Hawai‘i Statewide Energy Flowchart

Documentation, Methodologies, and Data Sources

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Prepared by:

Hawaiʻi State Energy Office
235 South Beretania St.
Honolulu, HI 96813

Questions?

W. Scott Marshall
warren.s.marshall@hawaii.gov

Notice

The data reflected in the initial February 2025 publication of the Hawaiʻi Statewide Energy Flowchart is representative of only 2022.

The primary data source that comprises the visual representation of the flowchart is the State Energy Data System (SEDS) which is managed by the United States Energy Information Administration (EIA). Upon the flowchart's February 2025 publication date, the most recent finalized data provided by SEDS is reflective of 2022. While there is SEDS data available on the EIA's Open Data Browser[1] that is reflective of 2023, the 2023 data cannot be scraped using EIA's API since the 2023 data is not yet finalized. Thus, the most recent SEDS data that was used for this project is that of 2022.

Once SEDS data for 2023 is finalized (expected in March-April 2025), the flowchart will be updated to reflect 2023.

This distinction between 2022 and 2023 is notable since the last coal-fired electric generation plant ceased operations in September 2022. Thus, coal-fired electric generation is present in 2022, but not in 2023.

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[1] See EIA Open Data PI Browser (https://www.eia.gov/opendata/browser/seds)

Acknowledgments

The Hawaiʻi State Energy Office's (HSEO) Statewide Energy Flowchart was developed and published under the leadership of Chief Energy Officer Mark B. Glick and Deputy Energy Officer Stephen C. Walls.

Original ideation for the project is thanks to Chris Yunker, HSEO's Managing Director of the Resilience, Clean Transportation, and Analytics Branch.

The flowchart project was led by W. Scott Marshall who began the project as a Data Science Fellow in partnership with the University of Hawaiʻi at Mānoa and concluded the project as the Energy Analytics Specialist at HSEO.

Thanks to Troy Wooton (former Data Science Specialist at HSEO) who provided the initial iterations of the flowchart project. Troy's work in the initial stages of the project was instrumental in the project's ultimate delivery.

Expertise provided by Monique Schafer, HSEO's Decarbonization Program Manager, was critical for accounting for the numerous intricacies and nuances that are present in Hawaiʻi's energy system.

Special thanks to Fahim Yasir (Data Science Fellow from the University of Hawaiʻi at Mānoa) for his data cleaning contributions to the project, Ron Chatterjee (Energy Efficiency Specialist) for his expertise regarding end use energy efficiency calculations, and Yvonne Hunter (Strategy and Marketing Officer) and Alyssa Taylor (Energy Climate Communication Associate) for their aid in constructing the flowchart's web page and communications strategy.

Thank you to the internal review team of Kevin Moy (Energy Resiliency Project Specialist), Justin Lolofie (Data Science Program Manager), Munashe Silverberg (Energy Analyst), and those previously mentioned.

The original flowcharts that this project was inspired by were constructed by Kimberly Kanani Mayfield and her team at Lawrence Livermore National Laboratory. Thank you to Kimberly for being a trusted advisor for this project.

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Abbreviations and Acronyms

API	Application Programming Interface
CFL	Compact Fluorescent Lamps
CO2	Carbon Dioxide
DBEDT	Hawai‘i Department of Business, Economic Development, and Tourism
DFO	Distillate Fuel Oil
DOT	U.S. Department of Transportation
EDA	Electricity Delivered Approach
eGRID	Emissions & Generation Resource Integrated Database
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FHWA	Federal Highway Administration
GEA	Generation Efficiency Approach
HGL	Hydrocarbon Gas Liquids
HHV	High Heating Value
HI	Hawai‘i
HID	High-Intensity Discharge
HNL	Daniel K. Inouye International Airport
HRS	Hawai‘i Revised Statutes
HSEO	Hawai‘i State Energy Office
ICE	Internal Combustion Engine

KIUC	Kauai Island Utility Cooperative
LED	Light-Emitting Diode
LLNL	Lawrence Livermore National Laboratory
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
MMBtu	One million British thermal units
MSW	Municipal Solid Waste
MW	Megawatt
MWh	Megawatt Hours
NAICS	North American Industry Classification System
PGV	Puna Geothermal Venture
PUC	Hawai‘i Public Utilities Commission
PV	Photovoltaic
RFO	Residual Fuel Oil
RNG	Renewable Natural Gas
RPS	Renewable Portfolio Standard
SEDS	State Energy Data System
SNG	Synthetic Natural Gas

Project Overview

The Hawaiʻi State Energy Office (HSEO) provides analysis to develop and inform policies to achieve statewide energy and decarbonization statutes. Promoting energy efficiency, renewable energy, and clean transportation are some of the engagements HSEO pursues to help guide the state toward its economy-wide net-negative emissions goal and its 100% renewable electric generation goal—both set for 2045.

The current state of the Hawaiʻi energy system must be understood to successfully deliver on the state's energy goals. In that spirit, HSEO is publishing the Hawaiʻi Statewide Energy Flowchart (to be referred to as "the flowchart").

Inspired by the energy flowcharts published by Lawrence Livermore National Laboratory (LLNL),[2] HSEO constructed an interactive data visualization to represent statewide energy flows. The flowcharts use publicly accessible data from federal and state government agencies, and when needed from private industry. Users can view how energy is used to power the statewide economy utilizing the flowchart's various filters.

