

Overview Of The New Jersey

Energy Flow Model

Model Version 4.5

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Introduction

Many states are grappling with how the energy infrastructure can be made more sustainable for the long term, and what changes from the current business as usual trajectory are necessary to achieve those changes. Are some changes more impactful or achievable than others, and how should we prioritize different alternatives? How do we measure our progress, and quantify what is working and what isn't so that policies and programs can be refined?

To plan and track this transition, especially in such a large and complicated system as NJ's energy infrastructure, we need a model that describes the use and flow of energy within the state. This document describes a Energy Flow Model for NJ that quantifies where all of NJ's energy comes from, how it is used within different end-use segments, and all the connecting flows. This model provides a framework for quantifying the use of energy within the state at any point, based upon objectively available information.

This document provides a brief overview of the NJ Energy Flow Model, as implemented through a spreadsheet and associated visualization infographic (Version 4.5). Please refer to the infographic and spreadsheet for details referenced in this overview.

Objectives

The NJ Energy Flow Model was developed in support of the following objectives:

- Provide a quantitative framework for describing how energy flows in NJ at a given point in time, including identification of all primary sources, a granular view of all end-use consumption sectors, and computation of two primary impact factors: CO2 emissions and the fraction of total energy coming from fossil fuels. This is an idealized logical flow, not actual physical flows.
- Base the model on well substantiated and harmonized data sources, through a credible methodology that allows validation and legitimate comparison from year to year.
- Characterize energy sources and uses within the state, in a form that can be understood by a wide audience of policy actors, program managers, and market participants. This characterization helps to identify relative impacts of different market elements, and provides a context for setting goals and establishing priorities. Effective visualization is a key objective.
- Provide a framework for establishing source and end-use baselines, and for quantifying possible changes (or interventions) in the market over time. This framework can be used as a tool to identify possible market changes, to develop design parameters for potential policies, programs, and technologies, and to quantify impacts of proposed changes from the baseline. Potential programs (or Sustainable Jersey actions) can then be prioritized and "scored" in proportion to their impact. This same tool can also be used to track (and visualize) progress toward transformation goals.

- Approach the model in a way that aligns cause-and-effect relationships with change-opportunities (especially policy) within the state; i.e. try to identify those energy transactions for which various New Jersey actors *should* and could be responsible.
- Specifically focus on CO2 emissions in support of the Global Warming Response Act objectives. This implies a baseline year of 2006, and a 2050 goal of an 80% reduction of GHG (including CO2) relative to 2006. Given the tight coupling between CO2 emissions and fossil fuel use, also consider fossil fuel fraction (of total energy use, at the point of primary supply) as a key impact metric.

Sources

There is a lot of data available for energy, but it suffers from massive volume, inconsistent and often incomplete representations, varied methodologies, and challenges in determining sources. There is no single source of all the information needed at the scope required, and combining data from across different sources is hazardous. Fortunately, most of the data needed can be developed (with careful synthesis and harmonization) from three key sources: the federal DOE Energy Information Agency (EIA), the PJM public record, and information from the NJ Clean Energy Program (CEP).

- EIA: the EIA is a service provided by the federal DOE that documents a wide variety of energy related information for the nation. It is essentially the nation’s “census for energy”. Of particular importance for this model, the EIA publishes a detailed inventory of physical fuel use (and related metrics for other resources, such as nuclear) within the state, by year and end use segment. This is the foundation for most of the primary supply information within the model, along with the EIA developed “State Energy Profile” (SEP) for New Jersey. Note that EIA information typically does not reflect on-site (behind the meter) energy sources.
- PJM: the regional grid operator provides information about energy use within its jurisdiction. Since NJ is part of PJM, and imports significant power from that broader network, PJM information is used to more deeply characterize electricity generation, particularly regarding imported electricity and its sources.
- NJ CEP: NJ manages a registration process for all renewable energy systems built within the state, and this information can be used to quantify renewable energy sources, particularly regarding customer-sited (behind the meter) assets. In this area, NJ CEP data is used instead of EIA information, since it is more granular and accurate.

Detailed references to these three primary sources, along with citations of other miscellaneous information used in synthesis of the information, are embedded within the spreadsheet itself.

