# SLOPE Scenario Planner 2021 Data Sources & Methodology

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# 1 Introduction

The Department of Energy's State and Local Planning for Energy (SLOPE) Platform, published by the National Renewable Energy Laboratory (NREL), aims to empower data-driven state and local energy planning. This documentation explains SLOPE's new web-based map interface called the SLOPE Scenario Planner, which delivers energy system scenario data down to a county-level spatial resolution. The SLOPE Scenario Planner offers users the chance to compare how various energy strategies would influence energy consumption, associated carbon dioxide ($CO_2$) emissions, and energy system costs out to 2050 at the county, state, and quasi-national (conterminous United States) levels. This document outlines the data that can be accessed via the SLOPE Scenario Planner, the sources of the data, and the methodologies used to create them.

## 1.1 Overview of Data and Analysis Sources

The SLOPE Scenario Planner illustrates the implications of various energy strategies out to 2050. Each scenario is defined by discrete assumptions related to the future of U.S. energy demand and electricity supply (Table 1), which are interrelated. Results for each scenario are summarized through three key energy system metrics—consumption, $CO_2$ emissions, and system costs—which can be presented at varying levels of spatial resolution ranging from county-level to quasi-national scale.

To define the energy scenario of interest, users select discrete variables within two high-level Scenario Selection categories in the SLOPE Scenario Planner's Control Panel: Electricity Supply Scenario and Electricity Demand Scenario. The Electricity Supply Scenario selection is defined by a $CO_2$ emissions reduction trajectory for U.S. electricity supply and the cost of new inter-regional transmission infrastructure, both of which apply to the bulk electric system only. Selections under the Electricity Demand Scenario category—including Level of Electrification, Level of Demand-Side Flexibility, and Level of Building Energy Efficiency—further define the evolution of energy demand into the future. The Level of Electrification varies the extent to which energy consumers choose to switch from nonelectric to electric end-use technologies in the buildings and transportation sectors. The Level of Demand-Side Flexibility varies customer participation rates in load-shifting programs for various services within the buildings and transportation sectors. The Level of Energy Efficiency varies the extent of customer adoption of commercial and research-grade energy conservation measures in residential and commercial buildings, resulting in energy savings compared to current typical efficiency levels.

The underlying data associated with all scenario settings were derived from previously published analyses, which primarily focused on state-level and national-scale results; therefore, additional models and data sources were applied to generate the county-level information that is available in the SLOPE Scenario Planner (Table 1). Most models listed in the first two columns of Table 1 were developed and are maintained by NREL, and each one represents the state of the art in techno-economic analysis in its field of inquiry. Each model makes use of the best available information and has undergone intensive validation.

### Table 1. Summary of Data Sources for All SLOPE Scenario Planner Inputs

| **Original Analysis Source (Models)** | **Additional Analysis** | **Relevant Scenario Selections** |
|---|---|---|
| | ***Electricity Supply*** | |
| 2021 Standard Scenarios (ReEDS and dGen) | SLOPE: Implementing all energy demand scenario settings to enable generation mix and emissions factors for each combination of settings | Electricity Supply Scenario,<br>Level of Electrification,<br>Level of Demand-Side Flexibility,<br>Level of Building Energy Efficiency |
| | ***Transportation Energy Demand*** | |
| Electrification Futures Study (EnergyPATHWAYS) | Transportation Energy & Mobility Pathway Options (TEMPO)[1]: produce county-level data from the original state-level analysis results | Level of Electrification,<br>Level of Demand-Side Flexibility |
| | ***Industrial Energy Demand*** | |
| 2019 Annual Energy Outlook (NEMS) | Cities-LEAP: produce county-level data from the original subnational analysis results | -- |
| | ***Buildings Energy Demand*** | |
| Electrification Futures Study (EnergyPATHWAYS) | ComStock[2] and ResStock[3]: produce county-level data from the original state-level analysis results | Level of Electrification,<br>Level of Demand-Side Flexibility |
| Scout Core Measures Scenario Analysis 2019 (Scout) | EIA Form-860[4]: produce county-level data from the original analysis results reported by NEMS Electricity Market Module region | Level of Building Energy Efficiency |

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[1] Muratori, Jadun, Bush, Hoehne, Yip, et al. 2021.
[2] "ComStock Analysis Tool." 2021. www.nrel.gov/buildings/comstock.html.
[3] "ResStock Analysis Tool." 2021; Wilson et al. 2017. www.nrel.gov/buildings/resstock.html.
[4] "Form EIA-860 detailed data with previous form data (EIA-860A/860B)." 2020. https://www.eia.gov/electricity/data/eia860/

Based on the scenario settings selected by the user, the SLOPE Scenario Planner presents projections for three primary energy system metrics (Table 2): energy consumption, energy $CO_2$ emissions, and energy system costs. Energy consumption and energy $CO_2$ emissions are presented for each economic sector at a county, state, or quasi-national scale, with further delineation between the electric and nonelectric portions of each. Energy system costs—including additional investment requirements as well as savings—are reported relative to the business-as-usual projection at a state or quasi-national scale; they are reported separately for the electric and energy demand sectors, and they are further delineated by various categories of capital and operating expenditures.

**Table 2. Summary of Information Presented on the SLOPE Scenario Planner**

| **Scenario Planner Energy Metric** | **Sectoral Breakdown** | **Categories** | **Spatial Resolution** | **Timeframe**[a] |
|---|---|---|---|---|
| **Energy Consumption** | Residential,<br>Commercial,<br>Industrial,<br>Transportation | Electric,<br>Non-Electric | County,<br>State,<br>National | Projected for 2020–2050 |
| **Energy $CO_2$ Emissions** | Residential,<br>Commercial,<br>Industrial,<br>Transportation | Electric,<br>Non-Electric | County,<br>State,<br>National | Projected for 2020-2050 |
| **Energy System Costs** | Electricity Supply,<br>Energy Demand (including buildings, industry, and transportation) | Energy Capital,<br>Energy Delivery Infrastructure,<br>Operations and Maintenance | State,<br>National | Projected for 2020–2050 |

[a] Information presented for 2020 is based on model results; such results have been calibrated against historical data, but they will not match exactly with reported energy data.

## 1.2 Interpreting Scenario Results

The SLOPE Scenario Planner includes two resources to assist users with the interpretation of scenario results. First, for any valid combination of scenario selections, a paragraph describing the chosen scenario is provided in a pane located below the SLOPE Scenario Planner window. The paragraph describes the types of strategies represented in the scenario and qualitative descriptions of how aggressively each strategy is pursued.

The second resource for assisting with the interpretation of scenario results is a set of five “planning metrics,” which provide quantitative information about the assumptions and results for a given set of scenario selections. The purpose of these planning metrics is to provide users with additional intuition about the scenario they are viewing in quantifiable, readily understandable terms that are related to energy goal setting and planning. The planning metrics are defined by the scenario selections, so they remain visible and unchanged regardless of which energy system metric is being visualized. The planning metrics are reported at the state and national levels; so, when a user views county-level data, the planning metrics displayed refer to the state the county is in. By clicking and dragging a slider, the metrics can be reported for any year between 2020 and 2050. Those metrics, along with the sources of data used to calculate them, are described in Appendix F.

Two of the five planning metrics are intended to provide users with intuition regarding the aggressiveness of the assumed extent of electrification (as defined by the Level of Electrification scenario selection). For example, one planning metric summarizes the fraction of residential and commercial space heating services that are supplied by electricity (inclusive of both air-source heat pumps and resistive heating). A second energy planning metric tracks the share of electric vehicles (including battery electric and plug-in hybrid electric vehicles) within the light-duty vehicle stock.[5]

The remaining three planning metrics are defined by the combination of Energy Demand and Electricity Supply Scenario selections. One summarizes the portfolio of electricity generation resources in terms of the share of electricity generation that is provided by renewable energy resources[6]; another presents the percentage reduction in energy $CO_2$ emissions relative to 2005 levels[7]; and another reports the net change in system cost relative to a business-as-usual projection, to provide an estimate for the level of additional investment that is required to achieve that scenario.

