DATABASE DOCUMENTATION

# EnergyPATHWAYS US Database

United States

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# 1 Overview

## 1.1 Scope

This document describes the United States input database for EnergyPATHWAYS (EP), the demand-side stock-rollover model in the EP and RIO modeling framework. The database holds the data EP uses to project energy service demand, equipment stocks, final energy demand, demand-side costs, and hourly load profiles for every end use in the US economy. The *EnergyPATHWAYS Model* document describes how EP uses these data, the *RIO Model* document describes the supply-side model, and the *RIO US Database* document describes the supply-side data.

The runs documented here use two demand cases, "reference demand" and "high electrification". The two cases use the same data for every input except measures. The reference demand case applies no measures, and the high electrification case applies the measures described in Section 5. Every data description, source, vintage, and number in this document refers to data that one of the two cases uses. Section 1.2 summarizes the run configuration, and Appendix A lists, for each input table, the sources of its data and the number of keys drawn from each source.

The data comprise:

- demand drivers, such as households, population, floor area, industrial activity indicators, and degree days;
- base-year and projected energy demand and service demand for each demand subsector;
- equipment stocks, sales shares, and technology characterization (cost, efficiency, lifetime) for subsectors with explicit technology representation;
- measures, which are optional data sets that change sales shares, efficiency, or fuel mix relative to the reference projection;
- hourly and time-slice load shapes;
- geography definitions and the spatial allocation keys used to move data between geographies;
- unit and inflation conversion tables.

This document describes what the data are, where they come from, and how they are organized. The calculations that use them are described in the *EnergyPATHWAYS Model* document.

## 1.2 Run configuration

| Setting | Value |
|---|---|
| Demand cases | Reference demand; high electrification |
| Model years | Annual, from a current year of 2024 to 2050 |
| Weather year for hourly profiles | 2023, the weather year used by RIO |
| Primary geography | us_eer2, 29 zones |
| Disaggregation geography | IECC climate zone by state, 112 units |
| Default allocation key | 2010 complete-count households |
| Units | Million Btu (MMBtu) for energy, kilograms for mass |
| Currency | 2025 US dollars, 2% inflation rate |
| Active subsectors | 94, of which 80 pass demand to RIO |

| Setting | Value |
|---|---|
| Subsectors whose technology mix RIO optimizes | 17 |
| Vehicle adoption logit | Not applied |

**Cases.** The two cases differ only in measures. The reference demand case applies none. The high electrification case activates the sales share, energy efficiency, and fuel-switching measures counted below. All other inputs are the same in both cases.

**Subsectors.** The run activates 94 subsectors. RIO reads demand for 80 of them, and these 80 are the subsectors this document describes (Section 1.3). EP also computes the other 14, which cover petroleum refining, oil and gas production and processing, LNG export liquefaction, the total-energy and finish-grinding subsectors of steel, cement, and lime production, and distributed generation; RIO represents these activities with its own supply technologies and does not read their EP demand.

Of the 80 subsectors, RIO optimizes the technology mix of 17: ten building end uses (residential and commercial space heating, water heating, and air conditioning; residential clothes washing and drying; residential and commercial cooking) and seven on-road vehicle subsectors (passenger car, passenger truck, medium duty truck, heavy duty truck, school bus, transit bus, and other bus). For these, EP passes technology definitions, service demand, sales share bounds, costs, and efficiencies. The other 63 pass final energy demand by zone, final energy type, and year, and RIO can change that demand only by adopting or declining the energy efficiency and fuel-switching measures passed with it.

**Measures.** The table counts the measures each case activates and the measures among them that apply to the 80 subsectors passed to RIO.

| Measure type | Reference demand | High electrification: activated | In subsectors passed to RIO |
|---|---|---|---|
| Sales share | 0 | 114 | 114 |
| Energy efficiency | 0 | 725 | 685 |
| Fuel switching | 0 | 228 | 216 |
| Total | 0 | 1,067 | 1,015 |

**Tables passed to RIO.** Both cases write the full set of tables EP passes to RIO, each marked with its case. The RIO runs use the following:

| Supplied by | Tables |
|---|---|
| High electrification | Final energy demand by subsector, except domestic and international shipping; baseline and maximum sales shares; technology service demand and service demand modifiers; technology capital cost, fixed operating cost, and efficiency; energy efficiency measure savings and costs; fuel-switching measure savings and additions; levelized demand-side cost and demand-side spending |
| Reference demand | Minimum sales shares; distribution feeder allocation; final energy demand of domestic and international shipping |

The high electrification case, with its sales share measures, therefore sets the baseline and the upper bound of RIO's sales of each technology, and the reference demand case, without measures, sets the lower bound.

**Vehicle adoption.** The database holds logit adoption parameters for the seven on-road vehicle subsectors that RIO optimizes. The runs use a price coefficient of zero for all seven, so the logit choice is not used. Vehicle sales in EP then follow the reference sales shares and the sales share measures (Sections 4.3 and 5.2), and the logit constants, maximum shares, and payback curves in the database do not affect the run.

### 1.3 Sectors and subsectors

EP divides final energy demand into four sectors. This document covers the 80 subsectors whose demand passes to RIO. A subsector is the basic accounting unit on the demand side: an end use (residential space heating), an industry (paper and allied products), or a transport mode (passenger car). The industrial sector is named "productive" in the database.

| Sector | Subsectors | Stock and service | Stock and energy | Service and energy | Energy | Link |
|---|---|---|---|---|---|---|
| Residential | 22 | 0 | 10 | 0 | 11 | 1 |
| Commercial | 15 | 7 | 0 | 0 | 8 | 0 |
| Productive (industrial) | 26 | 0 | 0 | 1 | 25 | 0 |
| Transportation | 17 | 9 | 0 | 2 | 6 | 0 |
| Total | 80 | 16 | 10 | 3 | 50 | 1 |

The subsector type (the sub_type column of DemandSubsectors) determines which input tables EP reads for that subsector:

| Type | Inputs | How EP computes energy |
|---|---|---|
| Stock and service | Service demand, equipment stock, technology characterization | Service demand is allocated to technologies in the stock and divided by technology efficiency |
| Stock and energy | Base-year energy demand, equipment stock, technology characterization | Base-year energy and technology efficiency imply service demand, which is then projected and served by the stock |
| Service and energy | Service demand and energy demand, no technology stock | The ratio of energy to service gives an aggregate service efficiency |
| Energy | Energy demand projection by final energy type | Energy is used directly; measures can modify it |
| Link | A stock that modifies the service demand of other subsectors | The residential building shell stock changes heating and cooling service demand |

Twenty-seven subsectors have explicit technology stocks. They cover residential and commercial heating, cooling, water heating, cooking, lighting, refrigeration, ventilation and appliances; the residential building shell; and on-road vehicles. The remaining 53 subsectors, including all industrial subsectors, are represented by energy demand, sometimes paired with service demand.

Each subsector carries a cost of capital used to annualize technology costs:

- 8% for residential equipment subsectors;
- 6% for most commercial subsectors, the industrial subsectors other than steel, cement, and lime, aviation, and domestic shipping;
- 5% for most other transportation subsectors, the residential building shell, data centers, streetlights, and the smaller residential subsectors;
- 3% for military use, passenger rail, steel, cement, and lime.

### 1.4 Final energy types

The subsectors in this document use 37 final energy types, defined in the FinalEnergy table: 32 energy carriers and 5 mass flows. The energy carriers are:

- electricity;
- pipeline gas, compressed and liquefied pipeline gas;
- petroleum products: diesel, gasoline, jet fuel, kerosene, LPG, residual fuel oil, other petroleum, petroleum coke, asphalt, and lubricants;
- coal;
- wood biomass and municipal solid waste;
- on-site and liquid hydrogen, and ammonia;
- solar and on-site hydropower;
- district steam, and steam carried as separate types by the fuel that raised it (biomass, coal, diesel, electricity, LPG, municipal solid waste, petroleum coke, pipeline gas, and residual fuel oil).

Ammonia appears only in the high electrification case, as the target of shipping fuel-switching measures. Solar and on-site hydropower appear only in commercial unspecified energy and are not passed to RIO.

The mass flows are non-energy CO2, product and bunkering CO2, steel, clinker, and lime. Steel, clinker, and lime are product demands that the supply-side model meets with its own production technologies. The two CO2 types carry emissions that are tied to demand activity but not to fuel combustion in EP.

The FinalEnergyRIOBlendGroups table maps each EP final energy type to the RIO energy carrier or product that supplies it (blends in the RIO database tables). For example, all steam types map to the RIO steam carrier, and the electricity used by the data center IT and data center cooling subsectors maps to a separate data center electricity carrier.

