.

Pop

Regional population data was taken from the U.S. Census Bureau state population projections released in 2005 and based on the Census 2000. Data can be found at www.census.gov/population/www/projections/projectionsagesex.htmal, *Table 6: Total population for regions, divisions, and states: 2000 to 2030*. Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are also taken from EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. The data have been adjusted to include Alaska and Hawaii.

GDP Deflator
Contains the Implicit Price Deflator (DOC, 2012) chart used to convert AEO prices to the year 2005.

P: Sector Workbook Description – Heavy Duty Transportation

Workbook Name:	EPAUS9r_12_TRN_HDV_v1.0.xlsx
Description Revision:	1.0
Revision Date:	12/31/12

Document describes the sources of the data and the calculations used to characterize the transportation heavy duty vehicle sector in the EPAUS9r MARKAL database.

Data Sources
The demands for heavy-duty subsectors were taken from the AEO. Some characteristics of on-road heavy-duty vehicle technologies were taken from the NEMS Advanced Technology Options File. Additional data are referenced on the worksheets where data is utilized.

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of billion vehicle miles traveled (bn-vmt) for on-road vehicles, billion ton miles (bn-t-m) for rail and marine freight, and billion passenger miles (bn-pass) for air and rail passenger travel.

Workbook Description
The following section gives a description of each of the 21 worksheets in the heavy duty transportation workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Declares the commodity names, units, and set memberships for all fuels (energy carriers), emissions, and demands in the transportation heavy-duty vehicle sector. The demands for heavy-duty sector are given the following names:

TA	Transportation Air
TB	Transportation Bus
TC	Transportation Commercial Trucks (Class 2b)
TM	Transportation Medium Duty Trucks (Class 3-6)
THS	Transportation Heavy Duty Trucks – Short Haul (Class 7-8)
THL	Transportation Heavy Duty Trucks – Long Haul (Class 7-8)
TRF	Transportation Rail – Freight
TRP	Transportation Rail – Passenger
TS	Transportation Shipping (Marine)

The energy carriers follow the following naming convention:

First 1-3 letters:	T or TRN for Transportation
Second letter:	(When not R) indicates the subsector using the fuel (i.e. B for bus, C for

commercial truck, or H for heavy duty)

Next 3-5 letters: indicate the particular fuel carrier (i.e. CNG for compressed natural gas, E85 for 85% ethanol, DSL for diesel, JTF for jet fuel, etc.)

Technologies*

Declares the technology names, units, and set memberships for all end-use and collector technologies in the commercial sector. The naming convention for technologies starts with the end-use demand (TA, TB, THL, etc.), followed by the fuel type, and finally either (a) "E" for existing technology, (b) the first year of availability for conventional technologies, or (c) an indicator of efficiency for improved (IM) or advanced (ADV) technologies. For example, "TBCNG15" refers to conventional CNG fueled buses with an initial availability in the year 2015. "TCGSLADV" refers to a gasoline commercial truck with advanced efficiency technology.

The sheet includes two emission collectors "SETRDSL" and "SETRB20" where criteria emissions are counted from diesel and B20 fuels used in rail.

TechData_RES*

Contains the parameter values for all heavy-duty vehicle technologies. Efficiency and operating and maintenance costs come from the subsector worksheets (**Air&Marine, Freight, Trucks, Rail&Bus, Rail&Bus2**) and the residual capacity values come from the **Resid** worksheet.

CommData*

Contains the demand values for transportation heavy-duty vehicles by region. The data are taken from **By Region** worksheet.

Constraints*

Declares the share constraint names for all user constraints in the transportation heavy-duty vehicle sector.

ConstrData*

Contains the data for fuel share splits and the passenger rail share splits (subway, intercity, and commuter) for all user constraints in the transportation heavy-duty vehicle sector. The 2010 values are pulled from the **AEOData, Resid, and Rail&Bus** worksheets. Fuel shares are allowed to shift through time. In most cases, constraints are relaxed 1-3% per period. For some fuels AEO projects increased usage in the future (for example, CNG usage in buses). For these fuels, the share is constrained to match AEO in 2035.

TechData_EMIS*

Contains the emission factors for all technologies listed in the **TechData_RES** worksheet. Values are pulled from the **Emissions** worksheet described below.

Air&Marine

Contains the technology characteristics data for ships and for passenger and cargo airplanes imported in final MARKAL units from ERG files. The data for the post-2010 technologies for these heavy duty classes were gathered from various sources. Raw data, calculations, and references are listed in the ERG workbooks: “MARKAL MV ERG Final” and “MARKAL Aviation ERG Final”. Technology characteristics from worksheets are passed to the MARKAL **TechData_Res** worksheet which uploads into ANSWER.