The interactive visualization, technical documentation, descriptions of methodologies, frequently asked questions, and notices of future updates are available on HSEO's website.

The data that comprises the flowchart is published on an annual basis; therefore, future updates will occur annually.

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[2] See Lawrence Livermore National Laboratory's Energy Flowcharts landing page (https://flowcharts.llnl.gov/)

Section 1 Data Sources

Sections 1.1 through 1.5 list and describe all data sources used for the flowchart and associated underlying assumptions. To view all information related to data sources used for the flowchart in a single table, refer to Table 2 in section 4.1.

1.1 U.S. Energy Information Administration (EIA)

1.1.1 State Energy Data System (SEDS)

The State Energy Data System (SEDS) aggregates current and historical energy statistics and updates are published annually by the EIA. SEDS was the foundational data set used to construct the flowchart.[3] Various changes were applied manually in the data cleaning process (see section 4.3), but SEDS data is predominantly responsible for the visual representation of the flowchart. The EIA publishes updates to the SEDS database annually, with a lag of 1-2 years.

A notable change occurred in the published SEDS data representative of 2022 relative to prior years. SEDS data representative of years 2022 and beyond instituted a methodology change for how noncombustible renewable energy sources used for electricity generation were calculated (e.g., solar, wind, hydroelectric, and geothermal). The new methodology calculates noncombustible electricity generation using the *captured energy approach* rather than the *fossil fuel equivalency approach*.[4] For more information about this change, reference the posted announcement on the SEDS website (https://www.eia.gov/state/seds/seds-change/index.php/).

Information collected in SEDS derives from both surveys conducted by EIA and other estimation methods by EIA. For more information on SEDS' data sources, estimation methodologies, and associated documentation, visit the SEDS website (https://www.eia.gov/state/seds/).

To view SEDS data, visit the EIA Open Data API (https://www.eia.gov/opendata/browser/seds).

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[3] State Energy Data System (SEDS). U.S. Energy Information Administration. (https://www.eia.gov/state/seds/)

[4] Changes to the State Energy Data System. U.S. Energy Information Administration. (https://www.eia.gov/state/seds/seds-change/index.php/)

1.1.2 Form EIA-821 Annual Fuel Oil and Kerosene Sales Report

Form EIA-821, known as the Annual Fuel Oil and Kerosene Sales Report, is the underlying data source for the Sales of Distillate Fuel Oil by End Use table hosted on the EIA's website.[5] The information represented teases apart the total sales of distillate fuel oil (DFO) into consumption estimates for end use sectors such as residential, commercial, industrial, and transportation (SEDS originally published energy consumed for any transportation purpose into one all-inclusive transportation sector).

When disaggregating DFO transportation consumption into separate air, ground, marine, and military transport sectors, Form EIA-821 was used to define the amount of DFO consumed for on-highway (ground transport), vessel bunkering (marine transport), and military uses.

The last year represented in this data set was 2020; reporting of this data was discontinued in SEDS. The values representative of 2020 were released in 2022 consistent with the lag in EIA reporting, but future updates in reporting were suspended. Despite the SEDS data only being available through 2020, Form EIA-821 was used to supplement the prior data and estimate the distribution percentages of DFO into the various transportation sectors for 2022 and beyond.

To view the data table and access accompanying documentation, visit the EIA website (https://www.eia.gov/dnav/pet/pet_cons_821dst_dcu_SHI_a.htm).

For more information, visit the Fuel Oil and Kerosene Sales landing page on the EIA website (https://www.eia.gov/petroleum/fueloilkerosene/).

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[5] Sales of Distillate Fuel Oil by End Use. U.S. Energy Information Administration. (https://www.eia.gov/dnav/pet/pet_cons_821dst_dcu_SHI_a.htm)

1.1.3 Form EIA-923 Power Plant Operations Report

Form EIA-923 is a survey form administered by the EIA that collects electric power data on various categories such as electricity generation, fuel consumption, and fossil fuel stocks.[6]

EIA-923 data was used by the flowchart to derive select input fuels for thermal electricity generation—biodiesel, coal, distillate fuel oil (DFO), and residual fuel oil (RFO). However, biodiesel consumption by the electric power sector was calculated differently than the other fossil resources. See section 3.1.3 for biodiesel consumption methodologies. SEDS had not allocated any biodiesel for electricity generation in Hawaiʻi for 2022—contrary to Form EIA-923.

For more information and to access Form EIA-923 data, visit the Form EIA-923 landing page on the EIA's website (https://www.eia.gov/electricity/data/eia923/).

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[6] Form EIA-923 detailed data with previous form data (EIA-906/920). U.S. Energy Information Administration. (https://www.eia.gov/electricity/data/eia923/)

1.2 U.S. Environmental Protection Agency (EPA)

1.2.1 Emissions & Generation Resource Integrated Database (eGRID)

The Emissions & Generation Resource Integrated Database (eGRID) is a database maintained by the U.S. Environmental Protection Agency (EPA) that tracks electric generation and associated environmental statistics for all electric power generation stations in the United States.[7]

The eGRID database is used in the project to determine the estimated thermal electric generation efficiency (i.e., the percentage of total input energy converted into electricity, relative to the total energy that is consumed for the electricity generation process). For each electricity-producing resource, an efficiency percentage was derived from eGRID's reported plant nominal heat rates (reported as Btu/kWh). A methodology description of the electricity generation efficiency calculations follows in section 4.3.5.