### 1.5 Geography and disaggregation

Input data are entered at the nation, census region (4), census division (9), state (50 states plus the District of Columbia), county, IECC climate zone, IECC climate zone by state, NERC region, or ReEDS zone.

EP converts data between geographies with the GeographiesSpatialJoin table. It lists every county and, where a county is split across regions, each county fragment. For each it gives the region it belongs to in every geography and a set of allocation weights, the geography map keys. Keys named by the data in this document include:

- 2010 census households, housing units, and population;
- heating and cooling degree days weighted by residential or commercial floor area;

- rail and marine fuel use;
- 2021 cement and lime facility emissions;
- bulk chemicals value of shipments;
- 2022 county employment by industry from the Quarterly Census of Employment and Wages, named by the state-level industrial drivers;
- 2007 employment and 2007 manufacturing earnings;
- 2005 irrigation water withdrawals;
- 2023 data center locations.

When an input table names a map key, EP uses that key to split or aggregate the data. When it does not, EP uses the default key, 2010 complete-count households. Data entered as totals are split in proportion to the key. Data entered as intensities are averaged with the key as the weight.

The runs use two geography levels:

| Level | Geography | Units | Purpose |
|---|---|---|---|
| Primary | us_eer2 | 29 zones | The zones reported by EP and passed to RIO |
| Disaggregation | IECC climate zone by state | 112 state and climate zone combinations | Intermediate geography for drivers, stocks, and weather-dependent shapes |

The 29 us_eer2 zones are built from counties. Most zones are single states or groups of whole states (for example Florida, Michigan, the Carolinas, and southern New England). Large states with distinct load regions are split: California into northern and southern zones, New York into New York City and upstate zones, and Texas into eastern and western zones, with parts of Texas also assigned to the desert southwest and southern plains zones.

Two smaller geographies are used by measures: a temperature category (warm, temperate, cold) and a two-way grouping of states by climate policy.

### 1.6 Years, units, and currency

EP runs annually from a current year of 2024 to 2050 and uses 2023 as the weather year for hourly profiles. Input data cover different periods. Historical stock and sales data reach back to 2000 or earlier, and projections generally run to 2050. EP interpolates and extrapolates each input to the model years (Section 1.8).

Input tables carry their own units. EP converts all inputs at load time to MMBtu for energy and kilograms for mass.

Costs are entered in the currency year of the source, recorded in each cost row. All cost rows used here are in US dollars, with currency years from 2013 to 2025. EP converts them to a single currency year with the InflationConversion table, an annual US dollar price index from 1999 to 2050 (index value 322.3 in 2025). Costs are reported in 2025 US dollars, with a 2% inflation rate.

### 1.7 Table structure

The database is a directory of comma-separated value (CSV) files read through the csvdb library. Each table is a single file or a directory of files that EP concatenates. Rows are keyed by a subsector, technology, driver, measure, or shape. Each row also records its geography, unit, interpolation and extrapolation methods, and source, and whether its

values are totals (for example TBtu in a state) or intensities (for example kBtu per square foot, or a share). Totals and intensities are mapped across geographies differently (Section 1.5) and combine with drivers differently (Section 2).

Beyond geography, data can be indexed by housing type (single-family, multi-family, mobile home), commercial building type (assembly, education, food sales, food service, health, lodging, mercantile and service, large office, small office, warehouse, other, unspecified), industry end use (heat, machine drives, lighting, HVAC, facility support, onsite transport, refrigeration, integrated steam, feedstock, other), and building construction-period group.

Where a table holds alternative data sets for the same key, the runs use the one described in this document. Values in this document without an external citation are set by assumption.

### 1.8 Projection across years

Input data rarely cover every model year. Each data set names an interpolation method for gaps between data years and an extrapolation method for years outside the data range. Methods used by the data in this document are:

| Method | Use |
|---|---|
| linear_interpolation | Default interpolation for almost all tables |
| nearest | Default extrapolation: hold the first or last value constant |
| logistic | S-shaped trajectories in sales share measures, most fuel-switching measure impacts, on-road vehicle mileage by age, and three motor home capital cost trajectories |
| exponential_interpolation | Data center demand |
| exponential_regression | Degree days |
| linear_regression | Extrapolation of commercial and industrial unspecified energy and of bus sales shares |
| decay_towards_linear_regression | Extrapolation of floor area and population drivers, aviation, shipping, rail, military, and recreational boat energy, and commercial lighting stock |

## 2 Demand drivers

### 2.1 Role of drivers

Demand drivers are activity variables that scale service demand, energy demand, or stock across years and geographies. A demand table names up to three drivers (driver_1 to driver_3) and up to two denominator drivers. When a table is entered as an intensity, EP multiplies the intensity by the drivers to obtain a total. When it is entered as a total for a base period, EP uses the drivers to project it forward and to allocate it across geography. A driver can name a base_driver, in which case EP disaggregates it to the disaggregation geography using the base driver's spatial pattern.

The runs use 40 drivers from the DemandDrivers table for the subsectors in this document: the drivers named by an energy demand, service demand, or stock row, and the base drivers those drivers name. The tables below list them.

## 2.2 Demographic and building drivers

| Driver | Geography | Years | Source |
|---|---|---|---|
| Households (by housing type) | Census division | 1997–2050 | AEO 2026 projection; disaggregated with ACS county households |
| ACS county households (by housing type) | County | 2009–2023 | American Community Survey 5-year estimates, table B25024 |
| Population | Census division | 1990–2050 | AEO 2026; disaggregated with state population projections |
| State population projections | State | 2000–2050 | University of Virginia Weldon Cooper Center, national population projections (2026 vintage; 2018 release for years before 2020) |
| Total residential floor area (by housing type) | Census division | 2015–2050 | AEO 2023; disaggregated with households |
| Total residential floor area by vintage group | Census division | 2015–2050 | AEO 2023; disaggregated with households |
| Commercial floor area (by building type) | Census division | 2013–2050 | AEO 2023 |

Households drive most residential energy and stock tables. Residential floor area drives residential lighting stock, and floor area by vintage group drives the building shell stock. Commercial floor area drives all commercial service demand, the commercial equipment stocks other than lighting, commercial unspecified energy, and district services energy.

## 2.3 Weather drivers

Heating degree days and cooling degree days by state come from the NOAA National Centers for Environmental Information, 1895–2023. Alaska heating degree days are North Dakota values multiplied by 1.2. Degree days are entered as intensities and projected with an exponential regression. Residential space heating energy uses heating degree days as its driver, residential secondary heating uses households and heating degree days, and residential air conditioning uses cooling degree days and households. Commercial space heating and air conditioning service demand use degree days as a second driver after floor area. Spatial allocation of weather-sensitive data uses map keys that weight degree days by residential or commercial floor area.

## 2.4 Industrial, agricultural, and mining drivers

Industrial energy projections are entered by census region and end use (Section 3.3). Drivers allocate each projection to states. The state drivers name a 2022 county employment map key for the industry (Section 1.5), which EP uses to split state values within states. The driver families used are:

| Driver family | Content | Geography and year | Source |
|---|---|---|---|
| ec2022: | Cost of fuels and of purchased electricity by state and industry | State, 2022 | 2022 Economic Census (CSTFU and ELECPCH series) |
| ec2022: (construction, coal mining) | Employment by state, combined with purchased electricity | State, 2017–2022 | Census County Business Patterns; 2022 Economic Census; EIA Form 861 commercial electricity prices |
| asm: | Industry output value by state | State, 2012–2022 | Census Economic Census |
| ghgrp: | Facility emissions by industry | State, 2015–2022 | EPA Greenhouse Gas Reporting Program |
| usda: | Harvested acreage and farm energy indicators | State, 2017–2022 | USDA NASS Census of Agriculture |
| msha: | Mining activity | State, 2018–2022 | Mine Safety and Health Administration |
| mining:gdp | Mining output by state | State, 1997–2017 | Derived from 2018 EPA Greenhouse Gas Reporting Program data |

The industrial data use the following drivers:

| Subsectors | Allocation driver |
|---|---|
| Bulk chemicals, food, wood, fabricated metals, computers and electronics, transportation equipment, plastics and rubber, electrical equipment, machinery, paper, aluminum, glass, steel | ec2022: fuel cost and purchased electricity |
| Light chemicals, other non-metallic minerals, other primary metals, miscellaneous finished goods | asm: output value |
| Construction, coal mining | ec2022: employment and purchased electricity |
| Agriculture (crops and other) | usda: Census of Agriculture |
| Metal and other non-metallic mining | msha: |
| Cement, lime | ghgrp: emissions, with a 2021 cement or lime emissions map key |
| Industrial unspecified | mining:gdp, which is constant after 2017 |