Methodology

The NJ Energy Flow Model is based on the following concepts:

- This is an ENERGY model that characterizes a) primary sources of energy, b) connecting flows from sources into end-use segments, and c) end-use consumption points. It is a bottoms up characterization of physical flows represented in an idealized map. This is not a market or econometric model, and does not consider factors related to power¹, pricing, peaking, or supply/demand directly. It is worth noting that key aspects of long term sustainability (CO2 emissions and fossil fuel fraction) are primarily functions of ENERGY supply and use, whereas other important factors (such as cost and reliability) are primarily a function of power. By design, given its focus on CO2 emissions and fossil fuel fraction, this model focuses on energy, while acknowledging the importance of related power factors.
- This is primarily a descriptive model that quantifies the NJ energy flow “as it is” for a given year based on historical data. That baseline can then be used “in reverse” to quantify potential changes (or interventions) against those baselines for hypothetical future years.
- The baseline version of the model is mostly “well organized data”, with little computational element other than what is needed to ensure unit-consistency and segment allocations. More computation is needed when working “in reverse” to quantify potential changes from baseline.
- The model is based on a Level One and Level Two scope, as defined by GHG protocol developed by the World Resources Institute and the World Business Council on Sustainable Development (<http://www.ghgprotocol.org>). This combined “Level One + Level Two” scope captures all direct energy use that is induced by consumption behaviors within NJ. This includes all on-site fuel consumption (mostly for heating of space and water), the energy and emissions related to electricity consumed within NJ (whether generated in-state, or imported from out of state), and all transportation that is originated within the state. Energy use and emissions for ships, trains, and planes are measured based on all fueling done for all departures.
- There is a significant choice to be made about how to account for energy use and emissions from trans-state consumption modes, especially planes and ships. As noted above, this captures energy use and emissions, in full, from all ships and planes that depart the state. Strong data sources are available for this approach, and if every jurisdiction were to use this methodology, the resulting global sum would be complete and accurate. This approach also makes sense physically since those vehicles are fueled within the state, their activity contributes to the state’s GDP, and it creates alignment between where the energy transaction is taking place and actions that might be taken by the state to influence behavior. Other approaches (such as doing “half and half” allocation between point of departure and point of termination, or assessing emissions based on “air

¹ In this document, “Power” is used in its technical engineering sense: the rate of flow of energy. Power is typically measured in units such as megawatts or Joules per second, whereas energy is typically measured in units like BTUs, Therms, or kilowatt*hours. In simple cases of constant power, Energy = Power X Time.

space traversed”) suffer from significant data sourcing and consistency issues (among other problems). Difference between models regarding methodology can result in significantly different results regarding CO2 emissions.

- This model distinguishes between electricity generated by the in-state power plant fleet, and electricity generated elsewhere in PJM and imported into the state. On a net annual basis, NJ is an importing state that consumes more electricity than it physically generates within its borders. This model therefore makes the simplifying assumption that all fuel consumed by the electricity generation sector is used to provide electricity for NJ consumption, which is then augmented by the import of additional electricity (typically at peak times) from PJM. This is probably NOT what happens physically, or within the flows of the wholesale market, but this is a useful simplification that leads to accountability alignment between NJ policies, programs, and behaviors and outcomes (consequences) for which NJ should rightfully be responsible.
- The model is based on a “Sankey Diagram”, which is an established method for describing flows in a wide range of applications. The DOE, particularly Lawrence Livermore Laboratory, has developed Sankey diagrams for national energy flows in selected years, and developed one specifically for NJ in 2008 (reference: <http://docs.wind-watch.org/USEnergyFlow2008-State.pdf>). The NJ Energy Flow Model differs from these LLL diagrams in a few important ways: a) this model can be developed for a variety of years, b) it is able to handle “cross-over affects” within the flow (such as CHP applications, or the use of electricity in transportation), and c) specifically allows for capture of on-site generation. In a Sankey diagram, energy is conserved (the outputs must sum to the inputs at any point), and the width of the flow connector is proportional to its magnitude. Color is used to show flows of different types. For more information about Sankey diagrams, see http://en.wikipedia.org/wiki/Sankey_diagram.
- Energy flow begins with a primary source, flows through a distribution system into end-use segments (sometimes with loss or transformation), is consumed in some useful way, and results in net emissions and wasted energy (as heat). The model quantifies energy at several different points in the flow:
 - **Primary Supply:** The term has common use within the industry and is used by DOE sources. It represents the “original source” of energy, and is as “far back” in the supply chain as it is possible to go in any practical sense. In most cases, primary supply represents a fuel that is harvested from finite resources (e.g. coal, fossil-fuel sources of petroleum), but also includes heat from a nuclear pile, and primary flows for renewable resources such as solar and wind. As a clarifying example, electricity and hydrogen are not primary supplies, since they each do not exist naturally (in useful form) and must be created from another primary supply resource. Primary energy is typically measured based on the energy content of the fuel, but other methods are required for non-fuel sources such as solar or wind, as detailed further below.

