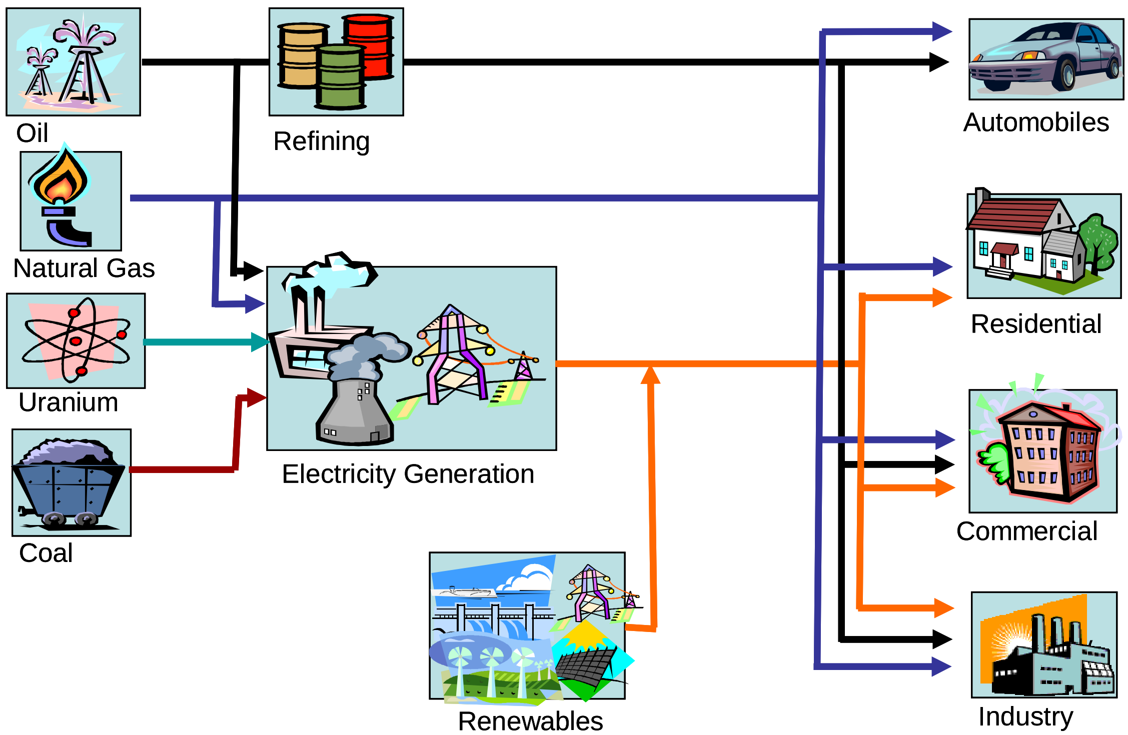
NE-12 MARKAL Final Report
Structure, Data and Calibration



Final Deliverable to Northeast States Center for a Clean Air Future under IRG Contract

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Background

The Northeast States Center for a Clean Air Future **(**NESCCAF) developed a New England MARKAL energy system model originally encompassing the six New England states (NE-MARKAL[1]) to provide the Northeast Center for Atmospheric Science and Policy (NCASP) with a powerful tool for planning current policy goals, and evaluating programs that may be required to maintain and improve air quality in the region, to promote cleaner, more efficient energy use, and to foster energy security, as well as address climate change. However, as several regional policy initiatives under consideration encompass states beyond New England alone, NESCCAF saw the need to characterize the entire Northeast power market from New England through New York and the Pennsylvania, New Jersey and Maryland power pool (PJM) in order to accurately assess the potential benefits of such programs within this broader region. With this end result in mind, NESCCAF contracted IRG to expand the NE-MARKAL model database and framework to encompass Pennsylvania, New Jersey, New York, Delaware, Maryland, and the District of Columbia, so as to cover the entire planning region, including all the states involved in the Regional Greenhouse Gas Initiative (RGGI) aimed towards the implementation of a regional power sector cap and trade program for CO_2.

As the economics of energy, desire for cleaner air, and necessity to reduce carbon emissions rise, policies and programs will need to move beyond the power sector, and strive to find the most cost-effective pathway to achieving these essential goals. This expanded coverage model of the Northeast (NE-12) is poised to provide important insights in this regard. The model will be housed at Northeast States for Coordinated Air Use Management (NESCAUM) and, in addition to regional analyses, is available to all member states to examine policy issues of particular interest to them.

1. Model Overview

1.1 Structure

As depicted in Figure 1, MARKAL is a comprehensive, multi-sector energy system model that tracks energy flows from resource extraction (e.g., mining or oil and gas wells) through conversion processes (e.g., refineries and power plants) all the way to end-use devices that meet the demand for energy services (e.g., space heating, air conditioning, passenger transportation, lighting, etc.). MARKAL represents all energy producing, transforming, and consuming processes as an interconnected network called the Reference Energy System (RES). The model selects technologies based on life-cycle costs of competing alternatives and evaluates all options within the context of the entire energy and materials system by:

- Balancing all supply and demand requirements,
- Ensuring proper process/operation,
- Monitoring in detail each process's capital stock turnover, and
- Adhering to user defined environmental and policy restrictions.

[1] NE-MARKAL: Adaptation of the MARKAL Modeling Framework for Application in the Northeast U.S., Prepared by Northeast States for Coordinated Air Use Management, December 2005.

The model allows the analyst to understand the interaction between technologies and fuels, and supply and demand side actions, with respect to achieving environmental and energy goals.

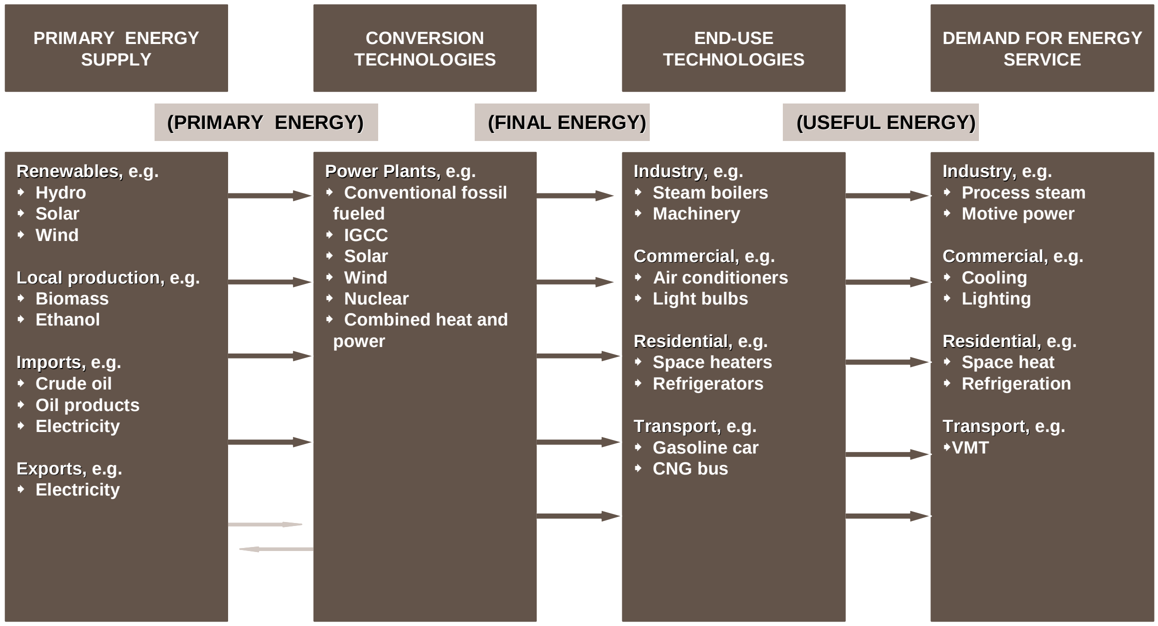

Figure 1: Overall Structure of the NE-MARKAL Model

As a first step in the NE-12 development process, the previous 6-state model (NE-MARKAL) was successfully migrated to the ANSWER-based data handling platform, and this model version was labeled NE-6. This migration allowed NESCAUM analysts to continue to use the existing NE-6 model while the NE-12 model was under development.

The basic structure of the new NE-12 model was then developed by imposing good RES design practices and strict naming convention for all energy carriers, technology names and descriptions, emissions, and user constraints to help organize the underlying data. The details of the naming convention are contained in Appendix A.

1.2 Data Sources

Development of the NE-12 model was closely linked to several authoritative data sources. Most notable among these are the data sources feeding the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) used to produce the Annual Energy Outlook (AEO). Technology characterizations have been extracted from NEMS, along with data on base year technology stocks, resource supply options, and the sectoral growth rates used in developing demand projections for each model region (state). Other data sources include: EIA's State Energy Data System (SEDS), which provides final energy use for each demand sector by fuel type; Gross State Product data from the Bureau of Economic Analysis; EIA's three sectoral energy consumption surveys; and the Environmental Protection Agency's eGRID emissions database. Each of these data sources and the type of data provided are described in more detail in Table 1.

Table 1: NE-12 Major Data Sources

Data Source	**Data Provided**
NEMS Model Outputs for 2002 by Census Division	Data on fuel prices, demand categories, fuel types, technology characterizations, base-year stock, and sectoral growth projections
SEDS-2002 data	Energy use for each demand sector by fuel type for each state
Bureau of Economic Analysis (BEA) 2002 Gross State Product (GSP) By NAICS code	GSP shares for commercial and industrial sub-sectors by state
Manufacturing Energy Consumption Survey (MECS)	End-use energy shares by sub-sector and fuel type by census division
Commercial Building Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS)	The end-use energy shares by sub-sector and fuel type that are taken from NEMS are derived from these surveys.
Annual Energy Outlook 2006 (AEO2006)	Current and projected final energy use and prices by sector and fuel type
MANEVU 2002 MOBILE data	VMT by vehicle class for light duty vehicles, trucks, and buses
National Transportation Energy Data Book, Edition 25	Energy consumption by type and fuel for buses
NESCAUM Analysis	Technology characterization for vehicle technologies including costs, efficiencies, and emissions
EIA Forms 860, 767, 759/906 and 1	ELC and CHP generating unit capacity, prime mover, fuel sources, location, plant operation and equipment design (including environmental controls), fuel consumption, and operating costs
EPA Emissions & Generation Resource Integrated Database (eGRID)	Emissions rates for existing power plants
RETSCREEN PV3	Solar PV capacity factors
NREL Wind Resource Data	Wind resource potentials for each state by wind class and distance from transmission lines.
Biomass Feedstock Availability in the United States, Oak Ridge National Lab	Estimated annual cumulative biomass resources available by state and price
US Environmental Protection Agency's Landfill Methane Outreach Program Database	Data on the size, location and capacity of existing and potential landfills
U.S. Hydropower Resource Assessment	State level assessments of small hydropower resources by rive basin.

1.3 Development Methodology Overview

Special purpose utility programs were developed for extracting datasets directly from EIA datasets and NEMS for the power, commercial and residential sectors. The fossil resource supply and industry sectors were also developed from NEMS data, but the “smart” workbook was developed manually rather than by means of a utility. The transportation sector was developed from MANEVU and NESCAUM-supplied data.

For the power sector, each power plant in a state above 25 MW is depicted individually. Plants under 25 MW are aggregated into state-specific “small” technology characterizations based on weighted averages by fuel and technology type and vintage. Technology characterizations for existing electricity and merchant CHP plants have been developed, including heat rates, operating costs, and emissions factors. Technology options for new builds have been developed from NEMS input assumption data.

The utilities for the commercial and residential sectors extract data from Annual Energy Outlook 2006 (AEO2006) NEMS sector modules which incorporate data from the EIA Commercial Building Energy Consumption Survey (CBECS) and Residential Energy Consumption Survey (RECS). This information is then cross-referenced with the sectoral consumption data available from the EIA State Energy Data Summary (SEDS) to disaggregate the regional characterizations down the necessary state level. Projections from AEO2006 are used as a guide for calibration in these sectors.

For the NE-12 industry sector, the data development methodology expanded the approach used to develop the NE-6 industrial representation. New and updated data sources were used to develop an approach to state-level modeling of the industrial sector using a combination of NEMS data at the regional level, Manufacturing Energy Consumption Survey (MECS) data on end-use application fuel shares, and state industrial output data from the Bureau of Economic Analysis. Industrial “captive” CHP plants are also modeled in the industrial sector, using similar data. The new approach to characterization of state-level industry sectors has proven to be robust, and in the next phase, the IRG team will consider automating the process with an extraction/processing utility.

For the transportation sector, extensive technology characterization data from NE-6 have been migrated to the NE-12 model and updated where needed. Base year technology stocks and demand projections for on-road vehicles were developed from state-level MOBILE data (MANEVU_2002). Other transport sectors have been simplified, with rail, ship, and air sectors absorbed into “Other” due to lack of data and future technology options. Consumption in Other has been modeled using AEO projections mapped to the state level used base year SEDS consumption data.

Fossil and nuclear supply options are based on EIA and NEMS data. Renewable resource and technology data for the NE-6 states have been migrated to NE-12, and data for the new states have been developed in collaboration with NREL. In addition, updated data from the IPM RGGI analysis were incorporated for some state-level renewable energy resources limits, technology characterizations and state policies.

The NE-12 model has been fully calibrated to SEDS data for the base year, and a reference case developed that tracks AEO2006 regional results, and incorporates regional and national policies including state renewable portfolio standards and new CAFE standards. The model has also been extensively run and tested as part of the Renewable Energy and Efficiency Modeling Analysis Partnership (REMAP) model comparison project, sponsored by DOE, NREL, and EPA.

