Documentation of the Applied Dynamic Analysis of the Global Economy (ADAGE) Model

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ABSTRACT

This paper documents the *Applied Dynamic Analysis of the Global Economy* (ADAGE) model. ADAGE is a dynamic computable general equilibrium (CGE) model capable of examining many types of economic, energy, environmental, climate-change mitigation, and trade policies at the international, national, U.S. regional, and U.S. state levels. To investigate policy effects, the CGE model combines a consistent theoretical structure with economic data covering all interactions among businesses and households. A classical Arrow-Debreu general equilibrium framework is used to describe economic behaviors of these agents.

ADAGE has three distinct modules: *International*, *US Regional*, and *Single Country*. Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure. This internally consistent, integrated framework allows its components to use relevant policy findings from other modules with broader geographic coverage, thus obtaining detailed regional and state-level results that incorporate international impacts of policies. Economic data in ADAGE come from the GTAP and IMPLAN databases, and energy data and various growth forecasts come from the International Energy Agency and Energy Information Administration of the U.S. Department of Energy. Emissions estimates and associated abatement costs for six types of greenhouse gases (GHG) are also included in the model.

This paper describes features of the ADAGE model in detail. It covers the economic theory underlying firm and household behavior, the specific equations and parameter estimates used in the model, and the dynamics that control transition paths from the model's baseline economic-growth path to new economic equilibria in the presence of policies. The paper also discusses data sources used in ADAGE and presents baseline estimates of economic growth, energy production and consumption, and GHG emissions.

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1. THE ADAGE MODEL: OVERVIEW

RTI International's (RTI's) *Applied Dynamic Analysis of the Global Economy* (ADAGE) model is a dynamic computable general equilibrium (CGE) model capable of examining a wide range of economic policies and estimating how all parts of an economy will respond over time to policy announcements. Among the feasible set of policies are many types of economic, energy, environmental, and trade policies that can be investigated at the international, national, U.S. regional, and U.S. state levels.[1] Of particular note is the ability of the ADAGE model to investigate climate-change mitigation policy issues affecting six types of greenhouse gases (GHG) at a range of geographic scales.

To investigate implications of policies, the ADAGE model combines a consistent theoretical structure with observed economic data covering all interactions among businesses and households. These economic linkages include firms purchasing material inputs from other businesses and factors of production (labor, capital, and natural resources) from households to produce goods, households receiving income from factor sales and buying goods from firms, and trade flows among regions. Nested constant-elasticity-of-substitution (CES) equations are used to characterize firm and household behaviors (which are intended to maximize profits and welfare, respectively), as well as options for technological improvements.

ADAGE uses a classical Arrow-Debreu general equilibrium framework to describe these features of the economy. Households are assumed to have perfect foresight and maximize their welfare (received from consumption of goods and leisure time) subject to budget constraints across all years in the model horizon, while firms maximize profits subject to technology constraints. Economic data in ADAGE come from the GTAP[2] and IMPLAN[3] databases, and energy data and various growth forecasts come from the International Energy Agency (IEA) and Energy Information Administration (EIA) of the U.S. Department of Energy.

ADAGE is composed of three modules: "*International*," "*US Regional*," and "*Single Country*." Each module relies on different data sources and has a different geographic scope, but all

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[1]RTI gratefully acknowledges partial funding of model development related to regional U.S. policies by the U.S. Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS). The OAQPS model was developed for analysis of nonclimate-related environmental policies under the name "EMPAX-CGE" (see Ross et al. [2004]). ADAGE relies on different data, assumptions, and model structure and is suitable for climate-change mitigation analyses at multiple levels of geographic disaggregation. All international and climate-related model development has been funded by RTI International. Development of state-level modeling capabilities has been largely being funded by the Pew Center on Global Climate Change. See http://www.pewclimate.org/ for information on their organization. Any opinions expressed in ADAGE policy analyses are those of the authors alone.

[2]See http://www.gtap.agecon.purdue.edu/ for information on the Global Trade Analysis Project.

[3]See http://www.implan.com/index.html for information on the Minnesota IMPLAN Group.

have the same theoretical structure. The internally consistent, integrated framework connecting ADAGE's modules allows its components to use relevant policy findings from other modules with broader geographic coverage. This allows the model to estimate detailed regional and state-level results that incorporate international impacts of policies, while avoiding computational issues that preclude solving for all U.S. states and world nations simultaneously.

ADAGE incorporates four sources of economic growth: (1) growth in the available effective labor supply from population growth and changes in labor productivity, (2) capital accumulation through savings and investment, (3) increases in stocks of natural resources, and (4) technological change from improvements in manufacturing and energy efficiency. By means of these factors, a baseline growth forecast is established for ADAGE using IEA and EIA forecasts for economic growth, industrial output, energy consumption and prices, and GHG emissions. Starting from the year 2005, ADAGE normally solves in 5-year time intervals along these forecast paths, which are extended into the future as necessary for each policy investigation.[4]

This paper describes these features of the ADAGE model in detail. Among the areas covered are the economic theory underlying firm and household behavior, the specific CES equations and parameter estimates used, distortions from the existing tax structure, and the dynamics that control transition paths from the expected baseline economic growth path to a new economic equilibria in the presence of a policy. The paper also discusses data sources used in ADAGE and shows baseline estimates of economic growth, energy consumption, and GHG emissions.

The ADAGE model description and data documentation provide a context against which model results can be interpreted. These results include, among others, estimates of the following:

- Hicksian equivalent variation (a metric used in economic analyses to describe overall policy effects, considering all impacts of changes in prices, income, and labor supply);
- gross domestic product (GDP), consumption, industry output, and changes in prices;
- employment impacts and changes in wage rates;
- capital earnings and real interest rates;
- investment decisions;
- input purchases and changes in production technologies of firms;
- flows of traded goods among regions;
- energy production and consumption by businesses and households; and

[4]Beyond the end of the model horizon (generally between 2050 and 2075), additional time periods are run to ensure that the model converges to a new steady-state equilibrium after a policy is imposed.

- fuel and GHG permit prices.

The rest of Section 1 gives an overview of CGE modeling in general and the broad structure of ADAGE in particular. Section 2 then provides additional details on the general-equilibrium theory, model structure, and parameter estimates that control economic behavior in the model. Section 3 discusses the dynamic processes in the model that control economic growth. Section 4 describes the economic data in the model and related assumptions about taxes and labor-supply decisions, while Section 5 covers energy data sources. Section 6 provides information on GHG emissions and the methods used to model emissions abatement costs. Finally, Section 7 illustrates how these model features interact to determine economic growth and presents tables covering data from the ADAGE model's baseline forecasts.

1.1 Overview of CGE Modeling

Typically, the theoretical foundations of CGE models are based on a Walrasian general equilibrium structure. As described by an Arrow-Debreu model (Arrow and Debreu, 1954; Arrow and Hahn, 1971), this includes components such as the following: households in the economy have an initial endowment of factors of production and a set of preferences for goods; business firms maximize profits and have constant- or decreasing-returns-to-scale production functions; market demands are the sum of all agents' demands and depend on prices; and an equilibrium solution is characterized by prices and production levels such that demand equals supply for all commodities, income equals expenditures, and production activities break even at solution prices in the model (for constant-returns-to-scale production).

Within this theoretical structure, CGE models capture all flows of goods and factors of production (labor, capital, and natural resources) in the economy. The "general equilibrium" nature of these models implies that all sectors in the economy must be in balance and all economic flows must be accounted for within the model. A simplified version of these circular flows in an economy is illustrated in Figure 1-1.[5] Households own factors of production and sell them to firms, which generates incomes for households. Firms produce output by combining productive factors with intermediate inputs of goods and services from other industries. Output of each industry is purchased by other industries or households using the income received from sales of factors. Goods and services can also be exported, and imported goods can be purchased from other countries. Capital flows among regions as they run trade deficits or surpluses. In aggregate, all markets must clear, meaning that supplies of commodities and factors of production must equal their demands, and the income of each household must equal its factor endowments plus any net transfers received.

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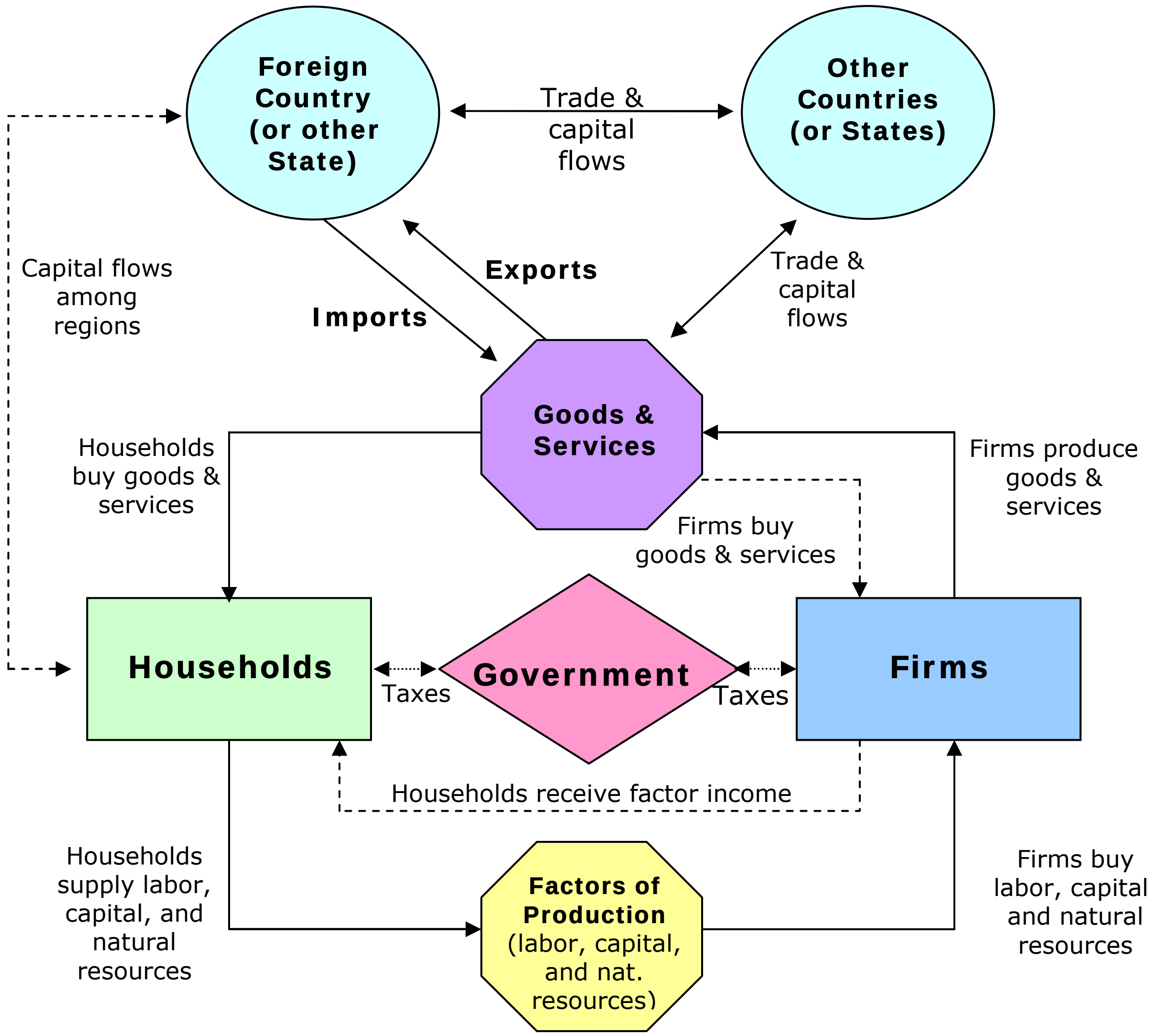
[5] Each foreign country, or state, also contains all the linkages among households, firms, and government shown in the figure.

Figure 1-1. Circular Economic Flows within CGE Models



Economic data specifying these circular flows are contained in a balanced social accounting matrix (SAM), which provides a baseline characterization of the economy that accounts for all interactions among agents in the economy (households, firms, government, and foreign countries). The SAM contains data on the value of output in each industry, payments for factors of production and intermediate input purchases by each industry, household income and consumption patterns, government purchases, investment, trade flows, and GHG emissions. These data reflect technologies currently used by firms to manufacture goods and households' preferences for consumption goods. The theoretical structure of the CGE model, along with its parameter estimates, then determines how production and consumption will change in response to new policies.

In this theoretical structure, households are assumed to maximize utility received from consumption of goods and services, subject to their budget constraints. CES functions are typically used to describe these utility functions, which show how willing and able households are to substitute among consumption goods in response to price changes. Firms are assumed to be perfectly competitive and maximize profits, which are the difference between revenues from sales and payments for factors of production and intermediate inputs. Profit maximization is done subject to constraints imposed by available production technologies, which are also typically specified using CES functions that describe how different types of inputs can be substituted for each other.[6] The extent of these substitutions is determined by elasticity parameters that control how easily trade-offs among inputs can be made.

To examine implications of climate-change mitigation policies, an additional constraint can be introduced into a CGE model that limits GHG emissions to a particular level. Based on this emissions cap, the model will estimate a shadow value on GHG emissions associated with the constraint, which can be interpreted as the price at which GHG allowances (or permits) would trade under a GHG cap-and-trade system. Allowance prices for a particular policy will be determined by emissions in the economy's baseline, the tightness of the cap, options for technological and energy-efficiency improvements, and the abilities and willingness of firms and households to switch into nonenergy goods.

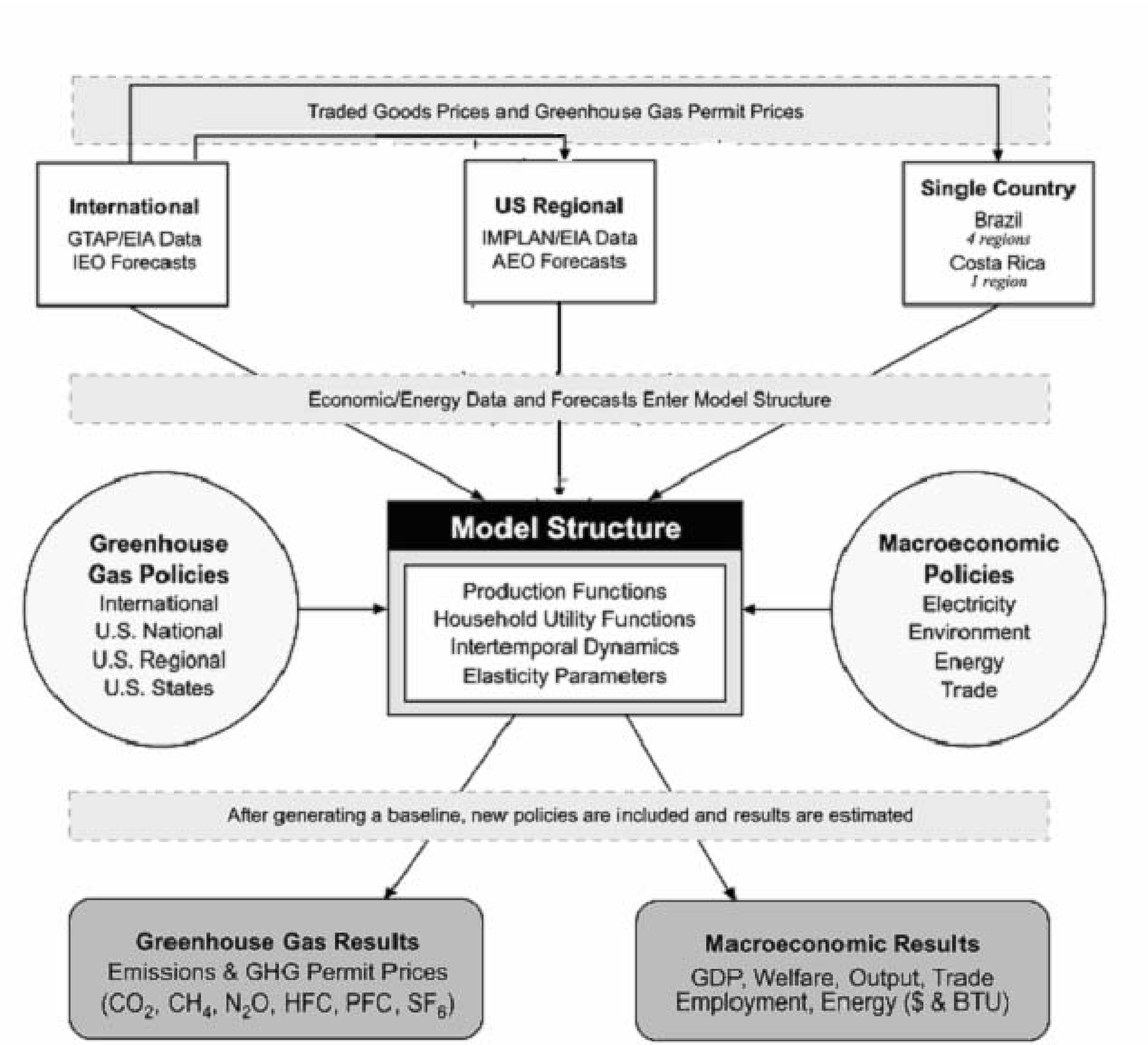
1.2 Components of the ADAGE Model

The ADAGE modeling system is composed of three modules: *International*, *US Regional*, and *Single Country.* As shown at the top of Figure 1-2, this framework begins with the *International* module. This component of ADAGE allows the model to conduct international policy investigations on any set of nations included in its database (within computational limits on the total number of regions in the model). After the data and forecasts enter the model structure, policies can be examined. From these studies, findings on prices of traded goods and, in the case of climate change mitigation policies, emissions permit prices can be passed to the *US Regional* and *Single Country* modules. By passing this information down to modules with additional regional disaggregation, ADAGE is able to incorporate effects of international policies in its regional simulations (see Balistreri and Rutherford [2004] for a discussion of this type of modeling structure and its application in a climate-policy context).

Within the *US Regional* module, states are combined using a flexible regional-aggregation scheme that allows an individual state of focus to be designated and modeled relative to other regions. Typically, around five primary regions (groups of neighboring states) and an individual state (modeled as a separate sixth region) are included in policy simulations. By

[6] Unlike input-output (I/O) models or partial-equilibrium models using fixed coefficients in production, a CGE model structure usually allows producers to change the technologies employed to manufacture goods.

Figure 1-2. The ADAGE Model: Integrated Framework of Connected Modules



running this aggregation scheme through all states of interest for a policy, findings can be obtained for multiple states in a computationally tractable, yet flexible and consistent, manner. (The same procedure can be used separate individual nations from national groupings in the *International* module). A similar CGE structure was used in Andriamananjara, Balistreri, and Ross (2005) to examine state-level impacts of international trade policies.[7]

[7]To the best of our knowledge, this aggregation methodology was originally conceived by Thomas Rutherford. See http://www.gams.com/solvers/solvers.htm#MPSGE for information on his work.

ADAGE uses a variety of economic, energy, and emissions data sources to characterize production and consumption decisions by firms and households. These data show current production technologies and demands by agents, and are combined with economic growth forecasts and estimates of future energy production, consumption, and prices:

- ***International***—GTAP economic data, IEA energy production and consumption data, and *World Energy Outlook 2004* forecasts from IEA (2004h). Carbon dioxide (CO_2) emissions related to fuel consumption are from IEA. Non-CO_2 GHG emissions are from the Stanford Energy Modeling Forum (EMF 21 on multigas abatement).
- ***US Regional***—Economic data from the Minnesota IMPLAN Group (2000), and energy data and forecasts from EIA: *Annual Energy Outlook 2004*, *Manufacturing Energy Consumption Survey 2002*, *State Energy Reports*, and various Industry Annuals. Fuel-related CO_2 emissions are from EIA, and non-CO_2 GHG emissions are from EMF 21.
- ***Single Country***—Individual country data where GTAP data are less comprehensive (currently for Brazil—International Food Policy Research Institute data[8]—and Costa Rica).

This integrated modular design (along with the flexible regional aggregations for U.S. states) has been adopted to overcome computational constraints that limit the total size of nonlinear, intertemporally optimizing CGE models such as ADAGE.

ADAGE model development would not have been possible without the MPSGE software (Mathematical Programming Subsystem for General Equilibrium; Rutherford [1999]).[9] ADAGE is solved as a mixed complementarity problem (MCP) within the Generalized Algebraic Modeling System (GAMS) language (Brooke et al. [1998]).[10] The GAMS/PATH solver is used to solve the MCP equations generated by the MPSGE software.

1.3 Data in the ADAGE Modules

ADAGE combines multiple data sources to create a balanced SAM for each module. The data are used to generate a balanced SAM for the year 2005 consistent with desired sectoral and regional aggregations. Although developing a "base" year for the SAM that is different from the initial year of the GTAP and IMPLAN sources requires additional effort, it provides several advantages: first, the different modules should be as consistent as possible and begin in the same year; second, in a perfect-foresight model, agents will adjust their behavior in all time periods as soon as a policy is announced so, if ADAGE began in the year 2000, policies under consideration today would show effects in that year; and finally, developing a SAM for the year 2005 outside of the model allows more opportunity to incorporate estimates of economic growth between the year of the data and the base year of ADAGE.

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[8]See http://www.ifpri.org/ for International Food Policy Research Institute (IFPRI) data and reports.
[9]See http://www.gams.com/solvers/solvers.htm#MPSGE for more information.
[10]See http://www.gams.com for more information.

The *International* module of ADAGE relies on the GTAP Version 6 database. These economic data include balanced SAMs for 87 regions containing 57 sectors, with information for the year 2001. Within the bounds of the regional and sectoral disaggregation of these data, ADAGE is fully flexible in choosing regions and industries. For climate-change mitigation policy analyses, this information is combined with IEA data on historical and forecasted energy production, consumption, and price data; types of electricity generation; and GDP growth.[11]

An international regional aggregation of the countries in GTAP is selected for an analysis based on the relevant international policy backdrop. Depending on the policy in question, it might include a group of regions such as

- United States,
- Europe,
- Japan,
- Russia,
- China, and
- rest of world.

The *US Regional* module is based on state-level economic data from the Minnesota IMPLAN Group[12] and energy data from EIA. These data are typically used to define approximately five broad regions within the United States (regional definitions are flexible along state boundaries, one potential aggregation is shown in Figure 1-3). To examine a particular state of interest, that state is modeled as a separate sixth region, which interacts simultaneously with the five broader regions. When examining energy/environmental policies, the broad regions within the United States are generally selected to capture important differences across the country in electricity-generation technologies and also to approximate electricity market regions defined by the North American Electric Reliability Council (NERC). Each region typically includes between 10 and 20 industries (such as those shown below), where the total number of industries (aggregated from the IMPLAN data, which includes over 500 industries) are controlled by dimensional constraints.

The *Single Country* module is designed to allow ADAGE to look at nations not covered by the GTAP data and/or look at regions within non-U.S. countries if data are available. IFPRI publishes a four-region SAM for Brazil that has been adapted for use in ADAGE. Similarly, a Costa Rica SAM from Rodriguez (1994) is used to specify a module for that country, combined with World Bank data on expected economic growth. These data sources are described in more detail in policy papers related to the specific countries in question and are not discussed here.

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[11]The necessary energy production and consumption data have been gathered for 32 countries and 6 regions to cover the 87 regions included in GTAP.

[12]Programs from Rutherford (2004) are used to organize and aggregate the IMPLAN data.

Figure 1-3. Potential U.S. Regional Aggregation (excluding specific states)

Industries represented in each module of ADAGE are aggregated from those in the underlying GTAP and IMPLAN databases to focus on the relevant economic sectors likely to be affected by the policy under investigation, while remaining within computational limits of CGE models. When using findings from one module in another, similar aggregations of industries are used across databases to ensure policy effects are translated accurately among modules. For example, when examining energy policies, data in each module are typically aggregated to five broad industries (with a focus on maintaining important distinctions in energy consumption and emissions) and five primary energy industries (with multiple forms of electricity generation):

- agriculture
- energy-intensive manufacturing
- other manufacturing
- services
- transportation

- coal
- crude oil
- electricity (*multiple technologies*)
- natural gas
- refined petroleum

ADAGE, however, is flexible across industries (and regions) contained in the databases underlying the SAMs for each region and can be reaggregated for particular policy investigations to include specific regions and industries of interest (where the total number of regions and industries is constrained by computational considerations).

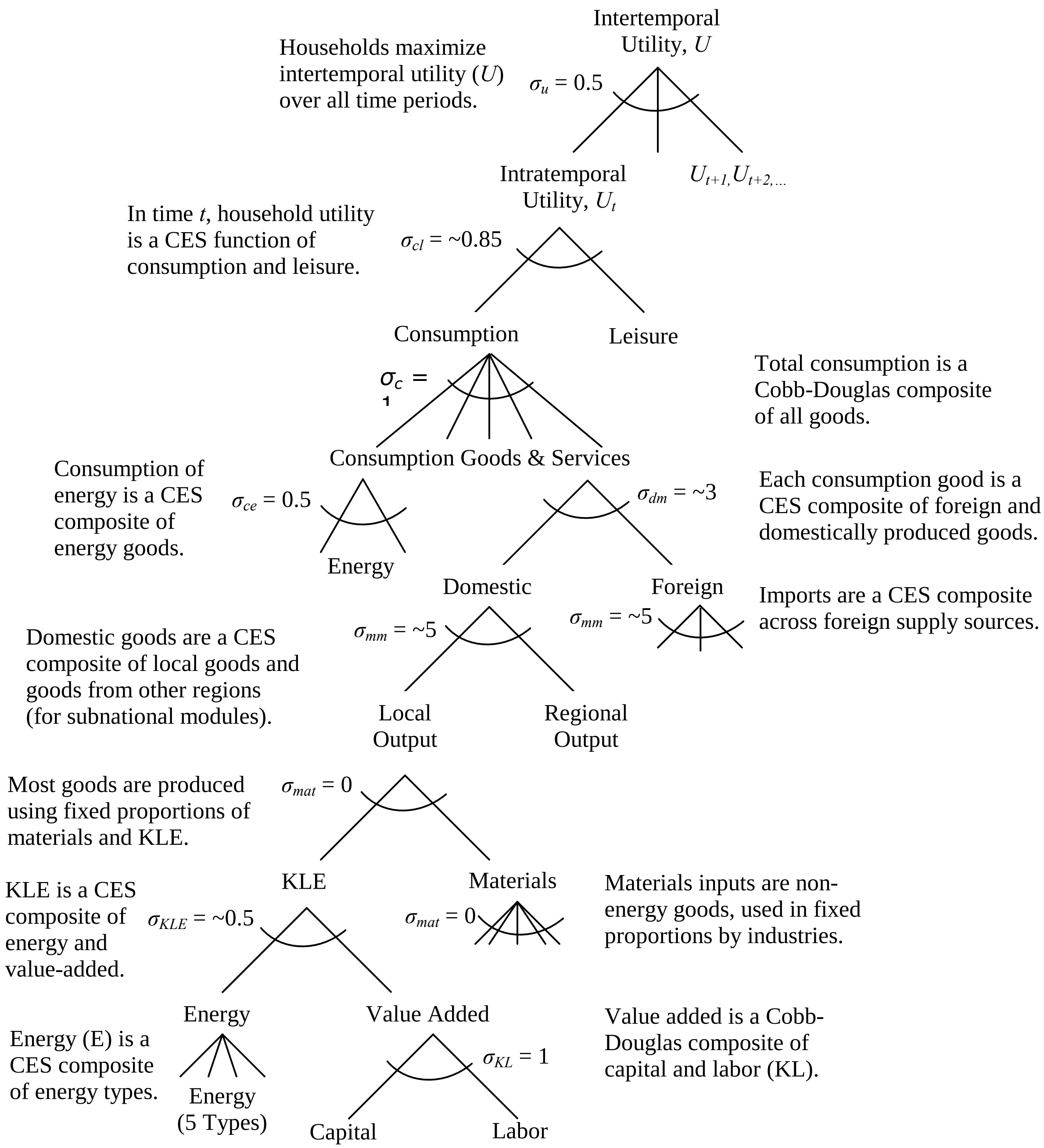
For policy investigations related to energy and climate-change mitigation, procedures are used to integrate the relevant economic and energy data. Although the GTAP and IMPLAN economic data contain information on the value of energy production and consumption in dollars, these data are replaced with IEA and EIA data for several reasons. First, when the policies being investigated focus on energy markets, it is essential to include the best possible characterization of these markets in the model, and the economic data do not always agree with energy information collected by IEA and EIA. Second, physical quantities of energy consumed are required for ADAGE to accurately estimate GHG emissions. IEA and EIA report physical quantities, while the economic databases do not. Finally, the economic data sources reflect the years 2001 and 2000, respectively, while the initial base year for ADAGE is 2005. Thus, *World Energy Outlook* (WEO) and *Annual Energy Outlook* (AEO) energy production and consumption, output, and economic-growth forecasts for 2005 are used to adjust the economic data.