Freight
Contains the technology characteristics data for rail freight imported in final MARKAL units from the ERG file “MARKAL Rail ERG Final”. The data for post-2010 technologies come from various sources. Raw data, references, and calculations are shown in the ERG workbook. The **Freight** worksheet also contains three tables of raw state-level data for commodity shipments used to determine the regional shares of rail, truck, and marine freight. The references for these tables are located in the **Freight** worksheet. Technology characteristics from worksheet are passed to the MARKAL **TechData_Res** worksheet which uploads into ANSWER. Regional shares from worksheet are passed to the **Transcalc** worksheet.

Trucks
Contains the technology characteristics data for all classes of on-road trucks from ERG files. Most of the data for post-2010 truck technologies were derived by ERG using the NEMS Advanced Technology Options file. Other sources used by ERG are referenced in the ERG workbook: “Onroad HD Trucks and Buses ERG Final”. Technology characteristics from worksheet are passed to the MARKAL **TechData_Res** worksheet which uploads into ANSWER.

Rail&Bus
Contains the raw data and calculations to determine national demands and regional shares for bus and passenger rail services. AEO provides data on the fuel energy used by buses and passenger rail but does not provide end-use services (See AEO table in the **AEO Data** worksheet.) Worksheet converts the fuel used to billion VMT for buses and billion passenger miles for rail. National demands and regional shares from worksheet are passed to the **Transcalc** worksheet.

Rail&Bus2
Contains the technology characteristics data for buses and the three types of passenger rail (subway, intercity, and commuter). Most of the data for the post-2010 bus technologies were derived by ERG using the NEMS Advanced Technology Options file. Data and references from other sources are listed in the ERG workbook: “Onroad HD Trucks and Buses ERG Final”. Passenger rail technologies are limited to those provided in the original 1997 MARKAL workbook. However, characteristics have been updated. Efficiencies have been updated from data sources on the **Rail&Bus** worksheet, and cost data updated from the “MARKAL Rail ERG Final” workbook. Technology characteristics from Worksheet are passed to the MARKAL **TechData_Res** worksheet which uploads into ANSWER.

Resid
Contains the calculations for regional residual capacity for existing heavy-duty vehicle types. Residual capacity in the year 2005 by fuel and by region [given in billion vehicle miles traveled (VMT) per year, billion ton-miles (T-M) per year, or billion passenger miles (PASS) per year] is calculated by multiplying the regional total demand (from the **TransDemand** worksheet) by the fraction of demand that is delivered by a specific fuel. The raw data for the fuel shares on this sheet come from various sources including AEO, the Transportation Energy Data book, and the

Census Bureau 2002 Vehicle Inventory and Use survey. Data from worksheet are passed to the MARKAL **TechData_Res** worksheet which uploads into ANSWER.

By Region
Organizes the data for all end-use demands by region. Demand data calculations are done on the **TransDemand** worksheet described below. Data from the **ByRegion** worksheet are passed to the MARKAL **CommData** worksheet which uploads into ANSWER.

TransDemand
Contains the calculations for the regional end-use demands. Regional demand is equal to the national demand times the regional fraction. These two values are pulled from the **Transcalc** worksheet.

TransCalc
Contains intermediate calculations for the national end-use demand and collects the regional fractions for all end use demands from the various technology worksheets. Initial values of national end-use demands are taken from the **AEO Data** worksheet. These values are used in the *TransCalc* worksheet to determine demand per capita so that overall national demand can reflect changes in population under this scenario condition. Population data are drawn from the **Pop** worksheet.

Pop
Regional population data were taken from the U.S. Census Bureau state population projections released in 2005 and based on the Census 2000. Data can be found at www.census.gov/population/www/projections/projectionsagesex.htmal, *Table 6: Total population for regions, divisions, and states: 2000 to 2030*. Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are taken from EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. The data have been adjusted to include Alaska and Hawaii.

AEO Data
Contains the raw data taken from the AEO tables for use in calculating national demands and fuel shares. Data extracted from the tables are: "Freight Transportation Energy Use" - medium and heavy duty VMT demand, medium and heavy duty fuel shares, freight rail ton-miles demand, domestic marine shipping ton-miles demand; "Air Travel Energy Use" – billion passenger miles demand; "Transportation Sector Energy Use by Fuel Type within a Mode" – fuel shares for commercial trucks, fuel shares for marine shipping, fuel shares for air transportation, fuel shares for buses, fuel shares for passenger rail; and "Transportation Sector Key Indicators and Delivered Energy Consumption" – commercial truck VMT demand.

