# Residential Demand Module

The NEMS Residential Demand Module forecasts future residential sector energy requirements based on projections of the number of households and the stock, efficiency, and intensity of use of energy-consuming equipment. The Residential Demand Module projections begin with a base year estimate of the housing stock, the types and numbers of energy-consuming appliances servicing the stock, and the "unit energy consumption" by appliance (or UEC—in million Btu per household per year). The projection process adds new housing units to the stock, determines the equipment installed in new units, retires existing housing units, and retires and replaces appliances. The primary exogenous drivers for the module are housing starts by type (single-family, multifamily and mobile homes) and Census Division and prices for each energy source for each of the nine Census Divisions (see Figure 5). The Residential Demand Module also requires projections of available equipment and their installed costs over the forecast

Figure 5. United States Census Divisions
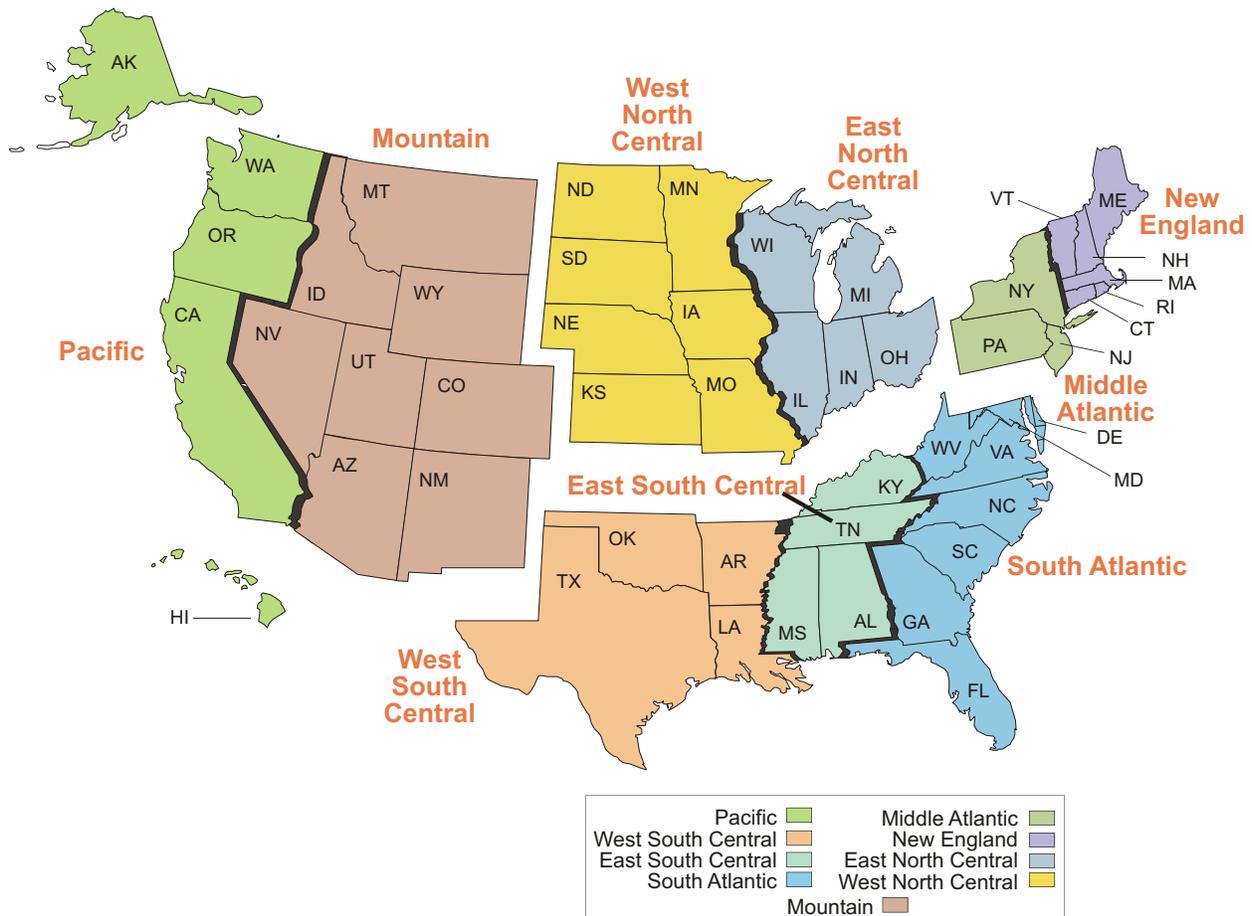
Source:Energy Information Administration,Office of Integrated Analysis and Forecasting.

horizon. Over time, equipment efficiency tends to increase because of general technological advances and also because of Federal and/or state efficiency standards. As energy prices and available equipment changes over the forecast horizon, the module includes projected changes to the type and efficiency of equipment purchased as well as projected changes in the usage intensity of the equipment stock.