Finally, despite the technical rigor and extensive validation that underlie all the data presented in the SLOPE Scenario Planner, it is important to note the inherent uncertainty in the results shown. This uncertainty stems from a combination of simplifying assumptions made by each model and the fact that our knowledge of the future is always imperfect. Therefore, all results should be interpreted with this uncertainty in mind.

The remainder of this documentation describes the analysis sources, data, and methodologies that were employed to populate the SLOPE Scenario Planner. The document is organized around the three energy system metrics that are available for user selection in the Control Panel.

# 2 Energy Consumption Data

The energy consumption data visualized in the SLOPE Scenario Planner are defined by the Level of Electrification and Level of Building Energy Efficiency scenario selections. Each of these selections will alter sector-level energy consumption relative to a “Reference” scenario, which serves as a baseline of comparison to the other scenarios. Under the “reference” scenario, electricity’s share of final energy grows modestly over the next three decades, primarily due to

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[5] The data sources for these metrics are service demand and end-use technology stock data from the Electrification Futures Study.

[6] Imports of electricity from Canada are assumed to consist of hydroelectric power, and as such they are included in this metric. This metric is calculated as the fraction of total end-use load plus losses that is supplied with renewable energy generation.

[7] Energy-related $CO_2$ emissions reductions are calculated from 2005 U.S. Energy Information Administration (EIA) state-level baseline values (“Energy-Related Carbon Dioxide Emissions by State, 2005–2016” 2019). Note that since the percentage $CO_2$ emissions reduction specified in the electricity supply scenario is enforced in ReEDS as a national constraint, individual states may be above or below the target in the year it is enforced.

the continued adoption of electric heat pumps to serve space heating needs in buildings and modest growth in light-duty electric vehicle adoption. Energy efficiency also increases modestly over time, based on recent trends in customer adoption of energy conservation measures.

Multiple Energy Demand Scenario settings allow the SLOPE Scenario Planner user to explore alternative trajectories for energy demand, based on varying levels of electrification and building energy efficiency; the former are derived from NREL's Electrification Futures Study (EFS) ("Electrification Futures Study: A Technical Evaluation of the Impacts of an Electrified U.S. Energy System" 2021), and the latter is derived from the Scout Core Measures Scenario Analysis 2019. The available selections are as follows:

- **Medium Electrification** represents widespread electrification in select sub-sectors with potentially lower barriers, but it does not result in transformational change. Electricity's share of final energy grows by approximately 50% over the next three decades, primarily due to an increase in transportation electrification, especially for light-duty vehicles.

- **High Electrification** represents transformational change in electricity's share of final energy consumption, such as that which could result from a combination of technology advancements, policy drivers, and consumer enthusiasm for electric technologies. Electricity's share of final energy nearly doubles over the next three decades due to the adoption of electric technologies in all major end uses.

- **High Building Energy Efficiency** represents the availability and adoption of more energy efficient equipment and building envelope technologies in U.S. residential and commercial buildings from 2022-2050. The represented energy conservation measures include both currently available technologies up to best available efficiencies, as well as higher efficiency technologies currently in development but expected to be commercialized between the present year and 2030. Technologies and building envelope components are assumed to be replaced at end of life; this scenario does not consider significant accelerated replacements (or early retirements), efficiency policy mandates, or incentives that reduce the total installed price of more efficient building technologies.

Each Level of Electrification defines the hourly demand for electricity and annual direct fuel use within the residential buildings, commercial buildings, transportation, and industrial sectors. Aggregate results are presented on the SLOPE Scenario Planner, but they are rooted in detailed information from the EnergyPATHWAYS model that tracks final energy demand by technology, sector, state, and year out to 2050 (Haley 2019). The Level of Energy Efficiency specifies site electricity and fossil fuel savings by building sector and end use for each of the 25 Electricity Market Module (EMM) regions in the National Energy Modeling System (NEMS).[8] These site energy savings are calculated using Scout, which quantifies savings relative to the NEMS "reference case" from the 2021 Annual Energy Outlook.

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[8] The EIA Electricity Market Module regions align with North American Electric Reliability Corporation subregions and Independent System Operator territories: https://www.eia.gov/outlooks/aeo/pdf/nerc_map.pdf.

Detailed documentation for the development of the Levels of Electrification and Demand-Side Flexibility presented on the SLOPE Scenario Planner can be found in the EFS publication series (NREL 2021). A detailed description of the Levels of Energy Efficiency scenario can be found in Langevin et al. (2019), where it is referred to as "scenario 3." Updated versions of the energy conservation measures included in the scenario, as well as documentation of changes since the initial scenario release, can be found on Zenodo (cite).

This section summarizes the additional processing steps that were required to disaggregate the state-level energy consumption data from the EFS and EMM region-level energy savings data from Scout to a county resolution and prepare the data for use in the SLOPE Scenario Planner. Wherever we introduce a proxy dataset in the following subsections, our disaggregation methodology was to simply allocate the state-level energy consumption in the category under discussion to the counties within each state, using the county-level values in the proxy dataset as weights. In each case, the county-level values in the proxy dataset were divided by the state sum, and the resulting fraction was multiplied by the state-level energy consumption to produce a county-level estimate. Some proxies offer projections out to 2050, while others only offer historical data. In the latter case, we assume no change in the intra-state distribution of energy consumption for the given end-use technology through 2050.

## 2.1 Residential and Commercial Energy Consumption

### 2.1.1 Level of Electrification

Building off the state-level EFS results for residential and commercial energy consumption in all 50 states, we disaggregated the results of each relevant EnergyPATHWAYS scenario to the county-level using building stock data from NREL's ResStock and ComStock models as a proxy. In particular, we used the ResStock and ComStock source input files to establish county-level data distribution factors, which we applied to the state-level final energy demand outputs for each EFS electrification level. The input files utilize Census Public Use Microdata Area (PUMA) geometries related to county geometries.

For the residential sector, the EFS input file values were separated into heating and nonheating demand sector categories. The PUMA-level heating file was used to generate state and county level summaries by fuel type, yielding county-level distribution factors by fuel type. The residential allocation factors for nonheat demand sectors were derived by weighting building-type distribution at the PUMA level and aggregating to state and county summaries.

A similar process was conducted for the commercial sector; however, the ComStock input file was already at the county level and, therefore, required less aggregation.[9] County-level distributions for commercial energy demand were derived by aggregating the building area by fuel type to the state and county levels for electricity, pipeline gas, and district services. Solar and diesel fuel allocations are derived from aggregations of total building area, irrespective of fuel type, at the county and state level.

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[9] Some alterations to the ComStock input files were necessary to correct for three outdated county FIPS values—two were renumbered, and the third was merged into another county FIPS record.

### *2.1.2 Level of Building Energy Efficiency*

Scout reports annual energy savings as a fractional reduction in annual energy consumption from the NEMS "reference case," broken out by sector and final energy (i.e., electricity vs. direct fuel consumption) for each of the 25 EMM regions. These regional fractional energy savings were applied to the EFS "Reference" scenario consumption at the county level by mapping counties to EMM region.[10] Finally, county-level fractional energy savings were multiplied by consumption from the EFS "reference" scenario for each year, sector (residential and commercial energy consumption), and final energy category (electricity and direct fuel consumption). Since Scout is based on NEMS simulations, energy consumption (or savings) data for the High Energy Efficiency scenario were only available for the conterminous United States. Therefore, the viewing of Alaska and Hawaii is disabled when the "High Building Energy Efficiency" setting is selected in the Scenario Planner Control Panel.