To access the data and for more information about the eGRID database, visit the eGRID database landing page on the EPA website (https://www.epa.gov/egrid).

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[7] Emissions & Generation Resource Integrated Database (eGRID). U.S. Environmental Protection Agency. (https://www.epa.gov/egrid)

1.3 Federal Highway Administration (FHWA)

1.3.1 Highway Statistics Series

The Federal Highway Administration (FHWA)—a division of the U.S. Department of Transportation (DOT)—publishes annual statistics relating to highway transportation that derive mostly from information provided by each state. This annual publication is known as the Highway Statistics Series and is compiled by the Office of Highway Policy Information at the FHWA. The 2022 publication used in the project is titled "Highway Statistics 2022".

Two tables were identified in "Highway Statistics 2022" to provide the information needed to help separate gasoline fuel use in the transportation sector into the various transportation sub-categories (air, ground, marine, and military):

- MF-21: Motor-fuel use[8]
- MF-24: Private and commercial non-highway use of gasoline[9]

Methodologies used for calculations follow in section 4.3.4.b.

To access the data and for more information on the Highway Statistics Series, visit the landing page on the FHWA website (https://www.fhwa.dot.gov/policyinformation/statistics.cfm).

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[8] Table MF-21, Motor-Fuel Use 2022. Federal Highway Administration (FHWA). (https://www.fhwa.dot.gov/policyinformation/statistics/2022/mf21.cfm)

[9] Table MF-24, Private and Commercial Nonhighway Use of Gasoline 2022. Federal Highway Administration (FHWA). (https://www.fhwa.dot.gov/policyinformation/statistics/2022/mf24.cfm)

1.4 Hawaiʻi Public Utilities Commission

1.4.1 Docket No. 2007-0008, RPS Annual Reports

The Hawaiʻi Public Utilities Commission (PUC) regulates the registered public utility companies operating in the State. HRS 269-91 requires each electric utility company that sells electricity for consumption in the State to follow a Renewable Portfolio Standard (RPS).

The RPS defines benchmarks of renewable energy progress by its stated goal of 100% electric net generation deriving from renewable sources by 2045. Originally, the metric gathered and reported was electric sales but was later changed in 2022 by H.B. 2089 to net electricity generation.[10] Since the passing of H.B. 2089, HSEO has tracked the RPS based on net electricity generation. Below are the following targets that the RPS has set:

- By the end of 2010… 10% of net electricity sales from renewable sources
- By the end of 2015… 15% of net electricity sales from renewable sources
- By the end of 2020… 30% of net electricity sales from renewable sources
- By the end of 2030… 40% of net electricity generation from renewable sources
- By the end of 2040… 70% of net electricity generation from renewable sources
- By the end of 2045… 100% of net electricity generation from renewable sources

Defined in HRS § 269-91, renewable energy is representative of electricity generated by any of the following sources:

- Wind
- The sun
- Falling water
- Biogas (including landfill and sewage-based digester gas)
- Geothermal
- Ocean water, currents, and waves, including ocean thermal energy conversion
- Biomass, including biomass crops, agricultural and animal residues and wastes, and municipal solid waste and other solid waste
- Biofuels[11]
- Hydrogen produced from renewable energy sources

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[10] See H.B. 2089 (https://www.capitol.hawaii.gov/sessions/session2022/bills/HB2089_SD2_.htm)

[11] Biodiesel is considered "biofuel" when pertaining to the RPS

Electric net generation values for all energy resources were fetched from both Hawaiian Electric and KIUC’s annual RPS reports and were used for the flowchart (reported as net megawatt hours).

The PUC collects annual reports from Hawai‘i’s two electric utilities—Hawaiian Electric and the Kauai Island Utility Cooperative (KIUC)—that publish electric net generation values from all energy resources. Such reports are filed in PUC Docket No. 2007-0008.

To access further information about the PUC’s collection of RPS reports, visit the PUC website (https://puc.hawaii.gov/energy/Hawai‘is-renewable-energy-and-energy-efficiency-policies/).

To access the annual RPS reports submitted by Hawaiian Electric and KIUC, visit the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

1.4.2 HRS § 269-45 Gas Utility Companies Renewable Energy Report

Adhering to Hawaiʻi Revised Statutes (HRS) § 269-45, each gas utility in Hawaiʻi report defined information relating to natural gas, biogas, biofuels, and bio-feedstocks produced and consumed in Hawaiʻi.[12] The Hawaiʻi Public Utilities Commission (PUC) collects and publishes such reports on or before March 31 of each year. As of 2024, only one entity submits such reports—The Gas Company dba Hawaiʻi Gas.

Hawaiʻi Gas' Annual Renewable Energy Report is used to identify the components of SEDS' originally defined energy resource "supplemental gaseous fuels"—a category inclusive of both renewable natural gas (RNG) and synthetic natural gas (SNG).[13] By parsing "supplemental gaseous fuels" into its components of RNG and SNG, better estimations can be made about the scope of renewable and fossil fuel-derived energy flows. Methodologies for how this data was included in the analysis are described in section 4.3.3.

To access the Renewable Energy Annual Reports pursuant to HRS § 269-45, visit the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-energy-annual-report-gas/).