The end-use services for which equipment stocks are modeled include space conditioning (heating and cooling), water heating, refrigeration, freezers, dishwashers, clothes washers, lighting, furnace fans, color televisions, personal computers, cooking, clothes drying, ceiling fans, coffee makers, spas, home security systems, microwave ovens, set-top boxes, home audio equipment, rechargeable electronics, and VCR/DVDs. In addition to the major equipment-driven end-uses, the average energy consumption per household is projected for other electric and nonelectric appliances. The module's output includes number

of households, equipment stock, average equipment efficiencies, and energy consumed by service, fuel, and geographic location. The fuels represented are distillate fuel oil, liquefied petroleum gas, natural gas, kerosene, electricity, wood, geothermal, coal, and solar energy.

One of the implicit assumptions embodied in the Residential Demand Module is that, through 2030, there will be no radical changes in technology or consumer behavior. No new regulations of efficiency beyond those currently embodied in law or new government programs fostering efficiency improvements are assumed. Technologies which have not gained widespread acceptance today will generally not achieve significant penetration by 2030. Currently available technologies will evolve in both efficiency and cost. In general, at the same efficiency level, future technologies will be less expensive than those available today in real dollar terms. When choosing new or replacement technologies, consumers will behave similarly to the way they now behave. The intensity of end-uses will change moderately in response to price changes. Electric end uses will continue to expand, but at a decreasing rate.[5]

Key Assumptions

Housing Stock Submodule

An important determinant of future energy consumption is the projected number of households. Base year estimates for 2001 are derived from the Energy Information Administration's (EIA) *Residential Energy Consumption Survey* (RECS) (Table 7). The forecast for occupied households is done separately for each Census Division. It is based on the combination of the previous year's surviving stock with projected housing starts provided by the NEMS Macroeconomic Activity Module. The housing stock submodule assumes a constant survival rate (the percentage of households which are present in the current forecast year, which were also present in the preceding year) for each type of housing unit; 99.7 percent for single-family units, 99.8 percent for multifamily units, and 97.5 percent for mobile home units. Projected fuel consumption is dependent not only on the projected number of housing units, but also on the type and geographic distribution of the houses. The intensity of space heating energy use varies greatly across the various climate zones in the United States. Also, fuel prevalence varies across the country—oil (distillate) is more frequently used as a heating fuel in the New England and Middle Atlantic Census Divisions than in the rest of the country, while natural gas dominates in the Midwest. An example of differences by housing type is the more prevalent use of liquefied petroleum gas in mobile homes relative to other housing types.

Table 7. 2001 Households

Census Division	Single-family Units	Multiple family Units	Mobile Home	Total Units
New England	3,491,245	1,750,832	164,920	5,406,997
Mid Atlantic	8,517,861	5,841,068	487,669	14,846,598
East North Central	12,434,352	3,823,487	833,176	17,091,015
West North Central	5,847,681	1,165,884	386,829	7,400,394
South Atlantic	14,789,885	3,994,812	1,503,227	20,287,924
East South Central	5,082,656	881,661	853,964	6,818,281
West South Central	8,714,591	2,191,011	896,583	11,802,185
Mountain	4,631,584	1,334,829	758,618	6,725,031
Pacific	10,154,346	5,509,759	921,178	16,585,283
	0	0	0	0
United States	73,664.201	26,493,343	6,806,164	106,963,708

Source: U.S. Deoartment of Energy, Energy Information Administration, *2001 Residential Energy Consumption Survey.*

Technology Choice Submodule

The key inputs for the Technology Choice Submodule are fuel prices by Census Division and characteristics of available equipment (installed cost, maintenance cost, efficiency, and equipment life). Fuel prices are determined by an equilibrium process which considers energy supplies and demands and are passed to this submodule from the integrating module of NEMS. Energy price, combined with equipment UEC (which is a function of efficiency), determines the operating costs of equipment. Equipment characteristics are

exogenous to the model and are modified to reflect both Federal standards and anticipated changes in the market place. Table 8 lists capital cost and efficiency for selected residential appliances for the years 2004 and 2020.