## 2.2 Industrial Energy Consumption

County-level industrial energy consumption data in the SLOPE Scenario Planner are replicated from the SLOPE Data Viewer.[11] As a result, the SLOPE Scenario Planner includes only one projection for industrial energy consumption, which means the data are independent of Energy Demand Scenario selections associated with electrification, energy efficiency, and demand-side flexibility. In other words, we do not assume any meaningful electrification of the industrial sector—because many energy-intensive activities are difficult to electrify—and we do not represent other strategies for increasing energy efficiency or reducing direct emissions from within the industrial sector.

Due to a lack of county-level data, we currently only consider industrial sector demand for natural gas and electricity; all other fuel types are excluded from the industrial energy consumption values presented on the SLOPE Scenario Planner. Figure 1.  compares historical energy demand from the U.S. industrial sector for all fuel types ("Monthly Energy Review - November 2021" 2021) against what is presented for industrial energy consumption in the SLOPE Scenario Planner. The resulting gap indicates that roughly half of the industrial sector's total energy consumption is not captured in the SLOPE Scenario Planner, primarily due to the lack of county-level data for petroleum demand ("Monthly Energy Review - November 2021" 2021) in our projection of industrial energy consumption.

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[10] The mapping from EMM region to county involved an interim step of matching counties with their ReEDS balancing areas (see Section 3.1). For the ReEDS balancing areas that overlap multiple EMM regions, we weighted the influence of each EMM region overlapping a given balancing area by the distribution of electricity generation capacity within the balancing area (from the EIA-860 database, as a proxy for energy consumption).

[11] A detailed methodology for the SLOPE projections of industrial sector demand for electricity and natural gas at a county level are available on the SLOPE Data Viewer: https://app.box.com/s/t0t3j6zztzan94a4tu1so8pse4btkkn1.

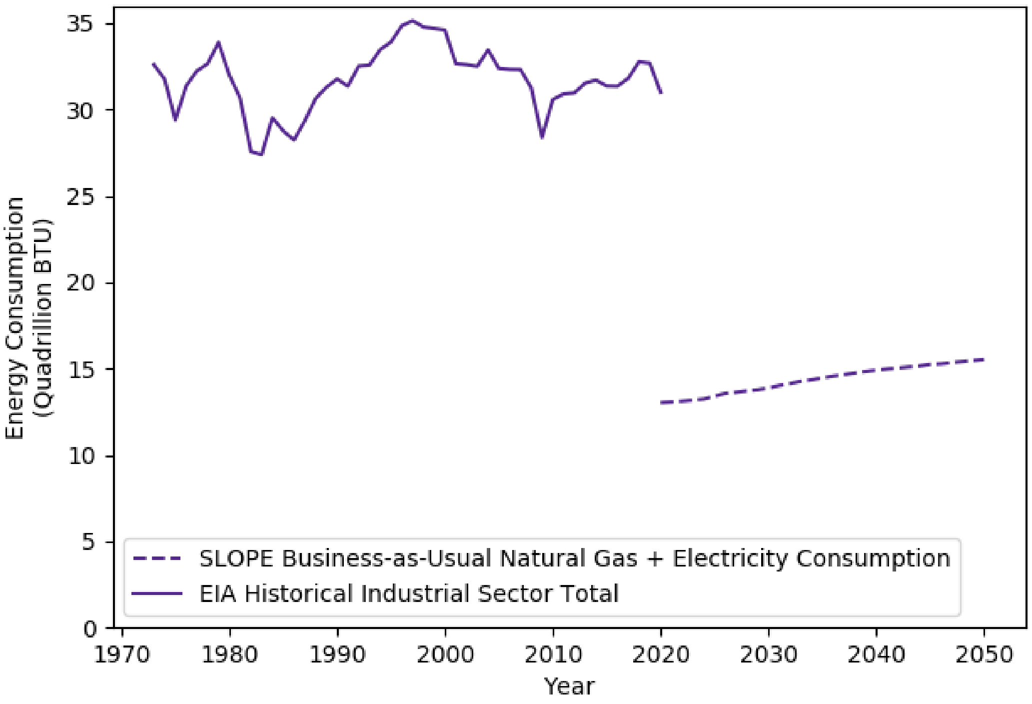

**Figure 1. Comparison of historical total U.S. industrial sector energy consumption against the SLOPE Scenario Planner's business-as-usual projection for industrial sector demand for natural gas and electricity**

## 2.3 Transportation Energy Consumption

The end-use technologies that make up the transportation sector's energy consumption are diverse in terms of their spatial distribution, and vehicles are mobile and exhibit distinct patterns of movement by type. Therefore, several different proxies were used to disaggregate the EFS state-level transportation energy consumption data to the county level.[12]

For all light-duty vehicles and motorcycles, county-level results from the TEMPO model were used as a proxy for the state-to-county level disaggregation. The TEMPO model was previously employed for the SLOPE Data Viewer to project county-level sales, stock, and vehicle miles traveled (VMT) for personally owned light-duty vehicles (by type) through 2050, consistent with the EFS Reference and High Levels of Electrification.[13] We leveraged the previously developed county-level VMT data to develop a mapping from each light-duty vehicle and motorcycle subsector (from the EFS) to corresponding vehicle types in the TEMPO dataset (see Appendix C, Table C- 2.). To generate a proxy dataset for the Medium Electrification scenario selection, we interpolated between the available VMT data from TEMPO for the Reference and High Levels of Electrification.

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[12] The mapping of each transportation subsector (as referred to in the detailed dataset available for download by the "SUBSECTOR" column) to the proxy used for disaggregation is listed in Appendix C, Table C- 1. .

[13] A detailed methodology behind the creation of the TEMPO projections is available on the SLOPE Data Viewer page: https://gds-files.nrel.gov/slope/SLOPE%20TEMPO%20Transportation%20Methodology.docx.

To spatially disaggregate the energy consumed by medium- and heavy-duty trucks and buses, we used a county-level dataset of total 2016 diesel fuel consumption created through previous SLOPE efforts as a proxy for the distribution of such vehicles. Appendix D details the methodology behind the creation of that dataset.

The SLOPE Scenario Planner data excludes energy consumption from all non-road transportation subsectors—including aviation, shipping, boating, and travel and shipping via rail—because we have not yet identified acceptable county-level proxy datasets. Altogether, these non-road transportation subsectors accounted for almost 10% of energy consumption within the transportation sector in 2020, and the EFS estimates that they could account as much as 21% of the sector's energy consumption by 2050 (Figure 2). Finally, while the EFS scenarios assume steady increases in the efficiency of the U.S. transportation fleet, the SLOPE Scenario Planner does not consider energy efficiency of vehicles in isolation. In other words, transportation energy consumption is unaffected by the Level of Building Energy Efficiency setting in the SLOPE Scenario Planner Control Panel.