- **Delivered Energy:** the energy that is measured at the customer’s meter as it flows into an end use consumption scenario. This is typically the energy flow present at a natural gas or electricity meter on a building, or the fuel metered into vehicles when fueled. As with Primary Supply, the energy is quantified based on the energy content of the fuel, or equivalent method for non-fuel supplies. Note that in the case of raw fuels consumed at a site (such as natural gas), Primary Supply = Delivered Energy. In the case of electricity flow, the Primary Supply is the fuel (or equivalent) that feeds into the power plant, and the Delivered Energy is the electricity produced. In this case, the Delivered Energy is less (typically by two-thirds) than the Primary Supply based on generation efficiency (and related losses). Since Delivered Energy is at the point of on-site metering, it implicitly captures distribution losses where applicable (in either fuel or electricity).
 - **Consumed Energy:** the energy value of the end-use, such as the amount of light from a light bulb, the energy present in heated water, the physical motion of a vehicle, etc. This energy is almost always the useful work performed by an energy consuming machine, and will be less than the energy supplied based on the equipment efficiencies. Natural units for Consumed Energy are highly diverse, and reflect the nature of the work done such as lumen-hours (for lighting), pounds of dried clothes (for an appliance), or vehicle miles traveled (for a reference vehicle type, terrain profile, and drive pattern), but they can ultimately all be converted to a standard energy unit (such as BTUs). The current model does not consider Consumed Energy directly, although that represents a possible “second level” extension of the framework.
 - **Emissions:** the end-point for the flow, including both physical emissions (such as CO₂ or other GHGs or waste products (water, criteria pollutants), as well as waste heat.
- The model is based on primary sources feeding end-use segments, connected by flow-paths. Connection paths are assumed to be lossless and do not transform the energy, but they may distribute it from a single supply point into multiple consumption segments. Key consumption segments include electricity generation (including both in-state generated energy, and imported energy from PJM), on-site fuel use (broken into residential, commercial, and industrial sub-segments), and transportation (broken into five sub-segments by vehicle class or type).
 - Primary Supply is consistently measured in Billion BTUs (B-BTU), based on the lower heating value content of the fuel. Delivered Energy, particularly electricity, is converted to its equivalent BTU units for consistency. Representations of “Energy Use” are based on the sum of Primary Supply involved with the scope in question. Note that summations of Delivered Energy do not represent an accurate view of real energy consumption, since it does not include the full energy resource needed to produce electricity.

- The Primary Supply inventory includes all fuels (mostly fossil-fuel based) that are used for energy purposes, and specifically excludes similar products used as feed-stocks or ancillary purposes (lubricants, etc). There is some ambiguity in the source data about some fuel use, especially miscellaneous petroleum products and by-products within the industrial sector. These energy flows are significant, and different interpretations (i.e. assumptions) can result in significantly different outcomes. This model assumes that fuel identified in the EIA sources as “other petroleum”, “miscellaneous petroleum” and “petroleum coke” are used for energy purposes, but “still gas” is used as a feedstock. Better allocation of these Primary Supplies within the industrial sector (between energy and non-energy uses) is a opportunity for improvement of the model.
- In the case of electricity generation, the model accounts for fuel used by power plants (as Primary Supply) and the resulting electricity generated and delivered through retail channels (Delivered Energy). Separate data is available for each set of numbers. In the case of renewable sources such as solar, data is only available to estimate the Delivered Energy (i.e. electricity produced). Primary Supply for these resources is based on assuming a conversion efficiency for an equivalent fossil fuel generation plant, and dividing generated-electricity by that factor to assess an equivalent Primary Supply number for those resources. The resulting Primary Supply number has no basis in physical reality, but is used for planning and analysis purposes. This is the methodology used by DOE on similar Sankey diagrams, and is useful because it puts renewable and non-renewable resources on a similar (apples-to-apples) comparison basis at the point of Primary Supply. In the case of nuclear energy, Primary Supply is estimated based on the amount of heat generated by the nuclear pile, and the resulting electricity (minus distribution losses) is the Delivered Energy.
- As noted in more detail below, the model structure accounts for electricity generated on-site, represented as an on-site consumption of Delivered Energy (fuel) that results in either just electricity, or electricity and heat . Although the structure is in place, it is not fully quantified due to a lack of on-site generation information. Reasonable information is available for the industrial use of on-site generation (as detailed below), but similar information is not available for the residential or commercial segments. This is a significant area for improvement of the model. Note that this omission does not harm emissions or overall energy use characterization, since that is based on Primary Energy consumption which is known regardless of whether it is used in on-site generation or another use.
- The model also accounts for on-site distributed (behind the meter) solar generation. Total electricity consumption is therefore captured as a combination of utility supplied energy (both in-state generated and imported), on-site fueled generation (such as CHP), and distributed solar. Small on-site wind is not represented since it is currently too small to measure, and unlikely to grow given lack of terrestrial resource for small wind in NJ. Other distributed sources of electricity could be added in the future if needed. Note that

the model distinguishes between grid-connected solar (or wind) delivered through the utility infrastructure, and distributed solar generated behind the meter. This is a significant difference between this model and other characterizations of the NJ energy market, and is appropriate given the significant growth of distributed generation assets now and in the future. Note that most characterization of electricity in NJ under-represents actual use since they typically do not account for on-site generation or distributed solar.