The following sections describe the development, data sources, and calibration of each sector of the model in more detail. They also note areas for possible future further development.

2. Commercial Sector Modeling

The NE-12 Commercial sector demands were based on the 14 Commercial Demand Sub-sectors in NEMS and their correlation to the categories of commercial energy use found in the AEO are shown in Table 2.

Table 2: Mapping of NE-12 Commercial Demand Sub-sectors to AEO Energy Use Categories

Name	Corresponding to these AOE Demand Categories
CCK	Cooking
CDG	Distributed Generation
CLT	Lighting
COE	Office Equipment (PC and non-PC)
COT	Other Uses and Non-Building Uses
CRF	Refrigeration
CSC	Space Cooling
CSH	Space Heating
CVT	Ventilation
CWH	Water Heating

2.1 Data Development Process

The overall flow of data from sources to model inputs is shown in Figure 2 and described in more detail below.

2.1.1 Base Year Demands and Residual Technology Stock

The base year demands are developed using a combination of NEMS Census division-level and SEDS state-level data for the year 2002. SEDS provides final energy consumption by fuel for the entire commercial sector for each state. The NEMS data are used to create shares to break out the proportion of each fuel's final consumption going to each end use demand. These shares are then applied to the SEDS data to get final consumption by end use for each state.

To convert to useful energy, or demands, final energy consumption must be multiplied by the stock average efficiency. Base year market share data from NEMS at the Census division level are used to create efficiency-weighted shares for each residual technology, by fuel type. When these shares are multiplied by the state-level final consumption and the efficiency, the result is the portion of the demand met by each technology. These are summed to derive the total state demand. They are also divided by the capacity factor to derive the residual technology stock (RESIDs).

2.1.2 Demand Projections and User Constraints

For the Commercial sector, the drivers for service demand growth over the model horizon can be "mined" from the NEMS regional commercial information available from EIA.[2] These

[2] Projected Service Demands are derived from Input File KTech.wk1 and Output File KSDOut.txt.

census division files are cross-referenced and allocated by state according to the SEDS data.

In each demand category, user constraints (UCs) are imposed to limit the rate at which fuel switching can happen and advanced, high efficiency devices can penetrate. In some demand categories, such as refrigeration and ventilation, where technology choice is constrained by conditions not represented in NE-12 or other considerations (such as building type), UCs are also used to limit switching between technology types (e.g., walk-in freezers cannot substitute for refrigerators). UCs are based on the base year share for the relevant fuel/technology type, and are allowed to relax by a user-specified amount over the model horizon as appropriate. For the Commercial Other demand (COT), UCs are used to guide fuel share evolution, based on the NEMS regional results.

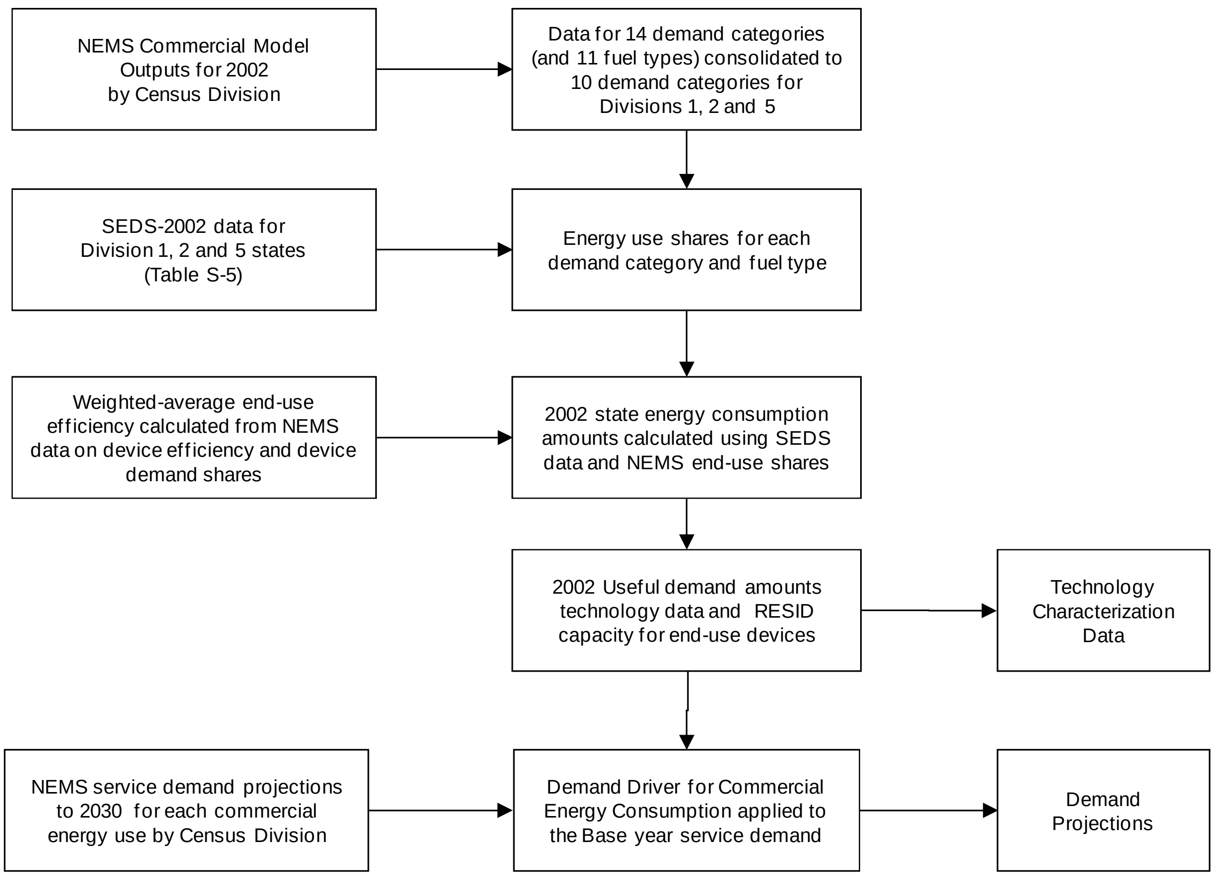

Figure 2: Data Sources and Processing for NE-12 Commercial Sector

2.1.3 Technology Characterizations

Commercial sector technology data for parameters start year (START), lifetime (LIFE), efficiency (EFF), investment cost (INVCOST), and fixed operating cost (FIXOM) are derived from the NEMS ktech file technology characterizations at the appropriate Census division level. An extraction and transformation mapping utility processes this information into a model-ready format, making updates and extension of the model to additional states much simpler. Capacity factor or utilization data (CF) are derived from the NEMS commercial model input filekcapfac.txt, which provides capacity factors by end use, building type, and region. NEMS service demands were used to weight them up over building types.

2.2 ANSWER Load Workbook

For the commercial sector, there are three ANSWER load workbooks for the NE-12 model: one for each census division. Each workbook currently contains 12 worksheets,[3] and a description of each sheet is provided below:

- **ANSv6.1_Home –** This sheet defines the Answer template region handling and version
- **Commodities** – Definition of all commercial sector demands and the input/output energy carriers for all commercial end-use technologies.
- **Technologies** – Definition of all end-use, transfer and dummy supply (for debug) technologies for the commercial sector.
- **Demand_Data** – Base year and projected energy service demands for all commercial sector demands in each state, along with load shape data for demands consuming electricity or heat that do not follow the default season/day time slices.
- **TechData_COM** – Technology characteristics (investment cost, O&M cost, capacity factor, residual amounts, and other data) for existing and new commercial end-use technologies in each state.
- **TechData_ZZ** – Characteristics (input commodity, output commodity, and cost) for the dummy technologies that can supply each commercial demand. These serve to avoid model infeasibilities during debugging and facilitate the identification and resolution of modeling errors.
- **Constraints –** Definition of user constraints for commercial sector fuel use shares and advanced technology uptake.
- **Constr_Data** – Model input data for the commercial user constraints in each state.
- **UC_Share –** Data development worksheet for the Constr_Data sheet with the sector share information.
- **Share_Data –** Data sheet from NEMS that provides end-use consumption shares by fuel type. These data are modified by SEDS data to develop share data for each end-use and state.
- **DM_Driver –** Worksheet to compile demand drivers from the ServDem_RX worksheet.
- **ServDem_RX –** Data sheet of commercial sector service demands for census division X (1, 2, or 5), compiled from NEMS Input File KTech.wk1 and Output File KSDOut.txt.

2.3 Areas for Improvement

The following are potential areas for improvement in the commercial sector:

Subsector simplification: Some of the commercial subsectors contain very large numbers of

[3] Underlined worksheets correspond to actual "smart" load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

technologies that are only applicable to a small subset of the 11 building types that NEMS tracks. In particular, there are nearly 50 ventilation technologies, and nearly 80 refrigeration technologies. As it stands, UCs are needed to heavily control penetration of these technologies: refrigerated vending machines cannot substitute for walk-in coolers, and vice versa. This amounts to a significant addition to model size and complexity simply to track electricity consumption for these demands. Little additional knowledge can be gained as a result of this extra disaggregation, however, unless additional detail is incorporated for a particular focused analysis on the commercial sector. We suggest a review of these subsectors, and the possibility of tracking consumption with dummy demand devices in subsectors that are not candidates for intensive analysis in the near future.

State-level demand projections: In NE-6, many demands were projected at the state level, using state GSP projections. Because we have not had access to similar, updated data for all of the NE-12 states, demands were projected at the census division level, as described in Section 3.1, using AEO2006 demand growth rates. Using this procedure, all states in a given census division grow at the same rate for each demand. Should state-level GSP projection data become available, this procedure could be reviewed.

3. Residential Sector Modeling

The NE-12 Residential sector demands were directly based on the 15 residential demand sub-sectors in NEMS and AEO as shown in Table 3.

Table 3: Mapping of NE-12 Residential Demand Sub-sectors to AEO Energy Use Categories

Name	Corresponding to these AOE Demand Categories
RSH	Space heating
RSC	Space cooling
RCW	Clothes Washers
RDW	Dish Washers
RWH	Water Heating
RCK	Cooking
RCD	Drying
RRF	Refrigeration
RFZ	Freezing
RLT	Lighting
RPC	Personal Computers
RTV	Television
RFF	Furnace Fans
ROA	Other Appliances
RSS	Secondary Heating

3.1 Data Development Process

The overall flow of data from sources to model inputs is shown in Figure 3 and described in more detail below.

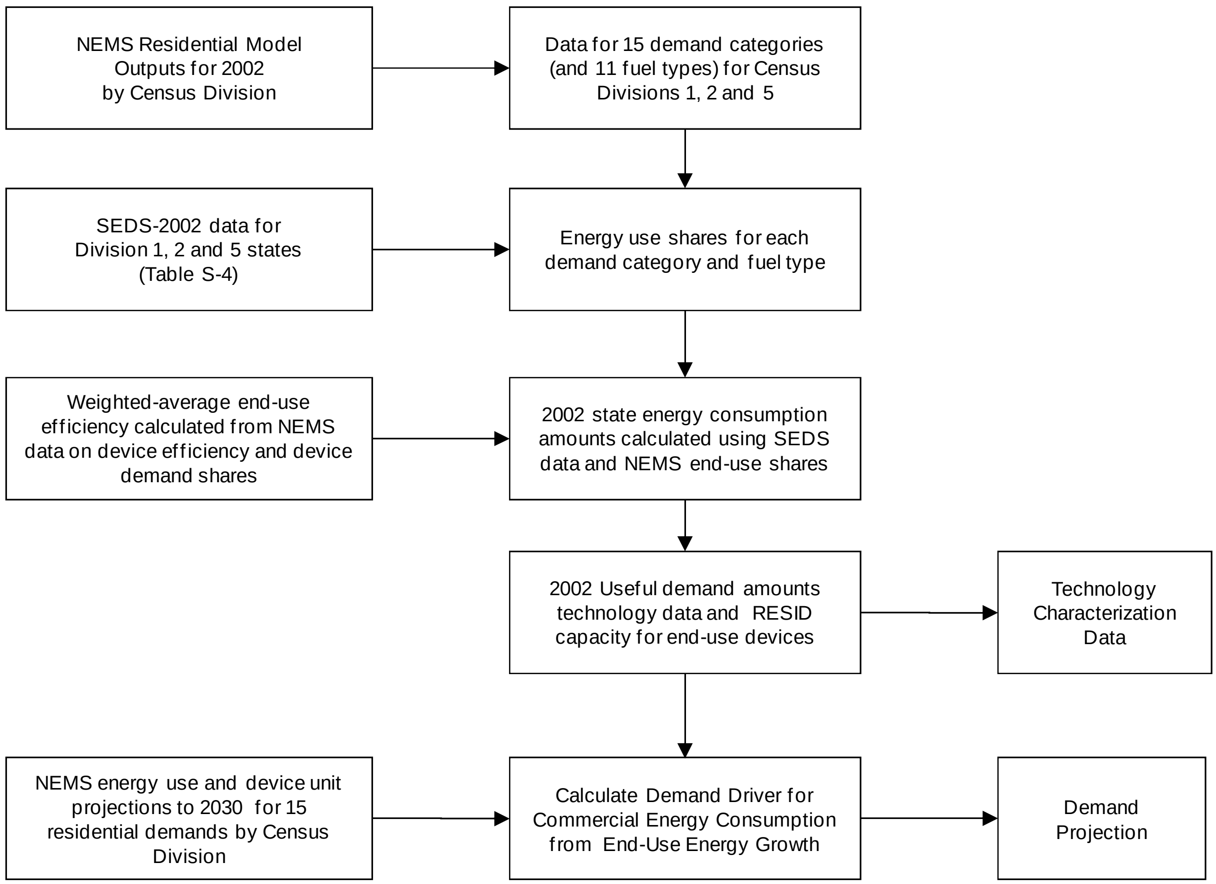

Figure 3: Data Sources and Processing for NE-12 for Residential Sector

3.1.1 Base Year Demands and Residual Technology Stock

Base year demands and RESIDs have been calculated using the same procedures as in the commercial sector.