1.4 General ADAGE Model Structure

Figure 1-4 illustrates the general framework of ADAGE, giving a broad characterization of the model and associated elasticities of substitution (noted by σ). At the top level, households in each region maximize intertemporal utility, or their overall welfare, across all time periods with perfect foresight. Within each time period, intratemporal household utility is a function of consumption and leisure. Below these utility functions, individual consumption goods are formed from domestic goods and foreign imports (plus regional domestic imports in the case of the *US Regional* module). At the bottom of the diagram, production technologies are specified that control how inputs can be substituted for each other. Although not illustrated in the figure, differences across industries exist in their handling of energy inputs, most notably between electricity generation and other manufacturing industries. In addition, the agriculture and fossil-fuel industries contain equations that account for the use of natural resource inputs.

As shown at the top of the figure, each region in ADAGE contains a representative household, which maximizes intertemporal utility over all time periods in the model subject to budget constraints based on endowments of factors of production (labor, capital, natural resources, and land inputs to agricultural production). Income from sales of factors is allocated to purchases of consumption goods and to investment. Within each time period, intratemporal utility is received by households from consumption of goods and leisure. All goods, including total energy consumption, are combined using a Cobb-Douglas structure to form an aggregate consumption good. This composite good is then combined with leisure

Figure 1-4. Consumption, Trade, and Production Structures in ADAGE



time to produce household utility. The elasticity of substitution between consumption goods and leisure, σ_{cl}, is controlled by labor-supply elasticities and indicates how willing households are to trade off leisure for consumption.

Factors of production owned by households are assumed to be intersectorally mobile within regions, but migration of productive factors is not allowed across regions so that changes in utility for representative households located in each region can be calculated.[13] It has also been assumed in the *International* and *Single Country* modules that the representative household in each country owns the natural resources located within it, as well as all capital stocks. For the *US Regional* module, ADAGE assumes that ownership of capital stocks and natural resources is spread across the United States through capital markets.

As shown in the middle of Figure 1-4, goods and services are assumed to be composite, differentiated "Armington" goods (Armington, 1969) made up of locally manufactured commodities and imported goods.[14] Within this basic framework in ADAGE, some differences across modules exist to accommodate the fact that goods produced in different regions within the United States are more similar than goods produced in different nations. In the *US Regional* module, output of local industries is combined with goods from other regions in the United States using the trade elasticity σ_{mm}. The high values for this elasticity indicates agents make relatively little distinction between output from firms located within their region and output from firms in other regions of the United States (i.e., they find them to be close substitutes). This module then aggregates domestic goods with imports from foreign sources using lower trade elasticities (σ_{dm}) to capture the fact that foreign imports are more differentiated from domestic output. The *International* (and some *Single Country*) modules skip the interregional step but include an aggregation across foreign supply sources.

Production technologies used by most industries and associated elasticities are illustrated in the bottom levels of Figure 1-4 (see Section 2 for industry-specific details on these equations). Within these technology constraints, each industry maximizes its profits. The nested CES structure of ADAGE allows producers to change the technology they use to manufacture goods. If, for example, petroleum prices rise, an industry can shift away from petroleum and into other types of energy. It can also choose to employ more capital or labor in place of petroleum, thus allowing ADAGE to model improvements in energy efficiency. The ease with which firms can switch among production inputs is controlled by the elasticities of substitution. Elasticities relating to energy consumption are particularly important when investigating environmental policies. If, for instance, an industry is able to substitute away from energy with relative ease, the price of its output will not change much when energy prices vary.

With the exception of electricity generation, the general nesting structure of production activities and associated elasticities have been adapted from the Emissions Prediction and Policy Analysis (EPPA) model developed at the Massachusetts Institute of Technology (MIT),

[13]Migration among nations and across regions of the United States is included in baseline forecasts.

[14]The one exception is crude oil, which is modeled as a homogeneous good that is identical across all regions and has the same baseline price across all regions and modules (from EIA price forecasts).

a well-known CGE model designed to investigate energy and GHG policies.[15] Researchers at MIT derived their CES nesting structures and elasticity estimates from a variety of empirical literature, expert elicitations, and "bottom-up" engineering studies. Figure 1-4 shows broadly how these equations control production technologies. A capital-labor-energy composite good (KLE) is combined with materials inputs to produce final output. The assumption that this is done in fixed proportions ($\sigma_{mat} = 0$) implies that businesses must either invest in more capital goods (i.e., new equipment) or hire more workers to achieve energy-efficiency improvements. The elasticity σ_{KLE} controls these improvements by specifying how value added (the combination of capital and labor) can be substituted for energy. The bottom level in Figure 1-4 then determines how capital and labor can be substituted for each other and, in the other nest, specifies energy substitution possibilities.

Taxes have been included in ADAGE because of the critical role that the existing tax structure can play in determining costs of a policy. If taxes drive a wedge between the cost of producing a good and the price paid by that good, producer and household behaviors are distorted, giving rise to an excess burden beyond the revenue raised by the tax. The *International* module incorporates taxes from the GTAP data, and the *Single Country* modules include any tax rates from their data sources. For the *US Regional* module, a variety of additional tax information has been integrated with the IMPLAN economic database, including marginal income tax rates from the NBER TAXSIM model. ADAGE also contains a user cost of capital formulation based on Fullerton and Rogers (1993), which estimates marginal effective capital tax rates as a function of their important components, most notably personal income and corporate tax rates.[16]

Distortions associated with taxes are a function of both marginal tax rates and labor-supply decisions of households. Thus, ADAGE includes a labor-leisure choice—how people decide between working and leisure time. Labor-supply elasticities related to this choice determine, to a large extent, how distortionary taxes are in the model. Based on a literature survey by Russek (1996) and estimates used in other CGE models, ADAGE uses 0.35 for compensated and 0.15 for uncompensated labor-supply elasticities. These values give an overall marginal excess burden (MEB) of approximately 0.31 and a marginal cost of funds from income taxes of around 1.25 in the *US Regional* module, measured at the baseline solution for the model.

In ADAGE, economic growth comes from four sources: growth in the available labor supply (encompassing both population growth and changes in labor productivity), capital accumulation through investment, increases in stocks of natural resources, and technological change associated with improvements in manufacturing and energy efficiency. Labor force expansions, economic growth rates, and industrial output are based on IEA and

[15]See Babiker et al. (2001) at http://web.mit.edu/globalchange/www/eppa.html for EPPA documentation.

[16]Marginal income tax rates and industry-specific marginal capital tax rates are around 40 percent.

EIA forecasts. Savings, which provide the basis for capital formation, are motivated through households' expectations about future needs for capital. The GTAP and IMPLAN datasets provide details on the types of goods and services used to produce the investment goods underlying each economy's capital stocks. Dynamics associated with formation of capital are controlled by using quadratic adjustment costs associated with installing new capital (these imply that real costs are experienced to build and install new capital equipment). Expected changes in energy consumption per unit of output are modeled as exogenous autonomous energy efficiency improvements (AEEI). These AEEIs are used to replicate energy consumption forecasts by industry and type of fuel from IEA and EIA forecasts, which also provide the growth rates for electricity generation, natural resource production, and energy prices.

Prior to investigating policy scenarios, a baseline growth path is established for ADAGE that incorporates these economic growth and technology changes expected to occur in the absence of any new policy actions. Beginning from the initial balanced SAM dataset, a "steady-state" growth path is first specified for the economy to ensure that the model remains in equilibrium in future years, assuming all endowments and output grow at a constant rate. Next, this assumption of constant growth is replaced by forecasts from IEA and EIA. Upon incorporating these forecasts, ADAGE is solved to generate a baseline consistent with them, after which it is possible to run "counterfactual" policy experiments.

In order to investigate energy and GHG-emissions policies, the ADAGE model tracks fuel consumption in physical units (British Thermal Units or Btus), based on IEA and EIA forecasts. Since CO_2 emissions from fuel use are tied to combustion of fossil fuels, the model is able to determine emissions levels in terms of millions of metric tons of carbon (MMTC). Substitution options for, and the costs of, replacing energy inputs to production are controlled by the CES equations and substitution elasticities discussed in Section 2. Households also have the ability to switch fuels, lower overall consumption, and improve energy efficiency.

ADAGE has also endogenized emissions abatement costs associated with five non-CO_2 gases (CH_4, N_2O, HFCs, PFCs, and SF_6), based on the approach used in the EPPA model (Hyman et al., 2002). Unlike CO_2, these gases are not emitted in fixed proportions to energy consumption, making the modeling of abatement costs more problematic. Rather than relying on exogenous marginal abatement cost functions, which ignore interactions among the economic sectors, emissions of non-CO_2 gases are modeled directly as an input to production. This allows specification of abatement cost curves representing industry-specific costs associated with achieving reductions. National baseline emissions of these gases are matched to EMF forecasts. Regional shares of EMF's national emissions for the United States are based on regional output and consumption from the IMPLAN and EIA data.

2. ADAGE MODELING FRAMEWORK

This section, which is organized along the lines of Figure 1-4, presents nesting structures detailing the CES equations used in ADAGE to describe household behavior, trade flows, and production activities. Associated elasticity parameter values that control the model's reactions during policy investigations are also given. These equations, along with the model's dynamics and its baseline economic and energy data, will determine impacts estimated for policies.

2.1 Households

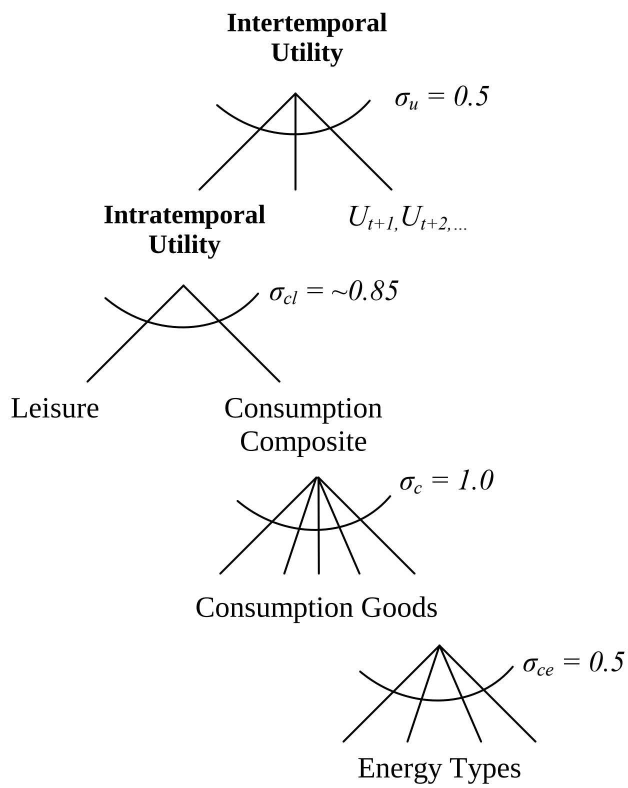
Each region in ADAGE contains a representative household, which maximizes intertemporal utility over time subject to its budget constraints. As shown in Figure 2-1, in determining intratemporal (within each time period) household preferences for goods, different types of energy are first combined into a single composite energy good with a relatively low elasticity (σ_{ce}). This reflects potential difficulties associated with households' attempting to switch among fuel types. The energy composite good is then combined with other consumption goods using a Cobb-Douglas structure to form an aggregate consumption good. This composite good is traded off against leisure time to form household utility. The elasticity of substitution between consumption goods and leisure (σ_{cl}) indicates how willing households are to trade off leisure time for consumption.

Over time, households consider the discounted present value of utility received from all periods' consumption of goods and leisure when attempting to maximize intertemporal utility.[17] The household utility function allows measurement of welfare changes associated with a policy, which capture a wide variety of effects influencing how households are affected by a policy (such as changes in income, changes in the costs of consumption goods, and changes in work effort). These welfare effects are measured by Hicksian equivalent variation, which is the amount of income needed to compensate households for the economic effects of a policy.

Households are endowed with the factors of production used by firms (labor, capital, natural resources, and land inputs to agricultural production). Factor prices are equal to the marginal revenue received by firms from employing an additional unit of that factor.

[17] ADAGE approximates the infinite horizon implied in Figure 2-1 using techniques described in Lau, Pahlke, and Rutherford (2002), since it is not computationally feasible to model an infinite number of time periods.

Figure 2-1. Household Utility Function



Factors are assumed to be intersectorally mobile within regions,[18] but it is assumed that factor prices depend on their use in production within each region (i.e., there can be regional price differences). It has also been assumed in the *International* and *Single Country* modules that the representative household in each country owns the natural resources located within it, as well as all businesses. For the *US Regional* module, ADAGE assumes that ownership of capital stocks and natural resources is spread across the U.S. through capital markets. Income from sales of all productive factors by households are allocated to purchases of consumption goods to maximize welfare.

When choosing the amount of labor to supply to firms, households consider their total endowment of time, the income received from labor sales, and how leisure time affects their welfare. These choices are controlled in ADAGE by a labor-supply elasticity, which expresses how the labor supply will respond to changes in wage rates and disposable

[18] Migration of labor across regions is not allowed so that welfare changes for the representative households located in each region can be calculated; however, migration among nations and across regions of the United States is included in ADAGE's baseline forecasts.

household income. Selection of this parameter is important because it interacts with tax rates in the model to determine the extent of distortions caused by the existing tax structure, with related implications for the costs of policies. If households are very willing to switch between leisure and work in response to changes in wages, existing labor taxes will have significantly distorted economic behavior from what would have occurred in the absence of the taxes, implying a large excess burden for labor taxes, and the reverse if households are not willing to substitute leisure time for work (and hence consumption goods).

Russek (1996) reviews the relevant literature, which cites estimates for total labor supply elasticities ranging between –0.1 and 2.3. Fuchs, Krueger, and Poterba (1998) also review estimated elasticities with similar findings. The values for labor-supply elasticities most commonly used in CGE models are in the mid-point of the range presented by Russek—typically around 0.4 for compensated elasticities and 0.15 for uncompensated elasticities (see, for example, Parry and Bento [2000], Williams [1999], Goulder, Parry, and Burtraw [1997], Bovenberg and Goulder [1996]).

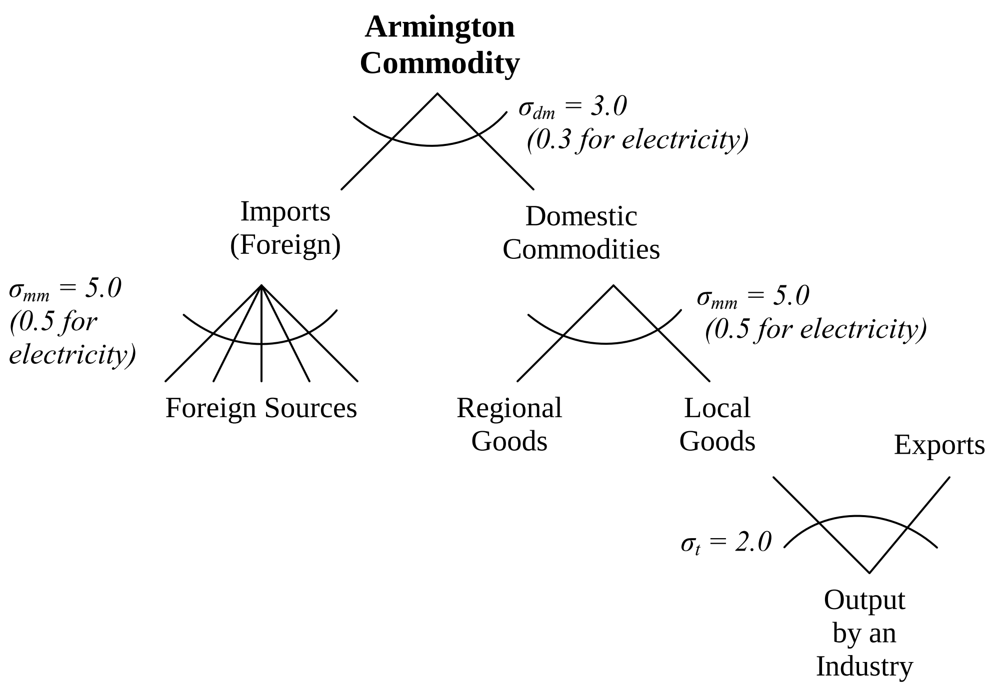
The elasticity of substitution between consumption goods and leisure (σ_{cl}) and the total time endowment of households can be selected to yield desired compensated and uncompensated labor-supply elasticities (Ballard, 1999). In ADAGE, the compensated labor-supply elasticity is set at 0.40 and the uncompensated labor-supply elasticity is set at 0.15, based on estimates in the CGE literature and the implications for tax distortions in the model (see Section 4 for tax rates and measurements of their distortions in ADAGE). These choices determine the elasticity between consumption goods and leisure (σ_{cl}) shown in Figure 2-1.

2.2 Trade

In each module of ADAGE, goods and services are assumed to be composite, differentiated "Armington" goods made up of locally manufactured commodities and imported goods (see Figure 2-2).[19] In this trade structure, output of local industries is initially separated into output destined for local consumption by firms or households and output destined for export using a CES transformation elasticity, σ_t. In the *US Regional* module, this local output is then combined with goods from other regions in the United States using trade elasticities that indicate that agents make relatively little distinction between output from firms located within their region and output from firms in other regions within the United States. This module finally aggregates the domestic composite good with imports from foreign sources using lower elasticities, which indicates that foreign imports are more differentiated from

[19]Unlike other goods, crude oil is modeled as a homogeneous good that is identical across all regions.

Figure 2-2. Trade Functions[a]



[a]These Armington elasticities are generally similar to those used in the EPPA model.

domestic output than are imports from other regions of the United States.[20] The *International* and *Single Country* modules skip the interregional step but include an aggregation across different foreign supply sources. The *US Regional* and *Single Country* modules are linked with the *International* module through the prices of traded goods determined by the *International* module. Findings on prices of internationally traded goods are passed down the chain so that the modules with more regional detail are able to incorporate the effects of international policies in their policy simulations (Balistreri and Rutherford, 2004).

2.3 Production

Following ADAGE's Arrow-Debreu general equilibrium structure, firms are assumed to be perfectly competitive and are unable to influence market prices. Production technologies exhibit constant returns to scale, except for the agriculture and natural resource sectors, which have decreasing returns as a whole because of the use of factors available in fixed supply (land and primary fuels, respectively). Industries maximize profits, subject to technology constraints characterized by nested CES equations that allow firms to change the

[20]The *US Regional* module includes additional detail on coal trade among states to distinguish among types of coal produced in different locations within the United States (see Section 5).

technologies used to manufacture goods. Most of these equations have generally been adapted, with some changes, from MIT's EPPA model (Babiker et al., 2001). Electricity production from fossil fuels is based on Balistreri and Rutherford (2004).

Production technologies in ADAGE allow for energy-efficiency improvements, the nature of which are controlled by the nesting structure of the production activities. Intermediate materials inputs (nonenergy, nonfactor inputs) generally enter production using fixed coefficients, or a Leontief structure. This implies that producers (or households) can adjust their energy consumption by changing total output (or consumption), substituting one type of energy for another, or using additional labor or capital to achieve energy-efficiency improvements. Along with how energy-efficiency changes are modeled, substitution elasticities related to energy consumption are particularly important when investigating energy, environmental, or climate-change mitigation policies. If, for instance, an industry is able to substitute away from energy with relative ease, or from one type of energy to another, the price of its output will not change much when energy prices vary.

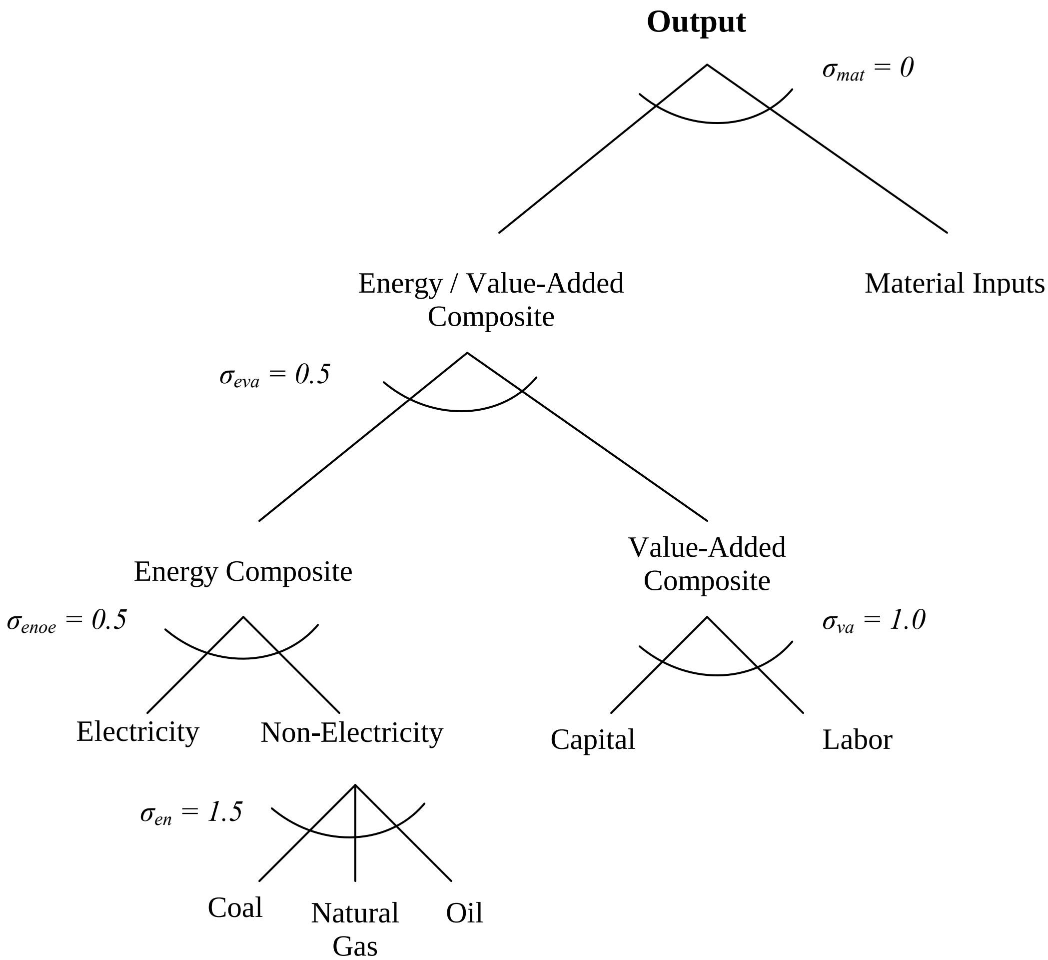
2.3.1 Manufacturing and Services

All manufacturing and services industries (including transportation services), which represent the majority of gross output in most economies, use the production nesting structure shown in Figure 2-3. Intermediate materials inputs, which are Armington composites of domestic and imported goods, enter at the top of the CES nest in fixed proportions (σ_{mat}) and can be traded off against a composite good of energy and value added (capital and labor). The energy/value-added elasticity (σ_{eva}) then controls overall energy-efficiency improvements that can be achieved by substituting capital and labor for energy in production.

ADAGE assumes that capital and labor are combined using a Cobb-Douglas function (σ_{va} of 1) to form the value-added composite good. Value-added is combined with an energy composite good made up of all available types of energy. Within the energy composite, another elasticity (σ_{enoe}) controls the ability of firms to shift between electricity and other types of energy. At the bottom of Figure 2-3, the σ_{en} elasticity shows how coal, natural gas, and refined petroleum can be substituted for each other.[21] Within this structure, the energy/valued-added elasticity and the two energy elasticities (σ_{enoe} and σ_{en}) have the most impact when examining energy and environmental policies because they control efficiency improvements and fuel switching.

[21]This elasticity is set to 1.5 to avoid the constant value share implications of a Cobb-Douglas formulation, which allows somewhat more fuel switching than would occur in the EPPA model.

Figure 2-3. Manufacturing and Services Production

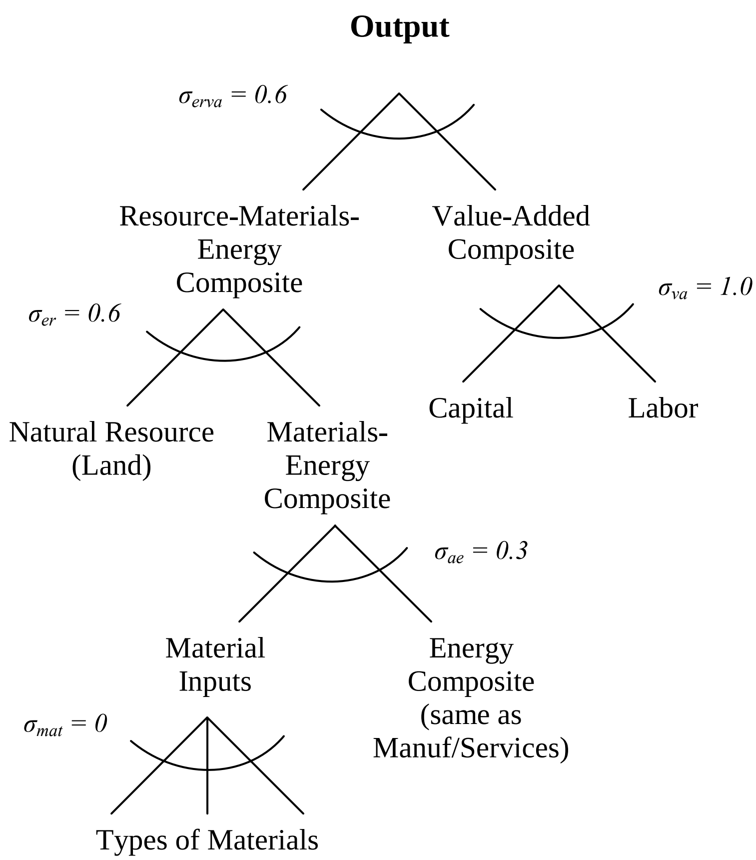


2.3.2 Agriculture

The CES nesting structure used for agriculture is designed to account for the use of land inputs to agricultural output because it is an essential fixed factor and is available in limited supply. The formulation also maintains a distinction between output per hectare of land and output per unit of labor and capital and allows agricultural output to be increased by adding land (if possible), materials, and energy, or capital and labor. At the top of the nest in

Figure 2-4, value added is substituted against a resource-materials-energy bundle (σ_{erva}), allowing agricultural efficiency per hectare of land to be improved by using additional capital or labor. Energy and materials (σ_{ae}) can be substituted with some difficulty for the fixed land resource (σ_{er}), indicating that land can be made more productive by using materials (e.g., fertilizer) or energy (e.g., heating greenhouses or running farm equipment).

Figure 2-4. Agricultural Production



Substitutions among energy types to form a composite energy good are the same as in manufacturing.

2.3.3 Electricity

Generation of electricity is unique from the manufacturing and services industries because the electricity sector depends critically on energy inputs. In addition, there are established theoretical and engineering bounds on how efficiently fossil-fuel inputs can be converted into electricity. Because of these considerations, and the importance of the representation of the electricity industry for estimated impacts of energy and environmental policies, the CES equations typically used for electricity generation are different from those in other industries.

At the top of the nested CES structure shown in Figure 2-5 (fossil-fuel electricity generation),[22] materials enter in fixed proportions and can be traded off against a

[22]The CES equations used in ADAGE for fossil generation are based on Balistreri and Rutherford (2004).

composite good made of capital, labor, and energy. As with other industries, ADAGE assumes that capital and labor are combined using a Cobb-Douglas function (σ_{va} equal to 1) to form the value-added composite good. Value added is combined with the energy composite, which is made up of all available types of energy. The energy value-added elasticity (σ_{eva}) is lower than in manufacturing, indicating that it is harder to achieve energy-efficiency improvements in the electricity sector, which relies heavily on energy for generation purposes.

Within the energy composite, the σ_{enoe} elasticity of zero eliminates the ability of utilities to increase generation by using additional electricity (i.e., electricity cannot be generated from electricity; it merely is necessary to run the boilers, etc.). The fossil-fuel nesting structure is unique to electricity generation and distinguishes it from other types of manufacturing. In electricity generation, the most important trade-off is between coal and natural gas, especially in developed countries, since many energy/environmental policies are likely to cause a shift between these two fuels. As shown in Figure 2-5, natural gas is combined with coal (σ_{cg}) with a relatively large degree of flexibility in fuel switching. Following that, the coal-gas composite is combined with oil (σ_{cgo}) using a lower substitution elasticity because oil generation is generally used for peaking generation, unlike coal and gas that provide more base-load generation.

As shown in Figure 2-6, electricity can be generated either from fossil fuels or by nonfossil means. The different types of generation are distinguished so that ADAGE can track fuel use per unit of electricity (i.e., heat rates—Btus of energy input per kilowatt hour, kWh, of electricity output) to ensure it is consistent with theoretical limits on energy conversion and available fossil-fired technologies.[23] An infinite elasticity of substitution indicates that no distinction is made between electricity produced across sources.

Given difficulties associated with representing feasible increases in nonfossil electricity generation within a CGE model, ADAGE currently does not allow generation from these sources to expand beyond baseline levels.[24] Although this assumption will lead the model to overestimate the costs of policies affecting electricity markets, it avoids the need to

[23]Tracking various nonfossil generation sources also assists in estimating baseline forecasts for individual states in the *US Regional* module (see Section 5). Data available to distinguish these types of generation differ slightly across modules.