- The model also accounts for the (hopefully growing) use of electric vehicles of all types. Significant care is needed, however, to avoid double-counting of electricity used for vehicle fueling. This is handled in the model by dedicated connectors for each segment (direct utility supplied generation in the case trains, residential charging of private commuter vehicles, commercial charging (charging of private commuter vehicles at work or via public infrastructure, and on-site charging of electric fleet vehicles), and industrial charging (both at-work charging of employee vehicles, and on-site charging of fleet vehicles). The electricity (and associated emissions) are counted ONCE as part of electricity generation, but are not counted as a separate consumption segment to avoid double-counting.
- Emission calculations are focused on converting the amount of a given fuel used in a particular end-use segment into its related emission based on standard CO₂/BTU factors as provided by the DOE (sources are embedded within the spreadsheet). Note that emissions for non-fossil fuels such as wood, waste, and bio-fuels (ethanol) are calculated based on their physical CO₂ emissions without adjustment. Further research is needed to develop a methodology for properly assessing CO₂ impacts to non-fossil fuels, depending on the extent to which carbon is really being recycled within the lifecycle. Pending more refined methodology, this model calculates CO₂ emissions for those fuels just like any other combustion fuel, without adjustment or offset. Decisions about this methodology could have a large impact on the CO₂ inventory, particularly as bio-fuel use grows in the future.
- The model calculates a “Fossil Fuel Fraction”, representing the fraction of total energy (in BTUs, across all consumption sectors) that comes from fossil fuel resources. The following resources are counted as fossil fuels: coal, mined natural gas, kerosene, LP (or LPG), and all mined petroleum fuels (motor gasoline, aviation gasoline, jet fuel, road/vehicle diesel, marine diesel, fuel oil (for building use), petroleum coke, still gas, and related supplemental gases). The following are counted as non-fossil fuels: solar in any configuration, wind in any configuration, large hydro, liquid bio-fuels (mostly ethanol currently, but could include bio-sources of methane and/or bio-diesel), wood (used either centrally or distributed), waste (including municipal solid waste, and landfill gas, and on-site use of process waste by industry), and geothermal.
- Every quantified point in the model is represented by a data code, and working familiarity with the data-code system is essential to understanding the model. The code is

based in the following form: X-Y-ZZ, where X represents the flow point at which the measurement is being made, Y represents the end-use segment, and ZZ is the energy type, typically a fuel or similar energy resource. Code nomenclature is as follows:

- Flow Point (X):
 - P = Primary Supply
 - D = Delivered Energy
 - C = Consumed Energy (not used in the current model)
- End Use Segment (Y):
 - E = electricity generation segment
 - R = residential segment, including on-site fuel use and end-point electricity use
 - C = commercial segment, including on-site fuel use and end-point electricity use
 - I = industrial segment, including on-site fuel use and end-point electricity use
 - L = light-duty vehicle segment of transportation, including passenger cars, motorcycles, pick-up trucks, mini-vans, and SUVs.
 - H = heavy duty segment of transportation (primarily on-road use), including buses, short haul vehicles (delivery vans), long haul vehicles (tractor trailers), other on-road heavy equipment (such as snow plows and garbage trucks), and miscellaneous off-road equipment (military, construction, agriculture)),
 - T = trains segment of transportation, including both commuter and freight, both intra-state and inter-state, based on departures from NJ.
 - S = ship segment of transportation (primarily commercial), including all passenger and freight departures from NJ.
 - P= plane segment of transportation (primarily commercial), including all passenger and freight departures from NJ.
 - V=All transport modes within the transportation sector in aggregate.
 - A=All use of the noted type and flow-point.
- Energy Type (ZZ):
 - GS = Grid Solar
 - GW = Grid Wind
 - LG = Large Hydro
 - CW = Central wood or waste (for electricity generation), including land-fill gas, municipal solid waste consumed as fuel, and bio-mass consumed as fuel.
 - NU = Nuclear

