The residential demand module (RDM) forecasts energy consumption by Census division for seven marketed energy sources plus solar and geothermal energy. RDM is a structural model and its forecasts are built up from projections of the residential housing stock and of the energy-consuming equipment contained therein. The components of RDM and its interactions with the NEMS system are shown in Figure 5. NEMS provides forecasts of residential energy prices, population, disposable income, and housing starts, which are used by RDM to develop forecasts of energy consumption by end–use service, fuel type, and Census division.

RDM incorporates the effects of four broadly-defined determinants of energy consumption: economic and demographic effects, structural effects, technology turnover and advancement effects, and energy market effects. Economic and demographic effects include the number, dwelling type (single-family, multifamily or mobile homes), occupants per household, disposable income, and location of housing units. Structural effects include increasing average dwelling size and changes in the mix of desired end-use services provided by energy (new end uses and/or increasing penetration of current end uses, such as the increasing popularity of electronic equipment and computers). Technology effects include changes in the stock of installed equipment caused by normal turnover of old, worn out equipment with newer versions which tend to be more energy efficient, the integrated effects of equipment and building shell (insulation level) in new construction, and in the projected availability of even more energy-efficient equipment in the future. Energy market effects include the short-run effects of energy prices on energy demands, the longer-run effects of energy prices on the efficiency of purchased equipment and the efficiency of building shells, and limitations on minimum levels of efficiency imposed by legislated efficiency standards.

Housing Stock Submodule

The base housing stock by Census division and dwelling type is derived from EIA's 1997 Residential Energy Consumption Survey (RECS). Each element of the base stock is retired on the basis of a constant rate of decay for each dwelling type. RDM receives as an input from the macroeconomic activity module forecasts of housing additions by type and Census division. RDM supplements the surviving stocks from the previous year with the forecast additions by dwelling type and Census division. The average square footage of new construction is based on recent upward trends developed from the RECS and the Census Bureau's Characteristics of New Housing.

Appliance Stock Submodule

The installed stock of appliances is also taken from the 1997 RECS. The efficiency of the appliance stock is deived from historical shipments by efficiency level over a multi–year interval for the following equipment: heat pumps, gas furnaces, central air conditioners, room air conditioners, water heaters, refrigerators, freezers, stoves, dishwashers, clothes washers, and clothes dryers. A linear retirement function with both minimum and maximum equipment lives is used to retire equipment in surviving housing units. For equipment where shipment data are available, the efficiency of the retiring equipment varies over the projection. In early years, the retiring efficiency tends to be lower as the older, less efficient equipment in the stock turns over first. Also, as housing units retire, the associated appliances are removed from the base appliance stock as well. Additions to the base stock are tracked separately for housing units existing in 1997 and for cumulative new construction.

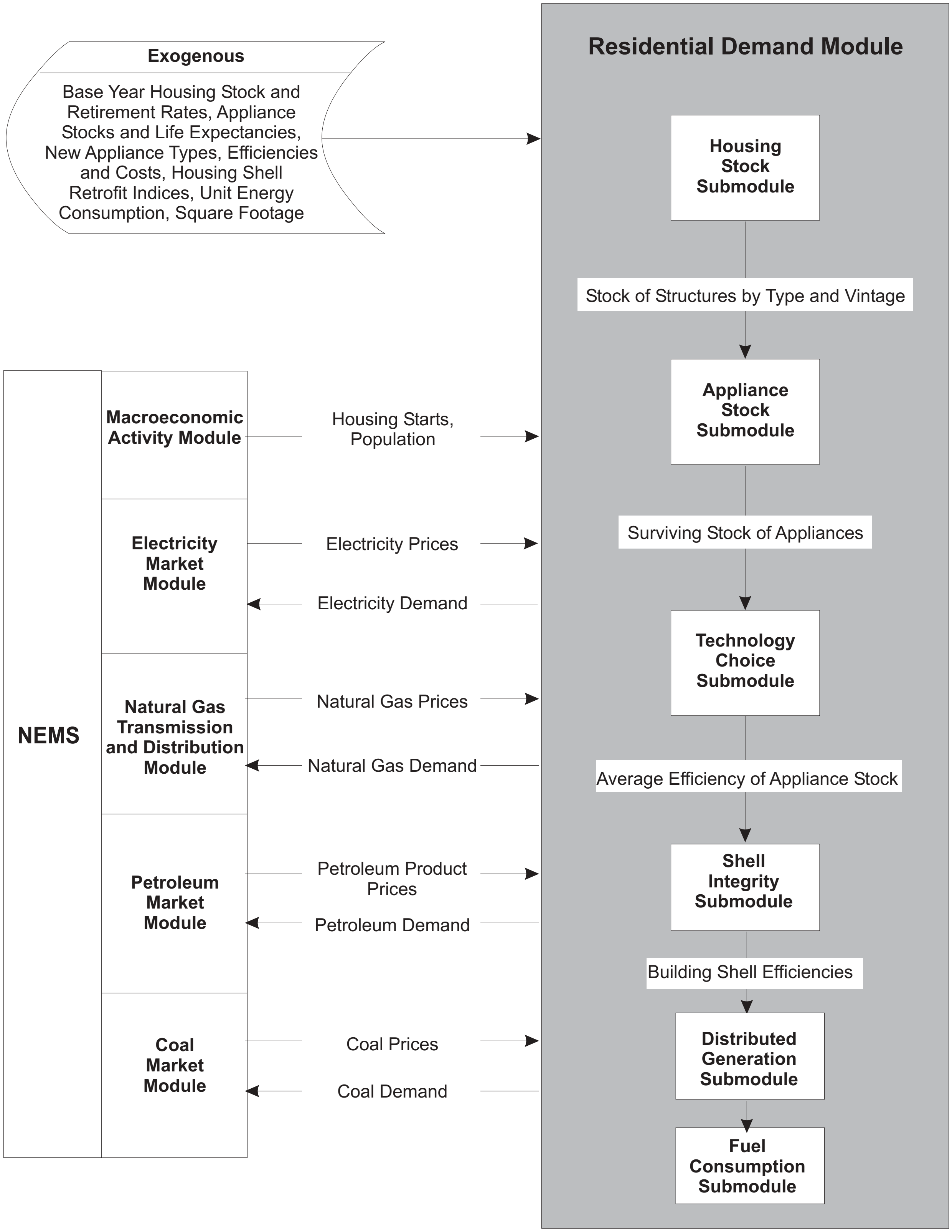
As appliances are removed from the stock, they are replaced by new appliances with generally higher efficiencies due to technology improvements, equipment standards, and market forces. Appliances added due to new construction are accumulated and retired parallel to appliances in the existing stock. Appliance stocks are maintained by fuel, end use, and technology as shown in the above table.