## 2.5 Transportation and other drivers

| Driver | Use | Years | Source |
|---|---|---|---|
| SEDS jet fuel consumption by state | Allocates aviation energy to states | 2022–2024 | EIA SEDS |
| Jet fuel sales by state | Military energy driver | 2017 | Derived from EIA SEDS (2010–2017 average) |
| Vessel bunkering sales by state | Allocates international and domestic shipping energy | 1984–2017 | By assumption |

| Driver | Use | Years | Source |
|---|---|---|---|
| Non-coal freight ton-miles by census division | Freight rail service demand | 1995–2013 | By assumption; disaggregated with population |
| Commuter rail passenger-miles by census division | Passenger rail service demand | 1995–2008 | By assumption; disaggregated with population |
| Other non-energy CO2 activity | Projects other non-energy CO2 by source category | 1990–2050 | EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks to 2023; AEO 2026 industrial output growth after 2023 (Section 3.3) |

Lubricants energy uses population as its driver. On-road vehicle service demand is entered directly as vehicle-miles traveled by state (Section 3.4), so on-road subsectors do not use drivers.

## 3 Subsector energy and service demand

This section describes the energy demand (DemandEnergyDemands) and service demand (DemandServiceDemands) data for each sector. Technology-level data for subsectors with stocks are described in Section 4.

### 3.1 Residential

Residential energy demand is based on the EIA 2020 Residential Energy Consumption Survey (RECS 2020). The data hold RECS energy consumption by end use, housing type, and IECC climate zone by state for 2020. For the nine subsectors with RECS stocks, the energy is broken out by technology and is marked as stock-dependent. EP combines it with the RECS 2020 equipment stock and technology efficiency to derive service demand per unit of equipment, and projects the stock with households.

| Subsector | Type | Energy data | Stock data | Energy drivers | Stock driver |
|---|---|---|---|---|---|
| Space heating | Stock and energy | RECS 2020 | RECS 2020 | Heating degree days | Households |
| Air conditioning | Stock and energy | RECS 2020 | RECS 2020 | Cooling degree days, households | Households |
| Water heating | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Cooking | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Clothes washing | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Clothes drying | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Dishwashing | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Refrigeration | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Freezing | Stock and energy | RECS 2020 | RECS 2020 | None | Households |
| Lighting | Stock and energy | AEO 2026, by census division and housing type, 2022–2050 | AEO 2026 bulb stock | Households | Residential floor area |

| Subsector | Type | Energy data | Stock data | Energy drivers | Stock driver |
|---|---|---|---|---|---|
| Building shell | Link | None | ResStock floor area by vintage group | None | Floor area by vintage group |
| Secondary heating | Energy | RECS 2020 | None | Households, heating degree days | None |
| Furnace fans and boiler pumps | Energy | RECS 2020 | None | Households | None |
| Ceiling fans, dehumidifiers, humidifiers, hot tubs, pool pumps, microwaves, televisions and peripherals, secondary cooking, other | Energy | RECS 2020 | None | Households | None |

Final energy types in the residential energy data are electricity, pipeline gas, LPG, distillate (stored as diesel fuel), and wood.

The residential building shell is a link subsector. Its stock is residential floor area by IECC climate zone by state, housing type, and construction vintage group for 2020, from NREL ResStock. Shell technologies carry service-link factors that scale space heating and air conditioning service demand (Section 4.6).

Service demand links tie some residential subsectors together (DemandServiceLink):

| From subsector | To subsector | Share of service demand linked |
|---|---|---|
| Clothes washing | Clothes drying | 1.00 |
| Clothes washing | Water heating | 0.11 |
| Dishwashing | Water heating | 0.06 |
| Space heating | Furnace fans and boiler pumps | 1.00 |
| Building shell | Space heating | 1.00 |
| Building shell | Air conditioning | 1.00 |

Several residential subsectors override the default service demand unit: clothes drying (tons of laundry), clothes washing (cubic foot cycles), dishwashing (cycles), refrigeration and freezing (cubic feet), and lighting (gigalumen-hours).

## 3.2 Commercial

Commercial end uses with technology stocks are stock-and-service subsectors. Their service demand is taken from AEO 2026 by census division, building type, and year (2019–2050), with technology detail. Commercial floor area (AEO 2023) is the driver for all of them; heating and cooling also use degree days.

| Subsector | Service demand unit | Data | Driver |
|---|---|---|---|
| Space heating | TBtu of delivered heat | AEO 2026 | Floor area, heating degree days |
| Air conditioning | TBtu of delivered cooling | AEO 2026 | Floor area, cooling degree days |
| Water heating | TBtu | AEO 2026 | Floor area |
| Cooking | TBtu | AEO 2026 | Floor area |
| Refrigeration | TBtu | AEO 2026 | Floor area |
| Lighting | Gigalumen-years | AEO 2026 | Floor area |
| Ventilation | Giga cubic feet | AEO 2026 | Floor area |

Commercial equipment stock is expressed in units of service capacity. The commercial stock data gives capacity factors by building type and census division (2012 data year; 2012 and 2013 for space heating), from which EP derives the stock needed to serve the service demand. The stock rows use commercial floor area as their driver, except lighting, which has none. The capacity factors are set by assumption.

Commercial subsectors without stocks are entered as energy:

| Subsector | Data | Detail |
|---|---|---|
| Commercial other | AEO 2026 | Census division, building type, 2019–2050; electricity, pipeline gas, distillate |
| Office equipment (non-PC) | AEO 2026 | Census division, building type, 2019–2050; electricity |
| Data center (on-site) | AEO 2026 | Census division, building type, 2019–2050; electricity |
| Commercial unspecified | Derived from EIA SEDS 2024, with AEO 2026 growth | State, 2024–2050; 14 final energy types; extrapolated by linear regression on floor area |
| District services | AEO 2023 | Energy intensity (kBtu per square foot) by building type for 2016; electricity, pipeline gas, distillate, steam |
| Streetlights | Single national value for 2021 in GWh, driven by households | By assumption |
| Data center IT | County-level projection, 2024–2050 | Derived from the EPRI (2026) high scenario, allocated to counties |
| Data center cooling | County-level projection, 2024–2050 | Derived from the EPRI (2026) high scenario, allocated to counties |

Commercial unspecified energy is the difference, by state and final energy type, between SEDS 2024 commercial consumption and the energy of the modeled commercial subsectors. For electricity, the residual is taken from SEDS commercial and industrial sales combined and split by the commercial share of the two. Years after 2024 add the AEO 2026 change by census division, allocated to states by their SEDS share. The 14 final energy types are electricity, pipeline gas, diesel, gasoline, LPG, kerosene, residual fuel oil, other petroleum, petroleum coke, coal, wood biomass, municipal solid waste, solar, and on-site hydropower.

Data center IT and cooling electricity is mapped to its own carrier for the supply-side model (Section 1.4).

### 3.3 Industrial

All 26 industrial subsectors are energy subsectors, except cement, which also has a service demand. The core industrial data are AEO 2026 projections of energy by industry, census region, end use, and final energy type for 2022–2050. Bulk chemicals are further split by chemical category (organic, inorganic, resin synthesis, agricultural chemicals). Steam is carried as separate final energy types by the fuel that raises it. Most subsectors name one driver that allocates the census region data to states (Section 2.4). The number of final energy types per subsector ranges from 1 (steel, cement, lime, industrial unspecified) to 18 (bulk chemicals).

| Group | Subsectors |
|---|---|
| Agriculture | Agriculture-crops, agriculture-other |
| Mining | Coal mining, metal and other non-metallic mining |
| Construction | Construction |
| Energy-intensive manufacturing | Bulk chemicals, paper and allied products, glass and glass products, aluminum industry, other primary metals, other non-metallic minerals |
| Other manufacturing | Food and kindred products, light chemicals, plastic and rubber products, wood products, fabricated metal products, machinery, computer and electronic products, electrical equipment and appliances, transportation equipment, miscellaneous finished goods |
| Steel, cement, and lime | Steel, cement, lime |
| Unspecified | Industrial unspecified |
| Non-energy | Other non-energy CO2 |

Steel, cement, and lime are represented as product demand. The steel, cement, and lime subsectors carry national demand for steel, clinker, and lime as mass-type final energy for 2022–2050, which the supply-side model meets with its own production technologies. The cement service demand series (national, 2018–2050) is set by assumption.