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[12] Hawaiʻi Revised Statutes (HRS) § 269-45. (https://www.capitol.hawaii.gov/hrscurrent/Vol05_Ch0261-0319/HRS0269/HRS_0269-0045.htm)

[13] For the context of Hawaiʻi, the source of biogas used to create RNG derives from wastewater treatment facilities while SNG derives from local petroleum refining operations.

1.5 Hawaiʻi State Energy Office (HSEO)

1.5.1 PATHWAYS Model

To model various decarbonization scenarios for Hawaiʻi, HSEO utilized the PATHWAYS model to quantify expected future electricity generation and energy consumption patterns under different scenarios.

SEDS data does not disaggregate or estimate the electricity being consumed by the transportation sector. To account for electric vehicles (EVs), electricity delivered to already-defined end use sectors was redirected to flow into the later-created end use sector of ground transport.

The PATHWAYS data was used to estimate the total energy consumption of EVs that would need to be redirected from other end use sectors and into the ground transport sector. Once a total electricity consumption value was fetched for the ground transport sector,[14] later assumptions were made to redirect the proper energy flows (methodology described in section 4.3.9).

To view and download the Hawaiʻi-specific PATHWAYS model results, visit the 2023 Decarbonization Report's landing page on the HSEO's website (https://energy.hawaii.gov/what-we-do/clean-energy-vision/decarbonization-strategy/decarbonization-report-development-assumptions-and-methods/).

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[14] Locate the sum of 2022 values reported for the "Reference" scenario and ground transportation uses, as the "Reference" scenario represents current EV use patterns.

Section 2 Electric Generation Accounting Methods

Before describing how the flowchart was constructed and the origins of each energy flow (see Section 3), the two methodologies of how the electric power sector was calculated and accounted for must be described.

The electric power sector (defined as the “electricity” category in the flowchart column labeled “Product”) consumes both renewable energy resources and fossil energy resources to generate electricity which is then delivered to the end use sectors (see Figure 1 to view the electric power sector from 2022).

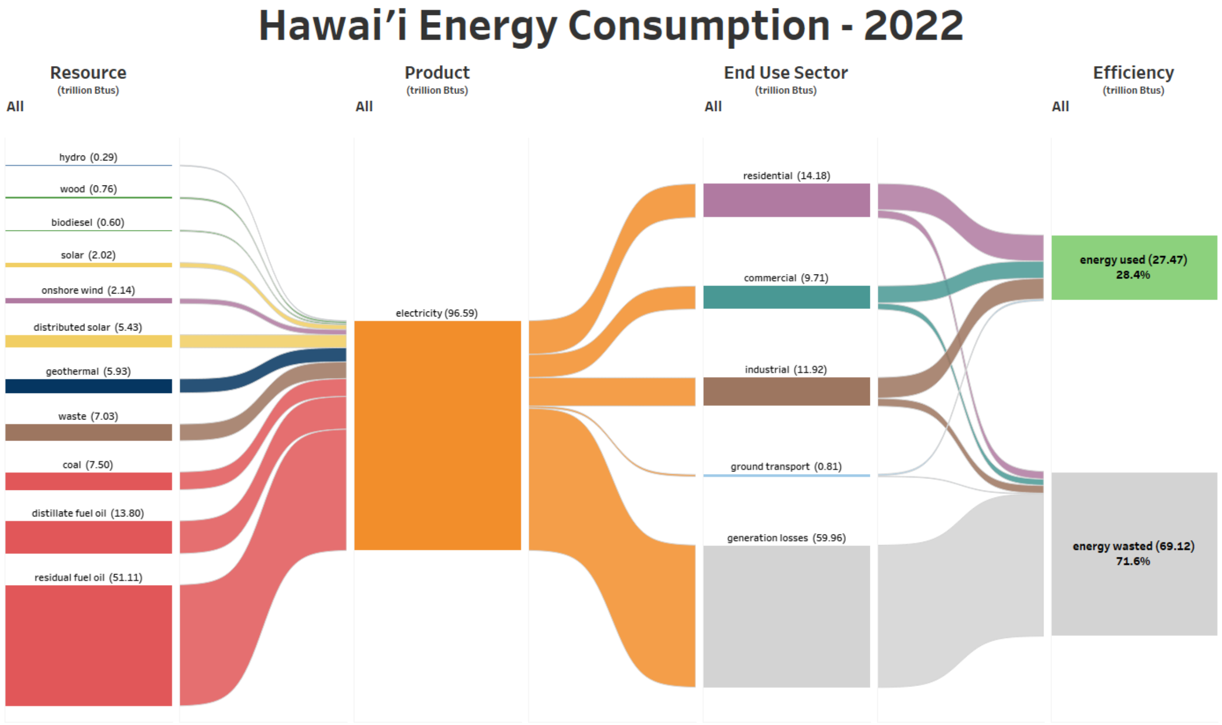

Figure 1 - Electric power sector (2022), with biodiesel, geothermal, waste, and wood estimated using GEA

When viewing the electric power sector (Figure 1), various energy resources contribute to the generation of electricity (see flowchart column “Resource”). Of the eleven electricity-generating energy resources, methods vary for how each resource’s electric generation losses were calculated.