Technology Choice Submodule

Fuel-specific equipment choices are made for both new construction and replacement purchases. For new construction, initial heating system shares

RDM Outputs	Inputs from NEMS	Exogenous Inputs
Energy demand by service and fuel type Changes in housing and appliance stocks Appliance stock efficiency	Energy product prices Housing starts Population	Current housing stocks and retirement rates Current appliance stocks and life expectancy New appliance types, efficiencies, and costs Housing shell retrofit indices Unit energy consumption Square footage

Figure 5. Residential Demand Module Structure



NEMS Residential Module Equipment Summary

Space Heating Equipment: electric furnace, electric air-source heat pump, natural gas furnace, natural gas hydronic, kerosene furnace, liquefied petroleum gas, distillate furnace, distillate hydronic, wood stove, ground-source heat pump, natural gas heat pump.
Space Cooling Equipment: room air conditioner, central air conditioner, electric air-source heat pump, ground-source heat pump, natural gas heat pump.
Water Heaters: solar, natural gas, electric, distillate, liquefied petroleum gas.
Refrigerators: 18 cubic foot top-mounted freezer, 25 cubic foot side-by-side with through-the-door features.
Freezers: chest - manual defrost, upright - manual defrost
Lighting: incandescent, compact fluorescent, mercury vapor
Clothes Dryers: natural gas, electric
Cooking: natural gas, electric, liquefied petroleum gas.
Dishwashers
Clothes Washers
Fuel Cells
Solar Photovoltaic

(taken from the most recently available Census Bureau survey data covering new construction, currently 2001) are adjusted based on relative life cycle costs for all competing technology and fuel combinations. Once new home heating system shares are established, the fuel choices for other services, such as water heating and cooking, are determined based on the fuel chosen for space heating. For replacement purchases, fuel switching is allowed for an assumed percentage of all replacements but is dependent on the estimated costs of fuel–switching (for example, switching from electric to gas heating is assumed to involve the costs of running a new gas line).

For both replacement equipment and new construction, a "second-stage" of the equipment choice decision requires selecting from several projected available efficiency levels. The projected efficiency range of available equipment represents a "menu" of efficiency levels and installed cost combinations projected to be available at the time the choice is being made. Costs and efficiencies for selected appliances are shown in the table on page 25, derived from the report *Assumptions to the Annual Energy Outlook 2003*.[21] At the low end of the efficiency range are the minimum levels required by legislated standards. In any given year, higher efficiency levels are associated with higher installed costs. Thus, purchasing higher than the minimum efficiency involves a trade-off between higher installation costs and future savings in energy expenditures. In RDM, these trade-offs are calibrated to recent shipment, cost, and efficiency data. Changes in projected purchases by efficiency level are based on changes in either the installed capital costs or changes in the first-year operating costs across the available efficiency levels. As energy prices increase, the incentive of greater energy expenditures savings will promote increased purchases of higher-efficiency equipment. In some cases, due to government programs or general projections of technology improvements, projected increases in efficiency or decreases in the installed costs of higher-efficiency equipment will also promote purchases of higher-efficiency equipment.