Industrial unspecified carries electricity only. It is the industrial share of the state residual between SEDS 2024 commercial and industrial electricity sales and the electricity of the modeled commercial and industrial subsectors, split by the ratio of SEDS industrial to commercial plus industrial sales in each state. It is entered by state for 2024 and held at its 2024 value.

The “other non-energy co2” subsector carries national non-energy CO2 from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks (2025 edition, 1990–2023), allocated with a bulk chemicals value-of-shipments map key. It is indexed by 14 source categories:

- aluminum, ferroalloy, glass, lead, zinc, phosphoric acid, silicon carbide, soda ash, and titanium dioxide production;
- carbon dioxide consumption;
- liming and other process uses of carbonates;
- urea fertilization and urea consumption for non-agricultural purposes.

The 2023 total is 34.9 million tonnes. After 2023 each category is projected with a driver equal to its 2023 value times the AEO 2026 growth in value of output of an associated industry. Aluminum production is held at its 2023 value.

## 3.4 Transportation

### 3.4.1 On-road vehicles

The nine on-road subsectors are stock-and-service subsectors. Service demand is vehicle-miles traveled (VMT) by state.

| Subsector | Technologies | VMT | Stock | Historical sales |
|---|---|---|---|---|
| Passenger car | Gasoline, diesel, HEV, PHEV, battery electric | MOVES 5.0 state VMT scaled to AEO 2026 national totals, by size class, 2000–2060 | MOVES state shares times AEO 2026 national stock by size class, 2021–2050; powertrain mix through 2024 from AFDC and FHWA registrations | AFDC registrations 2016–2024, Alliance for Automotive Innovation (S&P Global Mobility) new registrations, and Argonne national sales, with AEO 2026 size class shares |
| Passenger truck | Gasoline, diesel, HEV, PHEV, battery electric | MOVES 5.0 state VMT scaled to AEO 2026 national totals, by size class, 2000–2060 | MOVES state shares times AEO 2026 national stock by size class, 2021–2050; powertrain mix through 2024 from AFDC and FHWA registrations | AFDC registrations 2016–2024, Alliance for Automotive Innovation (S&P Global Mobility) new registrations, and Argonne national sales, with AEO 2026 size class shares |
| Medium duty truck | Diesel, gasoline, diesel HEV, battery electric, hydrogen fuel cell (FCEV and FCHEV) | NEMS AEO 2026 by state and vehicle class, 2021–2049 | NEMS AEO 2026 national stock allocated with VIUS 2021, by state and vehicle class, 2024–2049 | VIUS 2021 (model year 2021 vehicles) |
| Heavy duty truck | Diesel, gasoline, diesel HEV, battery electric, hydrogen fuel cell (FCEV and FCHEV) | NEMS AEO 2026 by state and vehicle class, 2021–2049 | NEMS AEO 2026 national stock allocated with VIUS 2021, by state and vehicle class, 2024–2049 | VIUS 2021 |
| School bus | Diesel, gasoline, CNG, battery electric, fuel cell | MOVES 5.0 scaled to AEO 2026, 2000–2060 | MOVES 5.0, 2000–2060 | ICCT market data, by state |
| Transit bus | Diesel, gasoline, CNG, battery electric, fuel cell | MOVES 5.0 scaled to AEO 2026, 2000–2060 | MOVES 5.0 | By assumption |
| Other bus | Diesel, gasoline, CNG, battery electric | MOVES 5.0 scaled to AEO 2026, 2000–2060 | MOVES 5.0 | AEO 2026 intercity bus fuel mix |

| Subsector | Technologies | VMT | Stock | Historical sales |
|---|---|---|---|---|
| Motor home | Gasoline, diesel, battery electric, fuel cell | MOVES 5.0 scaled to AEO 2026 | MOVES 5.0 | None |
| Motorcycle | Gasoline, battery electric | State VMT for 2021–2050, by assumption | MOVES 5.0 | None |

Light-duty vehicles are indexed by size class: passenger cars by eight classes (minicompact, subcompact, compact, midsize, large, 2-seater, small crossover, large crossover) and passenger trucks by eight (small and large crossover, small and large SUV, small and standard pickup, small and standard van). Medium duty trucks are indexed by vehicle class 3 to 6 and heavy duty trucks by twelve class 7 and class 8 configurations (tractors in three weight tiers, day cabs, sleepers, vocational trucks, and heavy haul). Per-vehicle mileage by age and vehicle class enters through service demand modifiers (Section 4.6).

Light-duty VMT in Texas is multiplied by 1.2286, which brings Texas light-duty gasoline use in 2024 into line with EIA SEDS gasoline consumption. The adjustment represents driving on roads that the FHWA statistics underlying the MOVES VMT do not count. VMT in all other states is unadjusted.

### 3.4.2 Aviation, rail, shipping, and other modes

| Subsector | Type | Energy data | Service demand | Allocation |
|---|---|---|---|---|
| Aviation | Energy | AEO 2026 jet fuel and aviation gasoline, national | None | SEDS jet fuel by state |
| Freight rail | Service and energy | AEO 2026 diesel | Ton-miles by census division, 1995–2013, driven by non-coal freight ton-miles | Rail fuel use map key |
| Passenger rail | Service and energy | AEO 2026 diesel and electricity by rail mode (commuter, intercity, transit) | Passenger-miles by census division, 2015–2040, driven by commuter rail passenger-miles | Households map key (energy); rail fuel use map key (service) |
| Domestic shipping | Energy | AEO 2026 distillate, residual fuel oil, LNG | None | Vessel bunkering sales; marine fuel use map key |
| International shipping | Energy | AEO 2026 distillate, residual fuel oil, LNG | None | Vessel bunkering sales; marine fuel use map key |
| Military use | Energy | AEO 2026 distillate and jet fuel | None | Jet fuel sales driver; households map key |
| Lubricants | Energy | AEO 2026 | None | Population driver; households map key |
| Recreational boats | Energy | AEO 2026 gasoline and diesel | None | Households map key |

Aviation, international shipping, and lubricants energy include a "product and bunkering CO2" mass flow that accounts for emissions from fuel bought in the US for international travel. In the AEO 2026 aviation and international shipping data, no international bunkering fuel is assigned to individual states.

# 4 Technology stocks, sales, and characterization

## 4.1 Technology definitions and lifetimes

The runs represent 199 demand technologies in 27 subsectors, defined in the DemandTechs table. These are the technologies that hold stock or sales in either case. Each row gives the technology's subsector, the unit in which its stock is counted, whether that unit is a piece of equipment or a quantity of service capacity, a lifetime distribution, a load shape where one applies, and a linked technology where one applies.

All lifetimes use a Weibull survival function. The database specifies either a mean lifetime and variance or a minimum and maximum lifetime. The table below gives the number of technologies and the range of average lifetimes (the mean, or the midpoint of minimum and maximum) by subsector.

| Subsector | Technologies | Stock unit | Average lifetime (years) |
|---|---|---|---|
| Residential space heating | 20 | Heating unit | 15.5–25 |
| Residential water heating | 11 | Water heater | 6–20 |
| Residential air conditioning | 6 | Air conditioning unit | 14–20 |
| Residential cooking | 4 | Cooktop or stove | 18.5 |
| Residential clothes washing | 4 | Clothes washer | 14.5 |
| Residential clothes drying | 4 | Clothes dryer | 15.5 |
| Residential dishwashing | 2 | Dishwasher | 14.5 |
| Residential refrigeration | 6 | Refrigerator | 16.5 |
| Residential freezing | 4 | Freezer | 21 |
| Residential lighting | 13 | Bulb | 0.66 (incandescent exterior) to 98.6 (LED linear) |
| Residential building shell | 1 | Square foot | 100 |
| Commercial space heating | 16 | kBtu per hour | 15–25 |
| Commercial air conditioning | 22 | kBtu per hour | 9.5–25 |
| Commercial water heating | 9 | kBtu per hour | 13–20 |
| Commercial cooking | 3 | kBtu per hour | 10 |
| Commercial refrigeration | 16 | kBtu per hour | 8.5–15 |
| Commercial ventilation | 4 | Thousand cubic feet per minute | 20 |
| Commercial lighting | 12 | Kilolumen | 3.8–24 |
| Passenger car | 5 | Vehicle | 15.7 |
| Passenger truck | 5 | Vehicle | 14.3 |

| Subsector | Technologies | Stock unit | Average lifetime (years) |
|---|---|---|---|
| Medium duty truck | 6 | Vehicle | 15 |
| Heavy duty truck | 6 | Vehicle | 18 |
| School bus | 5 | Vehicle | 12 |
| Transit bus | 5 | Vehicle | 12 |
| Other bus | 4 | Vehicle | 15 |
| Motor home | 4 | Vehicle | 18.3 |
| Motorcycle | 2 | Vehicle | 12.65 |

Residential lighting lifetimes are derived from AEO 2026 lighting data: the rated hours of each bulb type divided by the daily operating hours of its application, expressed in years. This is why LED linear lamps reach several decades and exterior incandescent lamps last under a year. Technology names follow a convention: “reference” and “high efficiency” variants of the same equipment class, hybrid heat pumps named by their backup equipment (for example “ashp hybrid - reference natural gas furnace”), and vehicles named by subsector and powertrain (for example “heavy duty truck_hydrogen fcev”).