3.1.2 Demand Projections and User Constraints

For the residential sector, the NEMS modeling approach is different than in the commercial sector, and the regional information files do not contain drivers for service demand growth. NEMS does provide information on final energy demand growth and number of end-use device units. In order to derive service demand drivers from this information, the average device energy consumption was calculated. For most demands, NEMS reports a decreasing unit energy consumption because of gradual end-use device efficiency improvement. However, the rate and manner of device efficiency improvement is to be investigated using the NE-12 model. Therefore, for most residential sub-sectors, service demand drivers were developed by using the base year average device energy consumption multiplied by the projected device population. For some sub-sector demands, especially lighting, personal computers, and miscellaneous energy demands, the average device energy consumption increases over time, and for those sub-sectors, the projected device energy consumption from NEMS was used to develop the demand drivers. These census division files are cross-referenced and allocated by state according to the SEDS data.

As in the commercial sector, initial fuel and technology type shares for each service demand are also derived from these data and used to construct user constraints that limit the rate at which switching can happen for each residential sector demand.

3.1.3 Technology Characterizations

Technology characterizations for the residential sector were developed using the same procedures as in the commercial sector.

3.2 ANSWER load workbook

For the residential sector, there are three ANSWER load workbooks for the NE-12 model: one for each census division. Each workbook currently contains 12 worksheets,[4] and a description of each sheet is provided below:

- **ANSv6.0_Home –** This sheet defines the Answer template region handling and version
- **Commodities** – Definition of all residential sector demands and the input/output energy carriers for all commercial end-use technologies.
- **Technologies** – Definition of all end-use, transfer and dummy supply (for debug) technologies for the residential sector.
- **Demand_Data** – Base year and projected energy service demands for all residential sector demands in each state along with load shape data for demands that do not follow the default season/day time slices.
- **TechData_RES** – Technology characteristics (investment cost, O&M cost, capacity factor, residual amounts, and other data) for existing and new residential end-use technologies in each state.
- **TechData_ZZ** – Characteristics (input commodity, output commodity, and cost) for the dummy technologies that can supply each residential demand. These prevent model infeasibilities during debugging and facilitate the identification and resolution of modeling errors.
- **Constraints** – Definition of user constraints for residential sector fuel use shares and advanced technology shares.
- **Constr_Data** – Model input data for the residential user constraints in each state.
- **UC_Share –** Data development worksheet for the Constr_Data sheet.
- **Share_Data –** Data sheet from NEMS that provides end-use consumption shares by fuel type. These data are modified by SEDS data to develop share data for each end-use and state.

[4] Underlined worksheets correspond to actual “smart” load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

- **DM_Driver –** Worksheet to calculate demand drivers from the data in the Projections worksheet.
- **Projections –** Data sheet of residential sector energy consumption and device units compiled from NEMS file ResDBOut-a06.txt.

3.3 Areas for Improvement

Areas for improvement parallel those in the commercial sector. They are:

- A review of the demand subsectors for possible areas for simplification; and
- The possibility of adding state-level demand projections, should relevant data become available.

4. Industrial Sector Modeling

For the NE-12 framework, the recommended approach to modeling Industrial sector energy use follows the approach used to model the industrial sector energy use for NE-6 in that all industry demands are mapped into the following general end-use categories using MECS data: steam boilers, process heat, machine drive, electro-chemical, feedstock, and other uses. The end-use technologies supplying each of the end-use categories are defined by fuel type and are tied together by ADRATIOs that start at the current fuel share but relax over time to allow fuel switching to occur. However, there are some differences from the NE-6 methodology. In particular, all the energy demands are in units of trillion BTUs. Although NEMS does provide physical output quantities for aluminum, cement, glass, paper and steel, it is not clear that there is value in defining these demands in these units. The RES structure is illustrated for the chemicals subsector in Figure 4.

4.1 Data Development Process

4.1.1 Base Year Demands and Residual Technology Stock

The NEMS Industrial Model provides breakouts of energy use for 15 industry sub-sectors and refineries for the four census regions[5] by fuel type. For NE-12, these 15 industry sub-sectors were consolidated into 6 sub-sectors as shown in Table 4. Each industry sub-sector had demands in most or all of the end-use demands as also shown in Table 4, but certain industries are not found in all states.

Table 4: List of NE-12 Industrial Sub-sectors and End-use Demands

NEMS Industry Sub-sectors	NE-12 Industry Sub-sectors	End-use Demands
Chemical	Chemical	Steam, Process heat, Electrochemical, Mechanical drive, Feedstock, Other
Durables	Durables	Steam, Process heat, Electrochemical, Mechanical drive, Other
Glass & Cement	Glass-Cement	Steam, Process heat, Electrochemical, Mechanical drive, Other
Steel & Aluminum	Metals	Steam, Process heat, Electrochemical,

[5] Northeast, South, Midwest and West.

		Mechanical drive, Feedstock, Other
Agriculture, Construction, Mining, Non-intensive & Food	Other	Steam, Process heat, Electrochemical, Mechanical drive, Other
Paper	Paper	Steam, Process heat, Electrochemical, Mechanical drive, Other

Figure 5 describes the process used to build up the industrial final energy use, base-year service demands and residual capacities. The data development for NE-12 started with the NEMS final energy consumption data for the Northeast and South Atlantic regions as detailed in the NEMS regional industrial tables[6] for 2002. This file provides fuel use data for each industry sector broken down into buildings, processes, steam/cogeneration and electricity generation. These data were collected into a subset of fuel categories that more closely matched the SEDS data and that will be more appropriate for model use.

This regional table of industrial energy consumption by fuel type was separated into state shares of industrial energy use using the data from the Bureau of Economic Analysis (BEA), which provides Gross State Product (GSP) data for a large number of industries by NAICS code. The 2002 GSP data, available from the BEA - Regional Economic Accounts,[7] were used to determine state shares of energy use for each industry sector based on the assumption that industrial energy use is proportional to industrial economic output.

The NEMS industry categories were mapped by their NAICS codes to match the NAICS codes used in the BEA breakdown. For now we have used the BEA breakdown, but some disaggregation may be desired at a future date. For example, BEA only reports primary metals manufacturing (331), which included both steel and aluminum. (The one exception to this procedure is in the refining industry, whose energy use is accounted for using dummy technologies in the supply sector. The GSP category “Coal and Petroleum Products” industry is much broader than just refining, and so its shares do not accurately reflect refining energy consumption. Shares of regional refinery capacity, calculated from EIA data in the supply template, are substituted for the GSP shares here. The SEDS-adjusted energy consumption calculated from these shares is then assigned to the dummy technologies in the supply template.)

[6] See file: NEMS Industry_regional.xls

[7] See http://www.bea.gov/bea/regional/gsp/

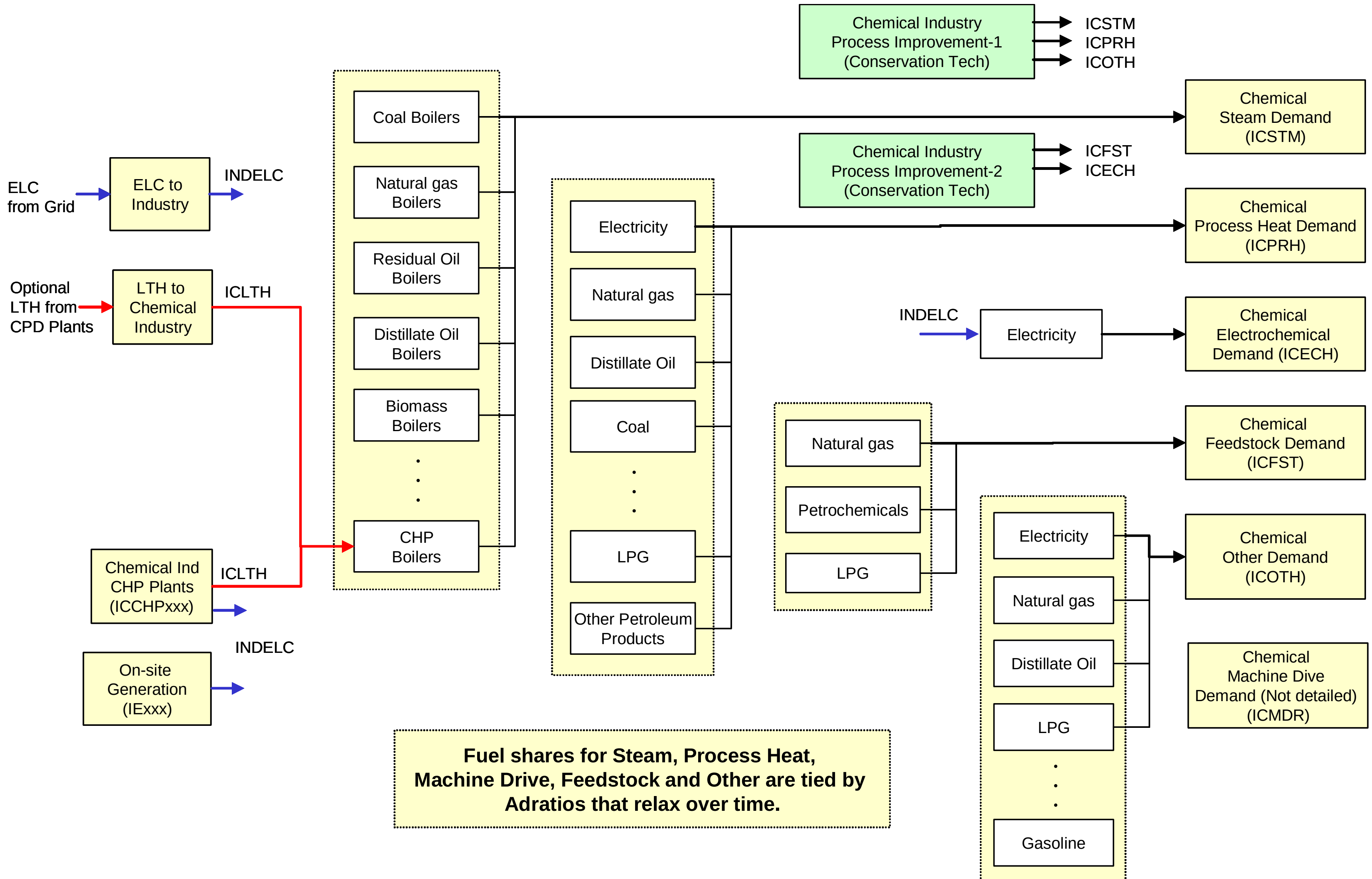

Figure 4: Example RES for Industrial Chemical Process Energy Use and CHP

Next, the state-level industry sector energy use shares – obtained by applying the state industry GSP shares to the regional industry sector values – were calibrated to the final energy use numbers provided in the SEDS industrial sector energy consumption table.[8] MECS data,[9] which provide national-average end use energy consumption by end-use type for a variety of industries by NAICS code, were then used to develop end-use shares for each industry sub-sector and fuel type for the applications of boiler steam, CHP, process heat, machine drive, electrochemical process and other uses. These shares were applied by state-level industry sector energy use to get base year final energy use by state, industry sector, fuel type and end-use. The base-year final energy data were then used to determine the current existing stock (RESID) of these generic devices for each state, industry sector, end-use application and fuel type.

4.1.2 Demand Projections

Future projections of the industrial energy demands were based on the 2006 NEMS Industrial Model final energy consumption projections for the Northeast and South Atlantic regions, which go to 2030. These final energy consumption projections already incorporate the EIA projected efficiency improvements of industrial energy consumption for both manufacturing and non-manufacturing sectors.

4.1.3 Technology Characterizations

O&M costs for existing technologies and both capital costs and O&M costs for new technologies were derived from the SAGE technology characterization database. The year 2000 dollars were converted to 2002 dollars using the GDP deflator from the Bureau of Economic Analysis.

Technology characterizations for industrial CHP plants have similarly been drawn from SAGE. See Section 7 for more details on CHP modeling.

4.2 ANSWER load workbook

For the industrial sector there are two ANSWER load workbooks for the NE-12 model. Each workbook currently contains 30 worksheets,[10] and a description of each sheet is provided below:

- **ANSv6.1_Home** – This sheet defines the Answer template region handling and version.
- **Commodities** – Definition of all industrial sector demands and the input/output energy carriers for all industrial end-use technologies.
- **Technologies** – Definition of all end-use, transfer and dummy supply (for debug) technologies for the industrial sector.

[8] SEDS Table S6: Industrial Sector Energy Consumption Estimates, 2002.

[9] MECS Table 5.2: End Uses of Fuel Consumption within NAICS Codes, 2002.