Electric generation losses (see "generation losses" category in the flowchart column labeled "End Use Sector") are broadly defined as the amount of energy lost in the electricity generation process (lost typically as heat). Since each energy resource generates electricity differently, the method for calculating electric generation losses is unique to each energy resource.

To represent these differences in electricity generation across energy resources, two methodologies were used: the Electricity Delivered Approach (EDA), and the Generation Efficiency Approach (GEA). Table 1 below indicates which methodology was used for each electric generation resource.

Table 1 - Electric generation methodologies

Category	Generation	Resource	Methodology	Accounting for Electric Generation Losses
Fossil	Thermal	Coal	Generation Efficiency Approach	Generation losses represented
		Distillate Fuel Oil	Generation Efficiency Approach	Generation losses represented
		Residual Fuel Oil	Generation Efficiency Approach	Generation losses represented
Renewable	Thermal	Biodiesel	Both (EDA & GEA)	Generation losses depend on methodology
		Geothermal	Both (EDA & GEA)	Generation losses depend on methodology
		Waste	Both (EDA & GEA)	Generation losses depend on methodology
		Wood	Both (EDA & GEA)	Generation losses depend on methodology
	Non-thermal	Distributed Solar	Electricity Delivered Approach	No generation losses
		Hydro	Electricity Delivered Approach	No generation losses
		Onshore Wind	Electricity Delivered Approach	No generation losses
		Solar	Electricity Delivered Approach	No generation losses

See section 2.1 for a summary of both EDA and GEA methodologies, sections 2.2 and 2.3 for descriptions methodology, and section 2.4 for the visual differences of select renewable resources using each methodology in the flowchart.

2.1 Summary of Methodologies

Electricity generation was represented using two different methodologies—the Electricity Delivered Approach (EDA) and the Generation Efficiency Approach (GEA). The primary difference between the methodologies is how electric generation losses are represented in the flowchart.

Electricity generation resources that are represented by **only the EDA** include: distributed solar, utility scale solar, hydroelectric, and onshore wind.

Electricity generation resources that are represented by **only the GEA** include: coal, distillate fuel oil (DFO), and residual fuel oil (RFO). Electricity generation resources that are represented by **both the EDA and the GEA**: biodiesel, geothermal, wood, and waste. For these resources, the user must select a methodology in the setting labeled "Generation Methodology", seen on the right-hand side of the flowchart.

By presenting both accounting methodologies in the flowchart, users can see how different accounting methodologies impact the characterization of the electric power sector. See comparison between Figure 2 and Figure 3.

2.2 Electricity Delivered Approach (EDA)

The EDA is a methodology used to represent electricity generation. The EDA methodology does not account for any electric generation losses. In other words, the EDA methodology shows the total amount of energy consumed to generate electricity equals the total amount of electricity delivered to end use sectors from that energy resource (which is not the case for thermal generation).

The EDA methodology values are consistent with Renewable Portfolio Standard (RPS) values which account for renewable energy net generation[15, 16] (see section 1.4.1 Docket No. 2007-0008, RPS Annual Reports).

Four electricity-generating renewable energy resources are represented in the flowchart only by the EDA methodology: distributed solar, hydroelectric (hydro), onshore wind, and solar.

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[15] Defined by the EIA Glossary as "The amount of gross generation less the electrical energy consumed at the generating station(s) for station service or auxiliaries".

[16] Fossil electric generation resources are grouped together as "fossil"

Electric generation from fossil energy resources (coal, distillate fuel oil (DFO), and residual fuel oil (RFO)) was not estimated using the EDA methodology since their energy conversion process involves thermal generation losses.

However, the remainder of the electricity-generating energy resources (the renewable resources of biodiesel, geothermal, waste, and wood) are estimated using both the EDA methodology and the Generation Efficiency Approach (GEA) methodology since their energy conversion process includes thermal generation losses. This choice between methodologies is indicated on the flowchart by the user-defined setting “Generation Methodology”. Depending on which methodology is selected, the visual representation of their electricity generation process changes in the flowchart.

2.3 Generation Efficiency Approach (GEA)

The GEA is a methodology used to represent electricity generation. The GEA methodology indicates that when an energy resource is used to generate electricity, a portion of the energy used is converted into electricity, which is then delivered to end use sectors, and the remainder of the energy is lost in the energy conversion process, usually as heat. Thus, as opposed to the EDA methodology, electric generation losses are represented using the GEA methodology.

Electric generation from fossil energy resources (coal, DFO, and RFO) was only estimated using the GEA methodology since their energy conversion process involves thermal generation losses.

Four electricity generating renewable energy resources are not represented in the flowchart by the GEA methodology: distributed solar, hydroelectric (hydro), onshore wind, and solar. For these electric generation energy resources, only the EDA methodology was used for their representation in the flowchart. Renewable resources including biodiesel, geothermal, waste, and wood are estimated using both the EDA and GEA methodologies since their energy conversion process includes thermal generation losses. This choice between methodologies is indicated on the flowchart by the user-defined setting “Generation Methodology”. Depending on which methodology is selected, the visual representation of their electricity generation process changes in the flowchart.