Paired heating and cooling technologies, such as an air source heat pump’s heating and cooling functions, are linked: the cooling technology is listed as linked to the heating technology with a stock ratio of 1.0, so the two stocks move together. The residential hybrid heat pumps are linked in the same way to the cooling function of the reference air source heat pump.

### 4.2 Initial stocks

DemandStock holds the stock data that initialize the rollover. Section 3 lists the stock source for each subsector. In summary:

| Subsectors | Stock source | Geography and detail |
|---|---|---|
| Residential appliances, space heating, water heating, air conditioning, cooking | RECS 2020 | IECC climate zone by state, housing type, technology; 2020 |
| Residential lighting | AEO 2026 | Census division, housing type, technology; 2020–2050 |
| Residential building shell | NREL ResStock | IECC climate zone by state, housing type, vintage group; floor area; 2020 |
| Commercial end uses | Capacity factors (Section 3.2) | Census division, building type |
| Passenger car and truck | MOVES state shares times AEO 2026 national stock; powertrain mix fitted to AFDC and FHWA registrations | State, size class, technology; 2021–2050 |
| Medium and heavy duty truck | NEMS AEO 2026 with VIUS 2021 | State, vehicle class, technology; 2024–2049 |
| Buses, motor homes, motorcycles | MOVES 5.0 | State, technology; 2000–2060 |

Where a stock row specifies technologies, EP holds the specified technology stock through the current year (2024) and computes later years by rollover. The light-duty technology stock is fitted so that its size-class totals follow the AEO 2026 national stock trajectory and its powertrain totals follow AFDC and FHWA registrations.

### 4.3 Reference sales shares

DemandSales gives the share of new sales by technology, by vintage and geography. These are the reference sales shares that apply when no measure changes them. Where a technology has no sales input, EP derives its sales share from the initial stock: each technology's stock divided by its lifetime, normalized across the subsector, so that retiring equipment is replaced in proportion to the existing stock composition. Vehicle sales follow the reference sales shares and the active measures.

| Subsectors | Sales data |
|---|---|
| Passenger car and truck | Historical shares by state, size class, and powertrain for the 2016–2025 vintages, from AFDC registrations, Alliance for Automotive Innovation new registration data (S&P Global Mobility), and NEMS AEO 2026 sales by size class, with national hybrid shares (all years) and plug-in shares (2016–2020) scaled to Argonne National Laboratory national sales; held constant after 2025 |
| Medium and heavy duty truck | Shares by state and vehicle class for model year 2021 vehicles, from VIUS 2021 |
| School bus | 2025 diesel and electric shares by state, derived from ICCT market data based on S&P Global Mobility (Polk) registrations |
| Other bus | A 2025 national share of 100% diesel, from the AEO 2026 intercity bus fuel mix |
| Transit bus (electric and fuel cell) and fuel cell school bus | National shares for the 2022–2035 vintages; by assumption |
| Residential building shell | A national share of 0.001 for the reference building shell (by assumption) |

### 4.4 Costs

Technology costs are held in three tables:

- DemandTechsCapitalCost: purchase cost per unit of stock for new equipment.
- DemandTechsInstallationCost: installation cost, as an absolute value or as a multiplier of a reference technology's cost.
- DemandTechsFixedMaintenanceCost: annual fixed operating and maintenance cost.

EP passes capital (including installation) and fixed operating cost by technology and vintage to RIO for the subsectors whose technology mix RIO optimizes, and levelized demand-side cost by subsector for cost accounting in all others.

Costs are entered by vintage and, for some technologies, by geography and other index, as absolute values or relative to a reference technology. All cost rows apply to new purchases.

The cost data use the following sources:

| Subsectors | Capital cost | Installation cost | Fixed O&M |
|---|---|---|---|
| Residential space heating, water heating, air conditioning | EIA 2023, with exceptions listed below | EIA 2023; EIA 2018 edition for hybrid heat pumps and electric hybrid boilers | EIA 2023; EIA 2018 edition for electric hybrid boilers |

| Subsectors | Capital cost | Installation cost | Fixed O&M |
|---|---|---|---|
| Residential appliances (cooking, laundry, dishwashing, refrigeration, freezing) | EIA 2023; Guidehouse BTB 2024 for electric and gas cooktops | EIA 2023 for laundry and dishwashing | EIA 2023 for clothes washers, refrigerators, and freezers |
| Residential lighting | EIA 2023 | None | EIA 2023 |
| Commercial heating, cooling, water heating, refrigeration, ventilation, cooking | AEO 2026 equipment cost data; EIA 2018 edition for hybrid heat pumps and electric hybrid boilers | AEO 2023 | AEO 2026 |
| Commercial lighting | Zero (fixture cost excluded from the comparison) | AEO 2023 | AEO 2023 |
| Passenger car and truck | AEO 2026 vehicle prices (Table 114) with NREL ATB 2024 Transportation mid-case trajectories for powertrain cost change | Charger installation from Wood et al. (2023), The 2030 National Charging Network | Burnham et al. (2021) per-mile maintenance at 12,000 miles per year; plug-in vehicles add a state registration fee from NCSL data |
| Medium and heavy duty truck | NREL ATB 2024 mid case combined with NEMS AEO 2026 (diesel and gasoline from NEMS) | Charging and fueling infrastructure from Borlaug et al. (2021) and ICCT (2023) | NREL ATB 2024 maintenance data (Hunter et al. 2016) |
| School, transit, and other bus | NREL ATB 2024 mid case (class 7 school bus and class 8 transit bus platforms) | Cadmus 2024 evaluation for the California Public Utilities Commission (electric); DOE H2@Scale depot estimates (hydrogen) | ICCT per-mile maintenance data with MOVES 4.0 mileage |
| Motor home | Slowik et al. (2023) | None | ICCT data with MOVES 4.0 mileage |

Residential space heating, water heating, and air conditioning capital costs come from the EIA study *Updated Buildings Sector Appliance and Equipment Costs and Efficiencies* (EIA 2023), with these exceptions:

- central air conditioners and air source heat pumps use the same data by IECC climate zone by state and housing type;
- one water heater uses the Guidehouse Building Technology Baseline 2024;
- the reference LPG water heater uses Massachusetts Clean Energy Analysis cost data;
- the residential hybrid heat pumps and electric hybrid boilers use the 2018 edition of the EIA equipment cost study.

Four building technologies have capital costs set by assumption: the cooling functions of the two commercial hybrid heat pumps, the dual-fuel cooktop, and the LPG cooktop. The installation costs of the cooktops, the instantaneous water heaters, the reference LPG furnace and water heater, the commercial solar water heater, and the reference commercial central air conditioner are also set by assumption. Commercial lighting capital costs are zero because the commercial lighting data treat fixtures as a cost outside the comparison.