[10] Underlined worksheets correspond to actual "smart" load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

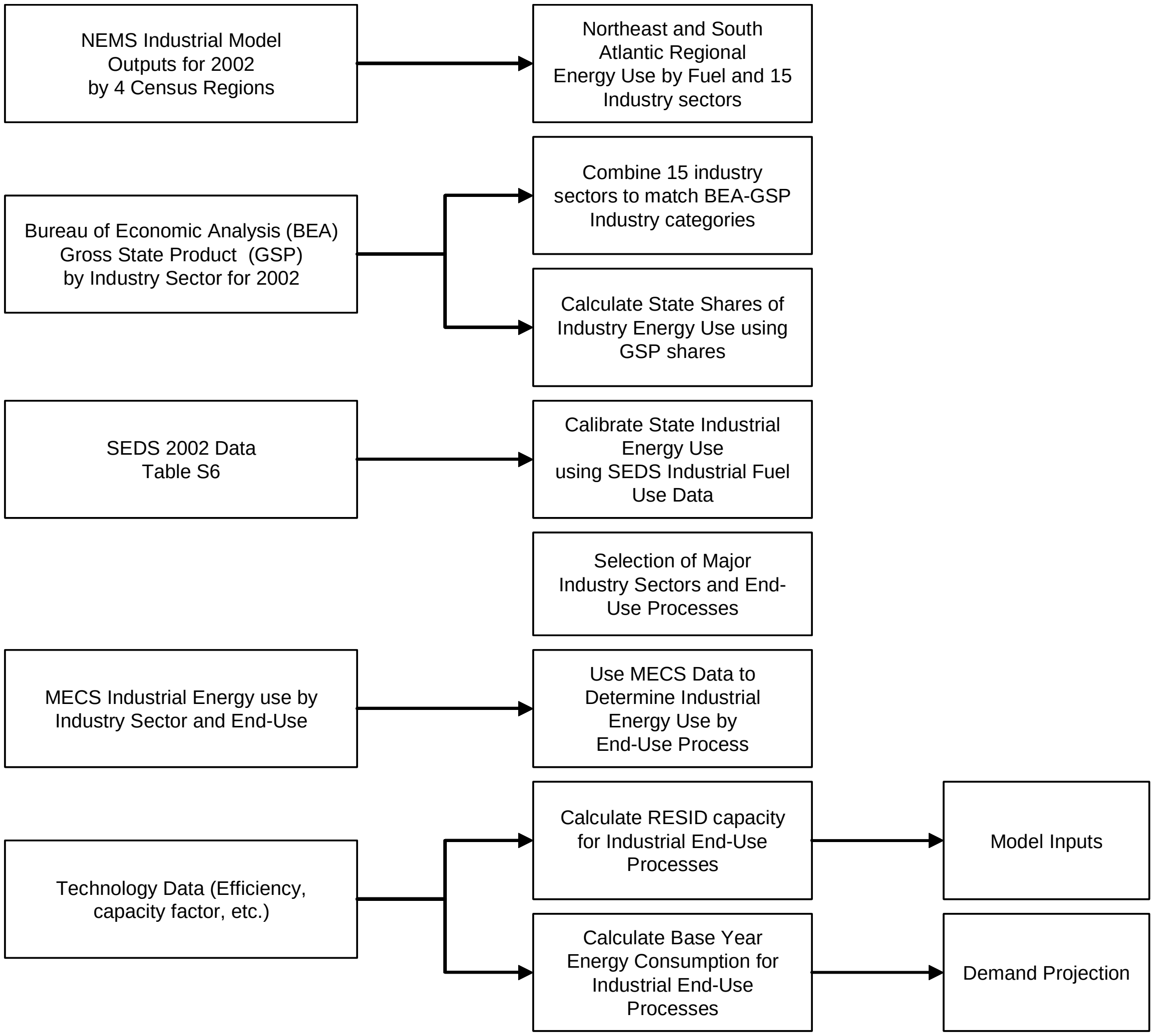

Figure 5: Data Sources and processing for NE-12 Industrial Sector

- **<u>Demand_Data</u>** – Base year and projected energy service demands for all industrial sector demands in each state along with load shape data for demands that do not follow the default season/day time slices.
- **Growth –** Worksheet to calculate the demand drivers from the NEMS Industrial Model outputs in the indreg sheet.
- **indreg –** Output data from the NEMS Industrial Model for the northeast census region.
- **DM_Calib –** Worksheet to calculate base year useful energy demand from final energy consumption and device efficiency for each state.
- **Time slice –** Data and worksheet to calculate the fraction of each demand in each season/day time slice for those demands not following the default time slice fractions.
- **<u>TechData_IC</u>** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial chemicals end-use technologies in each state.

- **TechData_IP** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial paper end-use technologies in each state.
- **TechData_IM** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial metals end-use technologies in each state.
- **TechData_ID** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial durables end-use technologies in each state.
- **TechData_IG** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial glass-cement end-use technologies in each state.
- **TechData_IO** – Technology characteristics (O&M cost, capacity factor, residual amounts, and other data) for existing industrial other end-use technologies in each state.
- **TechData_ZZ** – Characteristics (input commodity, output commodity, and cost) for the dummy technologies that can supply each industrial sub-sector demand. These prevent model infeasibilities during debugging and facilitate the identification and resolution of modeling errors.
- **TechData_New** – Technology characteristics (investment cost, O&M cost, capacity factor, and other data) for new industrial end-use technologies.
- **TechData_CHP** – Technology characteristics (investment cost, O&M cost, capacity factor, and other data) for existing and new captive industrial CHP conversion technologies.
- **IND_SAGE –** Data from the EIA SAGE model on the characteristics of industrial end-use technologies.
- **2002 Energy –** Worksheet for calculating industry fuel consumption for the 15 NEMS sub-sectors by fuel type, aggregating these to the 6 NE-12 sub-sectors, allocating these from the regional to the state level using GSP data, calibrating these results to SEDS data and determining base year final energy use according to the NE-12 sub-sectors, fuels and end-use applications.
- **SEDS 2002 –** Data from SEDS Table S-6.
- **End-Use –** A worksheet to calculate fuel shares by end-use application for each industry sub-sector.
- **2002 GSP –** Data and worksheet to calculate industry sub-sector shares by state.
- **MECS**-5.2 – MECS Table 5.2 - End Uses of Fuel Consumption, 2002.
- **Constraints –** Definition of user constraints for residential sector fuel use shares and advanced technology shares.
- **Constr_Data –** Model input data for the industrial user constraints in each state.
- **UC_Shares –** Data development worksheet for the Constr_Data sheet.
- **Relax_AD –** Worksheet for developing relaxation factors by fuel and sub-sector.
- **Tech_Filters –** Worksheet that records names and parameters of the TechItems Filters for the industry sector rule based adratios. These have been entered into the model.

- **ENV_Data –** Loadsheet for energy carrier based emissions accounting (not yet implemented.)
- **Emission –** Data for potential use in emissions accounting for the industry sector.
- **IND_Calib –** Worksheet for checking the calibration of the industry sector model and comparison its results to the AEO 2006 reference case.
- **Conv –** A list of conversion factors for use in the various data sheets.

4.3 Areas for Improvement

The key areas for improvement in the industrial sector relate to enhancing the energy efficiency and process improvement options. Currently, the SAGE industrial technology characterization data do not address future efficiency improvement options. Generic new technologies with improved efficiencies were incorporated into NE-12 structure. While these technologies address the incremental improvements in industrial boilers, furnaces, machine drives, etc., they do not address more fundamental process efficiency improvements. In the next phase, additional conservation technologies, depicted in the upper right hand corner of Figure 4, should be added to each of the industrial sub-sector demands that reflect possible industrial process or structural improvements that will reduce the need for energy in the future. Of course, developing the data to support these conservation technologies will be the major challenge.

5. Transportation

The NE-12 Transportation sector models three highway demand categories: light duly vehicles (TL), heavy trucks (TH), and buses (TB), and uses dummy "other" demands to account for total fuel consumption in the sector. There are five size classes for LDVs and two for heavy trucks. The full list of demands is shown in Table 5.

Table 5: Transportation Sector Demands and Size Classes

Name	Description	Size class	Abbrev.
TB	Buses		
TH	Heavy Duty Trucks	Heavy	HH
		Medium	HM
TL	Light Duty Vehicles	Large car	BC
		Large truck	LT
		Minivan	MV
		Small car	SC
		Small Truck	ST
TOA	Other - Aviation Gasoline		
TOD	Other - Diesel		
TOE	Other - Electricity		
TOJ	Other - Jet Fuel		
TOL	Other - Lubricants		
TOP	Other - LPG		
TOR	Other - Residual Fuel		

Owing to data problems, the following demand categories from NE-MARKAL have been aggregated: air travel (TA), ships (TN), and rail (TR), and total fuel consumption balanced by means of the Other sectors. It is recommended that these categories remain dropped unless and until analysis focusing on them is planned and resources can be devoted to addressing data gaps.

5.2 Data Development Process

5.2.1 Base Year Demands and Residual Technology Stock

For LDVs and heavy trucks, 2002 state level VMT is derived from the MANVEVU MOBILE report,[11] provided by Jung-Hun Woo of NESCAUM. MOBILE size categories are mapped to NE-12 size categories using the Table 6.

Heavy duty gasoline vehicles come in only one size category in the MOBILE data. They are apportioned to the NE-12 classes using the AEO2003 VMT shares for medium and heavy gasoline trucks.

For buses, 2002 state level VMT by fuel type is taken from MANEVU. VMT are apportioned to fuel type using national average figures derived from the Transportation Energy Data Book: Edition 25, Table 2.4.

Table 6: Mapping of MANEVU classes to NE-12 classes

	SC	BC	MV	ST	LT	HM	HH
LDGV	0.46	0.54					
LDGT1			0.22	0.78			
LDGT2					1		
2B Heavy Duty Diesel Vehicles						1	
Light Heavy Duty Diesel Vehicles						1	
Medium Heavy Duty Diesel Vehicles						1	
Heavy Heavy Duty Diesel Vehicles							1

Base year values for Other are taken from SEDS sectoral fuel consumption data. For diesel and electric, bus, truck, and LDV fuel consumption calculated from existing stocks (RESIDs) and efficiencies, to get the consumption going to Other.

5.2.2 Demand Projections and User Constraints

Demand projections for LDVs, trucks, and buses were based on VMT projections extracted by NESCAUM from the MANE-VU inventory data for 2009 and 2018, which were based on state-provided VMT projections.

For LDVs, the average growth rate for all size categories was used. For trucks, an average of the HDGT, MHDDV, and HHDDV classes, weighted by the base year shares for these classes

[11] MARAMA, Documentation of the 2002 Mobile Emissions Inventory for the MANE-VU States, Mid-Atlantic Regional Air Management Association, Baltimore MD (2006). Available online at: <http://www.marama.org/visibility/Inventory%20Summary/final_mob_manevu_rpt.pdf>.

in each state, was used. For buses, the HDDB category growth rate was used.

For the fuel-based Other demands, growth projections are derived from the growth of the consumption of these fuels in AEO 2006 regional results. The exception is Other Diesel, because AEO diesel consumption is dominated by heavy trucks, a demand we track explicitly. The growth rate for Other Diesel is the AEO annual growth rate for the sum of freight rail and domestic shipping, the two largest components of diesel consumption after heavy trucks. This is a national average growth rate.

Size class and fuel share constraints are imposed to shape evolution of reference case. In addition, CAFE, hybrid vehicle and fuel cell vehicle constraints representing existing state and federal policies have been developed based on data supplied by NESCAUM.

LDV size class constraints are used to keep the model from shifting all light duty travel into the smallest and hence most efficient size classes. 2005 shares are based on each state's 2002 RESID vehicle shares. 2029 shares are drawn from MOBILE projections and are identical for all states. A fuel share constraint on the maximum percentage of CNG LDV has also been added. Its value rises from 0.1% in 2005 to 1% in 2029, roughly tracking AEO results. Without this constraint, the model shifts heavily to CNG vehicles because it is the cheapest fuel and the capital cost premium is insufficiently high to prevent large scale adoption. The model does not represent the cost of building additional CNG delivery infrastructure for LDVs. Similarly, an upper bound on the share of DSL to LDV was imposed. These values are currently set at 1% and 10% respectively for 2029 and are user adjustable in the template.

For heavy duty trucks (TH) two constraints are used, a minimum share of heavy trucks (the largest of the two size classes) and a minimum share for gasoline trucks. 2005 shares are based on each state's 2002 RESID share. 2029 shares are allowed to relax 5% from 2005 shares.

For buses, fuel share constraints have been used to prevent excessive switching to alternative fuels. These are maximum shares in CNG and gasoline and a minimum share in diesel. The 2005 shares are based on the national share data used to calculate the existing stock (RESIDs). For 2029, the CNG and gasoline shares are allowed to evolve 10% from their 2005 levels, the diesel shares 20%.

For all LDVs other than conventional gasoline vehicles, a GROWTH constraint of 5% was imposed, with GROWTH_TID approx = 2.5% of 2002 state TL DM.

5.2.3 Technology Characterizations

Technology characterizations for buses, trucks, and light duty vehicles were developed by NESCAUM analysts for NE-6, and these were retained in NE-12. Light duty vehicle characterizations were reviewed and updated by NESCAUM analysts in fall 2006.

5.2.4 Calibration

Due to the use of MANE-VU data for calibration, NE-12 results do not match SEDS or AEO for this sector, so results are not directly comparable to SEDS and AEO as they are in other sectors. In particular, 2002 TRN gasoline consumption calculated from MANE-VU VMT and NE-12 vehicle technology efficiencies is between 1% (MA and NJ) and 41% (NY) higher than SEDS. After several discussions with NESCAUM on the methodology and vehicle characterizations, NESCAUM has confirmed both of these, so the discrepancy stands. Similarly, the MANE-VU VMT growth projections are lower than those of AEO, as

NESCAUM pointed out when providing them. In fact, they are lower than the rate of increase of average LDV fleet efficiency during the 2005-2020 period of the Reference case, resulting in decreasing gasoline consumption during these years.