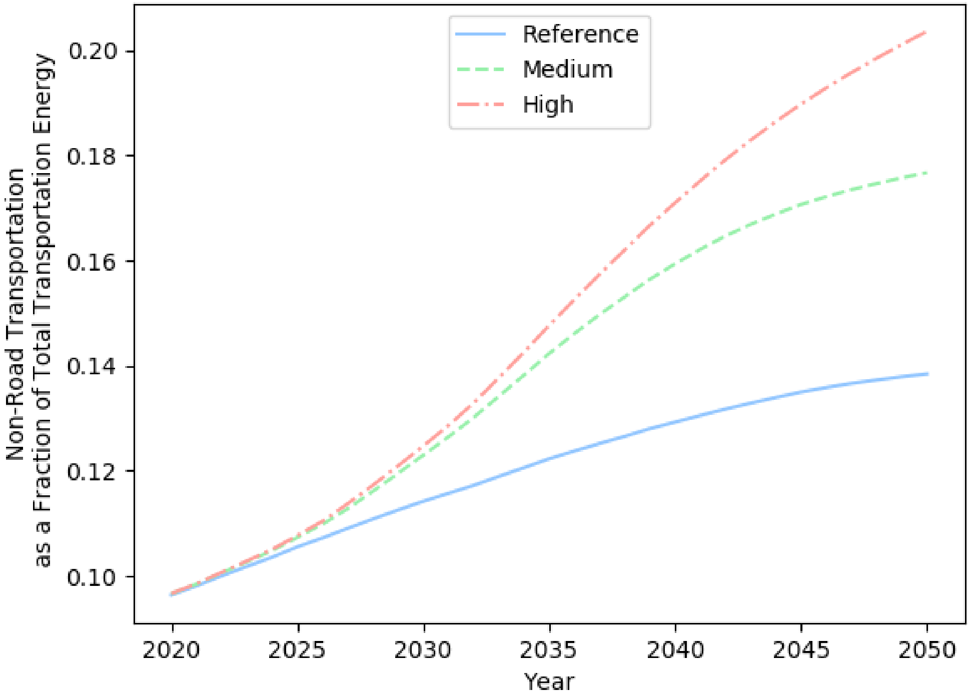

**Figure 2. The share of projected energy consumption from all non-road transportation subsectors, which are not included in the data reported in the SLOPE Scenario Planner (EFS 2021).**

# 3 Energy $CO_2$ Emissions

To translate the SLOPE Scenario Planner's energy consumption data (Section 2) into projections for energy $CO_2$ emissions levels, we applied annual emissions factors for electric and nonelectric energy sources. A unique emissions factor was developed for each Electricity Supply Scenario (Section 3.1), which was then combined with annual electricity demand to generate estimates for electricity-related $CO_2$ emissions for each energy demand sector (Section 3.2). To estimate emissions associated with direct fuel use in buildings, transportation, and industry, we applied emissions factors for each fuel type (Section 3.3).

## 3.1 Electricity Supply Scenarios from the ReEDS model

The Electricity Supply Scenarios available on the SLOPE Scenario Planner were developed using NREL's Regional Energy Deployment System (ReEDS)[14] and the Distributed Generation (dGen)[15] models. ReEDS is NREL's flagship power system planning model, which projects future bulk power system infrastructure investment decisions using data representing today's electric power system and various assumptions about future technology costs and improvements, policies, electricity consumption patterns, and operational constraints. To represent the evolution of distribution-sited systems, results from the dGen model for future customer adoption of distributed solar and energy storage are included as inputs to each ReEDS scenario.

Because of the complexity of the bulk electricity system, ReEDS aggregates the transmission network into regions termed "balancing areas" (Figure 3), within which no transmission limitations are represented. These balancing areas constitute the native spatial resolution for serving load and investing in generation and storage assets within ReEDS. Transmission of power can occur on interfaces across regions, and investments can be made within the model to expand the capacity of these interfaces. The ReEDS balancing areas respect state boundaries, such that native ReEDS results can readily be aggregated to the state level. However, the spatial extent of the ReEDS model does not include Alaska or Hawaii, so electric sector results (including emissions factors and power system costs) are not included for these states on the SLOPE Scenario Planner.

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[14] Ho et al. 2021.

[15] Prasanna et al. 2021; Sigrin et al. 2021.

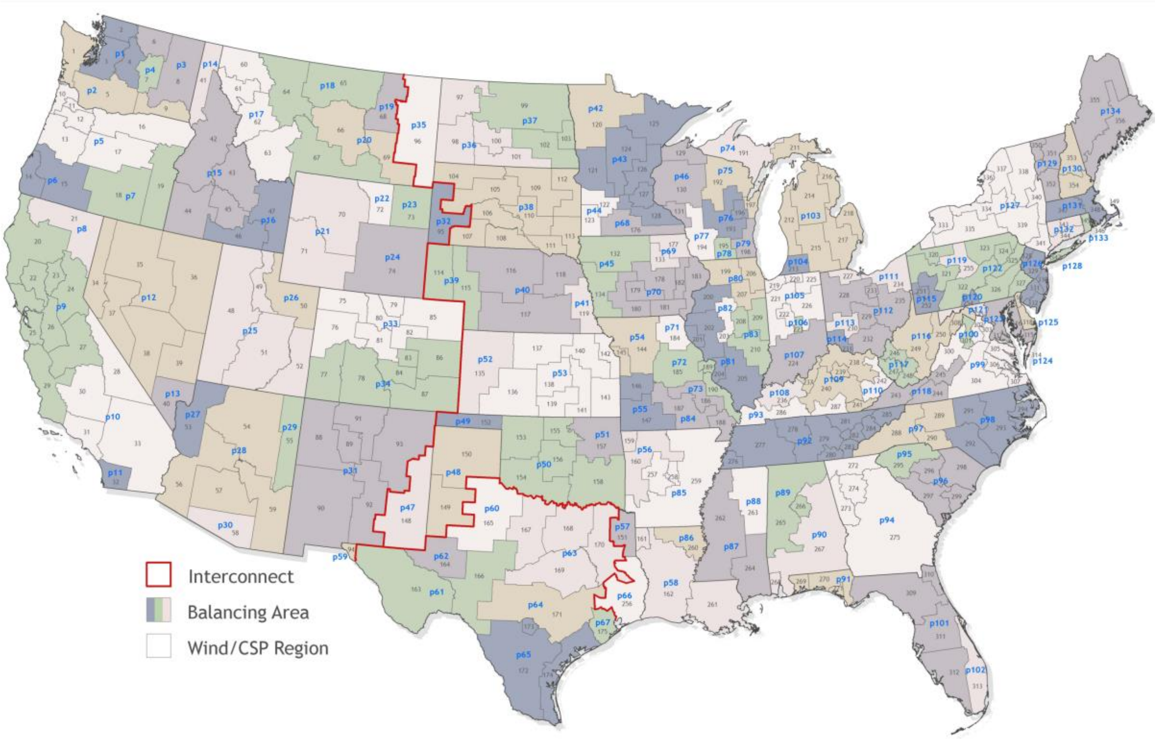

**Figure 3. Map of ReEDS balancing areas**

In developing the Electricity Supply Scenarios for the SLOPE Scenario Planner, we populated the ReEDS model with electricity demand profiles based on the highly detailed bottom-up projections of future changes in electricity demand patterns for each Level of Electrification (Section 2). Each electrification level also involves unique assumptions for the Level of Demand-Side Flexibility, which is defined by varying levels of customer-participation in load shifting programs that can help reduce peak demand and enable the alignment of electricity demand with low-cost sources of electricity generation.

To create an electricity demand profile representing the “High Energy Efficiency” Energy Demand Scenario, we applied fractional load derates to the “reference” electrification demand profile for each year and balancing area within ReEDS. These derates were calculated by mapping annual fractional electricity reductions (reported by Scout) from NEMS EMM regions to balancing areas, with weighting to account for each sector’s share of total electric load using the bottom-up energy consumption projections described in Section 2. This methodology assumes that the annually-averaged reductions in electricity consumption reported by Scout are spread evenly across all hours of the year. In addition, our implementation reduces *annual* electricity demand based on the spatial resolution and scenario outcomes from Scout, and it does not capture the potential effects of energy efficiency on the *shape* of electricity demand. Such effects could be captured in future updates if hourly load profiles associated with the widespread adoption of energy conservation measures are available.