- FO = Fuel Oil, as consumed in stationary applications, typically for on-site heating of space and water. Note that “Fuel Oil” is physically identical to distillate diesel, but is named, distributed, and taxed differently.
- CL = Coal, of all types
- NG = Natural Gas, mostly methane, but including supplemental gases as is typical in utility distribution supplies.
- BF = liquefied Bio-Fuel, primarily ethanol at the current time. Currently used primarily in the transportation sector, but ultimately could also be used for on-site heating applications (in either methane or diesel forms).
- LP = Liquid Propane (or Liquefied Petroleum Gas), typically distributed via trucks for on-site applications in heating.
- KE = Kerosene, used for stationary on-site heating applications.
- MG = Motor Gasoline, as used in most passenger vehicles
- VD = Vehicle Diesel, the distillate diesel used for transportation (as distinct commercially from Fuel Oil)
- MD = Marine Diesel, which is a residual form of diesel, also known as “bunker fuel”. Used almost exclusively for ships.
- JF = Jet Fuel, a highly refined form of kerosene used exclusively in jets.
- AG = a specialized form of gasoline that is used in planes (typically smaller aircraft), which is physically very similar to premium grade motor gasoline (for cars) but which is named, distributed, and taxed separately.
- MP = Miscellaneous Petroleum, including various petroleum products in liquid and gas form, as well as high-carbon by-products from various industrial processes. This category includes a diverse range of fuels, including (as named by EIA) “miscellaneous petroleum”, “other petroleum”, petroleum coke, and still gas (when used for energy purposes). Chemically these products could include less common forms (butane, pentane, etc), but are typically similar to either diesel-mixes or natural gas-mixes.
- DW = distributed sources and uses of wood and waste products for energy purposes, primarily the use of “wood pellets” for space heating and internal reuse of waste for energy purposes by industry.
- DT = distributed geothermal, including both air-source and ground-source heat pumps, primarily in residential applications for space heating. Note that this primary supply is distinct from centralized geo-thermal wells used for electricity generation, which are not used in NJ.
- DS = distributed solar generation, primarily photovoltaics behind the customer’s meter for electricity generation. In theory, this category could include solar water heating applications, but currently that segment is very

small and there is no data available. For this model, all DS is assumed to be electricity generation.

➤ Examples:

- P-E-NG: energy value of Primary Supply (i.e. input fuel) associated with electricity generation based on natural gas.
- D-E-CL: energy value of Delivered Energy, as electricity (converted to BTUs) from coal fuel sources. Note that D-E-CL/P-E-CL is the overall efficiency of coal-based electricity generation.
- D-R-NG: the energy value of Delivered Energy (as measured at the building's meter), used on-site in residential sector, based on Natural Gas.
- D-L-MG: the energy value of Delivered Energy in the light-duty sector of transportation based on Motor Gasoline (i.e., gas in cars).
- E-H-VD: the CO2 emissions from use of Vehicle Diesel in Heavy Duty vehicles.

Spreadsheet Walkthrough

Please refer to the spreadsheet and associated infographic as cited in the following walk-through. This description is based on version 4.5.

Model Output Visualization: The Infographic And Related Summary Charts

The best way to understand the overall model is to look at the infographic that is the primary visual output from the spreadsheet. This visualization represents the majority of energy flows within the state on a single page, using a consistent set of energy metrics (Billion BTUs of energy, and Million Metric Tons of CO2). Very small flow-streams are not shown for clarity, but are included in the energy totals and emission inventories. The infographic has been developed in Powerpoint, and the file is named to refer to the year represented, and the version number of the model. Every infographic file is tied to a similarly named spreadsheet (by year and version number).

The infographic is broken out into several key sections: on the left, all centralized Primary Supply sources (primarily fossil fuels), in the middle are five primary consumption segments (electricity, residential, commercial, industrial, and transportation), and on the right are resulting emissions, including a representation of the fraction of total energy (measured at the point of Primary Supply) that come from fossil fuel sources, and an inventory of CO2 emissions (in MMT) by end-use and fuel-type segment. In between these elements are flow connectors, whose color represents the primary energy type, and whose width (approximately) represents magnitude of the flow. Note that the connector width is only suggestive and not to actual scale, since there is such a large range involved and the smaller flow (if represented accurately) would be invisible. Waste energy flows are easily calculated, but not shown in the infographic for clarity. All the numbers represent either Primary or Delivered Energy, as quantified in consistent B-BTU units.

Note that within the electricity segment, the numbers on the left represent the Primary Supply (by fuel type), and the numbers on the right represent the amount of generated electricity (in B-BTUs). The ratio of these two is overall generation efficiency, minus distribution losses. These generation flows (by fuel type) are summed to represent the in-state generation supply, which is combined with imports from PJM to provide the total “utility power” supplied within the state². This electricity flow is shown by distribution connectors to end-use segments (residential, commercial, industrial, and transportation (primarily trains)). Utility power is combined with on-site generation and electricity from distributed solar for use on-site by electric equipment. Typical building applications for electricity include lighting, climate control (both ventilation and cooling, and in some cases heating), electric appliances (clothes washers, etc), electronics (TVs, computers, chargeable devices, etc), and domestic water heating. A dotted line is shown from each of the major use segments into transportation to account for charging of electric vehicles within each domain.

In parallel with this electricity flow, raw fuels flow from primary sources into the on-site use segments (residential, commercial, industrial) and transportation. The dotted box at the left is a “black box” representation of the fuel distribution system by which fuels move from source to end-use consumption. This connecting fabric is extremely complicated, but that detail is not relevant to overall consumption and flow patterns, and is therefore represented by a simplified “black box” that shows net distribution to end-use segments by fuel type. Some fraction of this fuel is used for on-site generation (the resulting electricity of which is combined with utility power), and the rest is used for typical fueled applications such as space heating, water heating, cooking, some appliances (like clothes dryers), and non-feedstock uses in industrial processes (mostly heating related).