## 4.5 Efficiency

DemandTechsMainEfficiency gives the efficiency of each technology with respect to its main final energy type, by vintage. Efficiency is expressed as a ratio of numerator and denominator units, with a flag (is_numerator_service) that records whether the numerator is service or energy. Examples are Btu of heat per Btu of fuel, lumen-hours per watt-hour, miles per gallon of gasoline equivalent, and cubic feet of refrigerated volume per kWh. Some rows are relative to a reference technology. DemandTechsAuxEfficiency gives the efficiency for a second final energy type, used by dual-fuel technologies: plug-in hybrid vehicles, hybrid heat pumps with combustion backup, electric-hybrid boilers, dual-fuel cooktops, and solar water heaters with electric backup.

| Subsectors | Main efficiency source |
|---|---|
| Residential appliances, air conditioning, space heating, water heating | AEO 2026 residential equipment data (rsmess file) for most equipment, with exceptions listed below |
| Residential lighting | EIA 2023 |
| Commercial heating, cooling, water heating, refrigeration, ventilation, cooking | AEO 2026; NREL EFS medium efficiency for commercial hybrid heat pumps |
| Commercial lighting | AEO 2023 (ktek file) for 3 technologies; AEO 2026 for 9 |
| Passenger car and truck | AEO 2026 new vehicle fuel economy by size class (TRANREP ldvmpg) for the 2020–2050 vintages; NEMS AEO 2026 values for earlier vintages |
| Medium and heavy duty truck | NREL ATB 2024 Transportation mid case, by vehicle class, scaled to NEMS AEO 2026 new-vehicle fuel economy |
| Buses | NREL ATB 2024 mid case (class 7 school bus and class 8 transit bus platforms) |

The residential exceptions are:

- EIA 2023 for the reference geothermal heat pump, the electric furnace, the reference heat pump water heater, and the reference wood water heater;
- IECC climate zone-specific values for the high efficiency central air conditioner;
- NREL medium-efficiency values for the reference air source heat pump.

Truck efficiency is placed on the NEMS AEO 2026 level. For each vehicle class group, the diesel and gasoline trucks take the NEMS new-vehicle fuel economy through the 2024 vintage and follow the ATB trajectory afterwards. Hybrid, plug-in, battery electric, and hydrogen trucks keep the ATB ratio of their efficiency to that of the ATB diesel truck of the same class and vintage, applied to the NEMS-level diesel value. The vintage that represents the initial truck fleet takes the new-vehicle value times the NEMS ratio of fleet to new-vehicle fuel economy.

The vintage that represents the initial light-duty stock takes the new-vehicle curve value times the NEMS ratio of fleet on-road to new-vehicle on-road fuel economy in that year.

Twenty-eight technologies take their main efficiency from other sources. Four of them, the heating and cooling functions of the commercial hybrid heat pumps, cite the NREL Electrification Futures Study (EFS) medium-efficiency trajectory. The fuel cell motor home is entered relative to the diesel motor home, at the NREL ATB 2024 ratio of fuel cell to diesel efficiency for a class 6 box truck. The other 23 are set by assumption. They cover:

- the residential hybrid heat pumps with reference backup equipment and the electric hybrid boilers;

- the four instantaneous water heaters;
- the LPG boiler, the LPG clothes dryer, and the dual-fuel cooktop;
- the gasoline, diesel, and battery electric motor homes and both motorcycle technologies.

Auxiliary efficiencies come from AEO 2026 for plug-in hybrid light-duty vehicles and NREL medium-efficiency values for one residential heat pump. The remaining 9 dual-fuel building technologies are set by assumption.

DemandTechsUtilityFactor gives the share of service delivered with the main energy type for dual-fuel technologies:

| Technology group | Utility factor (share on main fuel) | Source |
|---|---|---|
| Plug-in hybrid passenger cars and trucks | 0.45 | ICCT (2024), Fully Electric, Not Plug-in Hybrid, Is Still the Future of the American Car |
| Commercial hybrid heat pumps with furnace backup | 0.70 | By assumption |
| Residential hybrid heat pumps with reference backup equipment ("ashp hybrid - reference ..." and "ashp hybrid - cordwood stoves") | 0 to 0.85, entered for individual state and climate zone units | By assumption |
| Electric-hybrid boilers | 0.70 | By assumption |
| Commercial solar water heater with electric backup, dual-fuel cooktop | 0.50 | By assumption |

DemandTechsParasiticEnergy gives standing electricity use in kWh per year for the reference natural gas and distillate furnaces, from EIA 2023 data.

### 4.6 Service demand modifiers and service links

DemandTechsServiceDemandModifier scales the service demand each technology delivers. For vehicles it gives annual miles per vehicle by vintage and age. Light-duty, bus, motor home, and motorcycle mileage by age comes from MOVES 4.0. Medium and heavy duty truck mileage comes from VIUS 2021 by vehicle class. For some building equipment it gives relative factors, which are set by assumption. For example, reference geothermal heat pumps carry factors of 4 (heating) and 2 (cooling), and room air conditioners a factor of 0.5, reflecting the share of a dwelling's service each unit provides.

DemandTechsServiceLink gives, for technologies in one subsector, the factor applied to the service demand of a linked subsector. The reference building shell carries factors on space heating and air conditioning service by IECC climate zone by state, housing type, and vintage group, from ResStock. Clothes washers and dishwashers carry factors on the hot water they draw, from AEO 2023. Furnaces and boilers carry a factor of 1 on furnace fan and boiler pump service, and heat pumps a factor of 0.

## 5 Measures

### 5.1 Measure structure and activation

A measure is an optional data set that changes the reference projection of one subsector. A measure applies only in the cases that activate it.

The reference demand case activates no measures. In the subsectors passed to RIO, the high electrification case activates 1,015 measures of three types:

| Table | Measures | Applies to |
|---|---|---|
| DemandSalesShareMeasures | 114 | Subsectors with technology stocks |
| DemandEnergyEfficiencyMeasures | 685 | Subsectors without technology stocks |
| DemandFuelSwitchingMeasures | 216 | Subsectors without technology stocks |

The case also activates 40 energy efficiency measures and 12 fuel-switching measures in subsectors whose demand RIO does not read (Section 1.2). Some measures use the temperature category and climate policy geographies described in Section 1.5.

### 5.2 Sales share measures

A sales share measure sets the share of new sales for a technology by vintage and geography. If it names a replaced technology (replaced_demand_tech), it moves that share of sales from the replaced technology to the new one. Otherwise it overrides the reference share and the remaining sales are rescaled. All 114 trajectories use logistic interpolation between a few specified points, which produces an S-shaped adoption path.

| Measure group | Content | Count |
|---|---|---|
| Building equipment substitution | A new technology replaces a named technology in residential and commercial subsectors | 102 |
| National electric vehicle trajectories | Battery electric and plug-in hybrid sales shares for on-road vehicles | 9 |
| Motor homes and motorcycles | Electric and fuel cell sales shares by climate policy state group | 3 |

The building equipment substitutions cover:

- Residential: space heating (air source, geothermal, and hybrid heat pumps, electric furnaces and unit heaters, electric hybrid boilers), water heating (heat pump and electric resistance water heaters), air conditioning, cooking (electric cooktops), and high efficiency clothes dryers and washers, dishwashers, refrigerators, and freezers.
- Commercial: space heating (air source, ground source, and hybrid heat pumps, electric boilers, electric resistance heat), water heating (heat pump and electric resistance storage water heaters), high efficiency air conditioning, refrigeration, and ventilation, cooking (induction ranges), and lighting (LED luminaires and lamps).

These trajectories run from 2021 to 2035 or 2040 (2012 to 2030 for commercial lighting) and reach up to 99.99% of sales. Space heating and water heating trajectories are entered by temperature category, the rest nationally.

The national electric vehicle trajectories are S-curves set by assumption. Battery electric sales shares reach 92% for passenger cars, 88% for passenger trucks, 80% for medium duty trucks, 70% for heavy duty trucks, 92% for school buses, 95% for transit buses, and 88% for other buses. Plug-in hybrids reach 10% of sales for passenger cars and trucks. The trajectories start in 2024 and reach their final value between 2042 and 2052.

The motor home and motorcycle measures set sales shares of 75% for electric motor homes, 5% for fuel cell motor homes, and 80% for electric motorcycles. They start between 2023 and 2035 and run to 2065 or 2070.

The building equipment and motor home and motorcycle trajectories are set by assumption.

### 5.3 Energy efficiency measures

An energy efficiency measure reduces the energy demand of a subsector by a fraction that is specified for each year, optionally limited to one final energy type or one index value such as an industry end use. EP applies the specified fraction to the subsector's energy in each year; where the savings of all measures on a subsector would exceed its demand, EP scales them down. Each measure also carries a Weibull lifetime, which EP uses only to roll over the stock of measures for cost accounting; the lifetime does not change the savings. Costs are in DemandEnergyEfficiencyMeasuresCost as levelized cost per MMBtu saved. The 685 efficiency measures are:

| Measure group | Content | Count |
|---|---|---|
| Industrial Assessment Center (IAC) measures | Savings by industry and end use from the DOE Industrial Assessment Center database of plant energy audit recommendations | 683 |
| IAC measure costs | Levelized cost per MMBtu saved | 683 cost entries |
| Sector-wide efficiency trajectories | Electricity savings in commercial other and residential other | 2 |

Each IAC measure group (end use, industry, and fuel group) is split in the database into four cost quartiles, each a separate measure. The high electrification case applies all four quartiles of every group: 170 measures in the lowest-cost quartile and 171 in each of the other three. The source column records the number of IAC recommendations behind each measure (2 to 461) and their implementation rate (0% to 75%).