2.4 Renewable Resources represented by both EDA & GEA

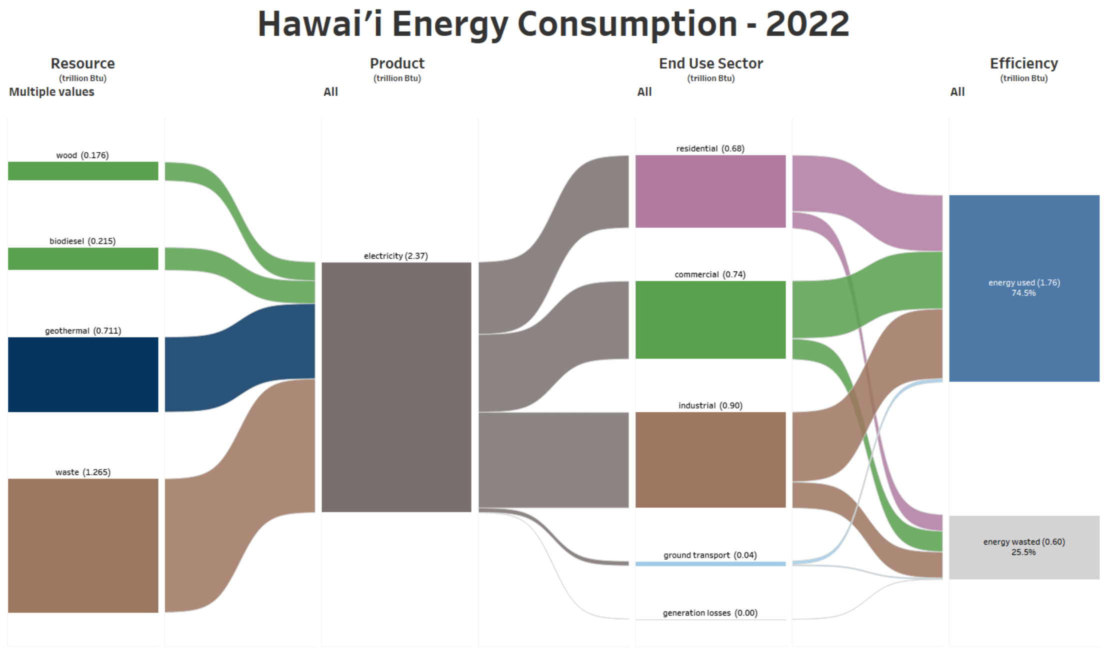

Figure 2 - Using EDA to estimate electric generation from biodiesel, geothermal, waste, and wood

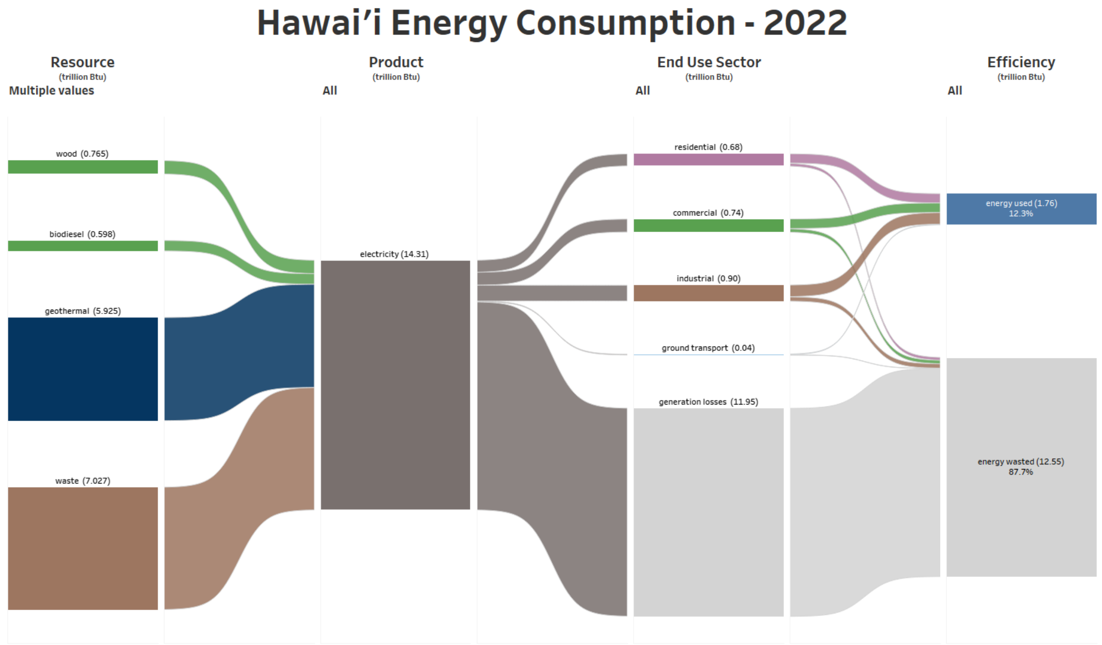

Figure 3 - Using GEA to estimate electric generation from biodiesel, geothermal, waste, and wood

Section 3 Descriptions of Energy Flows

The flowchart illustrates energy flows from specific energy resources to defined end use sectors. Each of the energy flows represented in the flowchart were either directly adopted primarily from the SEDS database, adopted directly from Hawaiian Electric's and Kauai Island Utility Cooperative's (KIUC) Renewable Portfolio Standard (RPS) reports collected by the Hawaiʻi Public Utilities Commission (PUC), or derived from thermal generation plant nominal heat rates published by the U.S. Environmental Protection Agency (EPA). The methodologies, key assumptions, data sources, and descriptions of each energy flow represented in the flowchart in sections 3.1 through 3.4.