5.3 ANSWER load workbook

For the transportation sector there is one ANSWER load workbooks for the NE-12 model. The workbook currently contains 22 worksheets,[12] and a description of each sheet is provided below:

- **ANSv6.0_Home –** This sheet defines the Answer template region handling and version
- **<u>Commodities</u> –** Definition of all transportation sector demands and the input/output energy carriers for all transportation end-use technologies.
- **<u>Technologies</u>** – Definition of all end-use, transfer and dummy supply (for debug) technologies for the transportation sector.
- **<u>CommData</u> –** Emissions accounting parameters for the transportation sector.
- **<u>Demand_Data</u> –** Base year and projected energy service demands for all transportation sector demands in each state.
- **<u>TechData</u> –** Technology characteristics (investment cost, O&M cost, capacity factor, residual amounts, and other data) for existing and new transportation end-use technologies in each state.
- **<u>TechData-RESIDs</u> –** Base year technology stocks for existing vehicles.
- **<u>TechData_ZZ</u> –** Characteristics (input commodity, output commodity, and cost) for the dummy technologies that can supply each transportation demand. These prevent model infeasibilities during debugging and facilitate the identification and resolution of modeling errors.
- **<u>Constraints</u> –** Definition of user constraints for transportation sector size class and fuel use shares and policy constraints.
- **<u>Constr_Data</u>** – Model input data for the transportation user constraints in each state.
- **<u>Constr_Data-Eff</u> –** Model input data for the CAFE standard user constraints.
- **Constraint Calcs –** Data development worksheet for the Constr_Data and Constr_Data-Eff sheets.
- **Calculations –** Data development worksheet demand growth and “Other” demands.
- **data-MANEVU –** Data summary sheet and data development worksheet for vehicle RESIDs, based on MANEVU data.
- **m.state –** Raw MANEVU data.
- **data-SEDS –** SEDS 2002 energy consumption data used to develop “Other” demands.
- **data-AEO –** AEO2006 energy consumption data used to project “Other” demands.

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[12] Underlined worksheets correspond to actual “smart” load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

- **NESC INVCOST –** Vehicle investment cost data provided by NESCAUM, derived from NE-6.
- **NESC FIXOM –** Vehicle fixed operating and maintainance cost data provided by NESCAUM, derived from NE-6.
- **NESC EFF –** Vehicle efficiency data provided by NESCAUM, derived from NE-6.
- **NESC Emissions –** Vehicle emissions data provided by NESCAUM, derived from NE-6.
- **Conv –** A list of conversion factors for use in the various data sheets.

5.4 Areas for Improvement

Another review of the calibration issues described above is recommended.

6. Electricity Generation and CHP

6.1 Overview and Modeling Issues

For electricity-only plants, the NE-12 modeling approach is to represent individual plants down to a minimum size threshold, and aggregated “small” plants below the threshold. Data are taken from EIA reports, NEMS, and eGRID.

For combined heat and power (CHP) plants, there are two types of CHP applications that need to be considered. The first is independent or merchant CHP plants that primarily sell electricity to the grid and are not integrated into industrial processes. The heat (usually steam) they produce can be used in a range of low to medium temperature applications including district heating, greenhouses, or industrial manufacturing. These plants are modeled in the electricity sector in the same manner as the electricity generation technologies.

The second class of plants is industry CHP plants that are more tightly integrated with the industrial processes they serve and often (but not always) use by-product fuels from industrial processing. The fuel consumption and residual capacity of these plants (and on-site generation) have been extracted from the NEMS industrial database and apportioned to the states according the SEDS data, just like the other industrial energy consumption data. The CHP end-use shares are derived from the MECS data, and specific CHP technologies are defined according to the fuel input. Technology characteristics are derived from the SAGE industrial technology database. An example RES for Industrial Chemical Processes is shown in Figure 6.

The important CHP modeling issue is to ensure that electricity and low-temperature heat (LTH) generated can be accessed by the demand sub-sectors – within reasonable limits. For electricity, these limits are quite minimal as electricity can be transmitted long distances over the grid. For the LTH demands, there is a much smaller range within which this energy can reasonably be transmitted, and so significant constraints exist that are largely based on proximity requirements. In the industrial sector, it is primarily the steam demands that are open to outside supply of LTH. Likewise, it is primarily industry generated steam that is available to supply non-industry LTH loads. In NE-12, the industrial CHP plants sell electricity to the grid that supplies electricity to the industrial demands and heat to the grid that supplies just that specific industry.

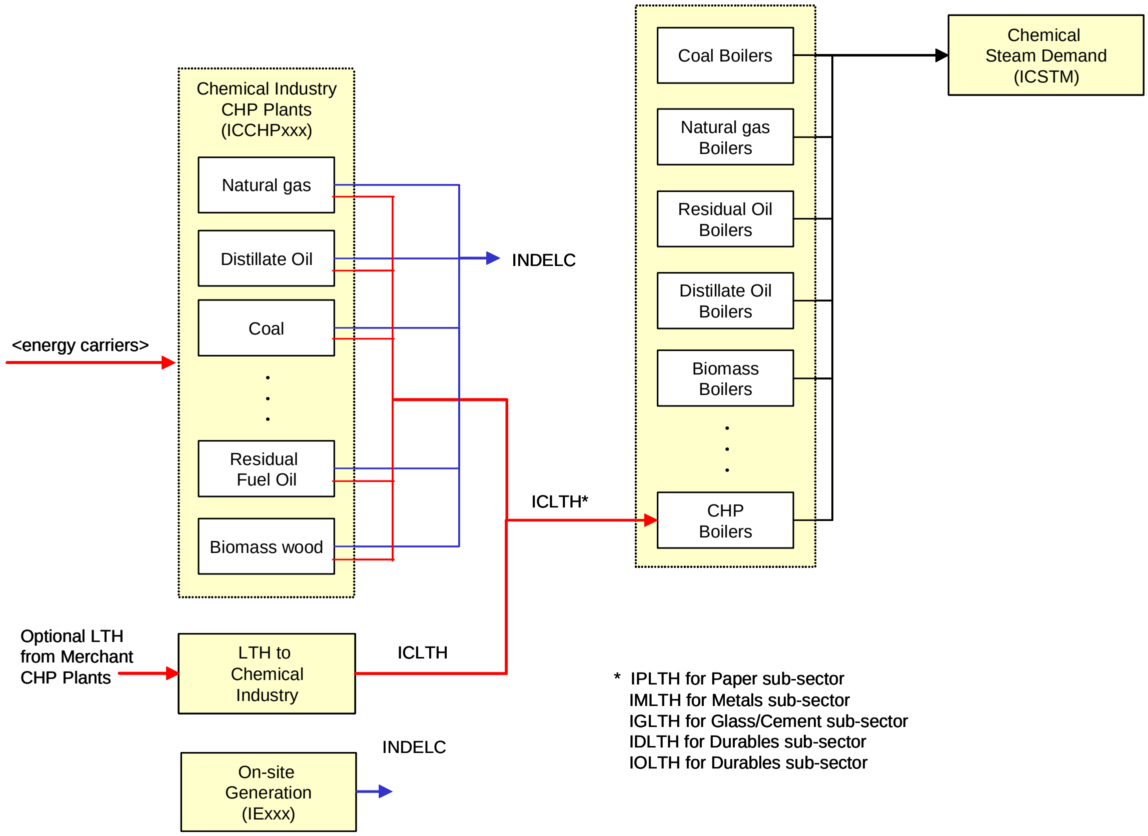

Figure 6: Industrial CHP Modeling

Currently, the heat produced by independent CHP plants is not hooked up to any sectoral heat demands. A more detailed analysis of collocation and supply opportunities for this heat will be needed to make these assignments and place appropriate bounds on the potential for co-generated heat delivery. In practice, many of these plants deliver minimal heat, and serve primarily as independent electricity generators. Making the heat produced by any subset of plants available to subsector demands can be accomplished with minimal changes to output energy carrier names and RES structure.

Currently, the option for industrial CHP plants to provide LTH demands to their sub-sector is modeled using the 2002 NEMS industrial model data, which are used to calculate the current ratio of CHP heat use to total steam heat by region and by industry sub-sector. This provided the starting bound for sub-sector based ADRATIOs. The selection of future bounds for the sub-sector based CHP activity is determined by setting the upper bound as a percentage increase over the current ratio of CHP heat to total steam heat. The percentage increase is a variable parameter in the ANSWER loadsheet, so that scenarios can be easily created.

Furthermore, the non-industrial LTH demand is not modeled because NEMS data indicated it is quite small and not expected to grow. However, the option for commercial sector CHP plants and for industry to provide LTH to the commercial and perhaps urban residential sectors can be added to the model in the future to support policy analyses in this area.

6.2 Data development process

6.2.1 Existing Plants

The data sources for existing electricity and independent CHP generation technologies are EIA Forms 860 (existing and planned units), 767, 759/906 and Form 1, which collectively list generating unit capacity, prime mover, fuel sources, location, plant operation and equipment design (including environmental controls), fuel consumption and quality, and, for the larger investor-owned plants, the non-fuel operating costs. Each survey form has its own universe of units covered. All units are covered by one or more of the forms.

A data mining utility has been developed to convert these data to ANSWER "Smart" upload templates. Because these forms list every plant regardless of size, small plants must be aggregated to an appropriate level to obtain a manageable number of technologies that still adequately represents the diversity of existing plants and their differential use in the system. All existing generation units above a specified capacity threshold are represented as individual technologies, retaining all unit-specific information. This threshold is currently set at 25 MW, but can be adjusted to obtain the desired level of detail in the sector.

Plants below the capacity threshold have been aggregated using the following characteristics[13] to define a plant type:

- fuel input type;
- plant type (taken from the Electricity Capacity Planning (ECP) designations in NEMS), and
- state/region.

For each grouping of aggregated plants, data for the representative MARKAL technology are derived by calculated a capacity weighted average of selected fields from the EIA forms and totaling other fields. The following fields have been averaged:

- heat rate;
- annual cap additions (added to fixed O&M costs);
- fixed and variable O&M;
- availability or capacity factor;
- scrubber efficiency, and
- NOx emission rate.

The following fields have been totaled:

- total of summer capacity, and
- total of winter capacity (used by adjusting the AF by season).

Rather than modeling plant retirement and life extension decisions in the current framework, the lifetime (LIFE) of all nuclear, coal, and large hydro plants runs the entire planning horizon. The majority of these plants within the region are expected to have their lifetimes extended. Addition of life extension charges and decisions could be added in future updates of

[13] Note that ECP designations separate coal units with and without scrubbers and by vintage. In addition, for coal units, the coal supply region providing the fuel input was used to further distinguish between units for aggregation purposes.

the model.

To facilitate understandability and analysis, the description of each plant contains the fuel type and a code for technology type, as shown in Table 7.

Table 7: Technology Types Represented

Abbreviation	Technology Type
ACC	Advanced Combined Cycle
ACS	Adv. Combined Cyc w/Sequestration
ACT	Advanced Turbine
ANC	Advanced Nuclear
BMS	Wood/Biomass
CAS	New Adv. Coal with Sequestration
CAV	New Advanced Coal
CCG	Gas Combined Cycle
CCO	Oil Combined Cycle
CCX	Oil/Gas Combined Cycle
CNC	New Coal Steam
CNU	Conventional Nuclear
COU	Coal Steam pre- 1965
CSC	Coal Steam with Scrubber
CSU	Coal Steam post- 1965
CTG	Gas Turbine
CTO	Oil Turbine
CTX	Oil/Gas Turbine
DGB	Distributed Generation-Base
DGP	Distributed Generation-Peak
FCG	Fuel Cell
GTH	Geothermal
HYC	Conventional Hydroelectric
HYR	Reversible Hydroelectric
MSW	Municipal Solid Waste
SPV	Solar Photovoltaic
STG	Gas Steam
STH	Solar Thermal
STO	Oil Steam
STX	Oil/Gas Steam
WND	Wind

6.2.2 New Fossil and Nuclear Plants

Technology characterizations for new fossil and nuclear plant options are drawn from NEMS. Interest During Construction (IDC) multipliers drawn from the IPM RGGI analysis[14] were used to adjust NEMS capital costs.

[14] "Assumption Development Document: Regional Greenhouse Gas Initiative Analysis," ICF Consulting, February 10, 2005.

6.2.3 New Renewable Plants

Technology characterizations and resource availability for new renewable plants are described in Section 7.3.

6.2.4 Emissions

Emissions rates for NOx for all existing technologies and SOx and mercury for existing MSW and residual fuel-dedicated technologies are mined from EPA's eGRID database. The eGRID database provides emissions rates at the plant level, whereas NE-12 technologies are represented at the unit level. Since a single plant may consist of several units that may burn different fuels and have greatly dissimilar emissions rates, assigning eGRID rates to the NE-12 existing technologies has been challenging. Calibration and testing will be necessary to determine if the current procedure is sufficient or if further development is needed, or alternatives sought (e.g., the EPA-CAMD National Electric Energy Data System (NEEDS) database, http://www.epa.gov/airmarkets/progsregs/epa-ipm/#needs).

Coal plants and flexible natural gas/oil plants are assigned SOx and mercury emissions based on sulfur and mercury content of the fuel burned. This allows for fuel switching and, in the case of coal plants, biomass co-firing. Coal pollutant content is derived from the NEMS coal supply database. Petroleum fuels were assigned a regional average sulfur content. Existing plants may pass their fuel through a scrubber retrofit technology to remove 95% of the sulfur content.

Because fuel markets and choices are constrained by many non-economic factors that cannot be modeled in NE-12, the rate of fuel switching has been constrained. The rate of switching to low sulfur western coal has been constrained for Mid-Atlantic states, and this fuel has been assumed to continue to be unavailable to the New England states. Similarly, a maximum use of residual fuel in gas/oil flexible plants has been imposed. To achieve state level emissions calibration, further refinements to constraints and to fuel sulfur contents may be necessary at the state and/or plant level. This process will require a detailed review of individual plant behavior and examination of state-specific conditions.