Raw Emissions
Contains the raw emissions factors collected and developed by Pechan. Original data and references from Pechan are shown in the following workbooks: "4 On-Road Emission Factors

Global Summary," "CMV Emission Factors," "Rail Emission Factors," and "Aircraft Emission Factors." As noted above, Pechan used data from ERG for aircraft emissions.

Emissions

Worksheet maps the technology classes from the **Raw Emissions** worksheet to the technology classes in the heavy duty sectors of this workbook. Data from this **Emissions** worksheet are passed to the MARKAL **TechData_EMIS** worksheet which uploads into ANSWER.

Conv Factors

Contains various conversion factors used throughout this workbook.

Q: Sector Workbook Description – Off-Highway Transportation

Document describes the sources of the data and the calculations used to characterize the transportation off-highway sector in the EPAUS9r MARKAL database.

Workbook Name: EPAUS9r_12_TRH_OH_v1.0.xlsx
Description Revision: 1.0
Revision Date: 12/31/12

Data Sources
The technology and end-use demand characteristics were taken from the AEO reference case. Emission factors were derived from the EPA's Clearinghouse for Inventories and Emissions Factors (CHIEF) National Emissions Inventory (NEI) Air Pollutant Trends Data and EPA diesel emissions analysis (EPA, 2004a).

Units
All costs are expressed in millions of 2005 dollars. All energy quantities are expressed in PJ. Demand units are given in terms of PJ. Emission factors are in kTonnes/PJ, except for system-wide CO_2, which is reported in MTonnes/PJ.

Workbook Description
The following section gives a description of each of the 12 worksheets in the off-highway transportation workbook. The worksheets are listed in the order they appear, from left to right, in the workbook. The worksheet names noted with an asterisk contain the data that are automatically uploaded to ANSWER when importing data from Excel.

Commodities*
Lists the commodity names, units, and set memberships for all fuels (energy carriers), emissions, and demands in the transportation off-highway sector.

There are two demand technologies:
TOHDSL = Off-highway diesel use
TOHGSL = Off-highway gasoline use

Technologies*
Lists the technology names, units, and set memberships for all end-use and collector technologies in the transportation off-highway sector.

Similar to the demands, there are two end-use demand technologies"
TODSL = Off-highway diesel technology
TOGSL = Off-highway gasoline technology

CommData_Demand*
Contains the demand values by end-use and by region.

TechData_RES*
Contains the parameter values for diesel and gasoline off-highway technologies.

By Region
Regional demand is re-sorted by region.

Reg Demand
Contains regional demand data calculated from the national demands and the regional shares for off-highway petroleum consumption.

Natl Demand
Contains national demands for off-highway petroleum consumption recalculated using a per capita measure to allow for automatic changes to the demands under different population assumptions in the **Pop** worksheet.

Off-Highway
Contains calculations for the national demands and regional shares for off-highway petroleum consumption. The demands for 2005 are calculated using data from the ORNL data (ORNL, 2004). Future year demands are calculated using a growth rate developed from AEO projections of agriculture, construction, and recreational transportation gasoline and diesel fuel use. Regional demand shares are calculated from state level data from the U.S. Department of Transportation's *Highway Statistics 2005*, Table MF-24: Private and Commercial Nonhighway Use of Gasoline – 2005."

Pop
Regional population data was taken from the U.S. Census Bureau state population projections released in 2005 and based on the Census 2000. Data can be found at www.census.gov/population/www/projections/projectionsagesex.htmal, *Table 6: Total population for regions, divisions, and states: 2000 to 2030*. Subsequent years out to 2055 were calculated using a linear extrapolation. Additional regional population projections are also taken from the EPA's Integrated Climate and Land-Use Scenarios (ICLUS) projections based on the Intergovernmental Panel on Climate Change's (IPCC) A1 Emissions Scenario. These data are found in the ICLUS workbook *ICLUS_population_population*. The data have been adjusted to include Alaska and Hawaii.

NO_x, SO_2, VOC, PM10, CO, PM25, and CO_2
These worksheets contain the calculations for off-highway gasoline and diesel technolgies. Data are taken from the NEI.

regulation
Contains the raw emissions data for land-based nonroad diesel engines. The data are drawn from the EPA regulatory analysis (EPA, 2004a).

reference
Contains raw data for off-highway gasoline and diesel use and national criteria air pollutant emissions taken from the Transportation Energy Data Book Edition 24.