Table 8. Installed Cost and Efficiency Ratings of Selected Equipment

Equipment Type	Relative Performance[1]	2004 Installed Cost ($2004)[2]	Efficiency[3]	2020 Installed Cost ($2004)[2]	Efficiency[3]	Approximate Hurdle Rate
Electric Heat Pump	Minimum	$3,800	10.0	$4,150	13.0	15%
	Best	$7,000	18.6	$7,000	18.8	
Natural Gas Furnace	Minimum	$1,500	0.80	$1,500	0.80	15%
	Best	$2,000	0.97	$2,000	0.97	
Room Air Conditioner	Minimum	$387	9.8	$387	9.8	140%
	Best	$760	11.7	$800	12.0	
Central Air Conditioner	Minimum	$2,000	10.0	$2,500	13.0	15%
	Best	$6,000	19.5	$6,000	20.0	
Refrigerator (23.9 cubic ft in adjusted volume)	Minimum	$600	510	$600	510	19%
	Best	$650	432	$650	400	
Electric Water Heater	Minimum	$350	0.90	$350	0.90	83%
	Best	$1,800	2.4	$1,800	2.4	
Solar Water Heater	N/A	$2,867	2.0	$2,200	2.0	83%

[1]Minimum performance refers to the lowest efficiency equipment available. Best refers to the highest efficiency equipment available.

[2]Installed costs are given in 2004 dollars in the original source document.

[3]Efficiency measurements vary by equipment type. Electric heat pumps and central air conditioners are rated for cooling performance using the Seasonal Energy Efficiency Ratio (SEER); natural gas furnaces are based on Annual Fuel Utilization Efficiency; room air conditioners are based on Energy Efficiency Ratio (EER); refrigerators are based on kilowatt-hours per year; and water heaters are based on Energy Factor (delivered Btu divided by input Btu).

Source: Navigant Consulting, *EIA Technology Forecast Updates*, Reference Number 117943, September 2004.

Table 9 provides the cost and performance parameters for representative distributed generation technologies. The *AEO2007* model also incorporates endogenous "learning" for the residential distributed generation technologies, allowing for declining technology costs as shipments increase. For fuel cell and photovoltaic systems, learning parameter assumptions for the *AEO2007* reference case result in a 13 percent reduction in capital costs each time the number of units shipped to the buildings sectors (residential and commercial) doubles.

The Residential Demand Module projects equipment purchases based on a nested choice methodology. The first stage of the choice methodology determines the fuel and technology to be used, the second stage determines the efficiency of the selected equipment type. The equipment choices for cooling, water heating, and cooking are linked to the space heating choice for new construction. Technology and fuel choice for replacement equipment uses a nested methodology similar to that for new construction, but includes (in addition to the capital and installation costs of the equipment) explicit costs for technology switching (e.g., costs for installing gas lines if switching from electricity or oil to gas, or costs for adding ductwork if switching from electric resistance heat to central heating types). Also, for replacements, there is no linking of fuel choice for water heating and cooking as is done for new construction. Technology switching upon replacement is allowed for space heating, air conditioning, water heating, cooking and clothes drying.

Once the fuel and technology choice for a particular end use is determined, the second stage of the choice methodology determines efficiency. In any given year, there are several available prototypes of varying efficiency (minimum standard, medium low, medium high and highest efficiency). Efficiency choice is based on a functional form and coefficients which give greater or lesser importance to the installed capital cost (first cost) versus the operating cost. Generally, within a technology class, the higher the first cost, the lower the operating cost. For new construction, efficiency choices are made based on the costs of both the heating and cooling equipment and the building shell characteristics.

The parameters for the second stage efficiency choice are calibrated to the most recently available shipment data for the major residential appliances. Shipment efficiency data are obtained from industry associations which monitor shipments such as the Association of Home Appliance Manufacturers. Because of this calibration procedure, the model allows the relative importance of first cost versus operating cost to vary by general technology and fuel type (e.g., natural gas furnace, electric heat pump, electric central air

Table 9. Capital Cost and Performance Parameters of Residential Distributed Generation Technologies

Technology Type	Year of Introduction	Average Generating Capacity (kW)	Electrical Efficiency	Combined Efficiency (Elec. + Thermal)	Installed Capital Cost ($2003 per KW of Capacity)[1]	Service Life Years
Solar Photovoltaic						
	2005	2.0	0.16	N/A	$8,577	30
	2010	2.5	0.18	N/A	$6,944	30
	2015	3.0	0.20	N/A	$5,310	30
	2020	3.0	0.22	N/A	$4,627	30
	2030	4.0	0.25	N/A	$3,840	30
Fuel Cell	2005	10	0.30	0.696	$11,293	20
	2010	10	0.32	0.699	$7,802	20
	2015	10	0.335	0.705	$6,160	20
	2020	10	0.350	0.712	$4,517	20
	2030	10	0.360	0.723	$2,669	20

[1]Installed costs are given in 2003 dollars in the original source document.