These electricity demand assumptions were then combined with the Electricity Supply Scenario definitions from the 2021 Standard Scenarios analysis (Cole et al. 2021). In particular, we leveraged two scenario definitions from the 2021 Standard Scenarios, which represent carbon policies (or caps) that force a linear reduction in U.S. bulk power system $CO_2$ emissions to: (a) 95% below 2005 levels by 2050 or (b) 95% below 2005 levels by 2035 and net-zero by 2050. These carbon policy assumptions were layered with all available Energy Demand Scenario settings presented on the SLOPE Scenario Planner, including (a) all Levels of Electrification, in isolation and in combination with both Levels of Demand-Side Flexibility, and (b) all Levels of Building Energy Efficiency (in isolation), with the option of further assuming increased costs for new long-distance transmission.[16] Therefore, when SLOPE Scenario Planner users select a given Electricity Supply Scenario setting,[17] the corresponding emissions projections reflect ReEDS scenario results based on the combination of all user selections.[18]

## 3.2 $CO_2$ Emissions from Electric Energy Consumption

Emissions that result from electricity consumption are defined by the portfolio of generation resources being used to supply power to the grid; therefore, we calculated emissions factors from the ReEDS results, based on the dispatch decisions for each year and Electricity Supply Scenario.[19] We included only direct emissions of $CO_2$ to the atmosphere in the calculation of emissions factors; other life cycle emissions associated with building or maintaining power system infrastructure were not considered.

To calculate emissions associated with electricity consumption for each sector, we summed state-level $CO_2$ emissions reported by ReEDS for each year and allocated them proportionally according to the electricity consumed by each sector and county. Although the native spatial resolution in ReEDS (the balancing area) could allow us to calculate emissions at a finer spatial resolution, we sum to the state level to approximate inter-balancing area transmission of electricity. This methodology was adopted to represent the pervasive trading of electricity supply, but it does not reflect the ability (and common practice) of transmitting electricity across state boundaries. Finally, by multiplying annual electricity consumption by annually averaged emissions factors, we assumed that the consumption by each end use is spread out evenly across all hours of the year—that is, we did not consider hourly variation in both the emissions from electricity generation and energy consumption by each end use technology within each sector.

## 3.3 $CO_2$ Emissions from Nonelectric Energy Consumption

To calculate annual $CO_2$ emissions from direct fuel use in buildings, transportation, and industry, the annual consumption of each fuel type was multiplied by an emissions factor representing the average mass of $CO_2$ emitted per MMBTU of fuel consumed. Those emissions factors, their sources, and any other assumptions made can be found in Appendix E and the footnotes below Table E-1. Most values are from the Environmental Protection Agency's Emissions Factor Hub

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[16] The use of balancing area generation mix results would yield electric sector emissions factors of zero in balancing areas that import 100% of their annual energy within ReEDS.

[17] The scenarios that specify "with limited transmission expansion" involve higher-cost assumptions for new or upgraded transmission, which are meant to represent political or economic barriers to such projects within ReEDS.

[18] 0 lists all the ReEDS scenarios included in the SLOPE Scenario Planner by Electricity Supply Scenario, Level of Electrification, and Level of Demand-Side Flexibility. The ReEDS scenario names are used as unique identifiers in the detailed data that are available for download.

[19] Each electricity generation technology in ReEDS is associated with an emissions rate for $CO_2$ and several other pollutants See Section 3.2 and Table 9 in the 2020 ReEDS model documentation for the rates of individual generation technologies and plant vintages (Ho et al. 2021).

and the EIA's published list of emissions coefficients (US EPA 2015; "Carbon Dioxide Emissions Coefficients" n.d.). By implementing average emissions factors by fuel type alone, our results do not explicitly capture the combustion efficiencies of the equipment options that are detailed in the EnergyPATHWAYS results from the EFS or the Scout Core Measures Scenario Analysis.

Finally, note that all sectoral and fuel-type exclusions described in Section 2 propagate through to the energy-related $CO_2$ emissions results as well. Therefore, industrial $CO_2$ emissions only include emissions associated with natural gas and electricity consumption, and transportation $CO_2$ emissions only reflect on-road transportation services. These exclusions explain why the national-scale results for energy $CO_2$ emissions on the SLOPE Scenario Planner are lower than annual data tracked by the EIA.

# 4 Energy System Costs

State-level energy system costs are reported on the SLOPE Scenario Planner as the change from a business-as-usual projection (i.e., "Reference Case" in Appendix A); investment levels that exceed those in the business-as-usual projection will appear as incremental costs (positive values), whereas reduced investment levels will appear as system cost *savings* (negative values). If a SLOPE Scenario Planner user selects the Reference level for all scenario selections, no costs will be displayed because the change from a business-as-usual projection will be zero for all cost categories. For a valid set of scenario selections, a net system cost level will also be presented, which reflects the sum of all cost categories in a given year.

We adopted the approach of presenting relative energy system costs (rather than absolute changes) because the EFS data that underlie the Levels of Electrification only tracks *incremental* costs associated with equipment capital in demand sectors (i.e., the change in capital cost for an air-source heat pump compared to a natural gas furnace). To provide some context for the system cost results presented in the SLOPE Scenario Planner, we note that calculations from the EFS estimate that the net present value of economy-wide expenditures related to energy supply and consumption under a business-as-usual projection are on the order of $28 trillion (through 2050); however, it is important to note that this is likely an underestimate.

All energy system incremental costs and savings represent annual cash flows discounted to 2019 at a 3% discount rate (in keeping with the EFS) and adjusted for inflation to be reported in 2020 dollars (Murphy et al. 2021). Our cost methodology closely follows that of Murphy et al. 2021; Appendix C, Section C.1 of that publication details the methodology used for the SLOPE Scenario Planner, provides more context, and explains limitations of the scope of the costs reporting.

## 4.1 System Costs Associated with Electricity Supply

Electricity system costs (displayed in shades of blue in the SLOPE Scenario Planner) are based mainly on ReEDS and dGen results, for which annualized system costs are aggregated to the state level. These costs represent capital expenditures associated with infrastructure investments as the debt service that would be incurred on those investments each year, assuming a 20-year financial lifetime for all bulk power system investments.

The electricity supply system costs for increasing Levels of Electrification will always be higher than those associated with a business-as-usual projection, and a carbon policy for the power system is similarly expected to increase investment requirements on the bulk power system; therefore, both of these scenario settings will result in incremental costs (i.e. positive values) on the SLOPE Scenario Planner. On the other hand, electricity supply system costs for increasing Levels of Building Energy Efficiency will be *lower* than those associated with a business-as-usual project, due to the reduced demand for electricity and, in turn, new investments in new electricity supply resources.

The following categories are delineated for the electricity supply system costs:

- **Electricity Supply: Generation and Storage** – reflects capital costs associated with new generation and storage investments, which are dominated by utility-scale projects.

- **Electricity Supply: Fuel and Operations and Maintenance (O&M)** – reflects annual expenses associated with operating the bulk electricity system, as dispatched within ReEDS, including fuel consumption costs and non-fuel O&M costs associated with electricity generation and storage.

- **Electricity Supply: Transmission and Distribution (T&D [Wires])** – reflects electricity transmission investment costs (from ReEDS) and estimates for revenue requirements associated with electricity distribution system upgrades (from EnergyPATHWAYS, based on different levels of electrification).

As with our calculation of $CO_2$ emissions, no cost adjustments were made to account for interstate energy trading.

## 4.2 Demand-Side Costs and Savings

### 4.2.1 Level of Electrification

Reported system costs for the energy demand sectors (displayed in shades of orange in the SLOPE Scenario Planner) are based mainly on the same EnergyPATHWAYS modeling that created the energy consumption projections for the various Levels of Electrification presented. Details of the methodology for producing these estimates for demand sector system costs can be found in Murphy et al. 2021.

Although EnergyPATHWAYS results were reported at the state level, the costs and savings associated with them were reported for the conterminous United States. To approximate state-level costs and savings, we first calculated state-level electrification (i.e., the increase in annual load versus the Reference Electrification level) as a fraction of the total electrification across the conterminous United States in each year.[20] We then multiplied the aggregate, quasi-national

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[20] To do this, we subtracted the annual state-level electricity load in the Reference Electrification level from the annual state-level electricity load in the Medium and High Electrification levels (as seen in ReEDS).

costs and savings from EnergyPATHWAYS by each state's fraction of electrification to apportion and report demand-side energy system costs and savings at the state level.