Within the overall transportation segment at the bottom, fuel use is broken out into five different vehicle types. Note that some vehicles types can be energized through either fuel or electricity (or both), as represented by the yellow arrows on the right. The electricity associated with this fueling is counted (once) within the segment within which the charging takes place (residential, etc), but is shown as entering the transportation segment for completeness.

The number in the title at the top of the infographic represents the total energy used, as induced by NJ consumption behaviors, and as measured at the point of Primary Supply. The “Activity Factors” at the bottom right summarize key factors for the given year that could influence energy use, including population, GDP (in 2005-\$), weather (as represented in Fahrenheit Heating Degree Days (HDD) or Cooling Degree Days (CDD)), and Vehicle Miles Traveled (VMT).

² It is unclear within the EIA data exactly how on-site generation (especially when sold to a separate off-taker or to the wholesale market), or Municipal Utility Authorities are represented. At the current time, pending further clarity, fuel consumption for those activities are assumed to be captured either as part of commercial or industrial fuel consumption, or as a consumption segment within wholesale power. That electricity use may therefore be under-represented at the point of consumption, but is accounted for at the Primary Supply and Emissions level.

These are the factors that should be used when considering “intensity” parameters for the state (e.g.. energy use per capita, or per GDP-dollar).

The pie charts after the infographic on the first page provide a high level characterization of energy use within the state for the given year. The first set of pie charts show total energy use (at the point of Primary Supply) for the key three segments, and resulting CO2 emissions for the same segments. Note that the percentage distributions are different between energy use and CO2 emissions, depending on how dirty (pounds of CO2 per BTU) the relevant fuels are. The next two pages provide detailed breakdowns by end-use segment and fuel type for both total energy use and CO2 emissions. The “2050” goals reference in these charts are the 80% reduction goals specified in the Global Warming Response Act.

The final page shows a “Top 10” inventory of the primary end-use/fuel-type segments, grouped in ways that reflect market structures, and ranked by CO2 emissions. Being able to identify, and quantify in a granular way, these use-modes is a primary output from the model. These “top 10” use-modes represent over 90% of NJ’s CO2 emissions (in 2006), and it is in these areas that changes need to be made (from the business as usual trajectory) to achieve the desired CO2 emission and fossil fuel fraction reductions by 2050. With these use-modes in-hand, policies and programs could be considered as interventions, design parameters can be identified (i.e. how much solar do we need), and impacts at various stages of adoption can be quantified.

It is worth noting that this infographic clarifies the types of changes that impact our primary indicators. There are only three types of changes that make a difference: a) reductions in end use energy needed (consumed energy) due to conservation behaviors, b) reductions in end-use energy needed due to equipment or building efficiency improvements (assuming constant end-use utility), including improvements in generation or distribution efficiency, and c) fuel switching. An example of these three different “intervention mode”: both primary supply, and resulting CO2 emissions, can be reduced by a) changing behavior (or installing automation) to turn the lights off when leaving a room (conservation), b) use an LED lightbulb, rather than an incandescent one (with no increase in run-hours, efficiency), and c) supplying the needed electricity from solar, rather than a coal plant (fuel switching).

The Spreadsheet

The infographic provides an effective visualization of the data within the detailed spreadsheet model. As noted previously, this “model” is mostly “well organized” data that has been synthesized from various sources, and massaged to be both consistent and complete. There is little computational element, other than what is needed to provide unit conversions or segment distributions. The spreadsheet is implemented in Excel, and named by year and version number. Please refer to the spreadsheet for more detail.

The spreadsheet is organized into several tabs:

- **Model Inputs And Calculations:** This is the primary input form for the model, and captures data from a variety of sources in a form that is consistent of for use within the model. As noted in the “sources” section, most of the data on this tab comes from DOE-EIA, PJM, or NJ CEP sources, with detailed references embedded in the spreadsheet itself.
- **Model Outputs:** This tab draws from the input data, and restructures it as needed for display by the infographic. The key numbers are identified by data-code, and it is structured to be similar to layout of the infographic itself. Emission calculations are performed on this tab.
- **EIA Data:** Given its key role in providing all the physical fuel supply data, the EIA data used for the model is provided on this tab. This information comes from the EIA’s State Energy Profile (SEP) for NJ for the year noted.
- **Other Data:** Most of the other non-EIA sources are collected on this tab for convenience, including information used from PJM (regarding imported power) and the NJ CEP (regarding solar generation).
- **Summary Charts:** The data from the outputs-page is summarized via a set of tables and pie and bar charts. These visualizations are used in the Powerpoint summary charts. For the most part (except for the pie charts), they update automatically whenever source data is changed.
- **Top 10:** This tab captures the “top 10” CO2 emission segments, and relevant statistics about each. The energy and emission totals reference data on the input, output, and summary pages.
- **Notes:** Miscellaneous notes about the spreadsheet, particularly a summary of datacodes.