[24]By limiting this generation, it is not necessary to model electricity from base-load sources as different from peaking sources in an annual context because these factors are already accounted for in the forecasts.

Figure 2-5. Fossil-Fuel Electricity Generation

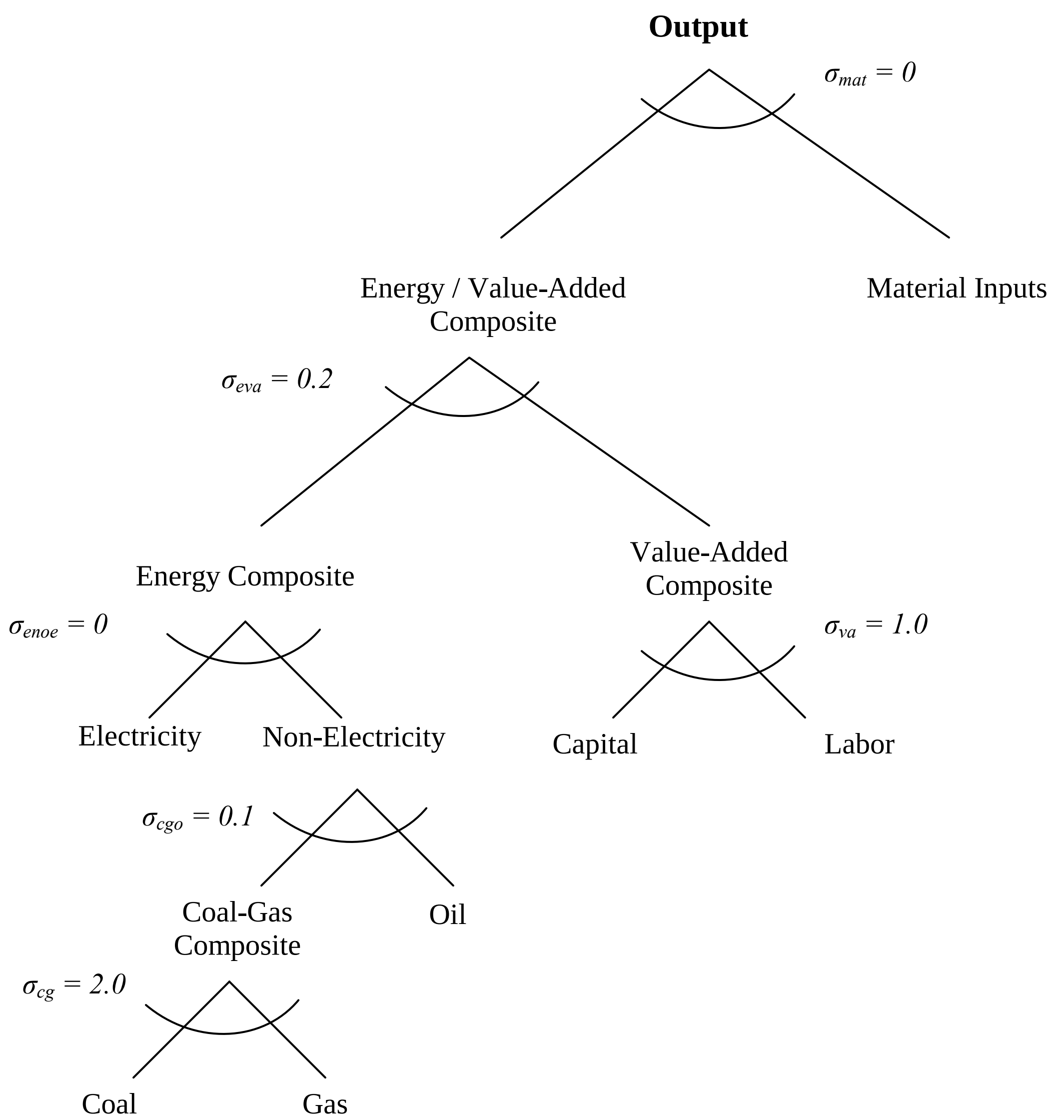
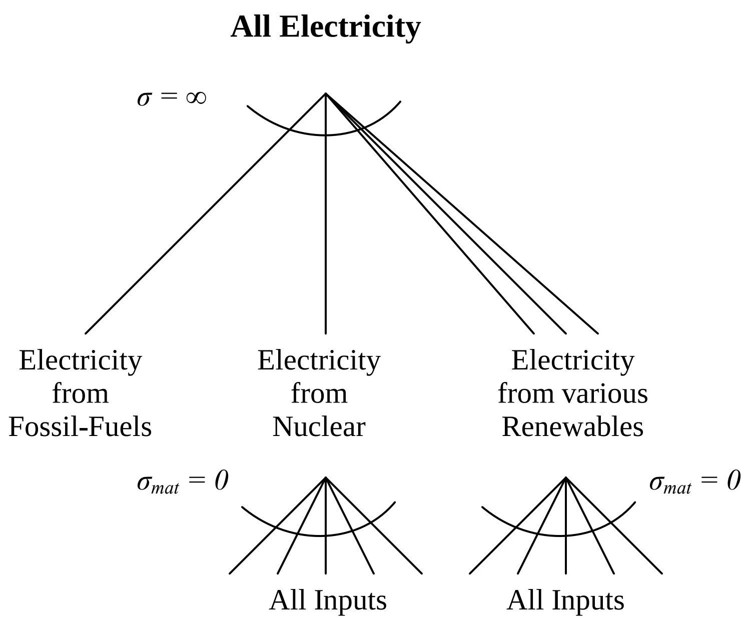


Figure 2-6. Total Electricity Generation

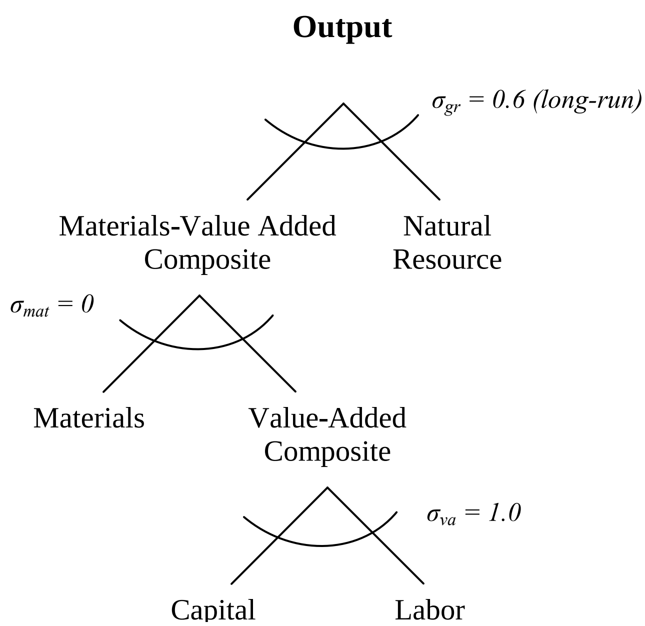


attempt to characterize how these sources will respond to policies. The MIT EPPA model is at the forefront of research on how to include renewable and advanced generation options in CGE models (Jacoby et al., 2004). However, a number of uncertainties remain about how to incorporate these features in policy investigations: the capabilities of wind and solar power are sensitive to parameter assumptions about how these sources can substitute for other types of generation, and feasible penetration rates for new technologies have to be exogenously assumed by modelers, as do future costs for these technologies. In addition, capabilities of nonfossil generation frequently do not depend solely on economic factors, for example, the building of new nuclear generation depends more on political decisions than economics, and wind/solar generation depends on site-specific characteristics (different classes of wind resources and days of sunshine) that are difficult to capture in a CGE model. Consequently, rather than risk having policy results from ADAGE be dependent on uncertain assumptions about electricity generation technologies, it has been deemed preferable at the moment to accept results that overestimate policy costs and acknowledge that fact (a long-term solution to these issues is being developed and will be documented at <http://www.rti.org/adage> when it is complete).

2.3.4 Fossil Fuels

Similar to agricultural goods, fossil-fuel supplies (coal, crude oil, and natural gas) are limited by the availability of a natural resource (the primary fuel reserves in the ground). Thus, a fixed factor in production is used to model resource constraints and give the production functions decreasing returns to scale across an economy. The formulation of the CES equations (Figure 2-7) captures the idea that, while it is possible to develop more efficient mining equipment or invest in discovering new resources, it is not possible to produce the natural resources themselves using only inputs like capital, labor, or materials. In the production nesting structure, the natural resource in the ground is combined with other productive inputs to extract it and make it available for use by other industries. Although some additional production is possible from using more factors or materials, these inputs must still be combined (elasticity σ_{gr}) with the fixed resource at the top of the CES nest.

Figure 2-7. Fossil Fuel Production (Coal, Crude Oil, and Natural Gas)

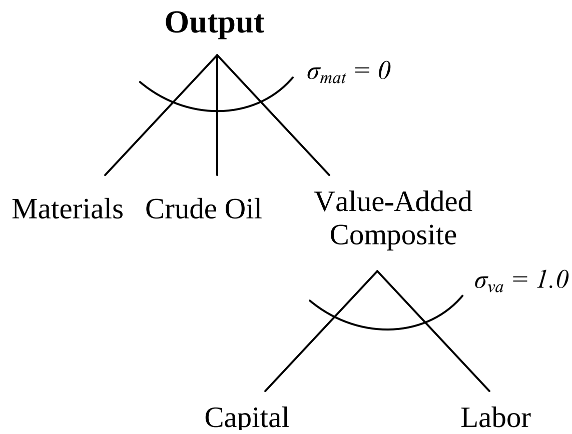


2.3.5 Petroleum Refining

Although petroleum refining is not a natural resource sector that relies on extraction of fossil fuels, its production is highly dependent on inputs of crude oil. The CES functions shown in Figure 2-8 capture this idea by allowing some substitution of factors (elasticity σ_{va}) but require that crude oil and materials enter the production structure in fixed proportions. This ensures that the model must use crude oil to produce petroleum products and cannot unrealistically increase output of refined petroleum by using other types of inputs.[25]

[25]Improvements in baseline refinery processing gains (as shown in the energy consumption forecasts) are handled through adjustments to the ratio of crude-oil inputs to petroleum output.

Figure 2-8. Refined Petroleum Production



2.4 Government

Government purchases of good and services are exogenous variables in ADAGE, which are maintained at their original levels and do not enter the optimization decisions of households and firms or adjust in response to policies. These purchase patterns are taken from the economic data sources used by ADAGE. Government expenditures are financed by taxes on output, personal income, consumption, capital, and imports/exports (see Section 4). Because the government is modeled as a separate agent in ADAGE, it is generally necessary to maintain its income during policy investigations to get meaningful welfare results for other agents (i.e., households) in the model. Unless a particular policy specifies an alternative approach, this is done through nondistortionary, lump-sum transfers between households and the government. Inclusion of a government sector and related revenue-generating taxes is important, however, because it allows ADAGE to consider how policies may interact with existing taxes, which can alter policy costs.

3. DYNAMICS, INVESTMENT, AND GROWTH

Economic growth in ADAGE comes from four sources: growth in the available labor supply from population growth and changes in labor productivity, capital accumulation through savings and investment, increases in stocks of natural resources, and technological change associated with improvements in manufacturing and energy efficiency. This section discusses these dynamic processes (data underlying actual growth paths in the model are discussed in Sections 4 and 5).

3.1 Labor Growth

At the beginning of the model horizon, households in each region in ADAGE are endowed with an initial supply of labor, the value of which is shown in the economic accounts used by the model. Similar to other CGE models, ADAGE then relies on exogenously specified rates of growth to determine how the value of labor endowments increases over time. Using the assumption of Harrod-neutral technical progress, the model tracks increases in effective units of labor available across the economy, encompassing both population growth and improvements in labor productivity. This approach facilitates incorporation of economic-growth forecasts from IEA and EIA, which also provide other forecasts used in ADAGE.

3.2 Investment, Capital Stocks, and Adjustment Dynamics

Decisions regarding savings by households and the associated capital formation control many of the behavioral responses estimated for policies. ADAGE models these decisions using a forward-looking, full intertemporal optimization approach in which households have perfect foresight and maximize the present value of all future consumption.[26] By allowing agents to anticipate new policies, ADAGE can show how people will begin to prepare for policies that are announced today, but that may not begin until sometime in the future.

The savings motivated through these expectations about future needs for capital determine aggregate capital stocks in ADAGE. Both the GTAP and IMPLAN datasets provide details on the types of goods and services used to produce the investment goods underlying each economy's initial capital stocks. The model uses these data to specify an aggregate investment sector generating the capital needed by the economy. The data sources, however, do not contain a representation of actual capital stocks, so it is necessary to calibrate these stocks from the observed earnings generated by the unobserved capital stocks.[27] Typically, capital stock data, even if available, are not considered as reliable as capital earnings data, so this calibration approach may be used even if stock data are available.[28]

Dynamic processes controlling how capital stocks evolve over time will determine the transition path the economy takes from its initial baseline forecast to a new equilibrium in response to policies. ADAGE models these dynamics through quadratic adjustment costs

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[26]The theoretical basis for this approach comes from Ramsey (1928), Cass (1965), and Koopmans (1965).

[27]Capital earnings (K_e) are equal to the interest rate (r) plus the depreciation rate (δ) times the capital stock. This allows the initial stock of capital (K_s) to be calculated as $K_s = K_e / (r+ \delta)$. The interest rate in ADAGE is assumed to equal 5 percent, based on the MIT EPPA model, and the overall depreciation rate is set at 7 percent, based on a weighted average rate across the capital assets shown in Table 4-7.

[28]See Babiker et al. (2001) for a discussion of the EPPA model's calibration of capital stocks.

associated with installing new capital (Uzawa, 1969).[29] These installation costs depend on the rate of gross investment in relation to the existing stock of capital and are expressed as

$$I_t = J_t \left(1 + \phi \frac{J_t}{2K_t}\right)$$

where I_t is gross investment (in period t), J_t is net investment, K_t is the existing capital stock, and ϕ reflects the speed of adjustment.[30] The formulation implies that rapid changes in capital stocks are expensive and that the rate of adjustment will decline as adjustment costs increase.

Available capital stocks in time period t (K_t) are equal to new net investment plus depreciated capital left from the previous time period:

$$K_{t+1} = K_t(1-\delta) + J_t \, .$$

Thus, net investment has to be sufficient to cover both economic growth (generating new capital demands) and depreciation of existing capital. Capital stocks are assumed to be perfectly malleable across industries within each region in ADAGE.

3.3 Fossil-Fuel Resources

Fossil-fuel resources (coal, crude oil, and natural gas), which are endowed to households in ADAGE, evolve over time through changes in quantities and prices. Expected future quantities and prices are matched to WEO and AEO forecasts from IEA and EIA (see Section 5); however, these forecasts do not provide information on the amount of resources available for extraction or the costs associated with extracting them. To address these limitations, ADAGE generates resource supply elasticities around forecasted production paths of the resources.

The supply elasticities reflect how production costs rise as more resources are extracted, along with effects of depleting the fossil-fuel resources. By selecting an elasticity of substitution between a resource and other production inputs in these industries (elasticity σ_{gr} in Figure 2-7), a given resource supply elasticity can be calibrated.[31] Fossil-fuel price paths from WEO and AEO forecasts are also matched by adjusting growth rates for the

[29]See Lau, Pahlke, and Rutherford (2002) for discussion of this and other modeling techniques related to dynamics.

[30]The adjustment cost parameter, ϕ, is set at 0.2, following Bovenberg and Goulder (2000).

[31]ADAGE uses an approach to resource supply elasticities that is similar to the EPPA model. Algebraic calculations (Babiker et al., 2001) can demonstrate that the resource supply elasticity (η^s) is equal to the substitution elasticity (σ_{gr}), adjusted by the share of inputs of natural resources used to produce output from the resource industry (S_{nr}): $\eta^s = \sigma_{gr} * (1 - S_{nr}) / S_{nr}$.

fixed-factor inputs to resource production so that prices in the baseline ADAGE solution are calibrated, as closely as is feasible, to desired forecasts.[32]

3.4 Energy Consumption

Energy consumption per unit of output tends to decrease over time through improvements in production technologies and energy conservation (although it is not necessarily true in developing countries as they move into more energy-intensive and less labor-intensive manufacturing processes). The energy mix in an industry may also shift as production techniques change. For example, natural gas use in electricity generation in the United States rose by almost 60 percent between 1990 and 2000, while coal use rose by less than 25 percent (EIA, *Annual Energy Review 2003*). When examining environmental policies, it is essential to include these technology shifts in the baseline forecasts of ADAGE.

Similar to other CGE models, ADAGE captures these energy consumption changes through autonomous energy-efficiency improvement (AEEI) parameters. An AEEI index is specified in the model for each fuel type and each industry. These indices alter the physical amount of energy needed to produce a given quantity of output by accounting for improvements in energy efficiency, conservation, and switching among fuel types.[33] Rather than apply generic trends to these parameters based on overall energy-efficiency improvements from historical data, AEEIs are used in ADAGE to match expected trends in energy consumption from WEO and AEO forecasts.

4. ECONOMIC DATA IN ADAGE

This section discusses data requirements for ADAGE, methodologies for establishing a base year and baseline forecasts for the model, and sources for the international and U.S. economic data used in the model.

4.1 Data and Model Baseline Overview

Most CGE models rely on a SAM, an economy-wide dataset showing how goods and factors of production flow through the economy at a specific point in time (see, for example, Shoven and Whalley [1992] or Lofgren, Harris, and Robinson [2002] for more discussions of SAMs). The framework for a SAM comes from traditional I/O analyses (Leontief, 1936). An I/O table contains the values of economic transactions at a particular point in time. As such, it shows how firms combine intermediate inputs and productive factors to manufacture

[32] This emphasis is somewhat different than taken by MIT's EPPA model. There is not an explicit modeling of unextracted fossil-fuel resources in ADAGE, instead the focus is on matching WEO and AEO price paths, which are determined by these underlying resource stocks and using a supply elasticity to reflect how production quantities will change in response to price changes.

[33] Edmonds and Reilly (1985) were the first to outline this approach. See Babiker et al. (2001) for a discussion of how this methodology was used in the EPPA model.

goods. This output is directed towards intermediate and final uses, where intermediate uses are the goods and services employed by other firms to make their products and final uses are the ultimate destination of goods purchased by households and government.

A SAM is an expanded version of traditional I/O tables. In addition to data normally in an I/O model, a SAM contains information on ownership of factors of production, allowing CGE models to estimate policy effects on the distribution of income. A SAM also includes data on direct taxes removed from income received by households and transferred to the government, and vice versa. I/O tables, which ignore income, typically only include indirect taxes that are levied on purchases of intermediate production inputs or on expenditures for final goods of production. By covering all economic flows among agents, a SAM provides the basis for building a static CGE model or for providing a base-year dataset in a dynamic CGE model.

ADAGE combines a variety of data sources to create a balanced SAM for each of its modules that characterizes a base year for the economy, accounting for all economic interactions among agents. The starting point for the *International* module is the GTAP data, while the *US Regional* module is based on IMPLAN data. Each of these SAMs contains data on the value of output of each industry, payments for factors of production and intermediate input purchases by each industry, household income and consumption patterns, government purchases, taxes, investment, and trade flows. The GTAP data (Version 6) contain a balanced SAM with 87 regions and 57 sectors for the year 2001, and the IMPLAN data cover similar information for the 50 U.S. states (plus the District of Columbia) and 528 industries for the year 2000.

Starting from these data, a balanced SAM is generated for each module in ADAGE with an initial base year of 2005 that is consistent with desired sectoral and regional aggregations. This base year, which is different from the years of the GTAP and IMPLAN data, is selected for several reasons. First, the databases of the different modules should be as consistent as is feasible so that results from one module can be used in another. Second, in an intertemporally optimizing model such as ADAGE, agents will adjust their behavior in all time periods as soon as a policy is announced. Thus, if ADAGE began in the year 2000, policies under consideration today for implementation in the future would show effects in the model in the year 2000.[34]

Finally, one of the most important reasons for developing a SAM for the year 2005 is that conducting this process outside of the model allows more control over the resulting dataset and a better opportunity to incorporate estimates of economic growth between the year of the data and the base year of the model. If ADAGE were to start in 2000, the model would

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[34]Attempting to fix model results for the year 2000 would distort the equilibrium solution because of the presence of factors of production available in fixed supply and would prevent meaningful interpretation of welfare results.

still need to determine an equilibrium solution for 2005, but it would be more difficult to incorporate growth forecasts in this solution. Several historical and forecast data sources are used to expand the original GTAP and IMPLAN datasets to the 2005 base year (described in Sections 4 and 5). The process of achieving a balanced SAM for this base year is similar to the techniques used to incorporate energy data into the economic accounts and is discussed at the end of Section 5. In general, the process involves rebalancing trade flows to account for differential regional growth between the GTAP and IMPLAN data years and the base model year of 2005.

Before investigating policy scenarios, a baseline growth path must also be established for ADAGE that incorporates forecasts of future economic growth and technology changes. Beginning from the initial balanced SAM of economic accounts, a "steady-state" growth path is first specified for the economy to ensure that the model remains in equilibrium in future years, assuming all endowments and output grow at a constant rate.[35] Once the model is able to replicate a steady-state growth path, the assumption of a constant growth rate is replaced by actual forecasts from the WEO and AEO. After incorporating these forecasts, ADAGE is solved (in 5-year time intervals) to generate a baseline consistent with the forecasts through 2025.

This baseline solution for ADAGE needs to reflect expected changes in the four sources of growth discussed in Section 3: growth in labor supplies, capital accumulation, increases in stocks of natural resources, and technological change associated with improvements in manufacturing and energy efficiency. Growth in labor endowments of households are adjusted to replicate forecasts of regional economic growth from the WEO and AEO. The capital accumulation needed to support these labor forces and consumption demands is determined endogenously by the model. The WEO and AEO forecasts are also used to establish target growth rates for natural resource quantities and associated prices.

Finally, a series of iterative model solutions are generated to find AEEI coefficients that replicate the energy consumption forecasts (see Section 5). Each model solve estimates the appropriate AEEI to match forecasts for energy use, and these findings are compared to desired results. Differences between model solution values and the desired forecasts are then used to adjust the AEEIs, and the model is resolved again until the baseline model solution is within a small percentage of the forecasts (generally within 0.1 percent to 1.0 percent of projections).[36] Once this baseline has been established, it is possible to run "counterfactual" policy experiments.

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[35] A steady-state growth path requires all variables in the model to grow at a constant rate over time, including labor, output, inputs to production, and consumption. If the model has been properly specified, the steady-state replication check will show that the economy remains in equilibrium in each year along this path.

[36] Productive adjustments to capital and labor are occasionally needed in the *US Regional* module to match energy production forecasts for electricity and petroleum refining.

4.2 International Module

The *International* module relies primarily on GTAP data (Version 6). These economic data for the year 2001 contain balanced SAMs for 87 regions with 57 industries. Forecasts for GDP growth and implied industrial production from IEA and EIA are used to extend these data to the base year in ADAGE of 2005 and provide subsequent economic growth patterns.[37] To improve the internal consistency of ADAGE, the state-level economic data described in Section 4.3 are used (at a national level) to represent the U.S. economy. While some differences exist between the GTAP definitions of industries and those in the U.S. state data, because there are over 500 industries in the U.S. data, it is generally feasible to define comparable economic sectors. Although this approach necessitates additional work to integrate the U.S. data with the GTAP international data, it improves the ability of ADAGE to apply results from the *International* module to regions/states within the United States.

4.3 *US Regional* Module

The state-level economic data used to develop a SAM for the *US Regional* module are provided by the Minnesota IMPLAN Group. The IMPLAN data show current manufacturing technologies and how goods are made from intermediate inputs and factors of production. These consistent state-level social accounts also show demand for goods and services by households and the government, along with how these expenditures are financed by households' sales of productive factors and by some types of government tax collections. The IMPLAN tax data are augmented with additional information on personal income, corporate, fuel, and sales taxes.

Each SAM from IMPLAN contains data on production and consumption of 528 different types of commodities for the year 2000, developed from a variety of government sources, including

- U.S. Bureau of Economic Analysis Benchmark I/O Accounts of the United States,
- U.S. Bureau of Economic Analysis Output Estimates,
- U.S. Census Bureau Economic Censuses and Surveys,
- U.S. Bureau of Economic Analysis REIS Program,
- U.S. Bureau of Labor Statistics Covered Employment and Wages (ES202) Program,
- U.S. Bureau of Labor Statistics Consumer Expenditure Survey,
- U.S. Census Bureau County Business Patterns,
- U.S. Census Bureau Decennial Census and Population Surveys,
- U.S. Department of Agriculture Crop and Livestock Statistics, and
- U.S. Geological Survey.

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[37] The procedures developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000), which are used to integrate economic and energy data, are also used to balance the economic data after these forecasts are included—see Section 5.3.

Since computational constraints limit the total size of intertemporally optimizing CGE models, industry (and regional) aggregations of the IMPLAN databases are used in policy investigations. From among the 528 sectors in IMPLAN, aggregations are selected based on their relevance to the particular policy in question.[38]

These IMPLAN data provide a starting point for developing balanced state-level SAMs with an initial base year of 2005, consistent with desired sectoral and regional aggregations. The process of estimating economic activity in 2005 involves projecting IMPLAN data for the year 2000 to the year 2005 using the following data sources:

- **State-level gross state product (GSP)**—*Regional Economic Accounts*, U.S. Bureau of Economic Analysis (BEA) (2004d). GSP by state and industry for 2000 and 2001.
- **State-level personal income**—*Annual State Personal Income*, U.S. Bureau of Economic Analysis (BEA) (2004a). Personal income by state and industry for 2001–2003.
- **State-level population projections**—*State Population Projections Program*, U.S. Census Bureau.
- **Economic growth rates for 2004–2005**—*Annual Energy Outlook 2004* (EIA, 2004). Tables 23 and 116. Growth in industrial value of shipments and real income by Census region. (these industrial and regional growth rates are also used to provide business-as-usual forecasts for the *US Regional* module through 2025).

The lack of a consistent data source showing changes in state-level output, consumption, and trade between 2000 and the ADAGE base year of 2005 necessitates estimation of state-level economic growth from several available sources. GSP growth rates by industry are used to extend the IMPLAN data from 2000 to 2001, after which personal income by industry is used to expand states' economies to 2003. Subsequently, overall growth rates by industry and income growth from the AEO are used to develop the state-level SAMs for 2005. In addition, household consumption and imports are assumed to follow population trends between 2000 and 2005. The resulting SAM is then rebalanced to ensure consistency, as discussed in Section 5.3.

Another issue with the IMPLAN data revolves around interstate trade flows, which can have important implications for regional impacts of policies. Although IMPLAN provides exports and imports of goods and services for each state, the data do not include information on bilateral interstate trade flows. To establish these trade patterns, a gravity model of trade is employed, which estimates trade flows as a function of income and distance (e.g., Bergstrand [1985 and 1989], Feenstra, Markusen, and Rose [1993], and Sanso, Cuairan, and Sanz [2001]). This approach generally exhibits a good correlation between empirical data and estimated trade flows (see Balistreri and Hillberry [2004] for a discussion of how these features can be calibrated in a CGE model). Once the economic data have been

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[38] These data are aggregated to desired product and regional levels using programs developed by Rutherford (2004).

aggregated into the sectors used in ADAGE and trade flows have been established, the state-level data can be aggregated into the regions used in ADAGE.

Additional data are occasionally used in the *US Regional* module of ADAGE to report policy impacts in terms of costs per household or changes in employment. Sources for these information include the following:

- **State-level population projections**—*State Population Projections Program*, U.S. Census Bureau.
- **State-level housing units—***Housing Units*, 2003, U.S. Census Bureau.
- **State-level employment**—*Income and Employment Tables*, U.S. Bureau of Economic Analysis (BEA). Tables SA05N, SA07N, SA25N, and SA27N—income and employment by industry.
- **National employment**—*Current Employment Statistics*, U.S. Bureau of Labor Statistics (BLS), Table B-12, employment by detailed industry for July 2004.
- **Trends in employment and households—***Annual Energy Outlook 2004* (EIA, 2004). Tables 4 and 116. Also U.S. Bureau of Labor Statistics (BLS) employment projections for 2012.

State-level population growth trends through 2025 from the Census Bureau are combined with existing housing unit data to estimate growth in the number of households. These results are then scaled to match AEO data (Table 4) on the total number of households in the United States. Detailed data on industry employment from the BLS are shared out to states using data on employment by state and industry from the BEA, which are then combined with industry and regional employment trends from the AEO (Table 116) and BLS employment projections to estimate national employment trends by industry. Regional employment estimates in the model then depend on regional industry output as determined by ADAGE.

4.3.1 Taxes in the US Regional Module

Attention has been paid to taxes in ADAGE because of the crucial role that tax distortions can play in determining the costs of a policy. If existing taxes drive a wedge between the cost of producing a good and the price paid for it, producer and household behaviors will be distorted, giving rise to an excess burden greater than the amount of revenue raised by the tax. Theoretical and empirical literature have examined these "tax interactions" and found they can substantially alter policy costs.[39] Given these potential impacts, it is important for ADAGE to consider how tax distortions may interact with policies when estimating economic impacts.