The following categories are delineated for the demand sector system costs:

- **Demand: Equipment Capital:** represents the incremental capital costs for electric end-use equipment compared to their direct fuel use counterparts.
- **Demand: Fuel Consumption and O&M:** represents direct fuel consumption costs in all demand sectors and O&M costs for end-use equipment.
- **Demand: Fuel Infrastructure:** reflects infrastructure and delivery costs outside the electric sector, and it is dominated by natural gas transmission and distribution pipelines.

The system costs for the energy demand sectors are largely independent of the chosen Electricity Supply Scenario, as they primarily depend on capital and operational expenditures within the buildings, transportation, and industrial sectors. However, the "Demand: Fuel Consumption and O&M" category does vary slightly depending on the selected Electricity Supply Scenario, because natural gas prices from ReEDS (which has an endogenous representation of the price elasticity of demand) are used to scale the cost of natural gas burned for nonelectric final energy demand. Moreover, final energy demand estimates are specific to the energy demand sectors of buildings, transportation, and industry; approximately 10 quads of annual energy consumption (at a national scale) from refining; oil, coal, and natural gas extraction; and combined heat and power are excluded from our final energy consumption results.

### 4.2.2 Level of Building Energy Efficiency

Based on the Scout scenario results, the efficiency measures deployed in U.S. residential and commercial building energy efficiency measures (from 2022-2050) influence two demand sector cost categories: *incremental equipment costs* associated with purchasing efficient technologies and *reduced consumer energy costs* due to energy savings. The total incremental equipment cost investment of $313 billion (from 2022–2050) leads to site energy savings in 2050 of 5.33 quads (1553 TWh) and consumer energy cost savings of $96 billion. Considering savings from all years across the full time horizon, site energy savings are 104 quads and consumer energy cost savings are $1.9 trillion.

Scout calculates incremental equipment cost as the difference between the cost of the efficient equipment adopted and the comparable baseline technology. For example, if a heat pump water heater that costs $2500 is adopted in place of an electric resistance water heater that costs $1000, the incremental equipment cost is $1500. The adoption of higher performance equipment yields energy use reductions. These energy savings lead to lower energy costs from lower utility bills, where the consumer energy cost savings are calculated as the difference in utility bills with the more efficient equipment adopted and if the baseline equipment were instead adopted.

To characterize these equipment costs for presentation in the Scenario Planner, we disaggregated *national* incremental equipment stock costs produced by Scout (for each year and building sector) based on state-level projections of energy efficiency potential from the Electric Power Research Institute. The study published estimates of potential reductions in electricity consumption for every five years from 2020 to 2035 given incentives ranging from $0–$20/MWh. We used savings projected for the $20/MWh incentive as our proxy for disaggregating equipment costs since it most closely reflects the conditions modeled by Scout for the “higher energy efficiency” scenario. Linearly interpolating between years and extrapolating no change in energy efficiency potential from 2035 onward, we disaggregated equipment costs to the state level by multiplying the national value (from Scout) by the fraction of national energy efficiency potential (from EPRI) for each sector and year.

Consumer energy costs (savings) are treated differently depending on the final energy consumption category. Energy savings due to reductions in electricity consumption are expressed in the “Electricity Supply” categories since lower electric load results in reduced electric system costs within ReEDS. Scout also provides energy savings data for non-electric energy consumption by EMM region, but the categorization of energy conservation measures did not map cleanly to the technology cost categories from the EFS. Therefore, we disaggregated the Scout non-electric consumer energy cost savings to states according to each state’s share of total commercial and residential building non-electric energy consumption within each EMM region. This assumption that savings are evenly distributed across fuels and demand technologies for EMM regions does not reflect the effects of climate zones within an EMM region, which would likely influence the localized savings potential associated with heating and cooling demands.

# 5 Data Access

In addition to downloading the data as displayed in the SLOPE Scenario Planner, more detailed datasets that include energy consumption and $CO_2$ emissions by subsector and technology (e.g., electric space heaters, light-duty internal combustion engine vehicles) are available for download from SLOPE, along with supporting metadata (e.g., a county name-to-FIPS code mapping). For user reference, this document includes the names of ReEDS scenarios and end-use electrification scenarios as they appear in this more detailed dataset (see Appendix A and Appendix B).

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# Appendix A. ReEDS Scenarios

**Table A- 1. ReEDS Scenarios and the Three Settings That Map to Each Scenario Within the SLOPE Scenario Planner**

| Scenario Set | Electricity Supply Scenario | End-Use Electrification | Demand-side Flexibility | Building Energy Efficiency | ReEDS Scenario Name |
|---|---|---|---|---|---|
| REFERENCE | Reference Case | Reference | Reference | Reference | Mid_Case |
| SUPPLY-SIDE VARIATIONS (ONLY) | 95% grid decarbonization by 2035 | Reference | Reference | Reference | Mid_Case_95_by_2035 |
| | 95% grid decarbonization by 2050 | Reference | Reference | Reference | Mid_Case_95_by_2050 |
| | 95% grid decarbonization by 2035 with limited transmission expansion | Reference | Reference | Reference | High_Trans_95_by_2035 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | Reference | Reference | Reference | High_Trans_95_by_2050 |
| ELECTRIFICATION VARIATIONS (ONLY) | Reference Case | Medium | Reference | Reference | Medium_Electrification |
| | Reference Case | High | Reference | Reference | Electrification |
| | Reference Case | Medium | Enhanced | Reference | Medium_Electrification_EnhancedFlex |
| | Reference Case | High | Enhanced | Reference | Electrification_EnhancedFlex |
| BUILDING EFFICIENCY VARIATIONS (ONLY) | Reference Case | Reference | Reference | High | Efficiency |
| ELECTRIFICATION+ SUPPLY VARIATIONS | 95% grid decarbonization by 2035 | Medium | Reference | Reference | Medium_Electrification_95_by_2035 |
| | 95% grid decarbonization by 2035 | High | Reference | Reference | Electrification_95_by_2035 |
| | 95% grid decarbonization by 2050 | Medium | Reference | Reference | Medium_Electrification_95_by_2050 |
| | 95% grid decarbonization by 2050 | High | Reference | Reference | Electrification_95_by_2050 |
| | 95% grid decarbonization by 2035 | Medium | Enhanced | Reference | Medium_Electrification_EnhancedFlex_95_by_2035 |
| | 95% grid decarbonization by 2035 | High | Enhanced | Reference | Electrification_EnhancedFlex_95_by_2035 |
| | 95% grid decarbonization by 2050 | Medium | Enhanced | Reference | Medium_Electrification_EnhancedFlex_95_by_2050 |
| | 95% grid decarbonization by 2050 | High | Enhanced | Reference | Electrification_EnhancedFlex_95_by_2050 |
| | 95% grid decarbonization by 2035 with limited transmission expansion | Medium | Reference | Reference | Medium_Electrification_High_Trans_95_by_2035 |
| | 95% grid decarbonization by 2035 with limited transmission expansion | High | Reference | Reference | Electrification_High_Trans_95_by_2035 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | Medium | Reference | Reference | Medium_Electrification_High_Trans_95_by_2050 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | High | Reference | Reference | Electrification_High_Trans_95_by_2050 |
| | 95% grid decarbonization by 2035 with limited transmission expansion | Medium | Enhanced | Reference | Medium_Electrification_High_Trans_EnhancedFlex_95_by_2035 |
| | 95% grid decarbonization by 2035 with limited transmission expansion | High | Enhanced | Reference | Electrification_High_Trans_EnhancedFlex_95_by_2035 |

| | | | | | |
|---|---|---|---|---|---|
| | 95% grid decarbonization by 2050 with limited transmission expansion | Medium | Enhanced | Reference | Medium_Electrification_High_Trans_EnhancedFlex_95_by_2050 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | High | Enhanced | Reference | Electrification_High_Trans_EnhancedFlex_95_by_2050 |
| BUILDING EFFICIENCY+ SUPPLY VARIATIONS | 95% grid decarbonization by 2035 | Reference | Reference | High | Efficiency_95_by_2035 |
| | 95% grid decarbonization by 2050 | Reference | Reference | High | Efficiency_95_by_2050 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | Reference | Reference | High | Efficiency_High_Trans_95_by_2035 |
| | 95% grid decarbonization by 2050 with limited transmission expansion | Reference | Reference | High | Efficiency_High_Trans_95_by_2050 |