Shell Integrity Submodule

Shell integrity is also tracked separately for the existing housing stock and new construction. Shell integrity for existing construction is assumed to respond to increases in real energy prices by becoming more efficient. There is no change in existing shell integrity when real energy prices decline. New shell efficiencies are based on the cost and performance of the heating and cooling equipment as well as the shell dharacteristics. Several efficiency levels of shell characteristics are available throughout the projection period and can change over time based on changes to building codes. All shell efficiencies are subject to a maximum shell efficiency based on studies of currently available residential construction methods.

Distributed Generation Submodule

Distributed generation equipment with explicit technology characterizations is also modeled for residential customers. Currently, two technologies are characterized, photovoltaics and fuel cells. The submodule incorporates historical estimates of photovoltaics (residential-sized fuel cells are not expected to be commercialized until after 2001) from its technology characterization and exogenous penetration input file. Program-based photovoltaic estimates for the Department of Energy's Million Solar

[21] Energy Information Administration, *Assumptions to the Annual Energy Outlook 2003*, http://www.eia.doe.gov/oiaf/aeo/assumption/pdf/0554(2003).pdf (Washington, DC, January 2003).

Roofs program are also input to the submodule from the exogenous penetration portion of the input file. Endogenous, economic purchases are based on a penetration function driven by a cash flow model which simulates the costs and benefits of distributed generation purchases. The cash flow calculations are developed from NEMS projected energy prices coupled with the technology characterizations provided from the input file.

Potential economic purchases are modeled by Census division and technology for all years subsequent to the base year. The cash flow model develops a 30-year cost-benefit horizon for each potential investment. It includes considerations of annual costs (down payments, loan payments, maintenance costs and, for fuel cells, gas costs) and annual benefits (interest tax deductions, any applicable tax credits, electricity cost savings, and water heating savings for fuel cells) over the entire 30-year period. Penetration for a potential investment in either photovoltaics or fuel cells is a function of whether it achieves a cumulative positive cash flow, and if so, how many years it takes to achieve it.

Once the cumulative stock of distributed equipment is projected, reduced residential purchases of electricity are provided to NEMS. For fuel cells, increased residential natural gas consumption is also provided to NEMS based on the calculated energy input requirements of the fuel cells, partially offset by natural gas water heating savings from the use of waste heat from the fuel cell.

Fuel Consumption Submodule

The fuel consumption submodule modifies base year energy consumption intensities in each forecast year. Base year energy consumption for each end use is derived from energy intensity estimates from the 1997 RECS. The base year energy intensities are modified for the following effects: (1) increases in efficiency, based on a comparison of the projected appliance stock serving this end use relative to the base year stock, (2) changes in shell integrity for space heating and cooling end uses, (3) changes in real fuel prices—(short-run price elasticity effects), (4) changes in square footage, (5) changes in the number of occupants per household, (6) changes in disposable income, (7) changes in weather relative to the base year, (8) adjustments in utilization rates caused by efficiency increases (efficiency “rebound” effects), and (9) reductions in purchased electricity and increases in natural gas consumption from distributed generation. Once these modifications are made, total energy use is computed across end uses and housing types and then summed by fuel for each Census division.

Characteristics of Selected Equipment

Equipment Type	Relative Performance[1]	2001 Installed Cost (2001 dollars)[2]	Efficiency[3]	2015 Installed Cost (2001 dollars)[2]	Efficiency[3]	Approximate Hurdle[4] Rate
Electric Heat Pump	Minimum	$2,930	10.0	$3,500	12.0	15%
	Best	$5,600	18.0	$5,600	18.0	
Natural Gas Furnace	Minimum	$1,300	0.80	$1,300	0.80	15%
	Best	$2,700	0.97	$1,950	0.97	
Room Air Conditioner	Minimum	$540	8.7	$540	9.7	140%
	Best	$760	11.7	$760	12.0	
Central Air Conditioner	Minimum	$2,080	10.0	$2,300	12.0	25%
	Best	$3,500	18.0	$3,500	18.0	
Refrigerator (18 cubic ft)	Minimum	$600	690	$600	478	19%
	Best	$950	515	$950	400	
Electric Water Heater	Minimum	$337	0.86	$500	0.90	83%
	Best	$1,200	2.60	$1,100	2.6	
Solar Water Heater	N/A	$3,200	2.0	$2,533	2.0	83%

[1]Minimum performance refers to the lowest efficiency equipment available. Best refers to the highest efficiency equipment available.
[2]Installed costs represents the capital cost of the equipment plus the cost to install it, excluding any finance costs.
[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).
[4]The hurdle rate represents the consumer's "willingness" to invest in energy efficiency is by weighing the first cost and operating cost of competing technologies. The higher the hurdle rate, the less likely a consumer will invest in energy efficiency. These rates include all financial and non–financial factors (such as size, color) that influence a consumer's purchase decision.

Source: Arthur D. Little, *EIA Technology Forecast Updates*, Reference Number 8675309, October 2001.