- End uses: HVAC (124), thermal (116), combustion (100), operations (76), motors (76), lighting (64), steam (51), process cooling (44), electrical power (24), and industrial design (8).
- Industries (16): aluminum, bulk chemicals, computer and electronic products, electrical equipment and appliances, fabricated metal products, food and kindred products, glass and glass products, light chemicals, machinery, miscellaneous finished goods, other non-metallic minerals, other primary metals, paper and allied products, plastic and rubber products, transportation equipment, and wood products.
- Fuel scope: 416 apply to electricity, 12 to pipeline gas, and 255 to all of the subsector's fuel and steam use other than electricity.
- Savings are national. They start at zero in 2025 and rise linearly to their 2050 value. Savings in 2050 range up to 4.04% of the targeted energy (median 0.30%). Lifetimes are 12, 15, or 20 years.

IAC measure costs are levelized over the payback period that the IAC database reports for each recommendation, at a 6% cost of capital, in 2022 dollars. Values range from $1.94 to $155.74 per MMBtu saved, with a median of about $18. The quartile medians are $16, $17, $18, and $24.

The two sector-wide trajectories are set by assumption. Each reaches 24.5% electricity savings by 2050 with a 25-year lifetime. Their cost is $10 per MMBtu saved for the 2025 vintage and $30 for the 2050 vintage (2022 dollars, 6% cost of capital), set by assumption.

### 5.4 Fuel-switching measures

A fuel-switching measure moves a fraction of a subsector's demand for one final energy type to another. It uses three tables:

- DemandFuelSwitchingMeasures defines the measure: subsector, from and to final energy, and a Weibull lifetime (mean 20 years for all measures).
- DemandFuelSwitchingMeasuresImpact gives the share of the original fuel's demand switched in each year, from 0 to 1, nationally or by industry end use.
- DemandFuelSwitchingMeasuresEnergyIntensity gives the energy of the new fuel needed per unit of the old fuel displaced. This captures the efficiency difference between, for example, a gas-fired process heater and an electric one.

EP applies the specified share to the subsector's demand for the original fuel in each year. The lifetime is used only for cost accounting. The fuel-switching measures carry no cost. The fuel-switching trajectories are set by assumption.

The 216 measures cover 32 subsectors: 20 industrial subsectors (agriculture, mining, construction, and manufacturing), commercial other, commercial unspecified, district services, residential other, secondary heating, secondary cooking, and hot tubs, domestic and international shipping, freight and passenger rail, and recreational boats. They switch from diesel fuel (66), pipeline gas (48), LPG (40), coal (19), residual fuel oil (14), gasoline (11), other petroleum (8), LNG (7), petroleum coke (2), and kerosene (1) to the following:

| Target final energy | Measures |
|---|---|
| Electricity | 102 |
| Liquid hydrogen | 55 |
| On-site hydrogen | 52 |
| Ammonia (shipping) | 6 |
| Steam (district services) | 1 |

The switched share is entered by industry end use for 172 measures and nationally for 44. It starts rising between 2025 and 2035 and reaches its final value between 2035 and 2050. The highest final share across a measure's end uses is 20% for 100 measures, 100% for 55, between 50% and 90% for 53, and 10% to 40% for 6. Trajectories are logistic for 162 measures and linear for 54. Energy intensities range from 0.24 to 1.07 with a median of 0.66.

## 6 Load shapes and hourly profiles

### 6.1 Shape definitions

EP builds hourly electricity demand bottom-up from load shapes attached to subsectors and technologies. The runs use 31 shapes, defined in the Shapes table with data in the ShapeData directory. Each shape has a type, a geography, and an input type:

- A time-slice shape gives a repeating pattern indexed by month, hour, and day type (workday or non-workday), by day of year and hour, or by week, day of week, and hour. EP expands it to every hour of the weather year.

- A weather-date shape gives hourly values for specific calendar years (weather years). These shapes reflect the weather of each year, which keeps heating, cooling, and vehicle charging loads consistent with the weather used on the supply side. The runs use weather year 2023.

EP normalizes each shape so that it sums to one over each year, then multiplies it by annual energy, so only the relative pattern of a shape matters. Some shapes name a geography map key that weights the shape when it is converted to another geography, for example heating shapes weighted by heating degree days times floor area.

### 6.2 Shape inventory

| Shape | Type | Geography | Used by |
|---|---|---|---|
| res_general_space_heating, com_general_space_heating | Weather date | IECC climate zone by state | Residential and commercial space heating; residential secondary heating; furnace fans |
| res_general_space_cooling, com_general_space_cooling | Weather date | IECC climate zone by state | Residential and commercial air conditioning |
| res_heatpump, com_heatpump | Weather date | IECC climate zone by state | Heat pump technologies (one residential, three commercial) |
| res_hybrid_heatpump_lowtech32f, com_hybrid_heatpump_lowtech32f | Weather date, with separate electricity and backup fuel components | IECC climate zone by state | Hybrid heat pump technologies (seven residential, two commercial) |
| data_center_cooling | Weather date | IECC climate zone by state | Data center cooling |
| ev | Weather date (immediate charging at a fast rate) | IECC climate zone by state, by distribution feeder | Passenger car, passenger truck, motorcycle |
| reeds_load_data_2007-2023_detrended | Weather date, total load | ReEDS zone | Default electricity shape and top-down reconciliation target |
| com_lighting | Time slice (week, day, hour) | IECC climate zone by state | Commercial lighting |
| commercial_cooking, commercial_officeequipment, commercial_refrigeration, commercial_waterheating | Time slice (month, hour, day type) | Nation (cooking) or NERC region | Corresponding commercial subsectors |
| com_ventilation | Time slice (week, day, hour) | Nation | Commercial ventilation |
| lighting, clothes_washing, clothes_drying_electric, dishwashing, residential_cooking, residential_refrigeration, residential_freezing, water_heating_gas_nw_data_month_hour | Time slice (month, hour, day type) | Nation | Corresponding residential subsectors |
| industrial_other | Time slice | Nation | Productive sector default |

| Shape | Type | Geography | Used by |
|---|---|---|---|
| agriculture_pumping_dayofyear, agriculture_pumping_dayofyear_hour | Time slice (day of year, hour) | State, weighted by irrigation water withdrawals | Agriculture subsectors |
| mhdv_charging | Time slice (weekday, hour) | Nation | Trucks, buses, motor homes |
| streetlights | Time slice (day of year, hour) | State | Streetlights |
| flat_demand_side | Constant | Nation | Transportation sector default; data center IT and on-site; aluminum, bulk chemicals, glass, paper, light chemicals, other non-metallic minerals, other primary metals, coal mining, and industrial unspecified |

The default electricity shape is the historical hourly load series by ReEDS zone for 2007–2023 published with the NREL ReEDS model, detrended. The other shapes are set by assumption.

### 6.3 Shape assignment and reconciliation

EP assigns a shape to each part of electricity demand in the following order. A technology's own shape applies first, if it has one (heat pumps and hybrid heat pumps). Otherwise the subsector's shape applies. Otherwise the sector's shape applies (industrial_other for the productive sector, flat_demand_side for transportation). For subsectors with no shape at any level, which include the residential and commercial subsectors without their own shape, EP uses the default shape of the final energy type, which for electricity is the ReEDS load series.

After building the bottom-up hourly load for the weather year, EP compares it with a top-down estimate: base-year electricity demand by zone multiplied by the ReEDS historical load shape. The ratio of top-down to bottom-up load in each hour and zone becomes a reconciliation factor, which EP applies to every subsector's shape. This aligns the aggregate bottom-up profile with observed system load in the weather year while preserving the change in load shape that comes from changes in the technology mix.

### 6.4 Distribution feeders

DispatchFeedersAllocation allocates each subsector's electricity demand to three distribution feeder types: residential, commercial, and productive. The data are national shares for 2020 and 2023 for all 80 subsectors, set by assumption. The allocation is used to attribute load to distribution network types on the supply side. The vehicle charging shape is itself split by feeder.

## 7 Emissions accounting

The EP database holds no CO2 emission factors for fuel combustion. EP passes final energy by type to the supply-side model, which accounts for combustion emissions. The mass-type final energy flows described in Section 1.4 carry non-combustion and bunkering CO2.