All methodologies and underlying assumptions that SEDS made to calculate energy flows can be found on the SEDS landing page.

Refer to Figure 4 below for a visual representation when analyzing sections 3.1 through 3.4.

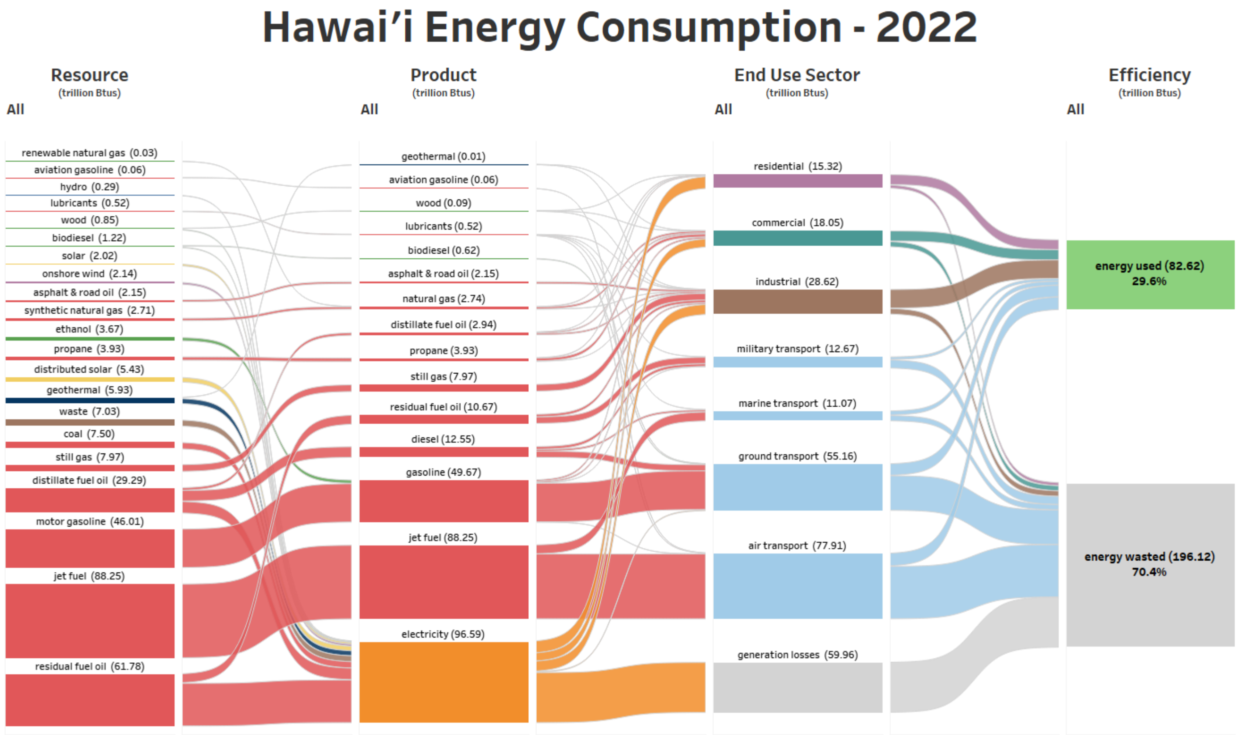

Figure 4 - Whole Energy System using GEA to estimate electric generation from biodiesel, geothermal, waste, and wood (2022)

3.1 Resources (first column of flowchart)

The first column of the flowchart represents the originating energy resources that comprise the products consumed by end use sectors. For example, when gasoline is the product consumed by an end use sector, the energy resources represented would be the two energy resources that comprise gasoline—motor gasoline and ethanol.

Some energy resources are consumed by end use sectors in the same form as they are represented in the “Resource” flowchart column. These resources (such as aviation gasoline and jet fuel) are visually represented in the flowchart in both “Resource” and “Product” columns, but they are only described as resources in section 3.1 of the documentation for simplicity.

3.1.1 Asphalt and Road Oil

Energy flows that represent the consumption of asphalt and road oil derive from SEDS estimates.

Per SEDS, asphalt and road oil are assumed to be consumed entirely by the industrial sector due to their predominant uses in construction. No adjustments were made to SEDS estimates of asphalt and road oil consumption.

Key Assumption(s):

- All consumption of asphalt and road oil occurs in the industrial sector.

Definitions from EIA Glossary:

- **Asphalt**: A dark brown-to-black cement-like material obtained by petroleum processing and containing bitumen as the predominant component; used primarily for road construction. It includes crude asphalt as well as the following finished products: cement, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to cut back asphalts.[17]
- **Road Oil**: Any heavy petroleum oil, including residual asphaltic oil used as a dust palliative and surface treatment on roads and highways. [18]

For more information on underlying data and assumptions that SEDS used to estimate asphalt and road oil consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[17] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[18] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.2 Aviation Gasoline

Energy flows that represent the consumption of aviation gasoline derive from SEDS estimates.

Aviation gasoline is assumed by SEDS to be consumed entirely for transportation uses. When disaggregating the SEDS transportation sector into separate air, ground, marine, and military transport sectors, it was assumed that all aviation gasoline was consumed by the air transport sector (representative of non-military/civilian uses). Further analysis to identify military versus non-military sectors was not done, since the data sources that SEDS uses to estimate aviation gasoline fuel consumption for military versus non-military sectors are unpublished.