While the GTAP data used by the *International* module contain tax information (especially regarding international trade), additional consideration has been given to tax rates in the *US*

[39] See, for example, Goulder and Williams (2003), Goulder, Parry, and Burtraw (1997), Bovenberg and Goulder (1996), and Fullerton and Rogers (1993).

Regional module because it has subnational detail and also there is a greater availability of data on tax rates and their determinants for the United States than at the international level. In addition, there is more empirical literature regarding the expected effects of U.S. taxes on CGE model results to which the ADAGE results can be compared.

Similar to GTAP, the IMPLAN economic database includes some tax data, but they are not comprehensive and also do not necessarily contain the data needed to determine distortions associated with taxes. Consequently, several additional sources are used to provide data on U.S. federal and state tax rates by type:[40]

- **FICA taxes**—IMPLAN economic data. Average FICA tax rates by state.
- **Wage (and other forms of income) taxes**—*U.S. Federal and State Average Marginal Income Tax Rates*, NBER TAXSIM Model. Marginal wage, interest, dividend, and long-term capital gains tax rates by state for 2003 (including federal rates).
- **Corporate income taxes**—*State Corporate Income Tax Rates*, The Tax Foundation. Corporate (2004a) income tax rates by state for 2004. *Federal Corporate Income Tax Rates*, U.S. Internal Revenue Service (IRS) (2004), Publication 542 with rates for 2003.
- **Sales and indirect business taxes**—*State General Sales and Use Tax Rates*, The Tax Foundation, sales tax rates by state for 2003. Also IMPLAN economic data.

In the IMPLAN data, payments related to the Federal Insurance Contribution Act, or FICA, taxes (i.e., Social Security plus Medicare) appear as a direct claim on labor income by the U.S. government. However, IMPLAN follows National Income and Products Accounts (NIPA) conventions and reports factor payments at gross-of-tax values. Thus, the tax payments and receipts associated with personal income taxes and corporate taxes are reported merely as transfers between households and the government, showing average tax rates but not the related marginal tax rates. Behavioral distortions caused by existing taxes, however, are a function of marginal rates, rather than average rates. Marginal rates affect business (and household) behavior when they are deciding whether to produce (or purchase) an additional unit of a good, the types of factors to use, and how much to invest. Since these decisions can significantly influence policy costs, additional data on average marginal income tax rates (the tax rate paid, on average, on the last unit of income earned) are collected from other sources and included in ADAGE.

The effective tax rate on labor is a function of FICA taxes and personal income taxes (PIT). The IMPLAN data on FICA taxes (covering both worker and employer contributions) is thus combined with state-level data on average marginal PIT tax rates. These rates are based on information from the TAXSIM model at the National Bureau of Economic Research (Feenberg and Coutts, 1993). TAXSIM is a microsimulation model of U.S. federal and state income tax systems that estimates average marginal tax rates for wage income, interest and dividend

[40]Energy taxes are covered in Section 5.

income, and capital-gains income.[41] The TAXSIM wage tax rate is applied to labor earnings in the *US Regional* module, along with FICA taxes. Following Ballard et al. (1985), ADAGE treats FICA as an *ad valorem* tax on labor and Social Security benefits as lump-sum transfers to households.[42] Combining FICA taxes from the IMPLAN data with TAXSIM's average marginal wage tax rate gives a total labor tax rate of approximately 41 percent.[43] This is similar to the 40 percent figure often cited in literature and used in CGE models (e.g., Williams [1999], Goulder et al. [1999], Browning [1987]).

4.3.2 Structure of Capital Taxes in the US Regional Module

This section discusses how data on corporate income-tax rates are combined with the TAXSIM income-tax data to calculate effective capital taxes. Characterization of the cost of capital in a CGE model can have significant impacts on estimated policy costs because capital taxes are relatively distortionary, influencing how households save and invest. This, in turn, affects the amount of capital available for future production, which controls economic growth. Capital costs depend on many factors such as interest rates, capital depreciation, personal income tax rates (because households pay taxes on capital earnings) and property taxes. Characterization of a marginal effective tax rate (METR) on capital earnings needs to account for how corporate tax rates affect the cost of capital, how PIT paid on capital earnings influences capital costs, how economic depreciation of capital assets (which depends on asset type) alters costs, how corporate structures in different industries shape treatment of capital taxes, and how capital taxes vary across industries as a result of these interactions.

To incorporate these features, the *US Regional* module of ADAGE incorporates a user cost of capital structure based on the Fullerton and Rogers (1993) CGE model of tax policies (subsequently referred to as FR).[44] The approach allows explicit specification of the METR on capital as a function of its important components, most notably the relationship between PIT rates and the cost of capital. The FR documentation of how capital taxes were incorporated into their CGE model is relatively unique in its level of detail, both in terms of calculations and the associated data sources and parameter estimates. For these reasons, ADAGE uses a similar approach, although data used in the FR calculations have been updated where feasible.

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[41] See NBER TAXSIM Model at <http://www.nber.org/~taxsim/> for these average marginal effective income tax rates by income type and state.

[42] Sales/excise taxes are also modeled as ad valorem taxes on output and purchases by households.

[43] Average FICA payments in the IMPLAN data represent an approximately 13 percent tax rate, which takes into account phasing out of employee contributions above certain income levels.

[44] The theoretical basis for this approach has a long history. See Jorgenson (1963) for development of theory related to capital costs and investment behavior. See Auerbach (1983) for a review of the literature on the cost of capital and CGE modeling work by Ballard et al. (1985) for additional information.

The tables and equations below outline this approach, along with data sources, parameter estimates, and calculated METR by industry. Tables 4-1 and 4-2 define parameters used in the METR computations, followed by a discussion of the relevant equations as described by Fullerton and Rogers. Table 4-2 also presents some of the parameter values used and their sources. Other data sources and calculations are then described.

Table 4-1. Endogenous Variable Definitions

Parameter	Description
ρ_c^k	Corporate-sector gross-of-tax capital costs of type k
ρ_{nc}^k	Noncorporate sector gross-of-tax capital costs of type k
i	Nominal interest rate
r_c	Corporate sector discount rate (weighted average)
r_{nc}	Noncorporate sector discount rate (weighted average)
r_d	Discount rate on debt financing
r_{re}	Discount rate on retained earnings
r_{ns}	Discount rate on new shares
r_e	Discount rate on equity
w_k	Property tax rate on capital of type k
δ_k	Economic depreciation rate of capital of type k
z_c^k	Present value of depreciation allowance for corporate capital of type k
z_{nc}^k	Present value of depreciation allowance for noncorp capital of type k

For corporations, the cost of financing is a function of interest payments on debt, costs of retained earnings, and costs of new shares.[45] As a weighted average across financial instruments, the overall corporate discount rate can thus be expressed as

$$r_c = c_d r_d + c_{re} r_{re} + c_{ns} r_{ns} \tag{4.1}$$

and the noncorporate discount rate can be expressed as

$$r_{nc} = n_d r_d + n_e r_e. \tag{4.2}$$

[45] Following FR assumptions, ADAGE assumes that industries have fixed financial structures.

Table 4-2. Exogenous Variable Values

Variable	Description	Value	Source
r	Real interest rate	0.05	MIT EPPA model
π	Inflation rate	0.03	AEO 2004 (Table 20)
u_f	Statutory federal corporate tax rate	0.35	IRS Publication 542
u_s	Statutory state corporate tax rates	~0.06	The Tax Foundation
u	Statutory corporate tax rate (federal plus state)	~0.39	See Table 4-3 below
τ_{PIT}	Personal income tax rate	~0.29	NBER TAXSIM model
τ_d	Income tax rate on interest income (debt financing)	~0.28	NBER TAXSIM model
τ_{re}	Income tax rate on accrued capital gains (retained earnings)	~0.05	FR and NBER
τ_{ns}	Income tax rate on dividend income (new shares)	~0.28	NBER TAXSIM model
τ_{nc}	Income tax rate on noncorporate income (or PIT)	~0.29	NBER TAXSIM model
c_d	Proportion of corporate investment financed by debt	0.34	FR: Table 3-17
c_{re}	Proportion of corp. investment financed by retained earnings	0.33	FR: Table 3-17
c_{ns}	Proportion of corporate investment financed by new shares	0.33	FR: Table 3-17
n_d	Proportion of noncorporate investment financed by debt	0.34	FR: Table 3-17
n_e	Prop. of noncorp. investment financed by retained earnings	0.67	FR: Table 3-17

Arbitrage conditions among these rates of return will ensure that they are all equal on a net-of-tax basis, which implies that capital costs can be calculated from the net real return to holding debt [$r = i(1 - \tau_d) - \pi$] and leads to the following calculations. Because debt financing charges are deductible at the statutory corporate tax rate, firms pay the equivalent of the nominal interest rate excluding the statutory rate [$r_d = i(1 - u)$]. For retained earnings, the nominal net return is the corporation's discount rate, which is a function of taxes paid on debt and the tax rate applied to retained earnings [$r_{re} = i(1 - \tau_d)/(1 - \tau_{re})$]. Similarly, the nominal net return for new shares is a function of taxes paid on debt and on dividend earnings [$r_{ns} = i(1 - \tau_d)/(1 - \tau_{ns})$]. Eq. (4.3) presents these three components of the corporate discount rate, weighted by the shares of each in overall corporate financing:

$$r_c = c_d\left[i(1-u)\right] + c_{re}\left[i(1-\tau_d)/(1-\tau_{re})\right] + c_{ns}\left[i(1-\tau_d)/(1-\tau_{ns})\right]. \tag{4.3}$$

For firms with a noncorporate structure, interest payments are deductible at the personal income rate applied to equity earnings. Equity returns must equal the return to holding debt because of arbitrage conditions. Eq. (4.4) gives these two components of the noncorporate discount rate, which are weighted by the shares of each in overall noncorporate financing:

$$r_{nc} = n_d\left[i(1-\tau_{nc})\right] + n_e\left[i(1-\tau_d)\right]. \tag{4.4}$$

Using the arbitrage condition to determine the real return to capital, r, and simplifying the FR equations by assuming that the PIT is applied to equity returns of noncorporate firms implies that Eqs. (4.3) and (4.4) can be expressed as[46]

$$r_c = c_d\left[((r+\pi)/(1-\tau_{PIT}))(1-u)\right] + c_{re}\left[(r+\pi)/(1-\tau_{re})\right] + c_{ns}\left[(r+\pi)/(1-\tau_{ns})\right] \tag{4.5}$$

$$r_{nc} = n_d\left[(r+\pi)(1-\tau_{PIT})/(1-\tau_d)\right] + \mathrm{n}_e\left[(r+\pi)\right]. \tag{4.6}$$

After these real returns to capital have been determined, they can be incorporated into an expression of a firm's profit-maximization decision to determine gross-of-tax costs of capital, following the methodology of Hall and Jorgenson (1967) as described in Fullerton and Lyon (1988) and Fullerton and Rogers (1993). Eqs. (4.7) and (4.8), adapted from FR,[47] illustrate these calculations for each type of capital asset, k (equipment, structures, inventories, land, and intangibles such as knowledge). The capital costs are expressed as functions of real returns, inflation, depreciation, PIT, the present value of depreciation allowances (z, which is equal to allowances divided by allowances plus real net returns), and property taxes:

$$\rho_c^k = \frac{r_c - \pi + \delta_k}{1-u}\left(1 - uz_c^k\right) + \omega_k - \delta_k \tag{4.7}$$

$$\rho_{nc}^k = \frac{r_{nc} - \pi + \delta_k}{1-\tau_{PIT}}\left(1 - \tau_{PIT}\, z_{nc}^k\right) + \omega_k - \delta_k \tag{4.8}$$

METRs for capital can then be calculated for each asset class and corporate structure as the difference between the gross-of-tax capital cost (ρ) minus the net-of-tax cost (r) divided by the gross-of-tax cost. These METRs summarize the effects of all taxes applied to capital and characterize how changes in components of METRs will affect the cost of capital. Using these equations and the additional data sources discussed below, ADAGE develops a weighted average of the METR for each industry across all asset types and firm structures, based on the industry's share of corporate and noncorporate assets and associated types of capital.

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[46] τ_{re} is assumed to be equal to one quarter of the long-term capital gains rate, following Fullerton and Rogers (1993). This reflects the fact that taxes on capital gains can be postponed by not realizing the gains until a future date, thereby lowering the effective tax rate.

[47] The original FR equations included discounts for investment tax credits (since phased out).

Along with income tax data from the NBER TAXSIM model (for the variables τ_{PIT}, τ_{re}, τ_d, and τ_{ns}), information on corporate income taxes (u) and property taxes (w_k) is required in these equations. Data from the Tax Foundation on state-specific statutory corporate tax rates are combined with a federal statutory rate of 35 percent to determine region-specific corporate tax rates (see Table 4-3 for estimated rates at a regional level in ADAGE). Although the majority of states have only one tax bracket for corporations, some states have multiple brackets. The federal statutory tax rate also varies by income. In selecting the appropriate statutory rates, ADAGE is consistent with Fullerton (1987) and uses the top tax bracket in its calculations. In addition, it is necessary to assume that region-specific capital tax rates are applied to the capital earnings shown in the state-level IMPLAN data, given a lack of information on any differences between the location of earnings and the actual assessment of corporate taxes.

Table 4-3. Regional Income and Corporate Tax Rates

Region	PIT	Average State Corporate[a]	Combined State and Federal Corporate[b]
Northeast	31.4%	8.6%	40.6%
South	27.8%	6.0%	38.9%
Midwest	29.5%	6.2%	39.0%
Plains	26.8%	2.5%	36.6%
West	30.5%	6.9%	39.5%

[a]In these examples, the capital earnings in each state from the IMPLAN data are used to weight the corporate tax rates across states within these regions.

[b] The total statutory corporate tax rate, based on combined state plus federal corporate tax rates, is calculated according to the method used in Fullerton (1987) as federal (35 percent) + state * (1 – federal).

Calculations of average effective property tax rates are based on calculations from King and Fullerton (1984) and updated using NIPA data (U.S. BEA, 2004e) on state and local property tax receipts. These data are available as a total figure covering personal and business property taxes (equal to $254 billion). Information from King and Fullerton (1984) on the relative shares of business property taxes in total property taxes, separated into land and structures versus equipment and inventories, is used to apportion this total. Multiplying the shares by total property taxes and then dividing the resulting figure by total capital assets of each type (see Table 4-7) gives the property tax rates shown in Table 4-4 (along with depreciation data from Fullerton and Rogers, 1993).

In addition to updating tax rates, recent data sources are used to calculate existing capital assets by industry. The user cost-of-capital equations require data on five types of assets (equipment, structures, inventory, land, and intangibles) owned by two different types of firms (corporate and noncorporate). Data on equipment and structures owned by industries

Table 4-4. Property Taxes and Depreciation by Asset Type

Asset Type	Property Tax Rates	Economic Depreciation	Depreciation Allowance
Equipment	0.00574	0.1300	0.3400
Structures	0.00865	0.0300	0.1350
Inventories	0.00574	0.0000	0.0000
Land	0.00865	0.0000	0.0000
Intangibles	0.00000	0.2100	1.0000

Sources: Property tax rates—authors' calculations (see text). Depreciation rates and allowances—Fullerton and Rogers (1993).

are available from the U.S. Bureau of Economic Analysis (BEA, 2004c). However, these data do not distinguish asset values by corporate and noncorporate organizations. Thus, BEA data that separate out legal organization forms by broad industry category are employed (see Table 4-5).

Table 4-5. Corporate and Noncorporate Equipment and Structures Assets

Asset Type	Corporate	Noncorporate
Farms		
Equipment and software	11%	89%
Structures	7%	93%
Manufacturing		
Equipment and software	98%	2%
Structures	98%	2%
Nonfarm nonmanufacturing		
Equipment and software	86%	14%
Structures	69%	31%

Source: U.S. Bureau of Economic Analysis (BEA). 2004b. "Current-Cost Net Stock of Nonresidential Fixed Assets by Industry Group and Legal Form of Organization, Table 4-1." <http://www.bea.doc.gov/bea/dn/faweb/AllFATables.asp>.

Data on inventories and land assets come from two sources. The U.S. Census Bureau publishes asset data for inventory and land for selected mining and manufacturing industries in the *Quarterly Manufacturing Reports* (U.S. Census Bureau, 2001). Similarly, the U.S. Department of Agriculture estimates land assets in the agricultural sector in the *Agricultural Economics and Land Ownership Survey* (USDA, 2000). For most of the mining and manufacturing data, asset values are distinguished by corporate and noncorporate sectors using the Federal Reserve Board's *Flow of Funds Accounts* (see Table 4-6). In cases

Table 4-6. Corporate and Noncorporate Inventory and Land Assets

Asset Type	Corporate	Noncorporate
Inventories	75%	25%
Land	70%	30%

Source: Federal Reserve Board. 2004. *Flow of Funds Accounts of the United States*, Coded Tables for Z.1 Release. Tables B.102 and B.103. <http://www.federalreserve.gov/releases/Z1/20040115/Coded/coded.pdf>.

where updated information could not be identified, data from Fullerton and Rogers (1993) were used to estimate asset distributions.

For the final type of assets, intangibles, values are estimated using the methodology described in Fullerton and Lyon (1988). Development of intangible capital (i.e., knowledge or information) requires investment by firms, but these assets are treated differently than other types of assets (in part because there is no tangible asset to measure). The kinds of investments used to generate intangible capital include advertising expenditures, research and development (R&D), and expenses related to training and customer relations. Unlike other assets, these investments are usually deducted from business income immediately, instead of being depreciated over time. This preferential tax treatment has implications for capital tax rates that are accounted for by the FR user cost-of-capital approach.

Following Fullerton and Lyon (1988), intangible capital stocks are assumed to comprise the depreciated present values of advertising and R&D expenditures. The U.S. Internal Revenue Service publishes flows of advertising deductions by industry (U.S. IRS, 1995–2001). Implied capital stocks associated with these flows are computed using data for the period 1994 through 2000, based on an annual depreciation rate of 33 percent. Asset values connected to R&D expenditures are taken from the National Science Foundation's (NSF's) *Industrial Research and Development Information System*. Data by industry from 1980 to 2000 (NSF, 2001a and 2001b) are employed to estimate capital stock values using an annual depreciation rate of 15 percent. In the absence of other data, Fullerton and Lyon (1988) data are used to distribute these stocks between corporate and noncorporate sectors.

The combination of the tax rates and asset data above, along with general ADAGE assumptions about real interest rates (set at 5 percent, following the MIT EPPA model), are sufficient to allow calculation of the marginal effective tax rates on capital, based on Eqs. (4.1) to (4.8). Table 4-7 presents the results of the estimates of capital assets by industry and associated marginal tax rates for 30 industries (generally following NAICS industry classifications). The *US Regional* module of ADAGE then uses weighted averages of these rates across the relevant industries in a particular policy run, where the METR enters the model as a tax on capital earnings by industry. These estimated rates range from around 25 percent in industries such as computers that depend heavily on R&D assets

Table 4-7. U.S. Capital Stocks and Average Marginal Effective Tax Rates by Industry

Industry Group	Specific Industries	Percent of Total Capital Stock					Total Capital Stock in 2000 ($million)	Marginal Effective Tax Rate
		Equipment	Structures	Inventories	Land	Intangibles		
Non-Manufacturing	Agriculture	19.0%	25.0%	6.0%	49.9%	0.1%	$991,706	35.6%
	Construction	19.0%	8.9%	47.7%	22.6%	1.8%	$515,704	45.8%
	Mining	31.1%	55.3%	1.1%	11.5%	1.0%	$73,585	41.0%
	Services	29.6%	51.9%	3.3%	8.6%	6.5%	$7,253,948	38.9%
	Transportation Services	32.5%	39.8%	2.3%	24.7%	0.8%	$988,119	40.1%
Manufacturing	Food	33.3%	27.2%	16.6%	2.0%	20.9%	$255,506	37.7%
	Beverages and Tobacco	25.8%	21.1%	12.8%	1.6%	38.7%	$75,608	32.0%
	Textile Mills	41.9%	38.4%	12.8%	0.5%	6.3%	$25,574	42.1%
	Textile Product Mills	41.9%	38.4%	12.8%	0.5%	6.3%	$13,529	42.1%
	Apparel	38.1%	34.9%	11.6%	0.5%	14.9%	$32,771	39.6%
	Leather	24.1%	41.2%	13.1%	0.5%	21.2%	$4,641	38.0%
	Lumber and Wood	34.6%	35.4%	16.5%	10.1%	3.5%	$48,957	43.5%
	Paper	53.0%	19.9%	11.4%	8.4%	7.4%	$150,607	42.0%
	Printing and Publishing	44.6%	32.8%	10.8%	2.6%	9.3%	$94,167	41.3%
	Chemicals	30.0%	20.9%	12.1%	1.7%	35.4%	$481,973	34.0%
	Rubber and Plastic	45.1%	24.8%	15.9%	1.4%	12.8%	$102,290	40.5%
	Nonmetallic Minerals	44.5%	28.6%	12.7%	7.8%	6.4%	$82,916	42.4%
	Primary Metals	49.9%	29.6%	13.6%	3.6%	3.2%	$171,545	43.2%
	Fabricated Metal	46.2%	24.9%	16.3%	1.3%	11.3%	$133,914	40.9%
	Machinery	27.9%	20.7%	15.4%	1.1%	34.9%	$136,837	34.3%
	Computer and Elec Equipment	16.1%	12.0%	8.9%	0.6%	62.4%	$383,811	26.3%
	Electronic Equipment	36.0%	26.7%	26.7%	1.5%	9.0%	$277,762	42.0%
	Transportation Equipment	23.8%	15.7%	20.4%	1.0%	39.1%	$427,302	33.7%
	Furniture	25.1%	33.2%	23.8%	2.0%	15.9%	$28,633	39.9%
	Miscellaneous	8.3%	8.5%	26.1%	1.5%	55.6%	$96,769	28.9%
Energy	Coal	32.4%	52.2%	1.2%	13.1%	1.0%	$54,431	41.2%
	Crude Oil	12.7%	80.1%	0.6%	6.2%	0.5%	$508,043	40.3%
	Electricity	20.8%	50.2%	2.2%	26.6%	0.3%	$1,096,476	40.0%
	Natural Gas	11.3%	58.2%	2.1%	28.0%	0.4%	$363,872	39.7%
	Petroleum Refining	26.8%	35.9%	10.4%	16.6%	10.3%	$156,400	43.2%

(which can be deducted from business profits immediately) to more than 40 percent in sectors such as primary metals where assets mainly comprise equipment and structures that receive less favorable tax treatment. Most industries have METRs of around 40 percent, which is similar to what is typically assumed in CGE modeling of tax distortions (e.g., Goulder et al. [1999]).[48]

4.4 Labor Supply Decisions of Households and Interactions with Tax Distortions

As discussed above, economic literature has found that interactions between the distortions caused by an existing tax structure and a new economic policy can substantially alter estimated policy costs, implying that these distortions need to be carefully considered in a CGE model. The extent of the distortions associated with taxes are a function of both the marginal tax rates in the model and the labor-supply decisions of households. Thus, similar to CGE models focused on interactions between tax and environmental policies (e.g.,

[48]As noted in Fullerton (1987), METR tend to show less variation across industries than average tax rates. Thus, use of METR will imply lower overall distortions from capital taxes in a CGE model than average rates.

Bovenberg and Goulder [1996], Goulder and Williams [2003]), an important feature of ADAGE is its inclusion of a labor-leisure choice—how people decide between supplying labor to businesses and leisure time.

Labor-supply elasticities related to this choice determine, to a large extent, how distortionary taxes are in a CGE model. If households are very willing to switch between leisure and work in response to changes in wages, existing labor taxes will have significantly distorted economic behavior from what would have occurred in the absence of the taxes, implying a large excess burden for labor taxes, and the reverse if households are not willing to substitute leisure time for work (and hence consumption goods). Existing taxes on labor income have two effects on labor supply: a *substitution effect*—a reduction in the amount of labor available for production because they lower income received by households providing the labor and an *income effect*—an increase in work effort because taxes have lowered overall income levels. The interaction of these two effects is an empirical question.

Russek (1996) reviews the relevant empirical literature, which cites estimates for total labor supply elasticities (covering women and men) ranging between –0.1 and 2.3. Fuchs, Krueger, and Poterba (1998) also review estimated elasticities with similar findings. Following these findings, the values for labor-supply elasticities most commonly used in CGE models are in the mid-point of this range—typically around 0.4 for compensated elasticities and 0.15 for uncompensated elasticities (e.g., Parry and Bento [2000], Williams [1999], Goulder, Parry, and Burtraw [1997], Bovenberg and Goulder [1996]).

The selection of labor-supply elasticities must also take into consideration their implications for measurements of the distortions caused by the existing tax structure in the CGE model. These distortions are typically measured in two ways: marginal cost of funds (MCF) and marginal excess burden (MEB) (see Bovenberg, Goulder, and Gurney [2003]). MCF is the cost of raising an additional dollar of government revenue in terms of household income, where government-supplied public goods are separable from household utility. MEB is the same cost assuming that the tax revenue is returned to households in a lump-sum fashion, rather than being spent on public goods. Both measures attempt to quantify efficiency costs associated with taxes (i.e., how taxes have caused households to alter their behavior in ways that reduce household welfare).

Ground-breaking CGE modeling by Bovenberg and Goulder (1996) on interactions between environmental policies and existing tax structures estimates MCF for PIT as ranging between 1.24 and 1.29. This implies it costs around $1.25 in welfare terms (as measured by Hicksian equivalent variation) to raise an additional dollar of government income through the PIT. Distortions associated with corporate taxes are typically higher, but an accepted empirical range is less well established and most literature focuses on income taxes. MEB estimates presented in the CGE literature are generally around 0.3 (measured as the incremental cost of raising taxes and then returning the revenue to households).[49]

Labor supply elasticities have been chosen for ADAGE such that measurements of MCF and MEB in the *US Regional* module are similar to these estimates (for consistency and due to a lack of estimates for international regions, the same elasticities are applied to all regions in the ADAGE model). To estimate MEB and MCF in ADAGE, equal-yield constraints on government income have been included in the model. These equations allow the model to replace an existing tax instrument with an alternative approach that raises the same amount of revenue—or maintains a given level of utility. Following Ballard et al. (1985), the equal-yield constraints in ADAGE are modeled as ensuring equal purchasing power for the government at the new prices prevailing under the alternative tax policy.[50]

Based on these calculations and the elasticity estimates from the other CGE models mentioned above, in ADAGE the compensated labor-supply elasticity (η_c) is set at 0.35 and the uncompensated labor-supply elasticity (η_{uc}) is set at 0.15. These choices imply that the elasticity between consumption goods and leisure (σ_{cl} in Figure 2-1) is approximately 0.85 (see Ballard [1999]). The MEB associated with these choices is 0.31. The various MCF for different types of taxes include across all taxes of 1.22, personal income taxes of 1.24, and corporate income taxes of 1.30.[51]

5. ENERGY DATA IN ADAGE

When investigating environmental and climate-change mitigation policies, the GTAP and IMPLAN economic data in ADAGE are supplemented with additional information on energy consumption and production for several reasons. First, when the policies under consideration focus on energy markets, it is essential to include the best possible characterization of these markets in the model, and the GTAP and IMPLAN economic data do not always agree with energy information collected by IEA and EIA. Second, physical quantities of energy consumption are required for ADAGE to accurately estimate GHG emissions. IEA and EIA report physical quantities, while the economic databases do not. Finally, the economic data sources, GTAP and IMPLAN, reflect the years 2001 and 2000, respectively, while the initial baseline year for ADAGE is 2005. Thus, WEO and AEO energy production and consumption, output, and economic-growth forecasts for 2005 are used to adjust these data to reflect the 2005 baseline year for the model.

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[49] See, for example, Goulder et al. (1999), Goulder, Parry, and Burtraw (1997), Browning (1987), and Ballard et al. (1985).

[50] This avoids the need to specify a utility function for the government and limits the number of utility-maximizing agents in the model (which simplifies results interpretation).

[51] These results are based on all interactions among economic data, tax rates, CES production functions, and production and consumption elasticities, measured at the baseline solution in ADAGE. As noted in Bovenberg and Goulder (1996), the appropriate equilibrium at which to measure MCF is a post-policy equilibrium, so the MCF will also depend on the policy in question.

This section discusses the relevant energy data sources needed to develop balanced energy markets for ADAGE (in physical units and value terms) and how these data are integrated with the economic data in the model. Note that, as with the economic data, all energy data used in the United States' region of the *International* module in ADAGE come from discussions pertaining to the *US Regional* module (see Section 5.2), rather than the international data sources. This may introduce some inconsistencies between the energy forecasts used for the United States and those for other nations—to the extent that the WEO forecasts for the United States differ from the AEO forecasts. However, the approach maintains internal consistency within ADAGE and allows results from the *International* module to be applied to regions/states within the United States, which has been deemed the preferable option since a single forecast covering both U.S. states and international countries is not available.