Models Inputs and Calculations: This tab is the heart of the model, and is the foundation upon which all other calculations and results are based. Most entries are color coded, with yellow representing a hard input parameter taken from an outside source (as cited), purple representing an input parameter that is inferred from intermediate calculation (and ultimately traceable back to an outside source), and green being a calculated output parameter from the model. It is organized vertically into three main sections (on-site fuel use, electricity generation, and transportation), and horizontally with primary supply on the left, flowing into delivered energy on the right. Most numbers are in Billions of BTUs (B-BTUs).

The “On-Site Fuel Use By Sector” section captures all data related to use of raw fuel at an end-use consumption point. Each row represents fuel use by a given segment (residential, commercial, or industrial) by fuel type. Column B is the physical volume of the Primary Energy consumed state-wide (barrels, or short-tons, etc). This is a primary data point, mostly taken from EIA data. Each EIA datapoint is identified by a code, as shown in column G. This code ties each data point used by the model back to the specific source data provided by EIA (and as reproduced for convenience on the EIA data tab). These physical units are converted to energy using factors noted in column D (with sources as noted in the cell comment), resulting in the

energy content of that fuel (in B-BTUs) in column E³. These numbers represent the Primary Supply for all on-site fuel use in each segment. Note that in some cases physical supply values are not known (or relevant), in which case energy values are provided directly from EIA sources (without calculation). There is a special calculation (starting on cell I40) regarding the fraction of on-site fuel used for electricity generation by either a dedicated generator or CHP, within the industrial sector, and the fraction of that energy that is converted to electricity. This data comes from a detailed on-site energy use profile for the industrial (primarily manufacturing) sector, as developed by DOE-EIA. This data is summarized in source form on the “Other Data” tab. Note that the EIA data is a national profile, and the associated percentages are assumed to be applicable to NJ industry, but as applied to known NJ industry fuel use. Specific EIA data is available for 2006 and used in the 2006 model, but the 2012 version is based on the EIA 2010 profile (the last year for which data is available). New industry profile data (MECs) is expected this year for 2013, at which point a more accurate extrapolation (to 2012) should be possible. The assumption that national profiles apply to NJ is risky, so better data about on-site generation in the industrial (and other sectors) would be an improvement to the model.

The second section deals with electricity generation, breaking out in-state generation, imports from PJM, and solar generation (both distributed behind-the-meter capacity and centralized grid-supply). The centralized generation section follows the same structure as used for on-site fuel supply, and takes physical supply data (by energy type), and converts it to energy units to represent Primary Supply. In column K, retail sales of electricity (by fuel type) are shown, taken from a separate EIA or PJM source (as cited in the spreadsheet). This total (in cell K68) represents the amount of electricity distributed through retail channels that is generated in the state. The following sections drill down on calculations related to PJM supply and associated electricity import into NJ, solar generation within the state (from CEP solar project installation summaries, as noted on the “Other Data” tab), a summary of electricity-related data as used on the info-graphic, and the distribution of utility supplied power across various segments (based on EIA sources). The PJM calculation determines the fuel-mix for “PJM Imports” by taking the overall PJM fuel mix, backing out the known NJ component (from the section above), and computing the “PJM-without-NJ” fuel mix. This is the basis for PJM emission calculations. Note that the “Primary Supply” value for the PJM import is inferred from the known MHW delivery of electricity by dividing by an assumed average PJM-fleet efficiency (of 30%). The solar calculations are an ESTIMATE of solar production based on installed capacity as follows: 1.2 X (KW installed at the beginning of the year + 0.6 X KW installed throughout the year). 1.2 represents the typical production factor averaged across all NJ solar systems based on historical

³ The model was originally developed based on physical consumption units, which are then converted to energy. This was done since it was believed that it would provide a more accurate basis for eventual emissions calculations, and since in some cases physical units are needed (when exploring alternative supply scenarios, for example). In hindsight, however, it is possible to use EIA data to capture Primary Supply in energy units, and skip the physical-to-energy conversion entirely. This simplification would make sense especially since EIA numbers are being used to compute the physical-to-energy conversion factors anyway.

industry data (Mwhrs/KW), and the distribution in parenthesis accounts for full-year production by systems installed as of the beginning of the year, and partial-year generation for systems installed during the year (based on typical install rates and solar insolation values seasonally). Note that there is no reliable data source for actual solar production since it is not metered directly or sold through reported retail channels⁴.