# Appendix B. Electrification Scenario Name Mapping

**Table B- 1. Mapping of Electrification Scenario Names as Seen by Scenario Planner Users to the Detailed Datasets Available for Download**

| Term Used in Scenario Planner | Term Used in Downloadable Datasets |
|---|---|
| Reference | REFERENCE ELECTRIFICATION - MODERATE TECHNOLOGY ADVANCEMENT |
| Medium | MEDIUM ELECTRIFICATION - MODERATE TECHNOLOGY ADVANCEMENT |
| High | HIGH ELECTRIFICATION - MODERATE TECHNOLOGY ADVANCEMENT |

# Appendix C. Transportation Disaggregation Proxies

**Table C- 1. Mapping of Transportation Subsectors to the Proxies Used for Disaggregating Energy Consumption From the State to County Level**

| Subsector | Proxy Dataset |
|---|---|
| MEDIUM DUTY TRUCKS | Diesel fuel consumption |
| HEAVY DUTY TRUCKS | Diesel fuel consumption |
| LIGHT DUTY AUTOS | TEMPO Vehicle Miles Traveled |
| LIGHT DUTY TRUCKS | TEMPO Vehicle Miles Traveled |
| TRANSIT BUSES | Diesel fuel consumption |
| SCHOOL AND INTERCITY BUSES | Diesel fuel consumption |
| PASSENGER RAIL | Excluded[21] |
| FREIGHT RAIL | Excluded |
| AVIATION | Excluded |
| DOMESTIC SHIPPING | Excluded |
| MOTORCYCLES | TEMPO Vehicle Miles Traveled |
| INTERNATIONAL SHIPPING | Excluded |
| RECREATIONAL BOATS | Excluded |

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[21] The subsectors with the value “Excluded” in this column are off-road transportation subsectors that were excluded from the data reported in the SLOPE Scenario Planner because no adequate proxy dataset could be identified for disaggregating these values to the county level.

### Table C- 2. Mapping of End-Use Transportation Technologies to Vehicle Categories Within the TEMPO VMT Dataset for Use in Spatial Disaggregation

All demand technologies shown here are subsets of the subcategories denoted as using the "TEMPO Vehicle Miles Traveled" dataset for disaggregation.

| Demand Technology | TEMPO Vehicle Category |
|---|---|
| REFERENCE GASOLINE LIGHT-DUTY AUTO | ICEV_Gasoline[22] |
| ELECTRIC LIGHT-DUTY AUTO - 200 MILE RANGE | BEV[23] |
| PHEV - 50 MILE RANGE - LIGHT DUTY AUTO | PHEV[24] |
| PHEV - 25 MILE RANGE - LIGHT DUTY AUTO | PHEV |
| CNG LIGHT-DUTY AUTO | BEV |
| PROPANE ICE LIGHT-DUTY AUTO | BEV |
| HYDROGEN FUEL-CELL LIGHT-DUTY AUTO | BEV |
| DIESEL - ELECTRIC HYBRID LIGHT-DUTY AUTO | HEV_Gasoline[25] |
| GASOLINE-ELECTRIC HYBRID LIGHT-DUTY AUTO | HEV_Gasoline |
| REFERENCE TDI LIGHT-DUTY AUTO | ICEV_Gasoline |
| ELECTRIC LIGHT-DUTY AUTO - 100 MILE RANGE | BEV |
| ELECTRIC LIGHT-DUTY AUTO - 300 MILE RANGE | BEV |
| REFERENCE GASOLINE LIGHT-DUTY TRUCK | ICEV_Gasoline |
| ELECTRIC LIGHT-DUTY TRUCK - 200 MILE RANGE | BEV |
| PHEV - GASOLINE - 50 MILE RANGE - LIGHT DUTY TRUCK | PHEV |
| PHEV - GASOLINE - 25 MILE RANGE - LIGHT DUTY TRUCK | PHEV |
| CNG LIGHT-DUTY TRUCK | BEV |
| PROPANE ICE LIGHT-DUTY TRUCK | BEV |
| HYDROGEN FUEL-CELL LIGHT-DUTY TRUCK | BEV |
| ELECTRIC - DIESEL HYBRID LIGHT-DUTY TRUCK | HEV_Gasoline |
| ELECTRIC - GASOLINE HYBRID LIGHT-DUTY TRUCK | HEV_Gasoline |
| REFERENCE TDI LIGHT-DUTY TRUCK | ICEV_Gasoline |
| ELECTRIC LIGHT-DUTY TRUCK - 100 MILE RANGE | BEV |
| ELECTRIC LIGHT-DUTY TRUCK - 300 MILE RANGE | BEV |
| N/A[26] | ICEV_Gasoline |

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[22] Internal combustion engine vehicle.
[23] Battery electric vehicle.
[24] Plug-in hybrid electric vehicle.
[25] Gasoline-powered hybrid electric vehicle.
[26] This represents the MOTORCYCLES subsector, which does not have any demand technology specified.

# Appendix D. On-Road Fuel Consumption Methodology

## Author: Dylan Hettinger

## Overview

The data for aggregate 2016 vehicle fuel consumption for cities and towns[27] were derived through an analytical process performed by NREL. This process estimated fuel consumption by integrating publicly and commercially available datasets at various spatial resolutions describing traffic intensity, vehicle fuel economy, and regional fuel consumption totals. Table D-1 below outlines the source and characteristics of datasets used by NREL. The analysis methods are described in more detail in the Methods section below.

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[27] Data are available at https://data.openei.org/submissions/149.

**Table D- 1. Data Sources Used for Estimation of Fuel Consumption**

| Dataset | Measures | Source | Vintage | Publicly Available |
|---|---|---|---|---|
| Highway Performance Monitoring System (HPMS) Public Release Shapefiles | VMT Rural/Urban Road Class (seven types) State | FHWA Highway Performance Monitoring System | 2016 | Yes |
| Highway Statistics Series VM-2: Vehicle-miles of travel, by functional system | Total Vehicle Miles Traveled Rural/Urban Road Class (Seven types) | FHWA Highway Statistics Series | 2016 | Yes |
| Highway Statistics Series VM-4: Distribution of Annual Vehicle Distance Traveled | Percent of VMT Rural/Urban Generalized Road Class (three types) Vehicle Type (six types) | FHWA Highway Statistics Series | 2016 | Yes |
| Vehicle Inventory and Use Survey Microdata | Vehicle type (two types) Fuel economy (mpg) | U.S. Census Bureau | 2002 | Yes |
| Highway Statistics Series VM-1: Vehicle miles of travel and related data, by highway category and vehicle type | Vehicle type (six types) Fuel economy (mpg) | FHWA Highway Statistics Series | 2016 | Yes |
| Polk Counts of Light Duty Vehicle Registrations | Vehicle type (6 types) Fuel economy (mpg) Fleet type (personal, dealer, etc.) | RL Polk & Company | 2016 | No |
| EPA Fuel Economy Estimates | Combined Highway and City Miles Per Gallon | U.S. Environmental Protection Agency | 2019 | Yes |
| USDOT 2009 National Household Travel Survey | Average Trip Distance (mi) Urban/Rural | USDOT Bureau of Transportation Statistics | 2009 | Yes |

| | | | | |
|---|---|---|---|---|
| Highway Statistics Series MF-21: Motor Fuel Use | Vehicle Fuel Consumption (gallons)<br>Fuel type (gas/diesel) | FHWA Highway Statistics Series | 2016 | Yes |

## Methods

The fundamental dataset supporting the SLED estimates of vehicle fuel is the Federal Highway Administration (FHWA) Highway Performance Monitoring System (HPMS) Shapefiles. These data provide a highly spatially resolved estimate of traffic intensity across the United States. Specifically, they include estimates of the total annual VMT mapped to individual, geolocated road segments. NREL combined these data with average vehicle fuel economies (miles per gallon, or mpg) for representative vehicles along each road segment to estimate the fuel consumption associated with the reported traffic, following Equation 1.