5.1 *International* Module

The first step in balanced markets for the energy goods in ADAGE (coal, crude oil, electricity, natural gas, and refined petroleum) is to collect historical data on production, consumption, and trade. IEA provides these data for the year 2002 in physical units for a wide range of countries. This information is then combined with other IEA data on energy prices and associated taxes[52] to convert the physical units into value terms for the SAM used by the CGE model. International bilateral trade flows needed to balance world energy markets are also estimated, based on IEA historical data on trade patterns.

The necessary energy data for this process have been collected for 32 individual countries and 6 regions covering the rest of the world from the following publications (these data are aggregated to include the specific regions of interest in each policy investigation):

- **Energy Production and Consumption**: *Energy Balances of OECD Countries, 2001–2002*, and *Energy Balances of Non-OECD Countries, 2001–2002*, IEA (2004c, 2004d). National energy production, exports, imports, and consumption by sector and fuel type.
- **Energy Prices**[53]
  - *Energy Prices and Taxes*, IEA (2004e): Energy prices and tax rates by fuel and consumer. Also energy price indices by country and consumer and fuel import/export prices.
  - *International Fuel Prices 2003/2005* (Metschies, 2003/2005): International prices for diesel fuel and gasoline. (Tax rates from *International Fuel Prices 2003*).
  - *Beijing Energy Efficiency Center*: Data on China's coal and gasoline prices.
  - *Developing China's Natural Gas Markets* (IEA): China natural gas prices.
  - *Asian Development Bank Country Tables* (ADB): Supplemental price data.

[52]These tax rates are maintained at existing rates in the future in ADAGE, unless they are specifically designated to be phased out.

[53]See Dimaranan and McDougall (2002) and Malcolm and Babiker (1998) for discussions of most of these data sources and their use in developing the GTAP-E database.

- – *International Energy Annual 2002*, EIA: Additional price information.
- **Energy Trade**: *Coal Information 2004*, *Electricity Information 2004*, *Natural Gas Information 2004*, and *Oil Information 2004*, IEA (2004a, 2004b, 2004f, 2004g). Bilateral energy trade flows from IEA online data service.

Once historical data have been collected, forecasts from WEO are used to advance the representation of the energy markets to the base year in ADAGE of 2005 (these forecasts are subsequently used to provide business-as-usual growth paths for energy production, consumption and prices in the model):

- **Energy Consumption and Electricity Production**: *World Energy Outlook 2004*, IEA (2004h). National energy consumption by economic sector and electricity generation by type.
- **Nonelectricity Energy Production**: National forecasts from IEA (online data service and the *WEO 2004*).
- **Energy Prices**: *World Energy Outlook 2004*, IEA (2004h). World crude oil prices, and U.S. domestic prices, from *Annual Energy Outlook 2004* (EIA, 2004).

In addition to replacing U.S. energy data from IEA with information from the data sources described in Section 5.2, price forecasts for crude oil in all ADAGE modules are taken from the *Annual Energy Outlook* to improve consistency across model components. *WEO 2004* shows crude oil prices of $22 and $26 per barrel in 2010 and 2020, respectively. *AEO 2004* has prices of $24 and $26 per barrel in 2010 and 2020. By 2025, the AEO 2004 crude oil price is $27 per barrel, compared with approximately $27.50 in *WEO 2004*.

5.2 *US Regional* Module

Data on current and future state-level production and consumption of energy, and associated prices, are developed from a variety of EIA publications, as discussed below. In general, the process involves building up data on energy markets from state-level historical data and projecting this information along regional forecasts from the AEO.

5.2.1 U.S. Energy Production Data

This section discusses energy production data for the five types of energy in the model.

Coal Production. Coal production data are developed from historical state-level production data, while trends in production and prices come from AEO. Data sources include the following:

- **State-Level Coal Production**: *Annual Coal Report 2002* (EIA, 2002), Table 6. Production by state and coal rank.
- **Trends in Production and Prices**: *Annual Energy Outlook 2004* (EIA, 2004), Tables 111 and 112.
- **Coal Energy Content***:* *Assumptions to AEO 2004* (EIA, 2004), Table 71. Heat content per ton of coal by coal rank.

Following the historical data from the *Annual Coal Report*, trends for production and prices for each state are based on projections from the *Annual Energy Outlook*. In establishing these trends, each state is assigned to the most closely related coal-production region in the AEO forecasts according to the following scheme:[54]

- Northern Appalachia—MD, OH, PA
- Central Appalachia—KY, VA, WV
- Southern Appalachia—AL, TN
- Eastern Interior—IN, IL
- Western Interior—AR, KS, MO, OK
- Gulf Lignite—LA, MS, TX
- Dakota Lignite—ND
- Power and Green River Basins—MT,[55] WY
- Rocky Mountain—CO, UT
- Southwest—AZ, NM
- Northwest—AK, WA

These trends are applied at a coal-rank level before being aggregated to a single type of coal in each producing state prior to entering ADAGE. Regional minemouth prices from AEO are used to establish the value of coal output in each state because many of the state-level minemouth prices in the *Annual Coal Report* are withheld. Federal excise taxes on coal production from the Tax Foundation of between $0.55 and $1.10 per ton are then added to these prices. Units are converted from tons of coal to heat content (Btu) prior to entering the model.

Crude Oil and Natural Gas Production. Unlike the methodology used for coal, crude oil and natural gas production data are developed from AEO regional data to improve the fit with AEO forecasts (historical state-level production data are used to allocate state's shares of regional production), while trends in production and prices come from AEO. Data sources include the following:

- **State-Level Crude Oil Production**: *Petroleum Supply Annual 2003* (EIA, 2003), Table 14. Production by state in 2003 (barrels).
- **Regional Crude Oil Production**: *Annual Energy Outlook 2004* (EIA, 2004), Table 101. Lower 48 states' production in EIA's *Oil and Gas Supply Model* regions.
- **State-Level Natural Gas Production**: *Natural Gas Annual 2002* (EIA, 2002), Table 6. Production by state in 2002 (MMCF).
- **Regional Natural Gas Production**: *Annual Energy Outlook 2004* (EIA, 2004), Table 102. Lower 48 states' production by EIA Oil and Gas Supply Model regions.

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[54] States not shown do not produce coal.

[55] Trends in Montana lignite production and prices are based on the Dakota region of EIA's *Coal Market Module*.

- **Trends in Production and Prices**: *Annual Energy Outlook 2004* (EIA, 2004), Tables 1, 101, and 102.
- **Crude Oil and Natural Gas Energy Content**: *Annual Outlook 2004* (EIA, 2004), Appendix H. Conversion factors for production.

In establishing state-level production and prices, each state is assigned to the most closely related Oil and Gas Supply Model (OGSM) region in the AEO forecasts according to the following scheme:[56]

- Northeast—IL, IN, KY, MD, MI, NY, OH, PA, TN, VA, WV
- Gulf and Southwest—AL, FL, LA, MS, NM, TX
- Mid-continent—AR, KS, MO, NE, OK
- Rockies—AZ, CO, MT, ND, NV, SD, UT, WY
- West coast—CA, OR
- Alaska—AK[57]
- Offshore (lower 48 states)

To ensure that total U.S. production corresponds with AEO forecasts, state-level production is used to share out AEO regional production. AEO's regional wellhead prices for natural gas are used to determine marketed values of states' natural gas production, while AEO's world crude oil price forecast is used to determine the value of crude oil production (this assumption reflects the ADAGE model assumption of a uniform world crude oil price). When determining trends, the Southwest and Gulf regions in OGSM are combined because they divide Texas, one of the most important producing regions, in half. In the *US Regional* module, offshore production in the lower 48 states, which represents around 25 percent of natural gas production and 35 to 50 percent of crude oil production from the lower 48 states, is modeled as a separate region covering all offshore production since it is not contained within state borders.[58] Prior to determining retail natural gas values, distribution costs are added into these wholesale values.

Electricity Generation. Electricity data are developed from historical state-level data, while trends in production, fuel use, and prices come from AEO. Data sources include the following:

- **Electricity Generation**: *Electric Power Annual 2002* (EIA, 2002), historical spreadsheet. Generation by state, type of producer, and energy source. 1990–2002.

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[56]States not shown do not produce crude oil or natural gas.

[57]Data for Alaska are not shared out from regional AEO data.

[58]Although economic data typically combined crude oil and natural gas extraction since they are, to a certain extent, joint products, ADAGE separates them into separate industries to prevent the model from allowing imports of crude oil to be reclassified as natural gas.

- **Electricity Fuel Consumption**: *Electric Power Annual 2002* (EIA, 2002), historical spreadsheet. Fossil-fuel consumption by state and type of producer (coal, natural gas, and oil).[59]
- **Electricity Prices**: *Electric Power Annual 2002* (EIA, 2002), historical spreadsheet. Sales and revenue data by state.
- **Renewable Generation**: *Renewable Energy Annual 2002* (EIA, 2002), Tables C4 and C6. Renewable generation by state and type (geothermal, hydroelectric, municipal solid waste [MSW], biomass, solar, wind, and wood).
- **Trends in Generation, Fuel Use, and Prices**: *Annual Energy Outlook 2004* (EIA, 2004), Tables 60–89.

At the state level, generation and fossil-fuel consumption and fuel prices for the electricity industry are determined from historical data in the *Electricity Power Annual*. In ADAGE, this industry covers electric utilities, independent power producers (IPPs), and combined heat and power (CHP) intended for electric power.[60] Average state-level electricity prices are calculated as electricity revenues by state (2002$) divided by electricity sales (kWh). These prices are combined with total state-level generation to determine revenues associated with the electricity industry in each state.[61]

Following the historical data from the *Electricity Power Annual* and *Renewable Energy Annual*, trends for generation, fuel use, and prices for each state are based on projections from the *Annual Energy Outlook*. In establishing these trends, each state is assigned to the most closely related NERC region in the AEO forecasts according to the following scheme:[62]

- ECAR—IN, KY, MI, OH, WV
- ERCOT—TX
- MAAC—DC, DE, MD, NJ, PA
- MAIN—IA, IL, MO, WI
- MAPP—MN, ND, NE, SD
- NY—NY
- NE—CT, MA, ME, NH, RI, VT
- FRCC—FL
- SERC—AL, AR, GA, LA, MS, NC, SC, TN, VA
- SPP—KS, OK
- NPPA—ID, MT, NV, OR, UT, WA, WY
- RMPA—AZ, CO, NM

[59]Coal use in short tons, natural gas use in million cubic feet, and oil use in barrels are converted to Btus with conversion factors from AEO 2004, Appendix H, for electric utilities.

[60]CHP for commercial and industrial power, and its fuel use, is captured by industry-specific data in the model.

[61]As such, these revenues cover generation, transmission, and distribution costs to be consistent with the definition of the NAICS 2211 electric utility industry that is used in ADAGE.

[62]AK and HI trends are assumed to follow average U.S. growth paths.

- CA—CA

Trends for each state are based on projections for these associated NERC regions. Future growth in renewable generation shown in the AEO for these NERC regions (with the exceptions of ERCOT, NY, FRCC, and CA that encompass a single state) is shared out across states within regions according to the state's historical shares of each generation type.

Refined Petroleum Production. In general, petroleum refining is tracked at the PADD level (Petroleum Administration for Defense Districts), rather than state level, which necessitates a difference methodology for determining state-level production quantities and values. Data sources include the following:

- **Refinery Capacity (historical)**: *Petroleum Supply Annual 2003, Volume 1*, or PSA 2003 (EIA), Table 36. Capacity by state (barrels per calendar day).
- **Imports and Exports of Refined Petroleum Products**: *PSA 2003*, Tables 20 and 27. Imports and exports (barrels).
- **Output Quantities and Prices, Trends, and Capacity Additions/Utilization**: *Annual Energy Outlook 2004* (EIA), Tables 1, 2, 3, and 90–99.

In determining state-level refinery capacity, PADD regions are used, which are defined along the following state lines:

- PADD I—CT, DC, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, PA, RI, SC, VA, VT, WV
- PADD II—IA, IL, IN, KS, KY, MI, MN, MO, ND, NE, OH, OK, SD, TN, WI
- PADD III—AL, AR, LA, MS, NM, TX
- PADD IV—CO, ID, MT, UT, WY
- PADD V—AK, AZ, CA, HI, NV, OR, WA

Historical state-level refinery capacity data from the *PSA 2003* are combined with PADD-level capacity additions forecasts from the AEO. These capacity additions are assumed to be distributed across states within each PADD according to historical capacity shares. State-level refinery capacity forecasts are then combined with AEO forecasts for PADD-level capacity utilization rates to determine an "effective" capacity in each state over the 2000 through 2025 time horizon.

National output of refined petroleum by type of product, measured in either barrels or energy content (Btus), can be determined from data in the AEO forecasts. This is accomplished by using the equation: output equals total consumption (AEO, Table 2) plus exports minus imports (AEO, Table 1), where trade in specific types of petroleum is estimated by combining overall imports and exports from the AEO with data on current petroleum trade by product from *PSA 2003*, Tables 20 and 27. However, the wholesale value of production is more difficult to measure from AEO data because energy prices in AEO Table 3 are delivered prices that include taxes and distribution costs. Also, wholesale prices for different types of petroleum vary across grades because some, such as motor gasoline, command higher prices than other grades of petroleum. Consequently, to determine state-level wholesale values of petroleum products, it is first assumed that the mix of petroleum products refined from each barrel of crude oil is uniform across parts of the country. This allows national production quantities by type of oil to be shared out across states using the "effective" capacity forecasts discussed above (consumption of crude oil by refineries—AEO Table 1—is assigned to states using the same process). After this step, regional wholesale prices from AEO Tables 90 through 100 can be used to establish an overall wholesale value of petroleum production in each state, excluding taxes and distribution costs. When determining retail petroleum values, distribution costs and taxes (AEO Tables 90 through 99 and Table 5-1 below) are added back into wholesale values.

5.2.2 U.S. Energy Consumption Data

This section discusses energy consumption data for the five types of energy goods in the model. In general, EIA provides consumption information on four classes of energy consumers—residential, commercial, industrial, and transportation—which are adjusted as necessary to match sectors in ADAGE. The residential sector gives household energy use but only includes energy consumption for household appliances, heating, etc., and, thus, has to be combined with other EIA consumption data related to private transportation to match ADAGE. The commercial sector contains energy data on service-providing facilities and equipment, which corresponds to service industries (with the exception that government buildings are included in the commercial sector). The industrial sector covers energy use by manufacturing facilities and provides some industry-specific data. The transportation sector covers all energy use by vehicles whose primary purpose is moving people and goods (household and military fuel use in this sector is assigned to the appropriate sectors in ADAGE).

Household Consumption. Household energy consumption data are developed by combining historical state-level consumption data with national forecasts from AEO. Data sources include the following:

- **State-Level Energy Consumption**: *State Energy Data 2000 Consumption* (EIA) and *State Energy Data 2000 Price and Expenditure* (EIA). Residential energy consumption in physical units, energy content, expenditures, and prices ($/MMBtu) for the year 2000.
- **Electricity Demand**: *Electricity Power Annual 2002* (EIA), historical spreadsheet. Demand by state and type of consumer, 1990–2002.
- **Population Growth**: *Decennial Census and Population Surveys 2004* (Census Bureau), population estimates through 2025.
- **Trends in Consumption and Prices**: *Annual Energy Outlook 2004* (EIA). Tables 2, 3, 34, 60–72, 90–99, 105, and 106.

The process for estimating state-level electricity demand by households follows a process similar to establishing state-level electricity generation. Historical data from the *Electricity Power Annual* on sales in each state to different types of customer are combined with AEO's

NERC-level forecasts for demand growth and prices (Tables 60 through 72) to get future demand for and the value of electricity purchases by households.

In determining state-level consumption of natural gas by households (and by other sectors discussed in the following sections), AEO data from Tables 105 and 106 are used, which contain gas consumption and delivered price estimates by sector. These data are provided at a Census region level, defined along the following state lines:

- New England—CT, ME, MA, NH, RI, VT
- Middle Atlantic—NJ, NY, PA
- East North Central—IL, IN, MI, OH, WI
- West North Central—IA, KS, MN, MO, NE, ND, SD
- South Atlantic—DC, DE, FL, GA, MD, NC, SC, VA, WV
- East South Central—AL, KY, MS, TN
- West South Central—AR, LA, OK, TX
- Mountain—AZ, CO, ID, MT, NM, NV, UT, WY
- Pacific—AK, CA, HI, OR, WA

To estimate natural gas consumption by households in each state, current consumption by households from the *State Energy Data Reports* is combined with each state's expected population growth from the Census Bureau. The combination of these data is used to share out AEO's residential gas consumption data (Table 105), available at a Census-region level, to account for the existing distribution of consumption and any future changes across states as the result of population growth. This energy consumption is multiplied by estimated delivered prices from AEO Table 106 to determine the value of household gas purchases.

For the other types of energy used by households (coal and refined petroleum), the AEO mainly provides national estimates of consumption and prices, rather than Census or NERC region estimates. A similar process is used to determine state-level consumption of these types of energy, based on historical data from the State Energy Data reports and AEO forecasts. Coal use by households is relatively minor. Any coal consumption in the AEO data (Table 2) is shared out across states according to the historical data and price trends that come from the AEO forecasts (Table 3). National petroleum use by households includes both residential use of heating oil (AEO Table 2) and use of motor gasoline (AEO Table 34—light-duty, noncommercial use of motor gasoline). The process for sharing out this petroleum use to states depends on historical state-level data for both residential and transportation use of oil, weighted by expected population growth, and scaled to match national totals. State-level price differences are maintained by extending each state's historical petroleum prices along national forecast paths from the AEO. Similarly, state motor gasoline tax rates (see Table 5-1) are extended along AEO's Census region forecasts

Table 5-1. Gasoline Taxes by State: 2003

State	Cents per Gallon	State	Cents per Gallon	State	Cents per Gallon
Alabama	16.0	Kentucky	15.0	North Dakota	21.0
Alaska	8.0	Louisiana	20.0	Ohio	24.0
Arizona	18.0	Maine	24.6	Oklahoma	16.0
Arkansas	21.5	Maryland	23.5	Oregon	24.0
California	18.0	Massachusetts	21.5	Pennsylvania	12.0
Colorado	22.0	Michigan	19.0	Rhode Island	30.0
Connecticut	25.0	Minnesota	20.0	South Carolina	16.0
Delaware	23.0	Mississippi	18.0	South Dakota	16.0
District of Columbia	20.0	Missouri	17.0	Tennessee	20.0
Florida	13.9	Montana	27.0	Texas	20.0
Georgia	7.5	Nebraska	24.6	Utah	24.5
Hawaii	16.0	Nevada	23.0	Vermont	19.0
Idaho	25.0	New Hampshire	18.0	Virginia	17.5
Illinois	30.0	New Jersey	10.5	Washington	28.0
Indiana	18.0	New Mexico	17.0	West Virginia	20.5
Iowa	20.0	New York	32.7	Wisconsin	28.5
Kansas	24.0	North Carolina	24.2	Wyoming	14.0

Source: The Tax Foundation. State Gasoline Tax Rates. Rates as of December 31, 2003. <http://www.taxfoundation.org/variousrates.html>.

for state tax rates (Tables 90 through 99). Diesel and jet-fuel tax rates for the transportation services sector also come from AEO Tables 90 through 99.

Manufacturing. Energy consumption by manufacturing industries is included in the industrial sector in EIA's historical data. At the national level, the AEO provides consumption by specific industries. Developing an estimate of energy consumption by different types of manufacturers involves the following data sources:

- **State-Level Energy Consumption**: *State Energy Data 2000 Consumption* (EIA) and *State Energy Data 2000 Price and Expenditure* (EIA). Industrial-sector energy consumption in physical units, energy content, expenditures, and prices ($/MMBtu) for the year 2000.
- **Industry-Specific Energy Consumption**: *Manufacturing Energy Consumption Survey 2002*, or MECS (EIA), and *Annual Energy Outlook 2004* (EIA), Tables 24–32.
- **Trends in Consumption and Prices**: *Annual Energy Outlook 2004* (EIA). Tables 2, 3, 24–32, 60–72, 105, and 106.

AEO forecasts provide energy consumption data for the following manufacturing sectors of the economy at the national level (Tables 24 through 32):

- food
- paper
- chemicals
- glass cement
- iron and steel
- aluminum
- petroleum refining
- agriculture
- construction
- mining
- metal-based durables
- other manufacturing

With the exceptions of mining, metal-based durables, and other manufacturing that cover multiple industries, the energy consumption data for these sectors is maintained in ADAGE. The mining sector covers coal, crude oil, natural gas extraction, and other types of mining. IMPLAN data on output of these sectors are used to share out energy consumption data, implying identical energy consumption per unit of output for these four industries. Historical MECS data on energy consumption industry and type of fuel are used to share out the metal-based durables and other manufacturing energy data to specific industries not covered in AEO forecasts.

To estimate state-level energy consumption by different industries, historical data from the *State Energy Data Reports* on industrial energy consumption (the industrial category in EIA data covers all manufacturing) are combined with energy consumption per unit of output from AEO forecasts and IMPLAN data on state-level output in the year 2000 (for energy industries, excluding electricity, the calculated energy production discussed above is used). First, the AEO energy consumption per unit of output data is applied to the IMPLAN data on output. These results are then scaled to match historical energy consumption by the industrial sector in each state to maintain differences in energy efficiency across the United States. Finally, for consistency with AEO forecasts, these state-level estimates are scaled to match AEO total energy consumption for the industries discussed above. Energy prices for manufacturing sectors are established by extending historical industrial prices along the AEO forecasts.

Service Sector and Transportation Services. Energy consumption by service and transportation industries is included in the commercial and transportation sectors in EIA's historical and forecast data (excluding government consumption as discussed in the following subsection). Developing an estimate of energy consumption involves the following data sources:

- **State-Level Energy Consumption**: *State Energy Data 2000 Consumption* (EIA) and *State Energy Data 2000 Price and Expenditure* (EIA). Commercial-sector energy consumption in physical units, energy content, expenditures, and prices ($/MMBtu) for the year 2000.
- **Trends in Consumption and Prices**: *Annual Energy Outlook 2004* (EIA). Tables 2, 3, 34, 60–72, 105, and 106.

The process for estimating state-level electricity demand by the services and transportation industries follows a process similar to establishing state-level electricity generation. Historical data from the Electricity Power Annual on sales in each state to different types of customers is used to share out AEO's NERC-level forecasts for demand in kilowatt hours and values (Tables 60 through 72).

To estimate natural gas consumption by the service and transportation industries in each state, current consumption from the *State Energy Data Reports* is combined with each state's expected population growth from the Census Bureau. The combination of these data is used to share out AEO's commercial and transportation gas consumption data, available at a Census-region level, to account for the existing distribution of consumption and any future changes across states as the result of population growth. This energy consumption is multiplied by estimated delivered prices from AEO Table 106 to determine the value of these natural gas purchases.

For coal and refined petroleum used by the service and transportation industries, the AEO provides national estimates of consumption and prices, rather than Census or NERC region estimates. A similar process is used to determine state-level consumption of these types of energy, based on historical data from the *State Energy Data Reports* and AEO forecasts. Coal use by these industries is relatively minor. Any coal consumption in the AEO data for these industries (Table 2) is shared out across states according to the historical data, and price trends come from the AEO forecasts (Table 3). National petroleum use by these industries comes from AEO Tables 2 and 34 (excluding household use of motor gasoline). The process for sharing out petroleum use to states depends on historical state-level data for commercial and transportation use of oil, weighted by expected population growth and scaled to match national totals. State-level price differences are maintained by extending each state's historical petroleum prices along national forecast paths from the AEO.

Government. Government energy consumption is included in the commercial sector in EIA's historical and forecast data and must be separated from energy use by service industries. Developing an estimate of government consumption involves the following data sources:

- **State-Level Energy Consumption**: *State Energy Data 2000 Consumption* (EIA) and *State Energy Data 2000 Price and Expenditure* (EIA). Commercial-sector energy consumption in physical units, energy content, expenditures, and prices ($/MMBtu) for the year 2000.

- **Government Building Energy Demand**: *Commercial Buildings Energy Consumption Survey*, or CBECS, (EIA), Table 1. Energy use by government and nongovernment buildings.
- **Military Fuel Use and Trends in Consumption and Prices**: *Annual Energy Outlook 2004* (EIA). Tables 2, 3, 34, 60–72, 105, and 106.

The CBECS data are used to separate AEO's commercial energy use (Table 2) into government and service-sector energy use. This is combined with delivered energy prices to the commercial sector (AEO Table 3) and military fuel consumption (AEO Tables 3 and 34) to determine national governmental energy use and expected trends. Historical data on state-level commercial-sector energy consumption are then used to determine state shares of the national total energy use. Similar to the process for other sectors, for electricity and natural gas consumption, the AEO NERC-region and Census-region data are used to establish prices and consumption trends.

5.2.3 U.S. Energy Trade

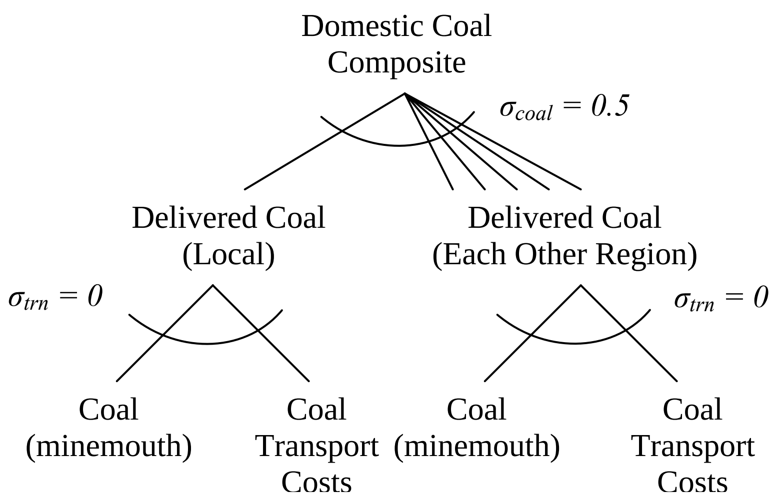
State-level energy trade patterns are developed from historical data, while quantities, values, and trends come from the AEO. Data sources include the following:

- **Coal Trade**: *Coal Industry Annual 2000* (EIA), Table 65. State-to-state coal trade flows and states' foreign trade (thousand short tons).
- **Electricity Trade**: *State Energy Data Report 2000 Consumption* (EIA) data on international imports and exports by states, along with net domestic trade flows into each state. *Annual Energy Outlook 2004* (EIA), Tables 60–72, with international and interregional trade in electricity across NERC regions. *Integrated Planning Model* (EPA), Table 3.4, with data on electricity transmission constraints among regions.
- **Natural Gas Trade**: *Natural Gas Annual 2002* (EIA), Table 12. State-to-state gas flows and states' foreign trade (MMCF). Also *Natural Gas Transportation 2001* (EIA), Table 1. Regional gas flows (average flows among regions).
- **Crude Oil and Refined Petroleum Trade**: *Petroleum Supply Annual 2003* (EIA), Volume 1, Table 32. Movements of oil among PADDs.
- **Quantities and Trends**: *Annual Energy Outlook 2004* (EIA), Tables 1, 3, 16, 60–72.

The *Coal Industry Annual* (CIA) provides origin and destination information on state-to-state and foreign coal trade flows. Foreign trade quantities are used to share out foreign coal trade from the AEO (Tables 3 and 16) in quantity and value terms. The values of exports from coal-producing states to other states are estimated by assuming that export shares, both to other states and of total production within a state, remain constant between the CIA data (year 2000) and the base year of ADAGE (year 2005). This allows determination of export values without transportation costs.

The *US Regional* module distinguishes among types of coal by origin to account for differences in sulfur and heat content. As shown in Figure 5-1, this is done by using the Armington assumption of differentiated commodities. Coal mined in each region, combined

Figure 5-1. U.S. Interregional Coal Trade



with transport costs, produces a different type of delivered coal, which is an imperfect substitute for delivered coal from other regions (σ_{coal}).

Following EIA (*Assumptions for the AEO 2004*), it is assumed that transportation costs for coal are the difference between minemouth prices and delivered prices in each region. Combining the export data with distances among state capitals (see Section 4.3) then allows estimation of the amount of transportation services (typically railroads) that have been used to supply coal from each producing state to each consuming state.[63] Future changes in transportation costs come from the *Assumptions for the AEO 2004*, which allows establishment of future trading links among states not currently trading coal. On average, this process estimates delivery costs equal to around 40 percent of the delivered value of coal, consistent with EIA data on coal transportation costs (EIA, *Coal Transportation Information*).

For the other types of energy in the model, less data are available on net interstate trade flows, which necessitates different estimation procedures. For electricity, the *State Energy Data Reports* provide state-level estimates of international trade in electricity. These data are used to share out AEO data on NERC-level international trade flows (Tables 60 through 72). Within each NERC region, total exports are assumed to be based on electricity generation, and total imports are assumed to be based on electricity consumption, in the absence of other data. Feasible state-to-state electricity transmission capabilities are

[63]It is assumed for coal and other energy goods that these transportation services are provided by the producing state.

established using data on transmission links from the EPA's Integrated Planning Model (IPM).