The next section in the spreadsheet focuses on Transportation, and like the preceding sections, translates physical consumption into Primary Supply energy. Note that this EIA data is aggregate for the state, and not broken out by vehicle class, so an additional step is needed to map the Primary Supply into end-use vehicle class. This data is tabulated in a special calculation starting on I113, based on federal DOT data. This is national data, but for the required year. To translate this to NJ fuel use, distribution percentages (of each fuel by vehicle class) are calculated based on the national data, then applied to the known NJ fuel-use profile. More direct fuel-use by vehicle class data may be available specifically for NJ, which is obtainable, would avoid the need for this estimate calculation. The final data starts in row 126, and summarizes fuel use (by type), in energy units, by vehicle class (mapped to the five aggregated segments used by the model).

The final section summarizes “Activity Factors” for the year noted, mostly pulled from the Rutgers University NJ GHG Inventory (released in 2015), and in some cases with confirming references from other sources.

Other Tabs: The “Model Outputs” tab pulls data from the first tab and organizes it based on the structure needed by the infographic. A summary table is also provided to assist with representation of summary statistics and calculation of the fossil-fuel fraction. The final emission calculations are performed on this tab, based on simple multiplication of each Primary Supply (by end-use segment and fuel-type) by a cited CO₂/BTU parameter. The basic calculation represents physical CO₂ emissions for combustion of the noted fuel without adjustment. The “discount factor” in Column “L” provides a mechanism for adjusting that calculation in cases where pure physical combustion does not provide a complete view. For example, in the case of bio-fuels, analysis of full lifecycle may indicate that a given bio-fuel has only 60% of the CO₂ impact of pure fuel combustion, based on recycling of CO₂ through plant growth. In that case, a discount factor (of 60%) could be applied to reflect that more accurate impact. In another example, the emissions from the physical combustion of Natural Gas may not sufficiently capture the GHG impact, since increased Natural Gas use typically results in increased rogue emissions of methane during extraction and distribution. In that case, a discount factor greater than one could be applied to better reflect full impact of that fuel’s use. For this version of the

⁴ Some researchers use SREC certificate count to estimate production, but this can be highly erroneous due to a) the fact that some systems don’t sell their SRECs, b) there are significant timing shifts between when an SREC is generated and when it is sold, and c) this “time shift” factor has become more severe as the number of “banked SRECs”, and aggregated contracts (especially through the utilities) has increased in recent years.

model, all discount factors are set at 1.0, but the structure is in place to allow more nuanced calculations as future methodology refinements might require.

The “EIA data” and “Other Data” tabs reproduce the raw sources of information used on the input tab, with embedded references in the spreadsheet. The “Summary Charts” and “Top 10” provide summary versions of the model outputs as described above. There are no new data incorporated, or calculations made, other than as needed to create the charts, on these tabs.

Cross-Check

The results of this bottoms-up model have been compared with independent calculations of similar scope. The results of this model are within reasonable deviations from other similar calculations.

- The 2006 version of the model was compared with the Rutgers GHG inventory, as issued in 2015 covering calendar year 2006. A subset of the Rutgers data was selected to represent the energy-related, CO₂-only emissions, consistent with the scope of this model. This model estimates 146.346 MMT of energy-related CO₂-only emissions, compared with 123.9 MMT in the Rutgers model. However, there is a key difference in methodology between the two studies: the Rutgers model arbitrarily sets CO₂ emissions for Planes (Jet Fuel) to 1.0 MMT, and for ships to 0.8 MMT, whereas this model computes emissions based on actual fuel consumption documented by EIA for those transport modes in NJ. After adjusting this model to use the arbitrary Rutgers CO₂ allocation for ships and planes (rather than actual fuel consumption), this model estimates CO₂ emissions as 125.6 MMT for 2006. In that methodology-adjusted case, this model and the Rutgers GHG inventory (at 123.9 MMT) are within 1.3% of each other. Given the large number of data points, room for ambiguity in interpretation, and sensitivity to key assumptions, this is considered a highly confirming correlation.
- The DOE (via Lawrence Livermore Labs) did a Sankey diagram specifically for NJ in 2008. It did not consider some of the more granular factors used in this model, but nonetheless provides a good cross check for overall model results. A gross comparison of the DOE model for 2008, with an extrapolation of this model (when adjusted for structure) for that year, yields very similar results. This provides confirmation that the basic structure is accurate and complete, and that the EIA data is being utilized with proper interpretation. Further validation of this type can be provided when this model is completed for 2008, based on EIA 2008 data.
- The 2012 version of this model was also compared with the 2012 GHG inventory developed by Rutgers. As noted for 2006, there is a significant methodology difference related to emissions for Planes and Ships. Even after adjusting for that difference in methodology, this model estimate slightly higher CO₂ emissions than those projected in the Rutgers report. Most of this difference appears to be in fossil fuel use within the industrial sector: the Rutgers inventory shows a huge drop in that emissions profile

between 2006 and 2012, and this model shows a significant drop, but of much smaller magnitude. Further comparison of the results from this model versus the Rutgers GHG inventory would be worthwhile.