## 8 Table reference

The tables below hold the data described in this document.

| Table | Content | Key |
|---|---|---|
| DemandSectors | Four sectors and their default shapes | name |
| DemandSubsectors | Subsectors: sector, type, cost of capital, shape, service unit override | name |
| DemandDrivers | Activity drivers | name |
| DemandEnergyDemands | Energy demand by subsector, final energy, geography, and index | subsector |
| DemandServiceDemands | Service demand by subsector | subsector |
| DemandServiceLink | Service demand links between subsectors | name |
| DemandStock | Initial technology stocks | subsector |
| DemandSales | Reference sales shares by technology | demand_technology |
| DemandTechs | Technology definitions and lifetimes | name |
| DemandTechsCapitalCost | Capital cost by vintage | demand_technology |
| DemandTechsInstallationCost | Installation cost | demand_technology |
| DemandTechsFixedMaintenanceCost | Fixed O&M cost | demand_technology |
| DemandTechsMainEfficiency | Main fuel efficiency | demand_technology |
| DemandTechsAuxEfficiency | Second fuel efficiency | demand_technology |
| DemandTechsUtilityFactor | Share of service on main fuel | demand_technology |
| DemandTechsParasiticEnergy | Standing energy use | demand_technology |
| DemandTechsServiceDemandModifier | Service per unit by vintage and age | demand_technology |
| DemandTechsServiceLink | Technology effect on linked subsector service | demand_technology |
| DemandSalesShareMeasures | Sales share measures | name |
| DemandEnergyEfficiencyMeasures, DemandEnergyEfficiencyMeasuresCost | Efficiency measures and costs | name, parent |
| DemandFuelSwitchingMeasures, ...Impact, ...EnergyIntensity | Fuel-switching measures | name, parent |
| Shapes, ShapeData | Load shape definitions and data | name |
| DispatchFeedersAllocation | Subsector allocation to distribution feeders | subsector |
| FinalEnergy | Final energy types and default shapes | name |
| FinalEnergyRIOBlendGroups | Mapping of final energy types to RIO carriers | final_energy |
| Geographies | Geographic units | geography |

| Table | Content | Key |
|---|---|---|
| GeographiesSpatialJoin | County-level crosswalk and allocation weights | None |
| GeographyMapKeys | Names of allocation keys | name |
| OtherIndexes | Members of non-geographic indexes | name |
| InflationConversion | US dollar price index, 1999–2050 | currency |

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## Appendix A Data sources

The table lists, for each input table, the data sources used for the subsectors in this document and the number of keys drawn from each source. A key is a subsector, technology, driver, measure, or shape, depending on the table; for capital and installation costs it is a technology and purchase type. Technology tables count the 199 technologies of Section 4.1, and measure tables count the measures in subsectors passed to RIO. The two demand cases use the same data, except that the measure tables apply only in the high electrification case. Sources use the short names of Section 9 and of the text. Where a row lists several sources, each key in it draws on one or more of them.

| Table | Keys | Source |
|---|---|---|
| DemandDrivers | 32 | 2022 Economic Census; AEO 2026; Weldon Cooper Center; EPA GHGRP; EPA GHG Inventory; USDA NASS; MSHA; EIA SEDS; by assumption (Section 2) |
| DemandDrivers | 1 | American Community Survey |
| DemandDrivers | 3 | AEO 2023 |
| DemandDrivers | 2 | County Business Patterns; 2022 Economic Census; EIA-861 |
| DemandDrivers | 2 | NOAA NCEI |
| DemandEnergyDemands | 1 | By assumption |
| DemandEnergyDemands | 1 | EPA GHG Inventory (2025) |
| DemandEnergyDemands | 1 | AEO 2023 |
| DemandEnergyDemands | 36 | AEO 2026; EIA SEDS |
| DemandEnergyDemands | 2 | AEO 2026 |
| DemandEnergyDemands | 2 | EPRI (2026) |
| DemandEnergyDemands | 20 | RECS 2020 |
| DemandEnergyEfficiencyMeasures | 685 | DOE IAC database; by assumption |
| DemandEnergyEfficiencyMeasuresCost | 2 | By assumption |
| DemandEnergyEfficiencyMeasuresCost | 683 | DOE IAC database |
| DemandFuelSwitchingMeasures | 216 | By assumption |
| DemandFuelSwitchingMeasuresEnergyIntensity | 216 | By assumption |

| Table | Keys | Source |
|---|---|---|
| DemandFuelSwitchingMeasuresImpact | 216 | By assumption |
| DemandSales | 5 | ICCT Race to Zero; AEO 2026; by assumption |
| DemandSales | 15 | AFDC; Alliance for Automotive Innovation; Argonne; AEO 2026; VIUS 2021 |
| DemandSales | 3 | By assumption |
| DemandSalesShareMeasures | 114 | By assumption |
| DemandServiceDemands | 4 | By assumption |
| DemandServiceDemands | 15 | AEO 2026; MOVES 5.0 |
| DemandStock | 1 | NREL ResStock |
| DemandStock | 7 | By assumption |
| DemandStock | 5 | AEO 2026; MOVES 5.0; AFDC; FHWA; VIUS 2021 |
| DemandStock | 5 | MOVES 5.0 |
| DemandStock | 9 | RECS 2020 |
| DemandTechsAuxEfficiency | 9 | By assumption |
| DemandTechsAuxEfficiency | 2 | AEO 2026 |
| DemandTechsAuxEfficiency | 1 | Jadun et al. (2017) |
| DemandTechsCapitalCost | 17 | EIA (2018); by assumption |
| DemandTechsCapitalCost | 69 | AEO 2026 |
| DemandTechsCapitalCost | 31 | NREL ATB 2024; AEO 2026 |
| DemandTechsCapitalCost | 3 | Guidehouse (2024) |
| DemandTechsCapitalCost | 54 | EIA (2023) |
| DemandTechsCapitalCost | 4 | EIA (2023); IECC 2021 |
| DemandTechsCapitalCost | 4 | Slowik et al. (2023) |
| DemandTechsCapitalCost | 12 | By assumption (zero values) |
| DemandTechsCapitalCost | 1 | Massachusetts Clean Energy Analysis |
| DemandTechsFixedMaintenanceCost | 26 | Hunter et al. (2016) via NREL ATB 2024; EIA (2018); by assumption |
| DemandTechsFixedMaintenanceCost | 12 | AEO 2023 |
| DemandTechsFixedMaintenanceCost | 64 | AEO 2026 |
| DemandTechsFixedMaintenanceCost | 6 | Burnham et al. (2021) |
| DemandTechsFixedMaintenanceCost | 4 | Burnham et al. (2021); NCSL |
| DemandTechsFixedMaintenanceCost | 51 | EIA (2023) |
| DemandTechsFixedMaintenanceCost | 18 | ICCT data; MOVES 4.0 |

| Table | Keys | Source |
|---|---|---|
| DemandTechsInstallationCost | 36 | Borlaug et al. (2021); ICCT (2023); Wood et al. (2023); EIA (2018); by assumption |
| DemandTechsInstallationCost | 72 | AEO 2023 |
| DemandTechsInstallationCost | 5 | Cadmus (2024); DOE H2@Scale |
| DemandTechsInstallationCost | 31 | EIA (2023) |
| DemandTechsMainEfficiency | 28 | Jadun et al. (2017); NREL ATB 2024; by assumption |
| DemandTechsMainEfficiency | 3 | AEO 2023 |
| DemandTechsMainEfficiency | 122 | AEO 2026 |
| DemandTechsMainEfficiency | 26 | NREL ATB 2024; AEO 2026 |
| DemandTechsMainEfficiency | 1 | By assumption, by IECC climate zone |
| DemandTechsMainEfficiency | 17 | EIA (2023) |
| DemandTechsMainEfficiency | 1 | Jadun et al. (2017) |
| DemandTechsParasiticEnergy | 2 | EIA (2023) |
| DemandTechsServiceDemandModifier | 25 | MOVES 4.0; by assumption |
| DemandTechsServiceDemandModifier | 18 | MOVES 4.0 |
| DemandTechsServiceDemandModifier | 12 | VIUS 2021 |
| DemandTechsServiceLink | 1 | NREL ResStock |
| DemandTechsServiceLink | 9 | By assumption |
| DemandTechsServiceLink | 6 | AEO 2023 |
| DemandTechsUtilityFactor | 16 | ICCT (2024); by assumption |
| DispatchFeedersAllocation | 80 | By assumption |
| ShapeData | 3 | By assumption |
| ShapeData | 28 | NREL ReEDS; by assumption |