All new coal plants are assumed to be built with scrubbers. Their SOx and mercury emissions rates are based on the sulfur and mercury content of the coal burned and scrubber removal rates. Scrubber removal rates and NOx emissions rates for all new plants are derived from NEMS.

6.2.5 Regional Greenhouse Gas Initiative (RGGI)

RGGI state power sector carbon dioxide emissions budgets and interstate trading in CO2 emissions permits for the RGGI states are represented in the model. States must reduce CO2 emissions by 10 percent from a 2009 emissions budget in 2015-2018. Each state's base annual emissions budget for 2018 must decline by 2.5% per year over this period. The resulting limits imposed are shown in Table 8 below. Emissions limits are currently assumed constant after 2018, but this policy can be explored through scenario analysis.

In the current reference case, which includes only small numbers of new coal fired power plants, the model has no trouble meeting these constraints. NESCAUM analysts have suggested that "hot air" built into the state budgets may also be a factor. This area deserves more analysis by NESCAUM.

Table 8: RGGI State CO2 Emissions Limits (Thousand Metric Tons)

	2008	2011	2014	2017	2020-2029
CT	9702	9702	9622	8975	8732
DE	6858	6858	6801	6344	6172
ME	5397	5397	5352	4992	4857
MD	34019	34019	33736	31468	30617
MA	24186	24186	23984	22372	21767
NH	7820	7820	7755	7234	7038
NJ	20768	20768	20595	19210	18691
NY	58342	58342	57856	53966	52508
RI	2412	2412	2392	2231	2171
VT	1112	1112	1103	1029	1001

6.3 Electricity trade

Electricity trade in the model is represented by interstate bilateral trade links and is limited by two types of constraints: 1) bilateral trade constraints and 2) joint constraints. Bilateral constraints represent the capacity transfer limit between two states. Joint constraints establish limits on the simultaneous flows into or out of a state. The joint and bi-lateral constraints represent the grid reliability and security concerns that need to be managed by the grid operators. The data to establish these limits for the NE-9 states were compiled from "Assumption Development Document: Regional Greenhouse Gas Initiative Analysis," ICF Consulting, February 10, 2005. Bilateral trade capacities for the additional NE-12 states were drawn from the IPM NEEDS database.[15]

The constraints are used in the model to represent the existing grid capability. One of the more difficult challenges is to ascertain the costs associated with increasing these limits. Because of the integrated nature of the grid and the limited ability to direct flows across specific paths, the cost of adding a new transmission line rarely represents the cost of increasing the transfer limits between two sections of a grid, e.g., two states. Periodically, the NERC performs a series of load flow studies to establish the impacts on the grid of significant new transmission facilities and may represent a potential source for this type of data. While there are selected transmission corridors that could get upgraded over the model horizon, we have no source of data that describes the costs or resultant increased transfer limits. As such, for the reference analyses, the model is not currently allowed to increase the transfer limits.[16]

Three areas regarding electricity trade in the NE-12 model need additional attention. The first is the treatment of potential flows from and to the 12 states being modeled. This is particularly important for states like Pennsylvania, which are situated between the relatively low cost electricity producing areas of Kentucky and Ohio and the high cost areas of New

[15] National Electric Energy Data System (NEEDS) 2006 and Documentation for EPA Base Case 2006 (v3.0), available at http://www.epa.gov/airmarkets/progsregs/epa-ipm/index.html#needs.

[16] It should be recognized that current transmission limits or constraints can be addressed by both adding new transmission facilities and by adding generating capacity on the constrained side of the interface. Since the model is assumed to be building new facilities to meet increasing demands and replace retiring units, for modeling purposes it is assumed these new facilities will be situated to relieve any known transmission constraint.

Jersey, Connecticut, and New York. Considerable amounts of power flow into and out of Pennsylvania and a more complete approach to dealing with this issue is needed.

The second related area is the treatment of Canadian imports and exports. New York in particular is affected by the power markets in Ontario and Quebec (as are other parts of New England). Again, a more complete approach is warranted to address these regions. This is particularly important if NESCAUM or the states want to understand the dynamics between various energy and climate policies as they are affected by international leakage or trade.

The third is depicting known bottle-necks within states (e.g., up/down state in New York, east/west in Connecticut, the Boston area in Massachusetts).

6.4 ANSWER load workbooks

There are 30 workbooks in this sector.

- 24 existing electricity and CHP plant workbooks, one each for each state. These contain basic ANSWER loadsheets with data developed using the mining utility as described in Section 7.2.1.
- Three simple workbooks to load power plant user constraints, state RPS policies, and RGGI. These contain basic declaration, data development, and load worksheets.
- One workbook characterizing new power plant technologies, described in more detail below.
- One workbook characterizing interstate electricity trade links, described in more detail below.

The new power plant technology workbook contains 11 worksheets,[17] and a description of each sheet is provided below:

- **ANSv6.0_Home –** This sheet defines the Answer template region handling and version
- **<u>Commodities</u>** – Definition of all input energy carriers and emissions for new power plant technologies.
- **<u>Technologies</u>** – Definition of all new power plant technologies.
- **<u>CommData</u>** – Transmission investment charge for new power plants.
- **<u>TechData</u>** – Technology characteristics (investment cost, O&M cost, heat rate, availability factor, emissions factors, and other data) for new power plants.
- **Current Costs&Perf –** NEMS input data used for technology characterizations.
- **Future Costs –** NEMS input data used for technology characterizations.
- **NEMS data –** NEMS input data used for technology characterizations.
- **IPM-NEMS data –** IPM modifications of NEMS data used to develop IDC multipliers.
- **Emissions –** Emissions factors from NEMS input data.

[17] Underlined worksheets correspond to actual "smart" load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

- **Conv** – A list of conversion factors for use in the various data sheets.

The electricity trade workbook contains 11 worksheets,[18] and a description of each sheet is provided below:

- **ANSv6.0_Home** – This sheet defines the Answer template region handling and version
- **Commodities** – Definition of all energy carriers names for trade links.
- **Technologies** – Definition of technologies for trade links.
- **CommData** – Transmission efficiencies for trade links.
- **DomELC_Trd** – Establishes allowed interregional trade links.
- **DomELC_XLim** – Residual capacity and costs for existing and expanded interregional trade links.
- **Inter-state12** – Data for interregional trade links from RGGI IPM analysis and IPM NEEDS database.
- **CA+O_Trd** – Establishes allowed trade links with Canada and non-NE-12 states.
- **CA+O_XLim** – Residual capacity and costs for existing and expanded extraregional trade links.
- **CA+Other** – Data for extraregional trade links from NEMS.
- **Constraints** – Definition of joint constraints on interstate trade links and net import constraints used for calibration.
- **JointLim+NetIMP** – Loadsheet for joint constraints on interstate trade links and net import constraints used for calibration.

6.5 Areas for improvement

In addition to the electricity trade improvements discussed in Section 7.3 above, potential areas for model improvement are listed here.

Modeling plant retirements and life extension: Remaining technical lifetimes for existing power plants are based on the year they came in to operation and an assumed total lifetime of 40 years. However, recent standard practice in the industry has been to extend the lifetimes of existing plants, particularly coal and nuclear plants. AEO2006 projects far fewer retirements than our 40 year lifetime would assume. The model presently has no means to model an economic choice for life extension. As noted above, we have addressed this by extending the lifetimes of existing coal, large hydro, and nuclear plants for the entire model horizon. Under more stressful policy scenarios (e.g., severe climate policies), the model will need to be able to dynamically deal with retirements of existing capacity. A mechanism to model the choice of retirement or life extension should be introduced.

Emissions data: As described in Section 7.2.4, the emissions factors assigned to plants and fuels may require additional hands-on adjustment at the technology and state level to achieve state level emissions calibration. For power plant emissions factors, the eGRID data mining

[18] Underlined worksheets correspond to actual “smart” load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

utility is limited in its current ability to assign emission limits to specific generating units versus entire plants. This is driven by the way the data are collected and reported in the eGRID database. Similarly, regional average sulfur and mercury emissions factors were assigned that may not sufficiently reflect the specific fuels used at the state and plant level. A detailed review of model behavior for the states and plants of interest is recommended.

Emissions reduction retrofits: As described in Section 7.2.4, a scrubber retrofit option for existing power plants has been developed. Most of the coal plants in the region will be forced to retrofit to some new environmental constraint or change in the economics of continuing with their current approach. Additional retrofit options for mercury and NOx and the interaction among control technologies are recommended.

Emissions constraints: Because the model region is a subset of the SO2 cap and trade region, the model is limited in representing responses to emissions limits. Along the same lines as discussed regarding electricity trade, the model needs a way to introduce outside influences, e.g., SO2 allowance prices, etc., to let it react to the "rest-of-the-world." If time and resources allow, this can be introduced in the form supply or demand curves allowing the model to see more than a single static valuation of the constraint.

Peak representation and time slices: The model currently represents electricity load in six time slices – three seasons and day/night – as has been the MARKAL standard. This approach is severely limited in its ability to let the model economically build peaking and intermediate duty technology (i.e., gas turbines). This is due to the large number of hours of load aggregated to represent a time slice. In the NE-9 framework, a 9 time slice version of the model was developed, adjusting the power sector characterization and the individual service demand load curves accordingly. However, the resulting model only improved this situation slightly and implies a need for 12 slices (or more) to be tried. Such "dicing" of the load will be important to allow for analysis of critical ozone days. This refinement is beyond the scope of the current project but should be given serious consideration in future model refinements. At present, state-level constraints forcing minimum gas generation at historical shares and a cross-region constraint forcing minimum generation at AEO2006 levels are used to maintain gas plant operation for peaking.

7. Resource Supply, Trade, and Upstream

7.1 Fossil Fuels

There is no indigenous fossil resource in New England, and so in NE-MARKAL a single fixed-price resource cost taken from AEO2006 was used.

As the model was expanded to the Northeast and Mid-Atlantic states, there are some indigenous resource supplies (particularly coal). However, it was decided that the NE-MARKAL approach should be continued, since the influence of regional policy on national market prices will continue to be minimal. In principle, coal production supply curves could be drawn from NEMS supply curves for the northern Appalachian region and apportioned to the state level. However, coal is traded nationally based on price, as well as short and long-term contracts. Representing this trade would require tight user constraints to fix the ratio of in-region production consumed versus exported, increasing model complexity without adding meaningful analysis options; or integrating into a compatible model of the entire US energy system.[19]

Accordingly, the region is modeled as a price taker. Imports of fossil resources and refined petroleum products are available in unlimited amounts at AEO2006 reference case sector delivered prices.[20] This approach has the drawback of permitting unlimited fuel switching with no cost penalty, and inhibiting partial uptake of fuels as they compete on a unit cost basis. One potential area for model improvement would be the estimation of supply curves to add cost penalties once consumption rises significantly above AEO levels.

Available coal types have been simplified from the forty-plus types NEMS tracks to Appalachian, western, and imported coals. Sulfur and mercury content are taken from the NEMS EMM database, and weighted averages for NE-12 coal types calculated using 2002 coal consumption by NEMS type. Carbon emissions[21] for all fuels are tracked by sector based on the carbon content of fuels.

7.2 Other Fuels

Cost curves for delivery of centralized and decentralized hydrogen are taken from an Argonne National Lab report.[22] Nuclear fuel costs are taken from NEMS.

7.3 Renewables

Renewable resources are indigenous to each state, and supply data for renewables have been modeled in the same manner as was developed for NE-MARKAL.

7.3.1 Wind Resources

Wind is potentially an important generation option for the northeast states, so NE-MARKAL includes a robust representation of wind in the model. The National Renewable Energy Laboratory (NREL) provided NESCAUM with wind potentials for on-shore and off-shore resources and as a function of wind class (3 through 7) and distance from grid transmission lines. NREL processed their standard state-level wind resource maps and transmission line data from PowerMap[23] for lines between 69 - 345 kV buffered to identify raw wind resource potential for 0-5, 5-10, 10-20, and >20 mile distance bands. The standard environmental, land use and other exclusion criteria were then applied to the data to produce a developable resource potential. These criteria are provided in Table 9.

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[19] A 9-census region nation model is under development by EPA Office of Research and Development, with contributions by the IRG MARKAL team, which could provide such a framework.

[20] AEO2006 Supplemental Tables 11 and 12 and PMMRPT file.

[21] Carbon emission factor data from EIA, *Emissions of Greenhouse Gases in the United States 2002*, Report #: DOE/EIA-0573(2002).

[22] Hydrogen Demand, Production, and Cost by Region to 2050, Argonne National Laboratory and TA Engineering, ANL/ESD/05-2.

[23] Platts - Dec 2006 update.

Table 9: Criteria for Defining Available Windy Land (numbered in the order they are applied):

Environmental Criteria	*Data/Comments:*
2) 100% exclusion of National Park Service and Fish and Wildlife Service managed lands	USGS Federal and Indian Lands shapefile, Jan 2005
3) 100% exclusion of federal lands designated as park, wilderness, wilderness study area, national monument, national battlefield, recreation area, national conservation area, wildlife refuge, wildlife area, wild and scenic river or inventoried roadless area.	USGS Federal and Indian Lands shapefile, Jan 2005
4) 100% exclusion of state and private lands equivalent to criteria 2 and 3, where GIS data are available.	State/GAP land stewardship data management status 1, from Conservation Biology Institute Protected Lands database, 2004
8) 50% exclusion of remaining USDA Forest Service (FS) lands (incl. National Grasslands)	USGS Federal and Indian Lands shapefile, Jan 2005
9) 50% exclusion of remaining Dept. of Defense lands	USGS Federal and Indian Lands shapefile, Jan 2005
10) 50% exclusion of state forest land, where GIS data are available	State/GAP land stewardship data management status 2, from Conservation Biology Institute Protected Lands database, 2004
Land Use Criteria	
5) 100% exclusion of airfields, urban, wetland and water areas.	USGS North America Land Use Land Cover (LULC), version 2.0, 1993; ESRI airports and airfields (2003)
11) 50% exclusion of non-ridgecrest forest	Ridge-crest areas defined using a terrain definition script, overlaid with USGS LULC data screened for the forest categories.
Other Criteria	
1) Exclude areas of slope > 20%	Derived from elevation data used in the wind resource model.
6) 100% exclude 3 km surrounding criteria 2-5 (except water)	Merged datasets and buffer 3 km
7) Exclude resource areas that do not meet a density of 5 km^2 of class 3 or better resource within the surrounding 100 km^2 area.	Focalsum function of class 3+ areas (not applied to 1987 PNL resource data)
Note - 50% exclusions are not cumulative. If an area is non-ridgecrest forest on FS land, it is just excluded at the 50% level one time.	