Source: Solar Technology Specifications: Solar Energy Industries Association, *Our Solar Power Future - The U.S. Photovoltaic Industry Roadmap through 2030 and Beyond* (SEIA, September 2004). Fuel cells: Discovery Insights, *LLC, "Installed Costs for Small CHP Systems - Estimates and Projections"* (April 2005).

conditioner, etc.). Once the model is calibrated, it is possible to calculate (approximately) the apparent discount rates based on the relative weight given to the operating cost savings versus the weight given to the higher cost of more efficient equipment. Hurdle rates in excess of 30 percent are common in the Residential Demand Module. The prevalence of such high apparent hurdle rates by consumers has led to the notion of the "efficiency gap" that is, there are many investments that could be made that provide rates of return in excess of residential borrowing rates (15 to 20 percent for example). There are several studies which document instances of apparent high discount rates.[6] Once equipment efficiencies for a technology and fuel are determined, the installed efficiency for its entire stock is calculated.

Appliance Stock Submodule

The Appliance Stock Submodule is an accounting framework which tracks the quantity and average efficiency of equipment by end use, technology, and fuel. It separately tracks equipment requirements for new construction and existing housing units. For existing units, this module calculates equipment which survives from previous years, allows certain end uses to further penetrate into the existing housing stock and calculates the total number of units required for replacement and further penetration. Air conditioning and clothes drying are the two end uses not considered to be "fully penetrated."

Once a piece of equipment enters into the stock, an accounting of its remaining life is begun. It is assumed that all appliances survive a minimum number of years after installation. A fraction of appliances are removed from the stock once they have survived for the minimum number of years. Between the minimum and maximum life expectancy, all appliances retire based on a linear decay function. For example, if an appliance has a minimum life of 5 years and a maximum life of 15 years, one tenth of the units (1 divided by 15 minus 5) are retired in each of years 6 through 15. It is further assumed that, when a house is retired from the stock, all of the equipment contained in that house retires as well; i.e., there is no secondhand market for this equipment. The assumptions concerning equipment lives are given in Table 10.

Table 10. Minimum and Maximum Life Expectancies of Equipment

Equipment	Minimum Life	Maximum Life
Heat Pumps	7	21
Central Forced-Air Furnaces	10	25
Hydronic Space Heaters	20	30
Room Air Conditioners	8	16
Central Air Conditioners	7	21
Gas Water Heaters	4	14
Electric Water Heaters	5	22
Cooking Stoves	16	21
Clothes Dryers	11	20
Refrigerators	7	26
Freezers	11	31

Source: Lawrence Berkeley Laboratory, *Baseline Data for the Residential Sector and Development of a Residential Forecasting Database*, May 1994, and analysis of RECS 2001 data.

Fuel Consumption Submodule

Energy consumption is calculated by multiplying the vintage equipment stocks by their respective UECs. The UECs include adjustments for the average efficiency of the stock vintages, short term price elasticity of demand and "rebound" effects on usage (see discussion below), the size of new construction relative to the existing stock, people per household and shell efficiency and weather effects (space heating and cooling). The various levels of aggregated consumption (consumption by fuel, by service, etc.) are derived from these detailed equipment-specific calculations.

Equipment Efficiency

The average energy consumption of a particular technology is initially based on estimates derived from RECS 2001. Appliance efficiency is either derived from a long history of shipment data (e.g., the efficiency of conventional air-source heat pumps) or assumed based on engineering information concerning typical installed equipment (e.g., the efficiency of ground-source heat pumps). When the average efficiency is computed from shipment data, shipments going back as far as 20 to 30 years are combined with assumptions concerning equipment lifetimes. This allows for not only an average efficiency to be calculated, but also for equipment retirements to be vintaged—older equipment tends to be lower in efficiency and also tends to get retired before newer, more efficient equipment. Once equipment is retired, the Appliance Stock and Technology Choice Modules determine the efficiency of the replacement equipment. It is often the case that the retired equipment is replaced by substantially more efficient equipment.