The IPM model defines the following NERC subregions:

- MECS Michigan Electric Coordination System
- ECAO East Central Area Reliability Coordination Agreement—South
- ERCT Electric Reliability Council of Texas
- MACE Mid-Atlantic Area Council—East
- MACW Mid-Atlantic Area Council—West
- MACS Mid-Atlantic Area Council—South
- WUMS Wisconsin—Upper Michigan
- MANO Mid-America Interconnected Network—South
- MAPP Mid-continent Area Power Pool
- UPNY Upstate New York
- DSNY Downstate New York
- NYC New York City
- LILC Long Island Lighting Company
- NENG New England Power Pool
- FRCC Florida Reliability Coordinating Council
- VACA Virginia—Carolinas
- TVA Tennessee Valley Authority
- SOU Southern Company
- ENTG Entergy
- SPPN Southwest Power Pool—North
- SPPS Southwest Power Pool—South
- CALI Western Systems Coordinating Council—California
- PNW Western Systems Coordinating Council—Pacific Northwest
- AZNM Western Systems Coordinating Council—AZNMSNV
- RMPA Western Systems Coordinating Council—Rocky Mountain Power Area
- NWPE Western Systems Coordinating Council—Northwest Power Pool East

Table 5-2 shows transmission capabilities, in maximum sustainable one-directional flows of power, among regions in IPM. They have been developed from NERC estimates of First Contingency Total Transfer Capability (FCTTC) links among parts of the country, adjusted to account for "sustainable" flows. This information is combined with data from the *State Energy Data Reports* on net interstate exports of electricity to provide estimates of state-to-state trade in electricity when balancing the energy data (discussed in Section 5.3).[64]

When estimating feasible interstate electricity trade flows, each state is assigned to the most closely related IPM region according to the following scheme:

[64]These two data sources are also helpful when examining ADAGE model results regarding electricity trade in policy simulations because they provide a reference point for feasible changes in electricity flows among states and regions of the United States.

Table 5-2. Transmission Capabilities Among Regions

From	To	MW	From	To	MW
AZNM	CALI	5,663	MECS	ECAO	2,250
	NWPE	638	NENG	DSNY	1,425
	RMPA	518	NWPE	AZNM	840
	SPPS	315		CALI	1,574
CALI	NWPE	1,184		MAPP	113
	PNW	4,922		PNW	2,145
DSNY	LILC	788		RMPA	413
	MACE	308	NYC	DSNY	3,750
	NENG	1,125		LILC	788
	NYC	3,750	PNW	CALI	5,903
	UPNY	3,750		NWPE	1,050
ECAO	MACW	2,957	RMPA	AZNM	518
	MANO	1,655		MAPP	233
	MECS	2,250		NWPE	413
	TVA	1,890	SOU	ENTG	1,902
	VACA	2,334		FRCC	4,516
ENTG	MANO	1,399		TVA	1,810
	MAPP	856		VACA	1,346
	SOU	1,136	SPPN	ENTG	636
	SPPN	292		MANO	1,228
	SPPS	292		MAPP	891
	TVA	1,278		SPPS	525
ERCT	SPPS	635	SPPS	AZNM	315
FRCC	SOU	21		ENTG	636
LILC	DSNY	938		ERCT	569
	NYC	788		SPPN	900
MACE	DSNY	1,130	TVA	ECAO	2,235
	MACW	1,500		ENTG	2,153
MACS	MACW	1,800		MANO	2,331
	VACA	3,075		SOU	2,052
MACW	ECAO	2,612		VACA	2,261
	MACE	3,368	UPNY	DSNY	3,750
	MACS	3,075		MACW	1,418
	UPNY	481	VACA	ECAO	2,822
MANO	ECAO	3,033		MACS	2,794
	ENTG	1,245		SOU	3,042
	MAPP	531		TVA	2,240
	SPPN	1,191	WUMS	MANO	1,080
	TVA	2,207		MAPP	676
	WUMS	608			
MAPP	ENTG	1,000			
	MANO	1,150			
	NWPE	150			
	RMPA	233			
	SPPN	1,172			
	WUMS	324			

Source: Documentation of the IPM Model, Section 3, Table 3-4. <http://www.epa.gov/airmarkt/epa-ipm/>.

- MECS—MI
- ECAO—IN, KY, OH, WV
- ERCT—TX
- MACE—DE, NJ
- MACW—PA
- MACS—DC, MD
- WUMS—WI
- MANO—IL, MO
- MAPP—IA, MN, ND, NE, SD
- UPNY, DSNY, LILC, and NYC—NY
- NENG—CT, MA, ME, NH, RI, VT
- FRCC—FL
- VACA—NC, SC, VA
- TVA—TN
- SOU—AL, GA, MS
- ENTG—AR, LA
- SPPN—KS
- SPPS—OK
- CALI—CA
- PNW—ID, OR, WA
- AZNM—AZ, NM
- RMPA—CO, WY
- NWPE—MT, NV, UT

The net interstate flows needed to balance electricity markets in each state are then estimated based on the relative sizes of transmission links among regions.

For natural gas, the *Natural Gas Annual* (NGA) provides foreign trade flows for gas in 2002, which are used to share out AEO data from Tables 1 and 3 (in physical quantities and values). However, interstate flows in NGA are gross of total movements of gas across state borders. Consequently, the *Natural Gas Transportation* report is used to provide regional net exports and imports of gas, which are shared out to states within these regions based on their production and consumption, respectively.[65] Similar to the procedure for estimating petroleum production, it is assumed that crude oil and petroleum imports are based on state-level "effective" refining capacity. As with regional gas flows, export and import flows of crude oil and petroleum among states are based on regional PADD-level data from the PSA 2003, shared out to states within regions based on their production and consumption, respectively.

[65]Similar to coal, natural-gas distribution costs are modeled as the difference between wellhead prices and delivered prices. Modeling these costs separately allows a better match between the natural gas industry and methane emissions associated with the production and transmission of natural gas.

5.3 Energy Data Balancing and Integration in the SAM

Once energy data have been collected, the energy markets must be balanced and then integrated with the economic data to give a balanced SAM for the base year in the model. Because the initial year in ADAGE is 2005, which is different than the historical economic data, applying region- and commodity-specific growth rates to the original data will result in an unbalanced SAM, as will the integration of new energy data. These imbalances must be corrected before data enter the model.

In this process, physical flows of energy goods are first balanced across all regions in each module. Energy prices (and taxes) are then applied, and the resulting value flows of energy goods are rebalanced by adjusting the values of trade flows as necessary. Prior to integrating these energy markets with the economic data, nonenergy intermediate inputs to energy production must be established. These inputs have been based on the value shares shown in the GTAP and IMPLAN databases, except for the values of extracted natural resources used in the coal, crude oil, and natural gas industries where value shares are based on MIT data from the EPPA model (Babiker et al., 2001). In addition, relative cost shares for nonfossil electricity generation are based on EIA data.[66]

Subsequently, the two types of data (energy and economic) must be integrated. Procedures developed by Babiker and Rutherford (1997) and described in Rutherford and Paltsev (2000) are used to integrate relevant economic and energy data (this approach was originally applied to energy data gathered by GTAP). The methodology relies on standard optimization techniques to maintain calculated energy statistics, while minimizing the changes needed in the economic data to rebalance the SAM. Once the data are integrated, a balanced SAM is generated that incorporates forecasts for economic and energy growth between the initial year of the data and the base year of 2005

6. GHG EMISSIONS IN ADAGE

This section discusses the estimates of GHG emissions in ADAGE and the techniques for modeling their abatement costs. The model is designed to consider a variety of approaches to limiting emissions through cap-and-trade programs: national caps, regional caps, sector-specific caps, and/or caps that exclude some emission sources (i.e., household emissions).

6.1 Carbon Dioxide

The ADAGE model tracks fuel consumption in physical units (Btus) using information from the WEO and AEO forecasts. Because CO_2 emissions from fuel use are tied directly to combustion of given quantities of fossil fuels, ADAGE is able to determine emissions levels in terms of millions of metric tons of carbon (equivalent), or MMTC(E)—see Section 7 for

[66]Table 38 in EIA's Assumptions to the *Annual Energy Outlook 2004*.

baseline emissions estimates. Substitution options for replacing energy inputs to production are controlled by the model's CES nesting structure and substitution elasticities. Households also have the ability to switch fuels, lower overall consumption, and improve their energy efficiency.[67] Costs of these CO_2 emissions reductions are determined by the elasticities of substitution shown in Section 2.

6.2 Other Greenhouse Gases

ADAGE has endogenized emissions abatement costs associated with five non-CO_2 gases using the innovative approach developed in Hyman et al. (2002) and used in recent work by MIT's EPPA model (referred to hereafter as the MIT approach). Their work (and forthcoming modeling efforts coordinated by the Stanford Energy Modeling Forum—EMF 21) finds that these non-CO_2 gases are a critical part of cost-effective GHG reduction policies and, because of these gases' high global warming potentials (GWP), they could contribute significantly to short-term efforts to lower atmospheric GHG concentrations. This section summarizes the MIT approach and the marginal abatement costs of emissions reductions (please see their paper for additional details).

Non-CO_2 GHGs come from a variety of sources: methane (CH_4) from fuel production and transport, landfills, and agriculture; nitrous oxide (N_2O) from agricultural and industrial activities and fuel combustion; hydrofluorocarbons (HFCs) from various industrial processes, perfluorocarbons (PFCs) from manufacturing aluminum, semiconductors, and solvents; and sulfur hexafluoride (SF_6) from electricity switchgear and transmission/distribution, along with magnesium production. However, because these gases are not emitted in fixed proportions to energy consumption in the same manner as CO_2, the modeling of abatement costs is more problematic.

Rather than relying on exogenous marginal abatement cost functions, which ignore important interactions among economic sectors, the MIT approach models emissions of non-CO_2 gases directly as an input to production (see Figure 6-1). This methodology allows specification of industry-specific abatement cost curves through selection of an elasticity of substitution (σ_{ghg}) between each GHG and all other inputs to production. Although the formulation rules out "no regrets" options and assumes a low initial GHG permit price ($1/MMTCE), the modeler is able to select a σ_{ghg} parameter that approximates abatement costs from "bottom-up" engineering studies. Emissions reductions can then be achieved at these costs in the CGE model by increasing the use of other productive inputs.

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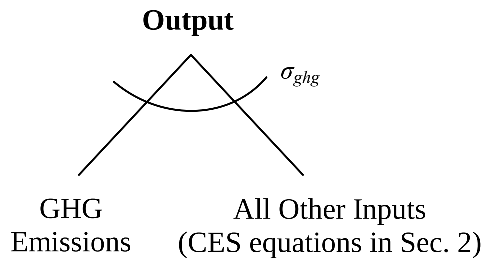
[67] The model also currently assumes that a generic backstop technology exists that can remove CO_2 emissions at a present-value cost of $150 per metric ton of carbon.

Figure 6-1. GHG Emissions Abatement Modeling



For most industries and gases, ADAGE uses the σ_{ghg} elasticities of substitution developed by MIT. In general, these elasticities imply that emissions of HFCs, PFCs, and SF_6 can be reduced significantly at relatively low cost; CH_4 emissions from manufacturing and energy-related sources can be reduced moderately at a moderate cost; and reduction opportunities for CH_4 and N_2O emissions from agriculture are more limited (with some variation across countries, depending on their crop mix). For CH_4 emissions associated with coal mining, GHG elasticities have been based on work by RTI regarding how technology improvements over time may influence abatement costs. From these data, it has been estimated for coal mining that σ_{ghg} equals 0.25 in 2010, 0.27 by 2020, and 0.29 by 2030 (Hyman et al. [2002] estimates 0.30).

National-level emissions and projected trends of non-CO_2 gases by source are taken from the Stanford EMF 21 data on multigas abatement.[68] For the United States, regional shares of EMF's U.S. emissions are assigned to states based on output and consumption from the IMPLAN and EIA data according to the logic below (estimated state shares of U.S. emissions are shown in Section 7).

Methane emissions from U.S. coal mines in the EMF data are apportioned to underground and surface mines using EPA (2005) data (*Inventory of U.S. Greenhouse Gas Emissions and Sinks*). Net emissions, accounting for methane recovery, from these mines are assigned to states based on state-level coal production (with underground mines in the eastern states and surface mines in the west). Methane emissions associated with natural gas transmission are assigned based on states' shares of national gas transmission, while emissions from petroleum products are determined by states' oil consumption. State-level agricultural emissions of methane from enteric fermentation, animal waste, rice cultivation, and crop residue burning are estimated based on state's shares of national agricultural production of the relevant commodities as shown in the IMPLAN data. Growth in each state's agricultural emissions depends on agriculture production growth within ADAGE as a

[68]See <http://www.stanford.edu/group/EMF/home/>.

share of national production. Similar logic is applied to emissions from the iron and steel and chemical manufacturing industries. Methane emissions from landfills are assumed to be a function of each state's population as a share of national population.

Emissions of N_2O from fuel combustion are based on the ADAGE state-level estimates of energy consumption. As with some types of methane sources, other N_2O emissions from agriculture and manufacturing depend on the IMPLAN production data and regional growth rates determined within the model. Similar logic is also applied to all HFC and PFC emissions and to SF_6 emissions related to magnesium production. SF_6 emissions from the electricity industry are based on the state-level estimates of electricity generation in ADAGE (in kWh).

7. BASELINE ECONOMIC AND ENERGY DATA IN ADAGE

This section presents tables with results from the baseline solution for ADAGE, covering general economic and industrial growth as well as energy production, consumption, and prices. Results from the *International* module are presented in Tables 7-1 to 7-8. Baseline results for the United States are shown in Tables 7-9 to 7-19, which provide additional detail on state-level results. Note that these baseline findings depend on all model parameters and will change if assumptions are altered – the tables and documentation will be updated when this occurs.

Table 7-1. International Macroeconomic Results ($ million)

Country	GDP		Consumption		Investment	
	2010	2020	2010	2020	2010	2020
Europe	$12,117	$15,178	$7,467	$9,398	$3,579	$4,264
Japan	$5,601	$6,835	$3,138	$3,821	$1,390	$1,634
China	$2,164	$3,299	$780	$1,333	$630	$923
Russia	$713	$944	$379	$542	$180	$239
Rest of World	$10,792	$14,523	$5,447	$7,786	$3,622	$4,664

Note: All dollar figures in tables in Section 7 are in U.S. $2000.

Table 7-2. International Output Revenues ($ million)

Country	Agriculture		Energy-Intensive		Other Manufacturing		Services		Transportation	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Europe	$418	$522	$3,375	$4,236	$5,740	$7,097	$10,438	$13,116	$1,147	$1,511
Japan	$127	$150	$1,457	$1,763	$2,738	$3,321	$4,700	$5,730	$589	$735
China	$380	$624	$976	$1,579	$2,331	$3,431	$1,207	$1,712	$318	$491
Russia	$76	$106	$242	$338	$337	$458	$397	$535	$87	$122
Rest of World	$1,593	$2,163	$3,758	$5,072	$6,143	$7,945	$6,779	$9,198	$1,377	$1,916

Table 7-3. International Energy Production (Quadrillion Btu and billion kWh)

Country	Coal		Crude Oil		Electricity		Natural Gas		Refined Petroleum	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Europe	3.1	3.2	10.3	8.7	2,945.3	3,190.2	9.2	8.8	25.0	27.0
Japan	0.0	0.0	0.0	0.0	1,157.5	1,304.5	0.1	0.2	8.3	8.8
China	33.8	43.2	5.9	4.8	2,402.4	3,628.2	2.0	2.8	11.0	15.8
Russia	4.9	5.4	18.7	19.1	930.0	1,083.8	21.8	26.1	7.8	9.0
Rest of World	37.1	43.6	114.7	146.9	6,765.0	9,260.4	54.3	76.5	69.0	87.3

Table 7-4. International Energy Prices ($ per MMBtu and $ per kWh)

Country	Coal		Electricity		Natural Gas		Refined Petroleum	
	2010	2020	2010	2020	2010	2020	2010	2020
Europe	$1.89	$1.89	$0.064	$0.064	$5.82	$5.61	$20.00	$22.20
Japan	$1.47	$1.41	$0.096	$0.096	$6.29	$5.82	$13.40	$15.22
China	$0.95	$0.79	$0.032	$0.024	$5.09	$4.68	$6.39	$5.39
Russia	$0.54	$0.53	$0.046	$0.055	$1.24	$1.54	$4.04	$4.18
Rest of World	$0.98	$0.84	$0.031	$0.025	$2.17	$1.78	$7.25	$6.78

* Average delivered prices

Table 7-5. International Electricity Generation (billion kWh)

Country	Coal		Natural Gas		Petroleum		Nuclear		Hydro		Other	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Europe	716.5	831.1	622.0	928.9	120.3	94.3	886.0	675.1	503.4	519.7	259.4	477.1
Japan	285.2	321.0	309.3	394.1	101.8	80.1	346.2	381.2	84.1	91.1	35.4	42.5
China	1,847.3	2,648.1	50.0	178.4	53.7	59.1	74.6	163.8	348.5	526.0	28.2	52.8
Russia	182.9	202.0	388.6	509.6	31.8	30.0	154.7	162.9	169.3	176.5	2.7	2.7
Rest of World	1,972.0	2,730.9	1,827.2	3,112.1	725.5	844.7	523.8	568.6	1,640.7	1,908.0	479.5	890.0

Table 7-6. International Household Energy Consumption (Quadrillion Btu)

Country	Electricity 2010	Electricity 2020	Natural Gas 2010	Natural Gas 2020	Petroleum 2010	Petroleum 2020
Europe	3.03	3.61	4.79	5.33	12.58	13.91
Japan	1.09	1.26	0.43	0.52	3.19	3.48
China	1.54	2.78	0.54	0.95	3.57	5.55
Russia	0.61	0.74	2.03	2.42	1.68	2.09
Rest of World	5.82	8.40	5.56	6.72	23.24	30.74

Table 7-7. International Energy Consumption by Industry (trillion Btu)

Country	Fuel	Agriculture 2010	Agriculture 2020	Energy-Intensive Manufacturing 2010	Energy-Intensive Manufacturing 2020	Other Manufacturing 2010	Other Manufacturing 2020	Services 2010	Services 2020	Transportation 2010	Transportation 2020
Europe	Coal	3	4	770	714	64	59	13	9	1	1
	Electricity	170	202	2,825	3,147	1,384	1,540	2,558	3,044	307	372
	Natural Gas	183	206	3,564	3,988	927	1,035	1,236	1,385	31	38
	Petroleum	567	517	3,488	3,506	506	507	790	720	4,646	5,315
Japan	Coal	0	0	820	879	91	97	0	0	0	0
	Electricity	6	7	629	710	864	974	1,137	1,316	61	92
	Natural Gas	0	0	120	138	384	437	246	306	0	0
	Petroleum	274	278	2,367	2,473	305	316	1,281	1,299	1,769	1,956
China	Coal	337	306	5,523	5,970	979	1,050	174	156	189	214
	Electricity	599	1,087	2,902	4,183	1,433	2,048	608	1,084	60	71
	Natural Gas	0	0	603	847	54	76	42	59	9	9
	Petroleum	1,051	1,496	2,604	3,239	393	484	1,008	1,407	2,628	4,232
Russia	Coal	11	15	513	597	16	21	16	20	0	0
	Electricity	97	117	1,049	1,335	368	468	279	335	301	361
	Natural Gas	23	28	2,024	2,580	137	176	112	134	1,362	1,654
	Petroleum	344	365	656	754	99	114	71	75	1,001	1,269
Rest of World	Coal	108	103	4,294	4,726	1,504	1,628	182	160	6	7
	Electricity	1,515	2,554	4,087	5,189	4,522	6,334	4,537	6,194	208	290
	Natural Gas	150	171	7,873	10,398	2,775	3,629	2,388	3,031	910	1,327
	Petroleum	2,881	3,548	9,260	11,249	3,065	3,612	2,245	2,565	12,547	16,639

Table 7-8. International Carbon Dioxide Emissions by Fuel (MMTC)

Country	Coal 2010	Coal 2020	Natural Gas 2010	Natural Gas 2020	Petroleum 2010	Petroleum 2020
Europe	242	259	264	321	490	522
Japan	115	127	58	72	208	216
China	934	1,227	32	51	272	390
Russia	136	147	226	264	106	121
Rest of World	863	1,070	697	985	1,480	1,872

Table 7-9. U.S. State-Level Macroeconomic Results ($ million)

	GSP		Consumption		Investment	
State	2010	2020	2010	2020	2010	2020
Alabama	$149,245	$194,992	$118,947	$156,060	$64,881	$82,802
Alaska	$34,285	$46,075	$18,282	$24,648	$10,543	$13,085
Arizona	$242,796	$355,309	$147,686	$220,915	$89,216	$124,642
Arkansas	$88,848	$119,200	$70,643	$96,496	$25,632	$33,375
California	$1,755,471	$2,356,258	$1,123,194	$1,516,789	$505,130	$657,828
Colorado	$234,553	$343,737	$145,333	$217,403	$75,951	$106,331
Connecticut	$203,838	$257,984	$127,163	$161,486	$46,983	$58,332
Delaware	$61,187	$83,396	$23,839	$33,400	$14,390	$19,075
Florida	$674,237	$933,558	$501,930	$703,732	$248,172	$331,016
Georgia	$385,124	$533,066	$246,034	$344,887	$114,053	$152,062
Hawaii	$56,189	$76,066	$35,502	$48,034	$17,820	$21,866
Idaho	$52,142	$76,040	$37,709	$56,500	$24,291	$34,277
Illinois	$560,025	$706,737	$387,777	$490,760	$140,985	$175,375
Indiana	$242,967	$305,996	$173,200	$219,289	$61,429	$76,266
Iowa	$126,549	$163,373	$82,424	$106,353	$31,442	$39,532
Kansas	$105,950	$136,399	$79,564	$102,758	$46,157	$58,470
Kentucky	$144,505	$187,383	$109,725	$143,728	$38,019	$48,460
Louisiana	$158,087	$212,704	$117,814	$161,166	$65,667	$86,950
Maine	$46,188	$58,362	$35,169	$44,678	$11,238	$13,750
Maryland	$253,116	$349,053	$172,620	$241,624	$90,007	$119,596
Massachusetts	$349,911	$443,358	$224,048	$284,406	$73,765	$91,954
Michigan	$390,590	$486,365	$286,351	$361,916	$98,133	$120,494
Minnesota	$244,611	$313,583	$159,964	$206,354	$67,775	$85,607
Mississippi	$81,356	$106,436	$71,046	$93,264	$24,764	$31,941
Missouri	$215,921	$277,043	$163,253	$210,470	$60,521	$75,905
Montana	$31,381	$45,491	$23,829	$35,755	$15,700	$22,189
Nebraska	$69,888	$90,259	$51,499	$66,545	$24,958	$31,543
Nevada	$118,381	$170,754	$68,113	$101,770	$37,049	$51,251
New Hampshire	$57,869	$73,783	$38,868	$49,393	$15,356	$19,167
New Jersey	$443,615	$552,197	$292,112	$364,959	$114,396	$139,493
New Mexico	$70,824	$103,196	$48,011	$72,024	$38,261	$53,418
New York	$991,758	$1,239,111	$624,676	$780,168	$219,090	$267,850
North Carolina	$377,488	$522,453	$241,372	$338,415	$139,637	$185,882
North Dakota	$25,491	$32,846	$18,103	$23,407	$10,102	$12,804
Ohio	$441,650	$556,374	$331,949	$420,004	$162,609	$200,733
Oklahoma	$115,289	$154,532	$94,254	$128,933	$37,598	$49,258
Oregon	$147,165	$196,883	$98,375	$132,584	$36,815	$47,864
Pennsylvania	$494,410	$617,312	$371,817	$464,789	$127,918	$156,241
Rhode Island	$44,828	$57,007	$31,307	$39,807	$10,771	$13,450
South Carolina	$151,730	$210,075	$108,680	$152,418	$44,214	$59,217
South Dakota	$31,889	$41,083	$22,336	$28,852	$12,070	$15,265
Tennessee	$236,638	$308,557	$170,058	$222,834	$88,496	$112,522
Texas	$972,314	$1,310,031	$643,112	$878,593	$353,003	$461,343
Utah	$95,832	$140,347	$57,358	$85,961	$35,106	$49,646
Vermont	$24,583	$31,555	$17,734	$22,573	$8,123	$10,371
Virginia	$371,838	$513,871	$225,311	$315,469	$105,383	$140,019
Washington	$286,856	$384,114	$201,494	$271,743	$93,522	$121,465
West Virginia	$53,635	$73,999	$47,063	$65,998	$27,511	$37,198
Wisconsin	$226,066	$285,587	$154,575	$195,751	$54,060	$66,948
Wyoming	$25,748	$37,043	$15,187	$22,805	$9,909	$14,437
United States	$12,764,857	$16,870,933	$8,656,414	$11,528,669	$3,868,624	$4,998,565

Table 7-10. U.S. State-Level Non-Government Employment and Number of Households (1000s)

State	Employment 2010	Employment 2020	Households 2010	Households 2020
Alabama	1,792	1,968	2,005	2,171
Alaska	265	318	275	315
Arizona	2,355	2,929	2,453	2,764
Arkansas	1,171	1,329	1,197	1,286
California	14,434	16,327	13,274	16,258
Colorado	2,261	2,810	1,984	2,174
Connecticut	1,630	1,750	1,361	1,476
Delaware	438	510	348	368
Florida	7,467	8,775	8,000	9,212
Georgia	3,879	4,557	3,612	3,981
Hawaii	549	629	491	583
Idaho	607	742	578	636
Illinois	5,695	6,091	4,847	5,175
Indiana	2,812	2,990	2,555	2,669
Iowa	1,456	1,574	1,209	1,252
Kansas	1,324	1,425	1,149	1,242
Kentucky	1,775	1,932	1,749	1,829
Louisiana	1,816	2,076	1,855	2,013
Maine	585	626	654	702
Maryland	2,462	2,890	2,185	2,388
Massachusetts	3,202	3,443	2,561	2,731
Michigan	4,188	4,418	4,155	4,303
Minnesota	2,654	2,871	2,119	2,267
Mississippi	1,045	1,152	1,173	1,242
Missouri	2,656	2,871	2,467	2,629
Montana	421	514	416	447
Nebraska	911	992	727	776
Nevada	1,148	1,420	941	1,007
New Hampshire	606	652	564	610
New Jersey	3,788	4,011	3,314	3,609
New Mexico	751	924	845	980
New York	8,093	8,581	7,445	7,921
North Carolina	3,770	4,400	3,768	4,087
North Dakota	332	360	286	303
Ohio	5,235	5,573	4,661	4,815
Oklahoma	1,442	1,629	1,539	1,692
Oregon	1,579	1,779	1,533	1,715
Pennsylvania	5,566	5,885	5,073	5,256
Rhode Island	476	512	431	467
South Carolina	1,778	2,083	1,846	2,019
South Dakota	381	412	328	345
Tennessee	2,683	2,940	2,533	2,725
Texas	9,311	10,595	8,867	10,164
Utah	1,107	1,372	850	943
Vermont	298	320	293	308
Virginia	3,448	4,037	3,042	3,332
Washington	2,691	3,028	2,630	2,995
West Virginia	702	820	803	818
Wisconsin	2,731	2,904	2,339	2,466
Wyoming	264	322	238	267
United States	128,030	143,066	119,569	131,734

Table 7-11. U.S. State-Level Non-Energy Output Revenues ($ million)