These developable wind resource data were converted into state-level upper resource bounds for eight distinct wind technologies. These technologies and some indicative data are shown in Table 10. Onshore-1 corresponds to less than 20 miles to a 68 kV or higher transmission line, and the cost of this technology was based on a recent assessment of wind farm costs compiled by Navigant Consulting[24] and used in the RGGI IPM analysis. Onshore-2 corresponds to greater than 20 miles to a high voltage transmission line and imposes an incremental investment cost on the wind technology based on the transmission line cost for an average 50 mile line length. Offshore-1 corresponds to 5 to 20 nm from shore (note, there is

[24] "New Jersey Renewable Energy Market Assessment," Navigant Consulting, August 2004.

a 100% exclusion for 0 to 5 nm from shore), and Offshore-2 corresponds to 20 to 100 nm from shore. The investment cost for the Offshore-2 wind technologies also contains an incremental transmission line cost. Note that there is no developable wind resource in the District of Colombia.

Table 10: Wind Resource Data

No.	Type	Wind Class	Base Year Investment Cost	Resource Upper Bound in 2020 (MW)										
				CT	MA	ME	NH	RI	VT	NJ	NY	PA	DE	MD
1	Onshore -1	4-5	1268	51	570	1,710	587	30	1,374	83	1,553	970	22	606
2	Onshore -1	6-7	1532	0	123	720	149	0	0	0	30	1	0	39
3	Onshore -2	4-5	1268	0	32	716	117	0	366	0	121	38	0	5
4	Onshore -2	6-7	1532	0	10	193	16	0	0	0	1.4	0	0	0
5	Offshore -1	4-5	2006	223	717	793	173	304	0	2,791	5,282	980	754	1,266
6	Offshore -1	6-7	2270	0	0	0	0	0	0	68	39	0	268	189
7	Offshore -2	4-5	2006	0	10,612	8,647	194	1,345	0	2,065	4,377	0	95	240
8	Offshore -2	6-7	2270	0	48,733	9,142	103	3,823	0	21,715	19,470	0	1,020	9,313

Capacity factor data for each wind technology were derived at the census division level from NEMS data and used for each at the state level. Growth constraints of 10% per year and hurdle rates of 25% were added to represent siting, financing, and other considerations expected to slow penetration of wind in the reference case. These may need to be relaxed or reconsidered in policy analysis cases.

7.3.2 PV Capacity Factors

For solar photovoltaic (PV) systems, the technical potential of the resource is theoretically tremendous, and thus does not provide a meaningful limit on the amount of resource that can be used. Rather the capacity factor for PV systems is the most meaningful parameter affecting performance, and thereby adoption. These were provided by NREL for each day/season time slice, and are shown in Table 11 for central PV systems for grid electricity generation. This technology was assumed to use one-axis tracking. Two other PV technologies were developed – for residential rooftops and commercial rooftops – and have capacity factors based on a fixed tilt orientation.

Table 11: Capacity Factors for Central Solar PV Systems

Region	AF(Z)(Y)~ID	AF(Z)(Y)~IN	AF(Z)(Y)~SD	AF(Z)(Y)~SN	AF(Z)(Y)~WD	AF(Z)(Y)~WN
CT	0.333	0.000	0.423	0.000	0.219	0.000
MA	0.340	0.000	0.443	0.001	0.224	0.000
ME	0.345	0.000	0.444	0.001	0.234	0.000
NH	0.333	0.000	0.434	0.001	0.232	0.000
RI	0.341	0.000	0.454	0.000	0.223	0.000
VT	0.322	0.000	0.437	0.001	0.200	0.000

NJ	0.334	0.001	0.411	0.008	0.226	0.000
NY	0.316	0.002	0.418	0.011	0.205	0.000
PA	0.329	0.003	0.415	0.011	0.209	0.000
DC	0.346	0.002	0.417	0.011	0.241	0.000
DE	0.346	0.002	0.418	0.010	0.239	0.000
MD	0.345	0.002	0.417	0.010	0.240	0.000

The principal constraint on PV systems is the growth rate that the industry can sustain over time. Thus, each PV technology contains an annual growth rate constraint. Based on historical growth rates, these were set at 10%, 20%, and 30% respectively for central, commercial, and residential PV technologies.

7.3.3 Biomass Resources

Oak Ridge National Laboratory (ORNL) has estimated the availability and delivered price of six types of biomass resources for the US.[25] For agricultural residues, the delivered price includes the cost of collecting the residues, the premium paid to farmers to encourage participation, and transportation costs. For NE-12, the values are all reported in trillion BTU and the costs have been updated to Yr 2002 dollars.

The workbook, NE-12 MARKAL Biomass Resource Data-tBTU.xls, contains the basic quality estimates in dry tons per year, applies availability estimates for each category as estimated by ORNL, and uses the lower heating value for each biomass type to determine the resource potential for each state. Woody biomass and agricultural wastes were combined as one aggregated biomass resource, as the technology differences for application of these two biomass types are not great.

Four biomass resource supply steps were developed for each state, corresponding to each price step in the ORNL data. The first three price steps start in 2002, as they correspond to existing supplies of forest and urban wood waste residues. The final step corresponds to energy crops, which ORNL assumed are available by 2010. The final step was constructed such that half the potential energy crop supply is available in 2008, and the full energy crop potential is available in 2011.

The resulting aggregated biomass resources by state are shown in the Table 12. It can be seen that Pennsylvania and New York contain significant biomass resource potential compared to the other nine states.

We have adjusted the state bounds in two cases to account for interstate biomass trade. First, following the IPM RGGI analysis, we have assigned some of New York's supply to Connecticut. Second, no biomass resource for the District of Columbia (DC) was estimated in the ORNL study, so we have made 30% of Maryland's resource available to DC and subtracted 10% from Maryland's, assuming that DC is receiving supplies from both Maryland and Virginia.

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[25] "Biomass Feedstock Availability in the United States: 1999 State Level Analysis," Marie E. Walsh, Robert L. Perlack, Anthony Turhollow, Daniel de la Torre Ugarte, Denny A. Becker, Robin L. Grahama, Stephen E. Slinsky, and Daryll E. Ray (updated January 2000).

Table 12: NE-12 Biomass Resource Supply (tBTU/yr) at Four Cost Levels- Yr 2002 dollars

Cost (M$/tBTU)	1.54	2.31	3.34	4.17
Connecticut	3.41	5.67	2.86	6.37
Maine	31.09	18.16	5.19	8.86
Massachusetts	5.79	7.17	1.21	5.32
New Hampshire	5.32	1.84	10.88	1.92
Rhode Island	0.41	0.70	0.10	0.38
Vermont	0.56	4.85	1.67	6.57
Delaware	0.54	0.77	1.95	5.06
Maryland	2.54	4.20	6.06	15.96
New Jersey	5.37	4.66	1.11	2.35
New York	16.12	28.47	6.37	55.53
Pennsylvania	7.89	22.54	9.96	65.69

Most of the increase at $50/dry ton is due to energy crops, which the ORNL data assume is all switchgrass because of its higher productivity. However, this may not be the best assumption for the six New England states. The ORNL methodology assumes that agricultural lands are used for energy crops, and it factors in competition between food production and energy crops. It discounts marginal or unused lands, such as interstate highway medians, which are not traditional crop lands. Therefore, these supply data underestimate the energy crop potential, especially for New England, which does not have much surplus agricultural land, but does have marginal lands suited for poplar and other energy crops. This issue should be addressed at a future date.

This biomass resource, as estimated by ORNL, was unable to meet base year consumption of biomass in all sectors in several states, as reported in SEDS data. It is unclear why this inconsistency exists. It could be that biomass is traded across state lines. Such trade is currently unrepresented in the model. It could also be that the ORNL data do not cover residential wood consumption, but only industrial and energy generation scale use. Under this latter assumption, a separate category of biomass supply, Biomass Residential Wood, was created that is available to serve residential demand only. Growth of this demand is tightly controlled and wood does not compete meaningfully with other fuels. This resource was made available across the model horizon at twice base year consumption levels.

Review of the RGGI IPM analysis input assumptions shows an apparently different interpretation of this same ORNL data. The differences remain to be investigated.

Biomass pulping liquor supplies for industrial consumption were taken NEMS projections and shared to states using 2002 SEDS consumption data.

7.3.4 Landfill Gas Resources

Landfill gas resource availability and technology characteristics were taken from the work performed for the RGGI Working Group and Stakeholders.[26] The state-level potentials are provided in Table 13 and were used to develop upper bounds for the two types of landfill gas systems shown in the table. The reference also provided technology characteristics for the two technologies.

Table 13: Landfill Gas Resource Potential (MW)

State	LFG – with Collection System (MW)				LFG – without Collection System (MW)			
	2005	2010	2015	2020	2005	2010	2015	2020
CT	2.6	12	14	16.3	0	3.9	4.4	5.2
MA	4.3	19.9	23.2	27	0	4.6	5.4	6.3
ME	1.1	4.9	5.8	6.7	0	1.3	1.5	1.8
NH	2.1	9.8	11.4	13.4	0	0	0	0
RI	0.7	3.2	3.8	4.4	0	0	0	0
VT	0.1	0.3	0.4	0.4	0	5.5	6.4	7.5
NY	17.4	81	94.5	110.3	0	7.9	9.3	10.8
NJ	31.7	147.7	172.4	201.2	0	8.8	10.3	12
PA	26.7	124.6	145.3	169.6	0	3	3.5	4.1
DE	7.4	34.4	40.1	46.8	0	20.9	24.4	28.5
MD	3.6	16.7	19.5	22.8	0	0	0	0
Total	**97.4**	**454.4**	**530.4**	**618.9**	**0**	**55.9**	**65.2**	**76.1**

7.3.5 Municipal Solid Waste Supplies

MSW supplies by state were taken from amounts of MSW generated and percentage available to energy production estimated by BioCycle.[27] Supplies of wood waste[28] were added to this value.

7.3.6 Small Hydropower Resources

The resource potential for small hydropower (SHP) plants was based on a report from the Idaho National Engineering Laboratory[29] and is presented in Table 14. Note that Delaware and the District of Colombia have no hydropower resources. The technology characterization data were based the range of high and low costs as reported to the RGGI Working Group and Stakeholders.[26]

[26] Assumption Development Document: Regional Greenhouse Gas Initiative Analysis, Prepared by ICF Consulting for Regional Greenhouse Gas Initiative (RGGI) Staff Working Group and Stakeholders, August 2006.

[27] BioCycle, The State of Garbage in America, April 2006, www.p2pays.org/ref/22/21411.pdf

[28] Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

[29] U.S. Hydropower Resource Assessment, Idaho National Engineering Laboratory, Renewable Energy Products Department, July 1995.

Table 14: Small Hydropower Resource Potential (MW)

	CT	MA	ME	NH	RI	VT	NJ	NY	PA	MD
Generic Impoundment Hydropower	24	77	815	26	10	162	5	657	292	32
Generic Run-of-River Hydropower	19	56	227	7	1	12	4	652	411	0

7.3.7 Production Tax Credit

As part of the REMAP analysis, the federal production tax credit (PTC) for wind, biomass, and landfill gas was added to the model. This provides a 10-year credit for facilities put in place by 2007 (2008 model year in NE-12). Adding the PTC required triplicating the eligible technologies to track vintage for plants purchased in 2005, 2008, and 2011 or later. The PTC is presently assumed not to be renewed after 2007.

7.3.8 State Renewable Portfolio Standards

Existing state renewable portfolio standards (RPS) requirements were added, as modeled by the RGGI IPM analysis, which simplified the standards to represent the percentage of generation to be met by new renewable plants. The standards are listed in Table 15.

Table 15: State RPS standards

	Percentage of Load Required			
State Program	**2005**	**2010**	**2015**	**2020**
CT Class 1	0.78%	6.05%	6.09%	6.12%
NJ- Class 1 Main Tier	0.00%	3.22%	5.55%	7.88%
NY- Main Tier		4.05%	6.43%	6.43%
PA - Tier 1 Main Tier		1.13%	3.02%	4.19%
MA	0.55%	2.72%	4.89%	7.06%
RI	0.00%	2.49%	7.97%	13.94%
MD Tier 1		1.58%	3.14%	5.04%
NJ- Solar Tier (PV only)	0.01%	0.20%	0.41%	0.62%
PA - Solar Tier (PV only)	0.00%	0.01%	0.24%	0.49%

The implementation represents the standards as they are on the books, without adjustment for how they might be met or fail to be met on the ground.

7.4 Refineries

A similar issue exists for in-region refineries as for in-region fossil resource production. For NE-12, the technology characterizations for PADD-I could be used, with state level refinery capacity data from EIA's Petroleum Supply Annual to establish the RESIDs for existing capacity. BOUNDs would be used to restrict future capacity additions to existing sites.