As the stock efficiency changes over the simulation interval, energy consumption decreases in inverse proportion to efficiency. Also, as efficiency increases, the efficiency rebound effect (discussed below) will offset some of the reductions in energy consumption by increased demand for the end-use service. For example, if the stock average for electric heat pumps is now 10 percent more efficient than in 2001, then all else constant (weather, real energy prices, shell efficiency, etc.), energy consumption per heat pump would average about only 9 percent less.

Adjusting for the Size of Housing Units

Information derived from RECS 2001 indicates that new construction (post-1990) is on average roughly 26 percent larger than the existing stock of housing. Estimates for the size of each new home built in the projection period vary by type and region, and are determined by a log-trend forecast based on historical data from the Bureau of the Census.[7] For existing structures, it is assumed that about 1 percent of households that existed in 2001 add about 600 square feet to the heated floor space in each year of the projection period.[8] The energy consumption for space heating, air conditioning, and lighting is assumed to increase with the square footage of the structure. This results in an increase in the average size of the housing stock from 1,716 to 2,004 square feet from 2001 through 2030.

Adjusting for Weather and Climate

Weather in any given year always includes short-term deviations from the expected longer-term average (or climate). Recognition of the effect of weather on space heating and air conditioning is necessary to avoid inadvertently projecting abnormal weather conditions into the future. In the residential module, adjustments are made to space heating and air conditioning UECs by Census Division by their respective heating and cooling degree-days (HDD and CDD). A 10 percent increase in HDD would increase space heating consumption by 10 percent over what it would have otherwise been. Over the projection period, the residential module uses a 30-year average for heating and cooling degree - days by Census Division, adjusted by projections in state population shifts.

Short-Term Price Effect and Efficiency Rebound

It is assumed that energy consumption for a given end-use service is affected by the marginal cost of providing that service. That is, all else equal, a change in the price of a fuel will have an opposite, but less than proportional, effect on fuel consumption. The current value for the short-term elasticity parameter is -0.15.[9] This value implies that for a 1 percent increase in the price of a fuel, there will be a corresponding decrease in energy consumption of -0.15 percent. Another way of affecting the marginal cost of providing a service is through altered equipment efficiency. For example, a 10 percent increase in efficiency will reduce the cost of providing the end-use service by 10 percent. Based on the short-term efficiency rebound parameter, the demand for the service will rise by 1.5 percent (-10 percent multiplied by -0.15). Only space heating and cooling are assumed to be affected by both elasticities and the efficiency rebound effect.

Shell Efficiency

The shell integrity of the building envelope is an important determinant of the heating and cooling load for each type of household. In the NEMS Residential Demand Module, the shell integrity is represented by an index, which changes over time to reflect improvements in the building shell. The shell integrity index is dimensioned by vintage of house, type of house, fuel type, service (heating and cooling), and Census Division. The age, type, location, and type of heating fuel are important factors in determining the level of shell integrity. Housing units which heat with electricity tend to have less air infiltration rates than homes that use other fuels. The age of homes are classified by new (post-2001) and existing. Existing homes are characterized by the RECS 2001 survey and are assigned a shell index value based on the mix of homes that exist in the base year (2001). The improvement over time in the shell integrity of these homes is a function of two factors—an assumed annual efficiency improvement and improvements made when real fuel prices increase (no price-related adjustment is made when fuel prices fall). For new construction, building shell efficiency is determined by the relative costs and energy bill savings for several levels of heating and cooling equipment, in conjunction with the building shell attributes. The packages represented in NEMS range from homes that meet the International Energy Conservation Code (IECC)[10] to homes that exceed the IECC by 50 percent. Shell efficiency in new homes would increase over time if energy prices rise, or the cost of more efficient equipment falls.