State	Agriculture		Energy-Intensive Manufacturing		Other Manufacturing		Services		Transportation	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Alabama	$5,120	$5,925	$27,391	$33,891	$74,131	$97,029	$189,038	$249,037	$8,464	$10,587
Alaska	$612	$692	$2,442	$3,021	$7,432	$9,673	$31,338	$41,500	$4,250	$8,790
Arizona	$4,259	$5,219	$9,157	$12,643	$103,459	$148,297	$273,454	$404,517	$10,859	$15,517
Arkansas	$6,694	$7,890	$23,381	$29,344	$42,077	$56,412	$86,288	$118,425	$8,632	$11,195
California	$43,208	$50,801	$132,906	$169,205	$576,764	$770,291	$1,883,588	$2,542,520	$74,388	$97,501
Colorado	$7,169	$8,801	$15,105	$20,683	$86,507	$124,105	$276,108	$410,032	$10,525	$14,685
Connecticut	$1,277	$1,417	$19,264	$22,501	$64,691	$81,277	$205,879	$262,570	$6,299	$7,822
Delaware	$823	$931	$19,028	$23,396	$14,312	$18,983	$53,424	$74,513	$1,824	$2,409
Florida	$10,235	$11,839	$31,231	$38,815	$197,784	$267,563	$865,597	$1,208,890	$35,115	$47,575
Georgia	$9,485	$11,492	$43,027	$55,781	$148,269	$202,722	$410,207	$574,511	$25,401	$34,197
Hawaii	$758	$901	$2,541	$3,440	$8,700	$11,757	$66,232	$90,037	$3,962	$5,154
Idaho	$4,722	$5,513	$7,828	$10,051	$22,310	$31,456	$60,846	$90,877	$3,061	$4,279
Illinois	$10,374	$11,525	$100,606	$119,309	$199,449	$251,600	$610,679	$777,535	$33,866	$41,646
Indiana	$7,437	$8,173	$50,097	$58,607	$153,137	$193,607	$219,357	$279,785	$15,688	$19,276
Iowa	$11,295	$13,037	$31,823	$40,560	$53,931	$69,552	$113,274	$147,373	$8,052	$10,166
Kansas	$10,314	$11,413	$20,224	$23,869	$49,085	$63,539	$141,302	$183,827	$7,728	$9,427
Kentucky	$3,323	$3,716	$25,739	$31,292	$88,209	$114,583	$133,751	$176,290	$13,801	$17,055
Louisiana	$3,291	$3,868	$25,970	$32,690	$51,999	$70,594	$191,238	$262,056	$15,172	$19,054
Maine	$1,130	$1,270	$6,813	$8,220	$18,182	$23,370	$48,545	$61,715	$2,613	$3,213
Maryland	$2,926	$3,382	$18,590	$23,890	$69,848	$94,286	$318,340	$442,620	$10,960	$14,792
Massachusetts	$2,100	$2,345	$26,730	$31,495	$109,360	$137,160	$371,326	$473,471	$11,931	$14,770
Michigan	$6,971	$7,699	$62,383	$73,116	$321,474	$397,900	$371,144	$467,661	$16,867	$20,551
Minnesota	$12,708	$14,462	$40,967	$49,897	$96,142	$123,410	$265,369	$343,213	$13,488	$16,905
Mississippi	$4,910	$5,701	$13,129	$16,281	$39,500	$52,241	$82,644	$109,539	$5,992	$7,674
Missouri	$8,554	$9,510	$35,662	$42,803	$103,431	$131,997	$244,018	$316,391	$16,079	$20,131
Montana	$2,598	$3,103	$2,507	$3,597	$10,736	$14,824	$42,282	$62,996	$2,722	$3,706
Nebraska	$19,678	$23,251	$19,863	$25,988	$25,316	$32,882	$82,918	$107,939	$7,575	$9,619
Nevada	$976	$1,133	$2,755	$3,498	$40,676	$56,118	$133,891	$196,007	$4,919	$6,925
New Hampshire	$448	$493	$4,037	$4,709	$26,585	$33,836	$61,292	$78,338	$2,152	$2,728
New Jersey	$2,177	$2,420	$83,973	$99,105	$91,028	$112,826	$494,087	$619,561	$23,897	$29,244
New Mexico	$2,931	$3,484	$3,576	$4,783	$21,920	$31,672	$94,379	$140,276	$3,276	$4,149
New York	$6,841	$7,442	$79,459	$91,410	$193,292	$238,456	$1,113,954	$1,400,593	$35,795	$43,595
North Carolina	$6,777	$7,706	$52,948	$65,711	$189,974	$259,064	$397,917	$558,739	$17,705	$23,745
North Dakota	$6,054	$6,949	$2,357	$3,057	$9,499	$12,604	$30,082	$39,380	$1,985	$2,532
Ohio	$7,177	$8,004	$88,295	$104,455	$230,619	$288,907	$542,762	$689,279	$24,797	$30,445
Oklahoma	$8,445	$9,679	$16,395	$20,398	$49,656	$66,904	$122,840	$168,665	$7,469	$9,136
Oregon	$6,698	$7,799	$15,457	$19,385	$63,369	$84,846	$143,682	$194,198	$8,077	$10,583
Pennsylvania	$7,504	$8,250	$109,652	$128,939	$172,255	$215,294	$535,548	$673,886	$28,918	$35,207
Rhode Island	$285	$320	$4,080	$4,726	$14,696	$18,645	$47,206	$60,286	$1,538	$1,982
South Carolina	$2,877	$3,269	$25,346	$31,477	$84,088	$115,281	$145,605	$205,362	$8,231	$11,061
South Dakota	$5,846	$6,668	$4,458	$5,480	$12,366	$16,265	$36,433	$47,546	$2,046	$2,601
Tennessee	$2,506	$2,868	$36,963	$45,488	$109,807	$142,314	$277,713	$364,445	$22,790	$29,076
Texas	$21,651	$24,565	$107,256	$131,190	$360,999	$486,864	$1,104,886	$1,508,996	$52,205	$66,199
Utah	$1,780	$2,162	$10,353	$13,909	$41,319	$58,946	$108,849	$161,764	$6,141	$8,826
Vermont	$844	$947	$3,087	$3,825	$14,063	$18,122	$27,236	$34,837	$1,298	$1,692
Virginia	$3,825	$4,444	$29,003	$36,712	$127,723	$173,307	$391,557	$546,829	$17,258	$23,204
Washington	$8,306	$9,551	$24,030	$29,957	$111,370	$148,357	$324,836	$438,176	$15,326	$19,967
West Virginia	$721	$823	$12,704	$15,783	$17,096	$23,522	$69,868	$98,595	$3,932	$4,973
Wisconsin	$10,286	$11,387	$57,330	$68,455	$116,075	$147,106	$213,175	$271,770	$13,258	$16,377
Wyoming	$1,995	$2,423	$2,467	$3,188	$8,634	$12,373	$21,625	$32,946	$2,508	$3,329
United States	$318,924	$366,661	$1,590,384	$1,940,023	$4,843,341	$6,352,740	$14,077,612	$18,810,313	$680,835	$875,275

Table 7-12. U.S. State-Level Energy Output Revenues ($ million)

State	Coal		Crude Oil		Electricity		Natural Gas		Refined Petroleum	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Alabama	$302	$382	$142	$117	$7,367	$8,867	$889	$1,015	$1,769	$2,150
Alaska	$19	$19	$7,796	$6,603	$642	$672	$2,119	$4,520	$5,090	$5,893
Arizona	$368	$418	$0	$0	$7,077	$8,007	$2	$2	$0	$0
Arkansas	$0	$0	$149	$130	$2,478	$2,940	$612	$783	$940	$1,143
California	$0	$0	$5,187	$5,048	$21,213	$18,740	$768	$793	$28,176	$36,377
Colorado	$567	$775	$485	$545	$2,852	$3,748	$4,160	$5,511	$2,011	$2,652
Connecticut	$0	$0	$0	$0	$2,810	$3,277	$0	$0	$0	$0
Delaware	$0	$0	$0	$0	$367	$538	$0	$0	$2,248	$2,470
Florida	$0	$0	$58	$48	$18,422	$24,451	$8	$10	$0	$0
Georgia	$0	$0	$0	$0	$7,272	$8,548	$0	$0	$432	$485
Hawaii	$0	$0	$0	$0	$1,090	$1,174	$0	$0	$1,994	$2,353
Idaho	$0	$0	$0	$0	$644	$677	$0	$0	$0	$0
Illinois	$836	$750	$245	$216	$13,858	$15,358	$1	$1	$12,552	$13,773
Indiana	$931	$902	$39	$35	$7,261	$8,989	$5	$7	$6,213	$6,776
Iowa	$0	$0	$0	$0	$2,781	$3,110	$0	$0	$0	$0
Kansas	$6	$5	$697	$607	$3,297	$3,568	$1,633	$1,950	$4,324	$4,694
Kentucky	$3,361	$3,498	$53	$47	$4,114	$4,882	$347	$436	$3,166	$3,450
Louisiana	$63	$58	$1,628	$1,346	$4,414	$6,131	$3,765	$4,835	$37,214	$45,692
Maine	$0	$0	$0	$0	$1,771	$2,302	$0	$0	$0	$0
Maryland	$168	$160	$0	$0	$2,658	$3,411	$0	$0	$0	$0
Massachusetts	$0	$0	$0	$0	$4,379	$5,230	$0	$0	$0	$0
Michigan	$0	$0	$137	$121	$9,766	$15,300	$1,133	$1,484	$1,043	$1,134
Minnesota	$0	$0	$0	$0	$2,791	$3,277	$0	$0	$4,954	$5,450
Mississippi	$38	$35	$299	$247	$2,606	$3,550	$285	$327	$4,956	$5,968
Missouri	$8	$7	$0	$0	$5,625	$6,284	$0	$0	$0	$0
Montana	$288	$316	$446	$504	$1,813	$2,811	$425	$569	$4,290	$5,854
Nebraska	$0	$0	$57	$49	$1,617	$1,840	$7	$8	$0	$0
Nevada	$0	$0	$11	$13	$4,507	$6,755	$0	$0	$26	$30
New Hampshire	$0	$0	$0	$0	$1,466	$1,591	$0	$0	$0	$0
New Jersey	$0	$0	$0	$0	$5,294	$7,569	$0	$0	$9,193	$10,298
New Mexico	$701	$994	$1,195	$992	$2,372	$2,981	$4,375	$5,131	$1,531	$1,889
New York	$0	$0	$3	$3	$13,249	$16,615	$149	$194	$0	$0
North Carolina	$0	$0	$0	$0	$8,086	$9,322	$0	$0	$0	$0
North Dakota	$264	$236	$675	$758	$1,678	$1,954	$276	$350	$842	$919
Ohio	$709	$698	$118	$104	$10,507	$12,336	$415	$539	$7,638	$8,345
Oklahoma	$41	$38	$1,352	$1,179	$3,664	$4,572	$5,962	$7,476	$6,553	$7,201
Oregon	$0	$0	$0	$0	$3,936	$4,395	$2	$2	$0	$0
Pennsylvania	$2,264	$2,298	$51	$45	$14,777	$18,534	$623	$786	$10,047	$11,076
Rhode Island	$0	$0	$0	$0	$553	$625	$0	$0	$0	$0
South Carolina	$0	$0	$0	$0	$5,403	$6,155	$0	$0	$0	$0
South Dakota	$0	$0	$28	$32	$525	$571	$5	$7	$0	$0
Tennessee	$50	$59	$7	$6	$5,272	$6,013	$8	$10	$2,508	$2,760
Texas	$743	$669	$7,290	$6,017	$27,516	$36,036	$14,232	$17,896	$59,842	$72,349
Utah	$453	$661	$303	$341	$2,746	$4,738	$1,357	$1,816	$3,742	$4,975
Vermont	$0	$0	$0	$0	$643	$715	$0	$0	$0	$0
Virginia	$746	$698	$0	$0	$4,447	$5,194	$316	$437	$751	$836
Washington	$94	$94	$0	$0	$6,444	$7,221	$0	$0	$8,393	$9,834
West Virginia	$3,743	$3,619	$28	$25	$5,114	$5,824	$744	$957	$251	$280
Wisconsin	$0	$0	$0	$0	$3,885	$4,311	$0	$0	$462	$502
Wyoming	$3,099	$3,710	$1,216	$1,377	$2,901	$5,110	$7,361	$9,836	$3,603	$4,920
Offshore			*$21,191*	*$19,353*			*$17,080*	*$26,660*		
United States	$19,863	$21,100	$50,887	$45,907	$275,971	$336,818	$69,062	$94,346	$236,754	$282,527

* Coal is in minemouth prices, Crude Oil is based on AEO forecasts in dollars per barrel, Electricity is averaged delivered prices, Natural Gas is in wellhead prices, Petroleum is in producer prices (excluding taxes and distribution costs).

Table 7-13. U.S. State-Level Electricity Generation by Type (billion kWh)

	Coal		Natural Gas		Petroleum		Nuclear		Hydro		Other	
State	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Alabama	80.6	93.9	16.9	27.6	0.2	0.3	32.7	33.9	10.6	10.6	1.7	2.2
Alaska	0.5	0.6	4.0	5.6	0.6	0.9	0.0	0.0	1.9	1.9	0.0	0.0
Arizona	36.4	57.7	28.1	20.3	0.1	0.1	31.6	31.6	8.0	8.0	1.2	1.4
Arkansas	25.8	30.1	5.0	8.1	0.1	0.2	14.9	15.5	3.2	3.2	0.0	0.3
California	3.4	6.0	85.6	80.1	1.2	1.2	34.9	35.2	42.4	42.4	30.4	50.5
Colorado	33.9	53.8	14.3	10.3	0.0	0.1	0.0	0.0	1.6	1.6	1.2	1.4
Connecticut	3.8	3.8	10.1	13.0	4.5	5.0	15.0	15.0	0.3	0.3	2.0	2.4
Delaware	4.2	4.6	2.2	3.4	0.2	0.5	0.0	0.0	0.0	0.0	0.1	0.1
Florida	111.8	144.3	72.4	115.3	15.0	23.6	33.9	33.9	0.2	0.2	4.1	5.0
Georgia	86.7	101.0	7.5	12.3	0.2	0.3	31.9	33.1	3.3	3.3	0.0	0.4
Hawaii	1.8	2.1	0.0	0.0	6.8	9.2	0.0	0.0	0.1	0.1	0.8	1.1
Idaho	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0	11.4	11.4	0.4	0.5
Illinois	106.6	112.7	20.6	27.4	0.1	0.2	93.5	95.3	0.1	0.1	1.8	1.9
Indiana	138.1	141.9	9.3	23.9	0.1	0.2	0.0	0.0	0.5	0.5	0.2	0.6
Iowa	42.9	45.4	1.0	1.4	0.0	0.0	4.7	4.8	0.7	0.7	2.3	3.3
Kansas	38.4	39.6	1.9	3.0	0.6	0.9	9.3	9.4	0.0	0.0	0.6	0.7
Kentucky	97.9	100.6	3.1	7.9	0.8	1.4	0.0	0.0	3.2	3.2	0.0	0.4
Louisiana	24.7	28.8	36.5	59.5	1.7	2.4	17.8	18.4	0.9	0.9	0.0	0.3
Maine	0.3	0.3	13.9	18.0	0.9	0.9	0.0	0.0	1.9	1.9	2.5	2.9
Maryland	35.5	38.9	3.5	5.4	0.6	1.5	12.6	12.8	2.0	2.0	0.8	0.8
Massachusetts	13.6	13.6	18.0	23.3	12.7	14.1	5.8	5.8	0.8	0.8	2.6	3.0
Michigan	77.2	79.3	40.4	104.4	0.3	0.5	31.4	31.4	1.3	1.3	4.4	4.7
Minnesota	34.2	39.7	1.4	4.2	0.2	0.6	13.2	13.2	1.1	1.1	4.4	4.8
Mississippi	16.7	19.4	19.4	31.6	0.0	0.0	10.3	10.7	0.0	0.0	0.0	0.3
Missouri	84.5	89.4	8.9	11.9	0.3	0.5	8.6	8.8	0.9	0.9	0.1	0.1
Montana	22.2	38.0	0.0	0.0	0.3	0.3	0.0	0.0	10.4	10.4	0.3	0.5
Nebraska	21.1	24.5	0.4	1.2	0.0	0.0	9.8	9.8	2.0	2.0	0.0	0.0
Nevada	23.8	40.6	23.9	26.0	0.0	0.0	0.0	0.0	4.0	4.0	5.1	12.0
New Hampshire	4.4	4.4	0.1	0.1	1.2	1.3	9.4	9.4	1.0	1.0	1.3	1.7
New Jersey	12.0	13.2	27.1	41.9	0.2	0.4	32.0	32.6	0.0	0.0	1.7	1.7
New Mexico	25.8	40.9	5.3	3.8	0.1	0.1	0.0	0.0	0.2	0.2	1.1	1.3
New York	23.8	23.9	46.3	65.4	10.1	11.8	40.3	40.4	26.8	26.8	3.5	3.4
North Carolina	83.3	97.1	4.1	6.7	0.4	0.5	40.7	42.2	2.4	2.4	2.9	3.6
North Dakota	31.3	36.4	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.3	1.5	1.6
Ohio	156.1	160.4	4.6	11.8	0.1	0.2	11.0	11.0	0.4	0.4	0.2	0.6
Oklahoma	38.5	39.7	22.6	35.2	0.0	0.0	0.0	0.0	2.3	2.3	0.6	0.7
Oregon	5.5	9.3	14.5	15.8	0.0	0.0	0.0	0.0	45.2	45.2	1.2	1.7
Pennsylvania	140.7	154.0	9.1	14.0	0.7	1.6	78.9	80.3	2.8	2.8	5.4	5.7
Rhode Island	0.0	0.0	7.4	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6
South Carolina	40.9	47.7	5.2	8.5	0.2	0.3	54.7	56.8	1.6	1.6	0.0	0.3
South Dakota	3.5	4.0	0.1	0.3	0.0	0.0	0.0	0.0	6.0	6.0	0.0	0.0
Tennessee	65.1	75.9	0.3	0.4	0.2	0.3	28.3	29.4	8.3	8.3	0.1	0.4
Texas	149.6	149.5	228.6	270.5	0.1	0.7	33.9	41.5	1.0	1.0	5.2	5.3
Utah	49.9	85.3	2.7	2.9	0.0	0.0	0.0	0.0	0.8	0.8	0.9	2.0
Vermont	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.0	1.0	1.0	0.9	3.3
Virginia	41.5	48.4	4.5	7.4	3.5	4.9	28.1	29.1	1.3	1.3	1.1	1.5
Washington	12.5	21.4	8.8	9.6	0.0	0.0	9.1	9.1	86.3	86.2	1.3	1.7
West Virginia	108.2	111.2	0.5	1.2	0.1	0.1	0.0	0.0	0.4	0.4	0.1	0.5
Wisconsin	48.5	51.4	4.7	6.2	0.1	0.1	12.8	13.1	1.6	1.6	1.5	1.7
Wyoming	60.4	103.2	0.7	0.8	0.0	0.0	0.0	0.0	1.4	1.4	2.0	3.1
United States	2,268.2	2,628.0	845.8	1,157.9	64.7	87.5	795.1	817.5	305.9	305.8	99.8	144.1

Table 7-14. U.S. State-Level Energy Prices ($ per MMBtu and $ per kWh)

	Coal		Electricity		Natural Gas		Refined Petroleum	
State	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Alabama	$1.42	$1.36	$0.052	$0.053	$4.58	$5.47	$9.10	$9.47
Alaska	$1.62	$1.58	$0.089	$0.074	$2.43	$2.77	$7.68	$7.89
Arizona	$0.90	$0.86	$0.068	$0.068	$5.01	$5.84	$9.82	$10.23
Arkansas	$1.42	$1.36	$0.050	$0.051	$4.99	$5.80	$8.94	$9.32
California	$1.52	$1.39	$0.107	$0.087	$5.84	$6.51	$9.52	$10.82
Colorado	$0.93	$0.89	$0.055	$0.055	$4.82	$5.53	$9.54	$9.62
Connecticut	$1.68	$1.62	$0.080	$0.084	$6.41	$7.01	$10.05	$10.42
Delaware	$1.50	$1.44	$0.056	$0.065	$5.23	$6.06	$7.98	$8.10
Florida	$1.60	$1.53	$0.078	$0.076	$4.60	$5.45	$8.63	$9.00
Georgia	$1.54	$1.48	$0.056	$0.056	$5.93	$6.64	$8.64	$9.00
Hawaii	$1.23	$1.17	$0.115	$0.094	$13.58	$14.64	$7.00	$7.40
Idaho	$1.30	$1.26	$0.053	$0.054	$4.97	$5.66	$9.45	$9.75
Illinois	$1.18	$1.14	$0.063	$0.065	$5.69	$6.50	$9.87	$10.34
Indiana	$1.13	$1.08	$0.050	$0.055	$5.12	$5.85	$9.08	$9.48
Iowa	$0.86	$0.83	$0.055	$0.057	$5.72	$6.41	$9.56	$9.96
Kansas	$0.98	$0.94	$0.065	$0.067	$4.92	$5.47	$9.43	$9.82
Kentucky	$1.14	$1.09	$0.042	$0.046	$5.54	$6.33	$8.57	$8.93
Louisiana	$1.32	$1.27	$0.054	$0.055	$3.67	$4.46	$7.35	$7.39
Maine	$1.85	$1.80	$0.091	$0.095	$4.11	$4.88	$8.58	$8.90
Maryland	$1.32	$1.27	$0.051	$0.058	$7.21	$7.95	$9.74	$10.14
Massachusetts	$1.66	$1.60	$0.082	$0.087	$6.83	$7.55	$9.33	$9.69
Michigan	$1.32	$1.27	$0.063	$0.069	$4.85	$5.36	$9.81	$10.20
Minnesota	$1.13	$1.09	$0.050	$0.050	$5.81	$6.29	$9.62	$10.11
Mississippi	$1.51	$1.46	$0.056	$0.057	$4.32	$5.16	$8.64	$8.73
Missouri	$0.92	$0.88	$0.054	$0.056	$5.68	$6.28	$9.31	$9.68
Montana	$0.93	$0.85	$0.054	$0.056	$6.42	$7.24	$8.43	$8.37
Nebraska	$0.58	$0.54	$0.048	$0.049	$5.61	$6.16	$9.46	$9.85
Nevada	$1.26	$1.21	$0.082	$0.085	$4.96	$5.70	$10.27	$10.71
New Hampshire	$1.47	$1.41	$0.084	$0.088	$7.72	$8.25	$9.28	$9.49
New Jersey	$2.24	$2.16	$0.072	$0.084	$5.93	$6.40	$8.59	$8.98
New Mexico	$1.55	$2.05	$0.068	$0.064	$5.77	$6.35	$9.20	$9.66
New York	$1.53	$1.48	$0.087	$0.096	$6.25	$6.88	$9.00	$9.32
North Carolina	$1.44	$1.39	$0.059	$0.060	$5.94	$6.70	$9.07	$9.31
North Dakota	$0.88	$0.84	$0.048	$0.049	$5.09	$5.66	$9.19	$9.51
Ohio	$1.45	$1.40	$0.060	$0.066	$5.51	$6.22	$9.54	$9.98
Oklahoma	$0.97	$0.94	$0.057	$0.059	$4.83	$5.69	$9.17	$9.56
Oregon	$1.06	$1.02	$0.061	$0.062	$4.62	$5.21	$9.88	$10.30
Pennsylvania	$1.25	$1.20	$0.062	$0.072	$6.29	$6.77	$9.51	$9.84
Rhode Island	$2.25	$2.17	$0.075	$0.088	$5.21	$5.73	$9.55	$9.38
South Carolina	$1.41	$1.36	$0.052	$0.053	$5.37	$6.27	$8.96	$9.21
South Dakota	$1.05	$1.00	$0.054	$0.055	$5.91	$6.38	$9.26	$9.65
Tennessee	$1.12	$1.08	$0.052	$0.053	$5.71	$6.52	$8.93	$9.35
Texas	$1.22	$1.17	$0.065	$0.076	$3.83	$4.67	$7.58	$7.70
Utah	$1.04	$0.99	$0.054	$0.055	$5.12	$5.78	$8.90	$8.65
Vermont	$2.30	$2.22	$0.091	$0.099	$5.92	$6.41	$9.81	$9.65
Virginia	$1.40	$1.34	$0.057	$0.057	$6.21	$6.95	$9.11	$9.48
Washington	$1.13	$1.05	$0.055	$0.056	$5.51	$5.98	$8.33	$8.74
West Virginia	$1.21	$1.17	$0.048	$0.053	$5.74	$6.48	$9.42	$9.79
Wisconsin	$1.04	$1.00	$0.056	$0.058	$5.47	$6.26	$9.43	$9.83
Wyoming	$0.80	$0.77	$0.048	$0.050	$4.32	$5.07	$8.34	$8.30
United States (avg)	$1.22	$1.17	$0.064	$0.066	$5.12	$5.82	$8.86	$9.18

* Average delivered prices

Table 7-15. U.S. State-Level Energy Consumption by Industry in 2010 (trillion Btu)

	Agriculture			Energy-Intensive Manufacturing				Other Manufacturing				Services				Transportation		
State	Electricity	Natural Gas	Petroleum	Coal	Electricity	Natural Gas	Petroleum	Coal	Electricity	Natural Gas	Petroleum	Coal	Electricity	Natural Gas	Petroleum	Electricity	Natural Gas	Petroleum
Alabama	4.7	4.8	9.8	47.9	56.3	145.7	54.1	5.5	58.0	66.8	24.1	1.1	65.8	25.5	7.2	1.8	0.7	199.8
Alaska	0.1	1.1	0.5	0.3	0.2	9.1	0.8	0.1	0.2	6.8	2.1	10.4	7.3	19.1	4.6	0.9	0.9	94.9
Arizona	2.9	1.5	7.0	6.2	11.4	11.4	16.0	3.6	27.8	15.3	35.0	0.0	72.6	30.6	4.1	1.4	0.6	205.7
Arkansas	4.9	6.7	20.7	4.9	27.4	95.4	44.4	0.4	25.9	35.6	21.8	0.0	31.1	27.6	3.8	1.8	0.3	126.0
California	15.8	49.1	49.5	30.6	73.1	631.6	179.6	5.9	131.7	368.3	112.4	0.5	359.7	232.0	16.0	8.8	3.2	1,416.2
Colorado	3.4	6.2	12.9	6.6	9.7	39.8	15.1	2.0	21.6	42.2	37.2	1.3	59.6	55.8	6.3	1.4	0.4	162.4
Connecticut	0.4	0.3	1.3	16.9	9.3	27.6	41.2	3.1	11.3	9.3	8.9	0.1	41.8	42.3	20.3	0.7	1.9	94.4
Delaware	0.3	0.3	1.0	6.6	8.7	27.4	43.4	0.6	2.8	2.4	2.5	0.0	13.0	4.4	3.9	1.5	0.0	31.2
Florida	5.9	8.7	24.5	38.7	23.6	93.4	70.2	11.0	34.8	64.8	87.9	0.2	260.0	46.0	17.9	4.4	1.2	650.2
Georgia	4.9	4.6	16.6	20.9	41.9	112.0	89.0	7.4	81.9	103.0	55.3	0.2	130.2	51.8	10.4	1.8	0.6	389.7
Hawaii	1.3	0.0	1.2	8.8	4.4	0.1	1.9	1.6	3.0	0.1	4.0	0.0	10.3	1.8	1.2	0.2	0.0	58.4
Idaho	5.6	4.3	16.5	7.2	11.3	23.6	15.7	0.8	17.2	11.7	16.7	0.4	25.9	13.0	4.0	1.1	0.3	56.3
Illinois	5.1	5.9	19.6	304.9	70.9	228.4	196.3	29.2	66.4	74.2	56.3	3.6	135.4	156.6	12.1	1.4	1.6	400.3
Indiana	4.3	4.9	13.0	137.2	82.4	218.5	120.4	11.2	74.6	80.6	38.0	4.6	68.0	70.8	9.9	2.5	0.7	278.3
Iowa	8.9	11.6	58.3	31.0	27.7	73.6	53.6	3.3	22.4	30.1	33.9	4.7	26.5	35.2	7.5	1.4	0.4	109.5
Kansas	5.1	9.2	31.5	1.4	12.9	56.6	38.6	0.3	14.3	27.3	23.5	0.2	43.5	32.1	4.7	1.9	1.9	104.4
Kentucky	5.4	2.6	24.2	75.2	56.5	64.0	141.2	13.7	59.8	30.4	52.8	3.6	46.0	37.6	7.3	2.5	0.7	181.9
Louisiana	2.4	5.7	9.5	43.0	41.2	354.5	219.9	4.5	18.4	52.4	47.8	0.0	62.6	21.8	12.9	1.8	2.3	360.8
Maine	0.8	0.1	8.5	5.1	7.3	3.6	28.0	0.4	7.2	1.4	24.7	0.1	13.2	2.6	18.3	0.7	0.3	51.3
Maryland	1.6	1.4	6.6	45.7	17.6	35.9	48.8	5.6	15.7	14.4	37.9	1.7	77.0	47.6	16.3	1.5	0.4	174.0
Massachusett	0.7	1.8	2.7	47.6	13.3	109.2	45.7	11.8	26.7	64.6	22.8	0.4	79.0	56.8	36.4	0.7	0.8	188.6
Michigan	2.5	3.9	9.6	36.6	46.5	214.1	161.1	8.5	88.1	131.0	41.6	0.3	118.8	144.1	14.3	2.5	3.0	325.8
Minnesota	8.3	4.9	22.3	20.3	42.4	65.0	45.8	2.3	52.6	28.1	32.4	0.1	58.9	77.2	8.9	0.9	0.6	212.9
Mississippi	3.7	3.7	8.3	1.8	17.1	49.3	25.3	0.3	28.7	29.2	12.8	0.0	39.3	21.1	3.9	1.8	0.9	141.8
Missouri	3.2	2.4	12.7	10.3	27.4	54.5	80.9	1.6	27.1	21.9	28.7	2.8	80.6	50.8	10.3	1.4	0.4	235.8
Montana	3.8	1.7	9.5	70.4	5.2	4.7	5.9	10.0	5.6	3.4	7.6	0.0	13.8	12.4	1.5	1.1	0.3	44.8
Nebraska	7.2	9.2	28.5	4.3	10.9	33.1	11.9	0.4	8.5	11.8	12.4	0.0	22.3	22.8	3.3	0.9	0.1	73.2
Nevada	2.3	2.0	1.5	2.2	8.5	16.3	3.2	1.8	28.4	40.9	16.7	0.0	28.1	24.5	2.1	1.1	0.0	94.3
New Hampshi	0.2	0.1	2.0	0.0	2.6	2.6	11.7	0.0	6.9	2.7	15.8	0.1	13.4	7.9	11.5	0.7	0.0	44.7
New Jersey	0.5	0.8	2.7	30.2	27.8	164.6	223.6	2.8	11.9	20.4	19.5	0.1	116.2	127.5	26.5	1.5	0.3	392.5
New Mexico	1.8	2.3	7.8	0.4	2.7	8.4	6.8	0.2	4.8	8.4	14.6	0.1	22.6	24.9	2.9	1.4	2.2	86.1
New York	2.6	5.6	13.8	136.8	46.2	277.5	199.9	23.1	44.1	95.1	65.6	1.8	185.3	315.5	138.4	4.8	1.3	390.6
North Carolina	5.5	3.1	21.9	35.2	39.1	71.6	153.3	20.1	90.5	60.6	58.8	2.3	131.2	37.6	20.7	1.8	1.1	310.7
North Dakota	3.2	3.6	14.7	25.4	1.6	4.3	1.9	8.5	3.2	4.0	6.8	1.3	10.3	8.8	2.2	0.9	0.5	29.6
Ohio	4.7	3.6	12.8	59.1	125.4	245.6	211.8	7.3	127.0	94.9	53.3	3.9	127.0	138.3	14.7	2.5	2.2	399.4
Oklahoma	3.4	5.4	8.9	14.3	15.0	70.3	31.7	2.2	19.9	31.6	12.4	0.0	42.5	35.1	3.0	1.9	1.0	177.2
Oregon	4.6	7.1	17.3	0.0	20.3	67.5	20.9	0.0	30.0	44.7	29.0	0.0	55.5	27.4	4.6	1.1	1.8	138.3
Pennsylvania	3.3	2.5	8.3	473.5	93.4	200.9	181.9	35.1	56.8	46.3	33.7	13.2	146.9	111.7	34.0	1.5	5.9	394.9
Rhode Island	0.1	0.6	0.3	0.0	1.5	28.5	4.1	0.0	3.3	24.9	2.3	0.0	10.6	11.3	6.1	0.8	0.2	28.4
South Carolin	2.8	1.5	4.7	22.4	45.7	75.5	69.0	6.0	82.7	49.7	21.1	0.0	60.7	19.1	5.8	1.8	0.5	166.6
South Dakota	2.4	2.4	22.6	6.7	2.1	3.7	2.4	1.5	3.6	3.1	8.8	0.0	9.3	8.2	2.4	1.0	0.2	34.1
Tennessee	2.6	2.1	7.0	38.8	47.4	90.0	68.3	7.0	64.3	48.3	32.5	2.4	88.7	54.1	8.3	1.8	0.4	252.8
Texas	14.4	32.6	103.0	30.2	133.7	975.0	1,086.5	4.4	129.7	304.3	373.3	0.2	287.7	164.1	40.2	5.7	2.8	1,167.1
Utah	1.1	1.2	2.8	23.1	9.9	27.3	14.3	4.4	13.3	15.9	14.1	1.1	31.6	31.0	3.1	1.1	0.1	105.5
Vermont	0.4	0.2	1.6	0.0	2.2	2.8	2.5	0.0	3.6	2.0	3.9	0.0	6.4	2.3	6.7	0.8	0.0	23.9
Virginia	2.4	2.3	9.3	65.6	27.7	66.0	60.6	17.4	41.2	47.1	51.1	1.6	100.2	57.5	23.2	1.8	1.2	300.8
Washington	8.2	4.4	23.3	31.4	43.1	51.3	48.5	6.0	54.0	29.2	50.3	0.5	90.7	49.3	6.0	1.1	1.4	283.6
West Virginia	0.6	0.4	1.3	38.6	25.5	46.0	55.3	1.9	7.6	5.6	6.3	3.8	22.0	21.7	2.5	2.5	4.6	61.7
Wisconsin	4.4	5.0	32.7	19.1	43.3	131.6	118.5	1.4	45.6	48.9	59.3	3.2	57.6	62.8	11.7	1.4	0.5	177.2
Wyoming	1.7	0.9	3.8	7.1	4.0	7.2	13.5	1.5	2.6	2.5	5.5	2.2	11.3	9.6	3.1	1.1	0.7	46.5
United States	186.4	246.1	750.3	2,090.6	1,525.3	5,416.4	4,384.5	297.8	1,807.3	2,358.1	1,835.8	74.0	3,618.0	2,689.3	647.0	89.0	53.0	11,474.9