Equation 1:

$$Fuel\ Consumption = VMT * 1/MPG$$

To determine representative fuel economy for each road segment in the HPMS dataset, NREL integrated several ancillary datasets on traffic intensity and fuel economy. First, NREL used the FHWA Highway Statistics Series VM-2 and VM-4 datasets, respectively, to backfill missing VMT data for minor road classes and disaggregate VMT along road segments by vehicle type (e.g., passenger cars, light trucks, etc.). Next, NREL integrated a series of sources describing vehicle fuel economies and fuel types for different classes of vehicles, including Polk Light Duty Vehicles for passenger cars and light trucks, U.S. Census Bureau Vehicle Use and Inventory Survey (VIUS) for single-unit and combination trucks, and FHWA Highway Statistics Series VM-1 for buses. From the latter two datasets, NREL derived regional (state and national, respectively) estimates of average fuel economy and proportions of vehicles by fuel type (diesel and gasoline), which NREL then applied to all roads by region.

Using this combination of ancillary data, NREL produced a refined version of the HPMS road segments that included estimates of both VMT and average fuel economy, segmented by vehicle type and fuel type. NREL applied Equation 1 to these refined data to estimate the fuel consumption by vehicle and fuel type along each road segment, and then used linear rescaling to calibrate the estimates to sum exactly to the reported total state vehicle fuel consumption totals for diesel and gasoline (FHWA Highway Statistics Series MF-21). Finally, for the purposes of reporting in SLED, NREL summed total fuel consumption by fuel type to the aggregate level of cities and towns and counties.

This analysis drew heavily on the methodology developed by Gately et al. (2015) and shares several core datasets, assumptions, and methods; however, the work performed by NREL diverges in a few key areas. First, for reasons outlined in their work, Gately et al. (2015) calculated their results natively at the county level. As a result, subcounty (e.g., city or town) level results require additional methods and assumptions for spatial disaggregation. In contrast, because NREL's results are resolved down to individual road segments, they can be easily summarized at a variety of spatial resolutions. Secondly, whereas Gately et al. (2015) used national average fuel economies for all road segments, NREL's method used regionally and locally resolved estimates of fuel economies to capture greater spatial variation in the composition of vehicles. Finally, to calibrate fuel estimates along road segments to reported state totals, Gately et al. (2015) applied a sophisticated optimization routine that allowed for small adjustments in various measures. For this same goal, NREL simply linearly rescaled road segment fuel consumption totals to precisely match the state totals.

# Appendix E. Emissions Factors for Nonelectric Energy Consumption

**Table E- 1. Emissions Factors and Data Sources Used to Calculate $CO_2$ Emissions From Primary Energy Consumption**

| FINAL_ENERGY | Sector | Emission Factor (kgCO2/MMBTU) | Source |
|---|---|---|---|
| DIESEL FUEL | | 73.15 | EIA Emissions Factors |
| PIPELINE GAS | | 53.06 | EPA GHG Emissions Factor Hub |
| LPG FUEL | | 61.71 | EPA GHG Emissions Factor Hub |
| BIOMASS - WOOD | | 93.8 | EPA GHG Emissions Factor Hub |
| KEROSENE FUEL | | 75.2 | EPA GHG Emissions Factor Hub |
| GASOLINE FUEL | | 71.26 | EIA Emissions Factors |
| COMPRESSED PIPELINE GAS | | 53.06 | EPA GHG Emissions Factor Hub |
| SOLAR | | 0 | EPA GHG Emissions Factor Hub |
| LIQUEFIED PIPELINE GAS | | 62.28 | EIA Emissions Factors |
| LIQUID HYDROGEN | | 73.13 | Assumed all SMR. ReEDS assumes 9.83 kg CO2/kg H2 from DOE/NETL-2011/1434. HHV of 141.8 MJ/kg H2 from NREL 47302 |
| RESIDUAL FUEL OIL | | 78.8 | EIA Emissions Factors |
| COAL | commercial | 95.35 | EIA Emissions Factors: "Coal: Residential/Commercial" |
| COAL | residential | 95.35 | EIA Emissions Factors: "Coal: Residential/Commercial" |
| COAL | industrial | 93.98 | EIA Emissions Factors: "Coal: Other Industrial" |
| OTHER PETROLEUM | | 76.22 | EPA GHG Emissions Factor Hub: "Other Oil" |
| PETROLEUM COKE | | 102.41 | EPA GHG Emissions Factor Hub |
| STEAM | | 66.33 | EPA GHG Emissions Factor Hub |
| JET FUEL | | 70.88 | EIA Emissions Factors: "Jet Fuel (Jet A,JP-8)” |
| LUBRICANTS | | 74.27 | EPA GHG Emissions Factor Hub |
| MUNICIPAL SOLID WASTE | | 90.7 | EPA GHG Emissions Factor Hub |
| ASPHALT | | 75.36 | EPA GHG Emissions Factor Hub |
| PETROCHEMICAL FEEDSTOCKS | | 71.02 | EPA GHG Emissions Factor Hub |
| LPG FEEDSTOCKS | | 71.02 | EPA GHG Emissions Factor Hub: "Petrochemical Feedstocks" |
| NATURAL GAS FEEDSTOCKS | | 53.06 | EPA GHG Emissions Factor Hub: "Natural Gas" |
| COKING COAL | | 93.71 | EIA Emissions Factor Hub: "Industrial Coking" |

# Appendix F. Description of SLOPE Scenario Planner Planning Metrics

**Table F- 1. Description of all Planning Metrics, Their Calculation, and Where They Can Be Found in the Files Available for Download From the SLOPE Website**

| Topic | Buildings | Transportation | Grid Mix | Energy $CO_2$ Emissions | System Cost |
|---|---|---|---|---|---|
| **Metric** | Residential and commercial heating demand electrified | EV stock | Renewable energy penetration | Supply and demand emissions | Net system cost impact |
| **Units** | % | % | % of total generation supplied by renewable energy sources | % reduction from 2005 levels | % difference in total cost across state from reference scenario |
| **Text to User** | Share of Space Heating Services Supplied by Electricity (%) | Battery- and Plug-In-Electric Share of Light-Duty Vehicles (%) | Share of Electricity Provided by Renewable Energy (%) | Reduction in Energy-Related $CO_2$ Emissions from 2005 (%) | Statewide Net Change in System Cost from Reference Scenario (Billions 2020 $) |
| **Source** | EnergyPATHWAYS | EnergyPATHWAYS | ReEDS results | $CO_2$ emissions as described in Section 3 | System costs as described in Section 4 |
| **Scenario Column Refers To** | Electrification | Electrification | ReEDS Scenario | ReEDS Scenario | ReEDS Scenario |
| **File** | intuition_metrics_demandside.zip | intuition_metrics_demandside.zip | intuition_metrics_supplyside.zip | intuition_metrics_supplyside.zip | intuition_metrics_supplyside.zip |