However, because in-region produced fuels could not meaningfully compete with the unlimited imports available under our price taker assumption for the region, adding refinery production plus UCs to control their output adds model complexity without adding additional analysis capability. Therefore, dummy demand technologies have been added to track refinery energy consumption and corresponding emissions at AEO 2006 levels, but the refinery products simply considered as imports regardless of whether or not they might have originated within the region.

7.5 ANSWER load workbook

ANSWER Load data for the resource supply, trade, and upstream sectors are contained in one "Smart"[30] workbook. The workbook currently contains 25 worksheets, and a description of each sheet is provided below:

- **ANSv6.1-Home –** This sheet defines the Answer template region handling and version.
- **Assumptions –** Provides energy carrier names, descriptions, data sources and other assumptions.
- **data-AEOsup –** Data from AEO Tables 11 and 12: Energy Prices by Sector and Source.
- **data-PMMRPT –** Data on delivery process for refined petroleum products from NEMS report PMMRPT.
- **data-AEO T93 –** Data from AEO Supplementary Table 93: Domestic Coal Supply, Disposition, and Prices.
- **Commodities** – Definition of all energy carriers and emissions.
- **Technologies –** Definition of all resource supply and transfer technologies along with and dummy supply (for debug) technologies and all renewable energy conversion technologies.
- **TechData_Sources –** Model input data for all resource supplies and transfer technologies.
- **data-H2** – Data on delivered hydrogen costs in the new England and Mid-Atlantic Regions by metropolitan and non-metropolitan areas.
- **data-biodsl –** Data on bio-diesel supply costs.
- **data-EMM del coal –** Data from the coal detailed delivery report from EMM database on NEMS.
- **data-Sulfur –** Data and worksheet to calculate the average sulfur content in coal delivered to each region.
- **data-biomass –** Biomass resource data and costs from ORNL report.
- **data-NUC –** Data and worksheet to calculate nuclear fuel costs.
- **data-emissions –** Data and worksheet to calculate CO2 emission factors.
- **data-refineries –** Data and worksheet to calculate energy consumption in refineries.
- **data-scrubber retrofits –** Data from NEMS used to calculate the cost of retrofits of stack scrubbers on power plants.
- **Commodity_Data –** Characteristics for commodities, such as energy carriers and tax credits.

[30] Underlined worksheets correspond to actual "smart" load sheets handled by ANSWER, permitting quality control to be done in the workbook via CheckSheet, and use of Import Model Data from Excel to directly load the model data into the ANSWER database.

- **TechData_RETechs** – Model input data for all renewable energy conversion technologies.
- **REtech-data –** Worksheet derived from NE-MARKAL but updated and used to calculate characteristics for all renewable energy technologies.
- **bound-data –** Worksheet to calculate upper bounds for all renewable energy technologies.
- **RGGI –** Data from the RGGI 2006 9-State Package Scenario Emission Caps and Offsets. (Not presently used.)
- **Constraints –** Definition of user constraints for residential sector fuel use shares and advanced technology shares.
- **Constr_Data –** Model input data for the residential user constraints in each state.
- **Conv –** A list of conversion factors for use in the various data sheets.

7.6 Areas for Improvement

The following are potential areas for improvement in the supply sector.

Fossil fuel supply steps: Better information on the costs of expanding the electricity grid would allow for improved representation of the possibilities for increasing electricity trade.

Fossil fuel supply steps: Although we cannot model the national fuels market in the absence of modeling supply and demand in the rest of the country, having no cost penalty for fuel switching seems too extreme a simplification. Methods for development of additional cost steps will be considered as NE-12 is developed.

Biomass supply: Review differences between ORNL, SEDS, and RGGI analysis data and conduct sensitivity analysis.

8. Model Calibration, Reference Case, and REMAP Runs

Model results have been compared to SEDS data for 2002, using the NE-12_Calibration_v4.xls workbook provided to NESCAUM. End use consumption in the commercial, residential, and industrial sectors, which were built from SEDS data, matches the historical results precisely. As described in Section 6, because the transportation sector was developed from other data, it does not match SEDS precisely. In the electricity sector, total generation at the state level is within 2% of historical data. The fuel mix for generation is somewhat less precise, owing to the behavior of individual plants, the representation of oil/gas flexible plants, emission requirements, and other local factors that may not be sufficiently represented in the model. As discussed in Section 7, the framework will allow an examination of individual plant behavior and emissions results to calibrate these results more closely if desired.

The initial reference case was guided using AEO regional results. In general, model results are currently within 10% of AEO results. The Excel workbook NE-12_Reference_v.1.1.xls provided to NESCAUM will enable further comparison and analysis.

8.1 User Constraints for Calibration

As described in Sections 3-7, user constraints were added as needed to slow fuel and technology switching and represent real-world constraints beyond the model's scope. Among these are these constraints:

Demand sectors: Constraints limit fuel switching, technology type switching, and advanced technology penetration are provided for all demand sectors. Relaxation rates for these constraints are under user control on the respective templates and in general allow for increased flexibility to switch over time.

Gas-fired generation constraints: As described in Section 7.5, state-level and cross-region constraints are needed to force gas plant capacity addition and operation in the absence of adequate peak representation. In a twelve-plus time slice version of the model, these constraints may be reduced or unnecessary.

Renewable penetration: Renewable technologies are often over-attractive to MARKAL because they have low or zero fuel costs. To represent siting, financing, and other factors expected to slow renewable penetration in the reference case, a hurdle rate of 25% was added to all renewable technologies. In addition, growth constraints were added for some technologies. The current values are shown in Table 16 below. (Values may change as analysis proceeds.)

Emissions other than CO2 remain to be calibrated. A 2002 emissions inventory covering the entire region will be needed for calibration.

Table 16: Constraints on Renewables

Technology	GROWTH rate	DISCRATE	Comments
Hydro	1%	25%	Hydro technologies are very attractive on a cost basis to MARKAL, but AEO projects almost zero increase in hydro capacity
Wind	10%	25%	
Biomass		25%	
MSW, landfill gas		25%	
Solar PV	10, 20, 30%	25%	GROWTH rates for centralized, commercial, and residential, respectively

8.2 REMAP analysis

The NE-9 model was run as part of the joint DOE-EPA Renewables and Energy Efficiency Modeling and Analysis Partnership (REMAP) model comparison exercise. Several different energy models, including NEMS, IPM, HAIKU, and WinDS, participated in this project to compare model structure, assumptions, and results for renewables modeling.

The first round of runs compared model results for reference case and two renewable portfolio standard policies, one reaching 20% by 2025 and the other 10% by 2025. Models showed substantially different renewable mixes for achieving these targets, with NE-9 within the range of variation. A second round standardized input assumptions in the models to AEO 2006 assumptions. Because NE-9/12 was built from AEO 2006 data, many of these assumptions were already in use; however, the new assumptions resulted in approximately 50% greater biomass availability. Again, NE-9 RPS costs were within the range of variation of the participating models. Generation and capacity results showed a regional pattern of resource utilization, particularly a much higher fraction of biomass use to meet the RPS than national average results. The comparison of the first and second rounds showed that RPS compliance costs were highly sensitive to assumptions about biomass resource and price, suggesting that this is an important area for further analysis.

9. Recommended Improvements

While NE-12 in its current form can serve as an adequate comprehensive model framework for examining energy and environmental issues for the states in the region, by definition a model needs to be a living entity that is subject to ongoing improvement, expansion, and evolution. The most important areas for improvement described in Sections 3-8 are summarized below:

- Simplify demand sectors;
- Move to twelve season/time of day time slices;
- Add capability to model existing power plant retirements and life extension;
- Review and calibrate power sector emissions data and develop characterization of emissions constraints, and the evaluation of the need for additional emissions reduction options;
- Obtain better data on the costs of expanding the inter-state electricity grids;
- Review and revise biomass resource data after reviewing ORNL and IPM-RGGI data and conduct sensitivity analysis, and
- Add additional supply steps with higher costs in order to model the costs of fuel switching.

Appendix A: Naming Conventions

This section documents the naming convention guidelines that are used in this ANSWER-based NE-12 MARKAL model.

A.1 Demand sectors

The four major demand sectors use the following names.

- Commercial (COM)
- Industrial (IND)
- Residential (RES)
- Transportation (TRN)

The sub-sectors in each of these sectors begin with the first letter of the sector name, and the next two to four characters identify the various end-use services within the sector.

A.2 Energy and Material Carriers

The names for the core energy carriers and materials employed in the model are listed in Table 17.

Table 17: Core Names of Energy and Material Carriers

Core Name(s)	Resource
ASP	Asphalt
AVG	Aviation gasoline
BPL	Biomass Pulping Liquor
BRW	Biomass – Residential Wood
BWD	Biomass – Wood and Ag waste
COA	Coal
COK	Coke
CNG	Compressed Natural Gas
DSL	Diesel Fuel & Heating Oil
ELC	Electricity
ETH	Ethanol
GSL	Gasoline
HYD	Hydropower
HYG	Hydrogen
JTF	Jet Fuel
KER	Kerosene
LPG	Liquid Petroleum Gas
LTH	Heat
MET	Methanol
MSW	Municipal Solid Waste
NGA	Natural Gas
NUC	Nuclear Fuel
OPP	Other Petroleum Products
PFS	Petrochemical Feedstocks
RFO	Residual Fuel Oil
SOL	Solar
WND	Wind

A.3 Technology Names and Descriptions

The 10-character technology names are subdivided according to the rules defined in Table 18.

Table 18: Recommended Naming Convention for Process, Conversion and Demand Technologies

Technology Type	Designators for character sectors			
	1st Group: 1 or 2 characters	2nd Group: 2-3 characters	3rd Group: 2 to 8 characters	Final Group: 2 or 3 characters
Individual Conversion Technologies	E for electric only or CHP plants		4-8-character sequencing number for existing power plants pulled from the EIA860 or NEMS database	
Aggregated Conversion Technologies	EE for electric only power plants EH for CHP plants H for Heating plants	State	3-5-character user-chosen descriptor (e.g., IGC, AFB)	

	(no electric output)			
Transport, Upstream & Accounting	X	3-character name for the sector the fuel is directed to, or the input fuel	3-character name for core energy carrier for sector fuels, or the output fuel	
End-Use Technologies	C for Commercial I for Industrial R for residential T for Transportation	2-character sub-sector descriptor (e.g., space cooling/heating = SC/SH)	2 or 3 character descriptor for the demand technology	2-character vintage corresponding to the year in which the technology is first available (00 for 2000, 05 for 2005, etc.) or <type> designator as discussed below

For technologies where vintages (year first available to the model) are not important, an alternative approach is used employing a <type> final designator with preliminary values as follows:

E – Existing tech (used for RESID only), and
N – New technologies.

A.4 Emission Names

The recommended names for emission commodities in NE-12 consist of a lead group of three characters designating the emission name followed by a second group of three characters for the sectoral breakdown, as shown in Table 19. This grouping is selected to allow natural sorting of emissions from all sectors for each emission type.

Table 19: Recommended Emission Names

Commodity	**Designators for Character Sectors**	
	1st Group: 3 characters	2nd Group: 3 characters
Emission	CO2 = Carbon dioxide CH4 = Methane HG = Mercury NOX = Nitric oxides P10 = Particulates < 10 microns SO2 = Sulfur dioxide	3-character descriptor corresponding to the demand sector

A.5 User-defined Constraints

User constraints fall into two general categories, absolute and share limits. Absolute and share constraints in the industrial sector follow the naming convention as summarized in Table 20.

Table 20: Naming Convention for Used-defined Constraints

User-defined Constraint	**Designators for Character Sectors**			
	1st and 2nd characters	3rd to 5th characters	6th up to 8th characters	Final 2-3 characters
Absolute Share	A_ S_	1 to 3-character descriptor corresponding to • the energy carrier	2 to 5 character descriptor for the constraint or commodity/technology	2-character vintage corresponding to the year in which the constraint is

		involved, or • the demand sub-sector(s)	involved	applied (if applicable)
Share in COM, RES, and TRN	1 character for sector (C, R, or T)	1-2 characters for demand subsector, followed by underscore	F for fuel or T for tech type L for lower or U for upper followed by underscore	3 characters for fuel or technology type

A.6 Description Guidelines

In addition to accessing and sorting model information (input data and case results) according to the component names, ANSWER[31] and VEDA-BE also allows the user to access and sort information according to descriptions of the various commodities and technologies of the RES.

This feature is most useful for filtering technologies, and the basic approach employed is that the description, which is limited to 100 characters, is divided into various components. Examples of the various description components are provided below. Each of the main components of the description should be separated by periods (.).

1. Short technology descriptor followed by a colon, such as
   - CONV REFINERY:
   - STEAM PP:
   - LIGHT TRUCK:
2. The year of availability, such as
   - EXISTING for all existing technologies (with RESIDs)
   - (.05.) for 2005
3. The category of technology, that is Conventional Fuel Vehicles (.CFV.) or Alternative Fuel Vehicles (.AFV.);
4. The main fuel consumed, such as (.DSL.) for diesel, sans any sector designation;
5. The efficiency that is standard (.STD.) or improved according to the Corporate Average Fuel Economy norms (.CAFE.), or some other standard;
6. Other particularities, like the size of the cars (.COMPACT.) or the detail of the CAFE norms, which can be standards (.STD.) or more efficient in terms of miles per gallon (.7.0MPG.), and
7. Any other descriptive information desired.

[31] A new “TechFilter” is has been to ANSWER as part of ADRATIO RATRULE that allows technology selection based upon short name/description masks, set membership, and input/output commodity. NE-12 names and descriptions have been designed to make extensive use of this feature.