Table 7-16. U.S. State-Level Energy Consumption by Industry in 2020 (trillion Btu)

	Agriculture			Energy-Intensive Manufacturing				Other Manufacturing				Services				Transportation		
State	Elec-tricity	Natural Gas	Petro-leum	Coal	Elec-tricity	Natural Gas	Petro-leum	Coal	Elec-tricity	Natural Gas	Petro-leum	Coal	Elec-tricity	Natural Gas	Petro-leum	Elec-tricity	Natural Gas	Petro-leum
Alabama	5.1	5.3	10.8	45.2	61.7	160.1	61.1	8.7	72.2	81.1	29.3	1.8	85.0	29.8	7.7	2.2	0.7	233.2
Alaska	0.1	1.1	0.6	0.4	0.3	10.5	1.0	0.1	0.2	7.9	2.9	11.3	9.1	22.4	5.2	1.1	1.5	119.4
Arizona	3.2	1.5	7.7	6.3	12.3	12.7	18.3	5.9	35.6	18.6	42.3	0.0	100.6	39.6	4.7	1.9	0.7	250.5
Arkansas	5.5	7.3	22.9	7.2	30.3	107.0	50.1	0.6	32.6	43.6	26.5	0.0	40.3	27.9	4.0	2.2	0.3	146.2
California	17.5	54.0	54.1	30.9	82.1	713.3	203.5	6.1	170.5	456.7	134.3	0.9	498.2	290.0	19.1	11.0	5.5	1,858.0
Colorado	3.8	6.9	14.2	6.5	11.0	45.3	17.2	2.0	27.7	51.5	44.5	1.3	82.2	69.9	6.8	1.9	0.7	191.4
Connecticut	0.4	0.3	1.5	16.3	10.4	31.0	47.2	3.2	14.6	11.7	10.7	0.1	48.8	46.7	21.5	0.9	3.0	110.0
Delaware	0.4	0.3	1.1	6.6	10.0	31.1	50.3	0.9	3.6	2.9	3.0	0.0	15.3	5.2	4.1	1.8	0.0	35.5
Florida	6.6	9.6	27.1	38.7	26.2	105.7	79.9	11.2	43.7	78.9	104.8	0.4	346.7	59.9	20.2	5.5	2.1	804.2
Georgia	5.4	5.1	18.3	20.9	46.0	126.2	101.1	7.7	100.9	124.2	67.2	0.3	168.7	64.8	11.4	2.2	0.8	463.5
Hawaii	1.4	0.0	1.4	9.2	5.0	0.2	2.2	1.6	3.7	0.1	4.8	0.0	12.8	2.1	1.3	0.3	0.0	74.5
Idaho	6.3	4.8	18.4	7.3	12.7	27.3	17.7	1.3	21.9	14.2	19.9	0.7	35.9	16.3	4.3	1.4	0.5	66.5
Illinois	5.6	6.5	21.6	283.7	79.5	255.8	224.1	29.9	85.3	92.5	67.6	3.5	152.0	161.7	12.6	1.6	2.5	459.1
Indiana	4.7	5.4	14.3	119.8	91.0	236.4	136.6	11.5	95.5	100.7	45.9	4.5	77.9	71.6	10.2	2.9	1.0	312.2
Iowa	9.8	12.8	64.3	30.5	29.8	83.3	60.8	3.4	28.6	37.2	40.7	4.6	29.8	36.1	7.6	1.6	0.6	121.9
Kansas	5.7	10.4	35.3	1.5	14.5	65.0	43.9	0.4	18.4	34.1	28.1	0.3	51.0	34.3	5.0	2.3	3.0	121.1
Kentucky	6.0	2.9	26.7	71.5	60.3	71.0	160.6	14.1	76.5	37.8	63.7	3.5	52.7	42.4	7.5	2.9	1.1	204.8
Louisiana	2.7	6.2	10.5	43.1	46.5	398.9	254.4	7.0	23.2	64.2	57.7	0.0	80.9	22.3	13.9	2.2	3.3	421.2
Maine	0.9	0.1	9.4	5.2	7.9	4.0	30.0	0.5	8.9	1.4	29.7	0.1	15.4	2.8	19.5	0.9	0.3	59.3
Maryland	1.8	1.5	7.3	43.1	19.7	39.6	55.6	8.5	19.7	17.5	45.6	2.7	91.0	59.1	17.8	1.8	0.4	205.4
Massachusett	0.7	2.0	3.0	46.9	14.8	122.7	52.0	12.2	34.0	79.3	27.6	0.5	92.5	61.8	38.5	0.9	0.9	216.7
Michigan	2.7	4.2	10.6	34.6	51.9	236.3	183.8	8.7	115.5	166.3	51.0	0.4	136.3	145.3	14.7	2.9	4.6	363.7
Minnesota	9.1	5.3	24.6	20.1	47.0	73.7	51.5	3.4	67.7	34.5	38.9	0.1	70.4	82.2	9.4	1.1	0.7	245.6
Mississippi	4.1	4.0	9.2	2.7	19.1	55.6	29.0	0.5	36.1	35.8	15.6	0.0	51.0	24.2	4.1	2.3	0.9	162.7
Missouri	3.5	2.6	14.0	10.3	30.1	61.4	92.3	1.7	34.8	27.2	34.4	2.8	90.5	53.6	10.8	1.6	0.6	270.0
Montana	4.2	1.9	10.6	73.3	5.5	5.3	6.7	10.5	6.9	4.0	9.1	0.1	19.1	15.2	1.6	1.4	0.5	52.0
Nebraska	8.0	10.1	31.4	4.3	12.5	38.3	13.5	0.6	10.8	14.5	14.9	0.0	26.6	24.1	3.4	1.1	0.1	83.9
Nevada	2.5	2.0	1.7	3.3	9.6	18.4	3.6	3.0	34.3	47.5	20.0	0.0	39.0	30.1	3.4	1.4	0.0	109.4
New Hampshi	0.2	0.1	2.2	0.0	2.8	3.0	13.2	0.0	8.6	3.3	18.9	0.1	15.6	8.6	12.1	0.9	0.0	51.7
New Jersey	0.5	0.9	2.9	30.0	31.4	184.3	256.4	3.9	14.8	24.9	23.4	0.1	136.8	133.6	28.6	1.8	0.4	460.0
New Mexico	2.0	2.6	8.6	0.4	3.0	9.7	7.8	0.2	6.0	10.1	17.3	0.1	31.3	33.2	3.3	1.9	2.5	107.5
New York	2.9	6.1	15.3	134.2	52.0	313.6	228.6	23.6	55.7	116.5	78.6	1.8	200.5	321.5	144.3	5.5	2.0	446.3
North Carolin	6.2	3.5	24.4	35.1	44.3	82.1	176.7	20.5	110.4	73.2	70.4	2.3	169.1	46.2	21.9	2.2	1.8	361.7
North Dakota	3.6	4.0	16.2	24.9	1.9	5.0	2.2	8.8	4.1	5.0	8.1	1.3	12.3	9.2	2.3	1.1	0.9	33.6
Ohio	5.2	3.9	14.0	53.0	138.4	267.6	241.5	7.6	162.9	117.9	65.1	5.9	145.9	139.1	15.1	2.9	3.3	445.4
Oklahoma	3.7	5.9	9.8	14.0	17.0	79.2	36.1	2.2	25.6	39.2	14.9	0.0	49.8	36.1	3.2	2.3	1.6	209.4
Oregon	5.0	7.8	19.0	0.0	21.7	74.8	23.3	0.0	38.0	55.0	35.2	0.0	76.9	31.4	5.1	1.4	2.1	166.7
Pennsylvania	3.6	2.8	9.2	435.5	104.5	222.7	207.6	35.9	71.8	56.9	40.5	12.8	172.9	110.8	34.6	1.8	9.0	439.5
Rhode Island	0.1	0.6	0.4	0.0	1.5	31.6	5.0	0.0	4.1	31.1	3.1	0.0	11.9	11.7	6.9	0.9	0.3	34.9
South Carolin	3.2	1.7	5.2	22.2	51.2	85.8	79.1	6.2	101.4	60.1	25.2	0.0	78.2	23.7	6.2	2.2	0.9	195.5
South Dakota	2.7	2.6	24.9	9.1	2.2	4.2	2.7	2.2	4.7	3.9	10.6	0.0	11.1	8.6	2.5	1.2	0.2	38.7
Tennessee	2.9	2.1	7.7	37.8	51.5	100.4	77.7	7.3	81.6	59.5	39.4	3.8	114.6	62.8	8.9	2.2	0.5	293.3
Texas	15.9	36.0	113.8	29.8	150.6	1,099.2	1,248.9	4.5	166.0	375.4	447.2	0.3	329.8	176.0	45.2	7.1	3.9	1,437.7
Utah	1.2	1.3	3.1	21.6	11.2	30.4	16.5	4.6	16.8	19.4	17.1	1.1	43.7	39.4	3.5	1.4	0.1	127.6
Vermont	0.5	0.2	1.8	0.0	2.6	3.2	3.1	0.0	4.6	2.4	4.9	0.0	7.4	2.3	7.1	0.9	0.0	29.7
Virginia	2.7	2.5	10.3	64.7	30.2	74.3	68.6	17.8	51.0	57.1	61.2	1.6	129.3	71.3	24.9	2.2	2.1	354.0
Washington	9.1	4.8	25.7	31.1	45.3	57.6	54.6	6.2	69.2	36.3	60.2	0.7	125.4	57.2	6.7	1.4	2.3	346.8
West Virginia	0.6	0.4	1.4	34.7	28.2	50.5	63.3	2.0	9.5	6.8	7.6	3.6	25.2	25.0	2.5	2.9	7.4	67.4
Wisconsin	4.9	5.5	36.1	18.3	47.6	149.0	131.6	1.4	58.3	60.8	71.5	3.1	64.7	64.1	12.1	1.6	0.7	200.7
Wyoming	1.9	1.0	4.2	7.3	4.5	8.0	15.5	1.7	3.2	2.9	6.5	2.3	15.6	12.4	3.5	1.4	1.1	56.3
United States	206.2	270.6	829.0	1,993.0	1,691.8	6,072.2	5,008.1	321.6	2,291.4	2,903.6	2,207.6	81.1	4,487.6	2,965.5	690.8	108.6	79.6	######

Table 7-17. U.S. State-Level Household Energy Consumption (trillion Btu)

	Electricity		Natural Gas		Petroleum	
State	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Alabama	115.7	135.5	56.4	62.3	352.8	405.4
Alaska	7.5	8.7	15.4	17.1	166.8	202.7
Arizona	104.3	128.2	51.0	64.3	352.8	423.6
Arkansas	59.8	70.2	47.0	46.7	221.2	252.9
California	293.7	337.1	650.9	763.7	2,421.6	3,108.6
Colorado	60.6	73.9	164.7	201.1	283.3	327.6
Connecticut	50.3	55.2	45.5	48.8	219.3	250.8
Delaware	15.3	16.8	11.1	12.4	59.8	66.4
Florida	428.3	510.8	20.0	24.3	1,113.8	1,352.4
Georgia	187.4	220.0	171.2	200.3	676.6	792.9
Hawaii	11.2	12.9	0.7	0.8	100.5	125.7
Idaho	30.1	35.1	28.4	34.8	101.2	117.1
Illinois	173.4	196.9	502.8	524.8	693.4	780.5
Indiana	123.2	140.0	173.9	177.6	489.1	538.7
Iowa	49.8	56.5	79.9	78.6	200.8	219.4
Kansas	49.2	56.8	79.8	82.0	183.5	208.7
Kentucky	98.9	112.4	76.5	81.3	317.7	350.3
Louisiana	108.3	127.0	56.4	56.5	618.6	712.4
Maine	18.2	20.1	1.2	1.3	124.7	142.0
Maryland	98.9	109.2	99.4	115.3	321.2	373.1
Massachusetts	75.3	83.0	128.0	135.8	406.9	460.1
Michigan	134.6	153.2	393.5	400.9	594.7	653.3
Minnesota	75.0	85.5	148.1	151.8	385.6	437.7
Mississippi	68.7	80.5	32.1	34.8	251.5	283.4
Missouri	122.0	138.6	130.5	132.1	416.4	468.0
Montana	17.3	20.2	28.3	33.9	79.3	90.4
Nebraska	32.7	37.1	46.7	47.4	128.9	145.1
Nevada	41.8	49.2	44.3	53.1	162.2	185.3
New Hampshire	16.3	17.9	8.6	9.2	100.9	114.6
New Jersey	104.2	114.5	230.6	233.2	714.6	822.9
New Mexico	20.6	25.2	50.6	65.5	151.8	185.8
New York	166.1	174.5	404.3	396.9	822.2	922.5
North Carolina	191.1	222.5	76.8	87.9	566.3	646.1
North Dakota	13.4	15.2	12.4	12.5	56.9	63.5
Ohio	198.3	225.9	371.3	377.4	708.9	777.7
Oklahoma	77.0	88.9	72.6	73.0	307.1	356.2
Oregon	75.5	88.5	49.7	53.6	240.0	284.8
Pennsylvania	186.5	204.6	262.2	250.6	770.8	842.1
Rhode Island	11.6	12.3	20.6	20.9	61.4	71.6
South Carolina	102.7	119.6	34.6	39.9	292.1	336.0
South Dakota	13.7	15.6	14.3	14.4	63.7	71.1
Tennessee	149.3	174.8	84.3	92.6	441.6	504.4
Texas	469.5	546.7	227.1	238.3	2,007.3	2,426.6
Utah	29.1	34.1	83.1	103.1	172.3	203.8
Vermont	8.3	9.4	3.2	3.3	53.6	63.6
Virginia	154.9	180.6	95.5	110.5	549.0	634.2
Washington	138.6	161.7	94.4	103.0	496.7	596.3
West Virginia	40.8	46.3	36.0	38.7	109.6	117.6
Wisconsin	83.1	94.4	145.2	149.7	329.5	366.4
Wyoming	9.6	11.2	18.5	23.2	80.2	95.6
United States	4,911.7	5,654.7	5,679.5	6,081.2	20,540.5	23,977.9

Table 7-18. U.S. State-Level Carbon Dioxide Emissions by Fuel (MMTC)

	Coal		Natural Gas		Petroleum	
State	2010	2020	2010	2020	2010	2020
Alabama	20.2	23.2	6.3	7.8	11.8	13.6
Alaska	0.8	0.9	4.3	5.0	5.5	6.7
Arizona	9.6	13.7	4.9	4.4	10.7	12.8
Arkansas	8.1	9.3	3.9	4.5	8.0	9.1
California	1.9	2.5	42.0	47.0	75.4	96.1
Colorado	9.8	14.3	7.1	7.8	9.5	11.0
Connecticut	1.4	1.3	2.9	3.4	8.2	9.4
Delaware	1.1	1.2	1.1	1.3	2.9	3.2
Florida	23.1	28.9	11.3	15.4	36.5	45.8
Georgia	19.0	21.5	7.2	8.8	21.4	25.1
Hawaii	0.7	0.7	0.0	0.1	4.2	5.3
Idaho	0.2	0.3	1.2	1.5	3.8	4.4
Illinois	40.5	41.9	18.1	20.1	25.8	29.2
Indiana	38.3	38.6	9.4	11.4	17.6	19.6
Iowa	15.3	16.0	3.6	3.9	8.3	9.2
Kansas	12.2	12.5	4.0	4.6	7.9	9.0
Kentucky	25.5	25.8	3.8	4.7	14.2	15.9
Louisiana	9.6	11.0	18.6	23.4	30.9	35.5
Maine	0.2	0.2	1.5	1.8	5.5	6.2
Maryland	8.2	8.8	3.4	4.1	11.3	13.2
Massachusetts	4.2	4.2	7.3	8.3	15.7	17.6
Michigan	20.9	22.3	17.5	23.8	20.0	22.3
Minnesota	11.1	12.5	5.1	5.6	13.4	15.3
Mississippi	4.6	5.1	4.7	6.2	8.5	9.6
Missouri	26.6	28.0	5.1	5.7	13.7	15.5
Montana	9.5	14.0	0.9	1.1	3.3	3.8
Nebraska	6.9	8.0	1.9	2.1	4.6	5.2
Nevada	5.7	9.1	4.6	5.1	4.9	5.6
New Hampshire	0.9	0.9	0.3	0.4	4.0	4.5
New Jersey	3.3	3.6	11.3	13.3	25.7	29.6
New Mexico	7.8	11.5	3.6	4.1	5.4	6.5
New York	8.9	8.9	21.8	24.2	31.5	35.8
North Carolina	18.1	20.3	4.1	5.0	19.7	22.6
North Dakota	15.7	17.5	0.7	0.7	2.3	2.6
Ohio	35.1	35.9	13.5	15.1	25.7	28.5
Oklahoma	12.5	13.0	8.0	9.8	10.3	11.9
Oregon	1.5	2.3	4.2	4.6	7.9	9.4
Pennsylvania	43.7	45.0	10.4	11.2	27.3	30.0
Rhode Island	0.0	0.0	2.1	2.3	2.1	2.4
South Carolina	8.7	9.6	3.1	3.9	9.9	11.4
South Dakota	1.3	1.5	0.5	0.5	2.4	2.7
Tennessee	15.1	16.8	4.2	4.8	14.7	16.8
Texas	51.7	51.5	66.1	74.8	106.9	126.2
Utah	12.1	19.5	3.1	3.7	5.8	6.9
Vermont	0.0	0.0	0.2	0.2	1.9	2.3
Virginia	10.8	11.9	4.5	5.5	18.9	21.8
Washington	5.2	7.9	4.5	5.1	17.5	20.8
West Virginia	23.8	24.6	1.9	2.3	4.3	4.7
Wisconsin	16.0	16.9	6.6	7.4	13.3	14.8
Wyoming	19.3	30.4	1.7	2.0	3.4	4.0
United States	646.7	725.4	378.2	439.9	764.5	891.8

Table 7-19. U.S. State-Level Shares of Non-CO_2 GHG Emission

State	CH_4		N_2O		HFC		PFC		SF_6	
	2010	2020	2010	2020	2010	2020	2010	2020	2010	2020
Alabama	1.4%	1.4%	1.0%	1.0%	1.5%	1.5%	1.7%	1.5%	3.2%	3.3%
Alaska	1.0%	2.9%	0.2%	0.2%	0.1%	0.1%	0.0%	0.0%	0.1%	0.2%
Arizona	1.1%	1.1%	0.5%	0.5%	1.9%	2.0%	4.8%	6.0%	2.3%	2.3%
Arkansas	1.4%	1.4%	2.0%	2.0%	0.9%	0.9%	0.8%	0.7%	1.0%	1.1%
California	7.5%	7.7%	4.9%	5.2%	12.2%	12.4%	16.7%	19.1%	4.7%	4.4%
Colorado	3.9%	4.2%	2.0%	2.2%	1.7%	1.9%	0.9%	1.1%	1.0%	1.1%
Connecticut	0.5%	0.4%	0.2%	0.2%	1.4%	1.3%	0.5%	0.4%	0.8%	0.8%
Delaware	0.1%	0.1%	0.3%	0.3%	0.3%	0.3%	0.1%	0.1%	0.2%	0.2%
Florida	2.5%	2.4%	0.7%	0.7%	3.6%	3.7%	1.9%	1.9%	4.6%	5.6%
Georgia	1.5%	1.4%	1.5%	1.5%	3.2%	3.3%	1.7%	1.6%	2.5%	2.7%
Hawaii	0.2%	0.2%	0.1%	0.1%	0.2%	0.2%	0.0%	0.0%	0.2%	0.2%
Idaho	0.8%	0.8%	1.4%	1.5%	0.5%	0.5%	1.5%	1.8%	0.3%	0.3%
Illinois	3.0%	2.8%	6.5%	6.4%	4.4%	4.2%	2.8%	2.4%	5.0%	4.6%
Indiana	2.1%	2.0%	3.6%	3.4%	3.1%	3.0%	4.5%	3.8%	4.1%	3.7%
Iowa	2.2%	2.2%	6.6%	6.7%	1.1%	1.1%	2.4%	2.2%	1.1%	1.1%
Kansas	3.1%	3.1%	4.8%	4.7%	1.0%	1.0%	0.3%	0.3%	1.0%	1.0%
Kentucky	3.2%	3.1%	1.7%	1.7%	1.7%	1.7%	3.1%	2.7%	2.2%	2.1%
Louisiana	2.4%	2.2%	1.5%	1.5%	1.1%	1.2%	0.5%	0.5%	1.8%	2.1%
Maine	0.2%	0.2%	0.2%	0.2%	0.4%	0.4%	0.2%	0.3%	0.4%	0.4%
Maryland	0.9%	0.9%	0.7%	0.7%	1.3%	1.4%	0.6%	0.6%	1.1%	1.1%
Massachusetts	0.8%	0.7%	0.3%	0.3%	2.5%	2.3%	2.0%	2.1%	1.1%	1.1%
Michigan	2.2%	2.0%	2.7%	2.6%	6.7%	6.3%	2.4%	2.0%	3.3%	4.1%
Minnesota	1.8%	1.8%	5.2%	5.1%	2.0%	2.0%	1.2%	1.2%	1.3%	1.2%
Mississippi	0.8%	0.8%	0.9%	0.9%	0.9%	0.9%	0.3%	0.3%	0.9%	1.1%
Missouri	1.4%	1.3%	3.2%	3.1%	2.0%	2.0%	2.1%	1.9%	2.6%	2.3%
Montana	0.8%	0.9%	2.1%	2.1%	0.2%	0.2%	0.3%	0.3%	0.8%	1.0%
Nebraska	2.3%	2.5%	5.6%	5.8%	0.5%	0.5%	0.0%	0.0%	0.6%	0.6%
Nevada	0.4%	0.4%	0.4%	0.4%	0.7%	0.7%	0.0%	0.0%	1.5%	1.7%
New Hampshire	0.2%	0.2%	0.1%	0.1%	0.6%	0.6%	0.6%	0.6%	0.3%	0.3%
New Jersey	1.2%	1.1%	1.2%	1.2%	1.9%	1.8%	1.3%	1.2%	1.9%	1.9%
New Mexico	2.6%	2.4%	0.6%	0.6%	0.4%	0.5%	0.8%	1.1%	0.7%	0.9%
New York	3.0%	2.7%	2.1%	2.1%	4.3%	4.1%	3.4%	3.1%	3.4%	3.3%
North Carolina	1.8%	1.7%	1.3%	1.3%	4.1%	4.3%	1.3%	1.2%	2.6%	2.7%
North Dakota	0.5%	0.5%	2.9%	2.9%	0.2%	0.2%	0.0%	0.0%	0.6%	0.7%
Ohio	2.7%	2.5%	3.4%	3.3%	5.0%	4.8%	6.2%	5.3%	4.5%	4.0%
Oklahoma	4.1%	3.9%	1.9%	1.9%	1.0%	1.0%	0.2%	0.2%	1.5%	1.6%
Oregon	0.7%	0.7%	1.2%	1.2%	1.4%	1.5%	4.9%	5.5%	2.4%	2.0%
Pennsylvania	4.4%	4.3%	2.8%	2.7%	3.8%	3.6%	5.4%	4.8%	7.0%	6.1%
Rhode Island	0.1%	0.1%	0.0%	0.0%	0.3%	0.3%	0.3%	0.3%	0.4%	0.3%
South Carolina	0.6%	0.6%	0.5%	0.5%	1.7%	1.7%	0.9%	0.9%	2.0%	2.0%
South Dakota	0.8%	0.8%	3.7%	3.7%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%
Tennessee	1.1%	1.1%	1.4%	1.4%	2.3%	2.3%	2.6%	2.3%	2.4%	2.3%
Texas	11.7%	11.2%	6.9%	6.9%	7.2%	7.4%	8.6%	9.5%	9.5%	9.1%
Utah	1.3%	1.4%	0.7%	0.7%	0.8%	0.8%	0.2%	0.2%	1.7%	2.0%
Vermont	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.8%	0.9%	0.1%	0.0%
Virginia	1.9%	1.8%	1.4%	1.5%	2.4%	2.5%	2.2%	2.2%	1.6%	1.7%
Washington	1.5%	1.5%	1.8%	1.9%	2.2%	2.3%	3.4%	3.2%	2.7%	2.5%
West Virginia	3.1%	2.9%	0.4%	0.4%	0.3%	0.4%	1.2%	1.1%	2.1%	2.0%
Wisconsin	2.0%	1.9%	4.0%	3.9%	2.4%	2.4%	1.8%	1.5%	1.4%	1.3%
Wyoming	4.9%	5.3%	0.7%	0.7%	0.1%	0.2%	0.0%	0.0%	1.2%	1.9%
United States	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

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