Legislation and Other Federal Programs

Energy Policy Act of 2005 (EPACT05)

The passage of the EPACT05 in August 2005 provides additional minimum efficiency standards for residential equipment and provides tax credits to producers and purchasers of energy efficient equipment and builders of energy efficient homes. The standards contained in EPACT05 include: 190 watt maximum for torchiere lamps in 2006; Dehumidifier standards for 2007 and 2012; and ceiling fan light kit standards in 2007. Manfactured homes that are 30 percent better than the latest code, a $1000 tax credit can be claimed in 2006 and 2007. Likewise, builders of homes that are 50 percent better than code can claim a $2000 credit over the same period. The builder tax credits and production tax credits are assumed to be passed through to the consumer in the form of lower purchase cost. EPACT05 includes production tax credits for energy efficient refrigerators, dishwashers, and clothes washers in 2006 and 2007, with dollar amounts varying by type of appliance and level of efficiency met, subject to annual caps. Consumers can claim a 10 percent tax credit in 2006 and 2007 for several types of appliances specified by EPACT05, including: Energy efficient gas, propane, or oil furnaces or boilers, energy efficient central air conditioners, air and ground source heat

pumps, hot water heaters, and windows. Lastly, consumers can claim a 30 percent tax credit in 2006 and 2007 for purchases of solar PV, solar water heaters, and fuel cells, subject to a cap.

National Appliance Energy Conservation Act of 1987

The Technology Choice Submodule incorporates equipment standards established by the National Appliance Energy Conservation Act of 1987 (NAECA). Some of the NAECA standards implemented in the module include: a Seasonal Energy Efficiency Rating (SEER) of 13.0 for central air conditioners and heat pumps; an Annual Fuel Utilization Efficiency (energy output over energy input) of 0.78 for oil and gas furnaces; an Efficiency Factor of 0.90 for electric water heaters; and refrigerator standards that set consumption limits to 510 kilowatt-hours per year in 2002.

Residential Technology Cases

In addition to the *AEO2007* reference case, three side cases were developed to examine the effect of equipment and building standards on residential energy use—a *2006 technology case,* a *best available technology case*, and a *high technology case*. These side cases were analyzed in stand-alone (not integrated with the supply modules) NEMS runs and thus do not include supply-responses to the altered residential consumption patterns of the two cases. *AEO2007* also analyzed *integrated 2006 technology* and *high technology cases*. The *integrated 2006 technology case* combines the *2006 technology cases* of the four end-use demand sectors, the *electricity low fossil technology case*, and the assumption of renewable technologies fixed at 2006 levels. The *integrated high technology case* uses the same approach, but for high technology.

The 2006 technology case assumes that all future equipment purchases are made based only on equipment available in 2006. This case further assumes that existing building shell efficiencies will not improve beyond 2006 levels.

The *high technology case* assumes earlier availability, lower costs, and/or higher efficiencies for more advanced equipment than the reference case. Equipment assumptions were developed by engineering technology experts, considering the potential impact on technology given increased research and development into more advanced technologies.[11] In the *high technology case.* All new construction is assumed to meet Energy Star specifications after 2010.

The *best available technology case* assumes that all equipment purchases from 2007 forward are based on the highest available efficiency in the *high technology case* in a particular simulation year, disregarding the economic costs of such a case. This case is designed to show how much the choice of the highest-efficiency equipment could affect energy consumption.   In this case, all new construction is built to the most efficient specifications after 2006.

Notes and Sources

[5] The Model Documentation Report contains additional details concerning model structure and operation. Refer to Energy Information Administration, Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System, DOE/EIA-M065(2006), (March 2006).

[6]   Among the explanations often mentioned for observed high average implicit discount rates are: market failures, (i.e., cases where incentives are not properly aligned for markets to result in   purchases based on energy economics alone); unmeasured technology costs (i.e., extra costs of adoption which are not included or difficult to measure like employee down-time); characteristics of efficient technologies viewed as less desirable than their less efficient alternatives (such as equipment noise levels or lighting quality characteristics); and the risk inherent in making irreversible investment decisions. Examples of market failures/barriers include: decision makers having less than complete information, cases where energy equipment decisions are made by parties not responsible for energy bills (e.g., landlord/tenants, builders/home buyers), discount horizons which are truncated (which might be caused by mean occupancy times that are less than the simple payback time and that could possibly be classified as an information failure), and lack of appropriate credit vehicles for making efficiency investments, to name a few. The use of high implicit discount rates in NEMS merely recognizes that such rates are typically found to apply to energy-efficiency investments.

[7] U.S. Bureau of Census, Series C25 Data from various years of publications.

[8] Sources: U.S. Bureau of Census, Annual Housing Survey 2001 and Professional Remodler, 2002 Home Remodeling Study.

[9] See DAHL, CAROL, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, October 1993.

[10] The IECC established guidelines for builders to meet specific targets concerning energy efficiency with respect to heating and cooling load.

[11] The high technology assumptions are based on Energy Information Administration, Technology Forecast Updates-Residential and Commercial Building technologies-Advanced Adoption Case (Navigant Consulting, September 2004).