Key Assumption(s):

- All consumption of aviation gasoline occurs in the air transport sector (representing non-military uses). See section 4.3.4 for more information.

Definition from EIA Glossary:

> **Aviation Gasoline**: A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in aviation reciprocating engines. Fuel specifications are provided in ASTM Specification D 910 and Military Specification MIL-G-5572. Note: Data on blending components are not counted in data on finished aviation gasoline. [19]

For more information on underlying data and assumptions that SEDS used to estimate aviation gasoline consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[19] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.3 Biodiesel

Energy flows in the flowchart that represent the consumption of biodiesel derive from SEDS estimates, Hawaiian Electric's reported net electric generation[20] from biodiesel, and estimated thermal generation losses calculated using plant nominal heat rates published in the EPA's eGRID database.

All biodiesel consumed in Hawai'i is locally produced by Pacific Biodiesel. Biodiesel feedstock is converted into ready-to-use biodiesel products that are consumed by the electric power sector and the ground transport sector. It is assumed that Pacific Biodiesel's fueling stations represent the only distribution point of biodiesel consumed by the ground transport sector.

Biodiesel consumption by the electric power sector is estimated from Hawaiian Electric's net electric generation values from biofuel resources (representative of biodiesel) as reported by the firm's RPS annual report. As of 2022, the only electric generating plants that actively consume biodiesel for electric generation are Hamakua Energy Plant, HNL Emergency Power Facility, and Schofield Generating Station—all within Hawaiian Electric's jurisdiction.

See Section 2 for methodology considerations (EDA vs. GEA) regarding biodiesel consumption by the electric power sector. See section 4.3.1 for electric power sector biodiesel consumption calculations.

Calculating biodiesel electric generation using the EDA, total biodiesel consumption by the electric power sector is set to Hawaiian Electric's reported net electric generation from biodiesel[21] and total electric generation delivered from the electric power sector is set to Hawaiian Electric's reported net electric generation from biodiesel.[22] Thus, no thermal electric generation losses are estimated or are visually represented in the flowchart.

To derive biodiesel electric generation using the GEA, total biodiesel consumption by the electric power sector was estimated by adding Hawaiian Electric's net electric generation from biodiesel

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[20] EIA definition of *net generation*: "The amount of gross generation less the electrical energy consumed at the generating station(s) for station service or auxiliaries"

[21] Biodiesel is reported in Hawaiian Electric's RPS report as the category "biofuels".

[22] Hawaiian Electric's reported net electric generation from biodiesel is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

to the thermal electric generation losses estimated to produce Hawaiian Electric's reported biodiesel-related net electric generation. Thermal electric generation losses were estimated using the average of the thermal efficiency rates (derived from the biodiesel plants' nominal heat rates) weighted by plant net generation.

Biodiesel consumption by the ground transport sector is derived from SEDS estimates. However, accounting for biodiesel used by the ground transport sector is less clear than other energy flows since the two values that comprise what is shown in the flowchart have nuances that must be illuminated and accounted for. See section 4.3.1 for a detailed description on calculations.

Key Assumption(s):

- Net electric generation from biodiesel defined in Hawaiian Electric’s RPS report represents electricity delivered to end use sectors from biodiesel-fueled electric generation plants
- EDA to estimate the electric power sector
    - Both the inputs and outputs of the electric power sector (only pertaining to biodiesel-fueled electric generation) are represented by Hawaiian Electric’s reported net electric generation from biodiesel. No thermal electric generation losses from biodiesel are represented.
- GEA to estimate the electric power sector
    - Biodiesel electric generation from the electric power sector is represented by Hawaiian Electric’s reported biodiesel net electric generation.
    - Biodiesel inputs to the electric power sector are derived by back calculating the total energy inputs needed to produce Hawaiian Electric’s reported net electric generation from biodiesel
        - Derivation accomplished by using EPA eGRID’s plant nominal heat rates for biodiesel resources
        - This value is equal to Hawaiian Electric’s biodiesel net electric generation summed with estimated biodiesel thermal electric generation losses from biodiesel thermal electric generation.
    - To calculate the thermal electric efficiency rate for biodiesel electric generation, plant nominal heat rates published in the EPA’s eGRID database were averaged (weighted on plant net electric generation). See section 4.3.5 for calculations.
- SEDS’ originally reported biodiesel consumption for the all-inclusive transportation sector is inclusive of biodiesel consumed by the electric power sector. Assumption validated by:
    - Form EIA-923’s total biodiesel consumption level by the electric power sector in Hawaiʻi is less than SEDS’ total biodiesel consumption level by the transportation sector
    - SEDS’ only reported biodiesel consumption sector was transportation, despite other EIA data sources such as Form EIA-923 indicating biodiesel consumption by the electric power sector
- Biodiesel directly consumed by the ground transportation sector is consumed as pure biodiesel fuel (B100)

Definition from EIA Glossary:

> **Biodiesel (B100)**: Renewable fuel consisting of mono alkyl esters (long chain fatty acids) that are produced through the conversion of animal fats, vegetable oils, and recycled grease feedstocks (transesterification) to produce biodiesel. Biodiesel is typically blended with petroleum diesel in concentrations of 2% to 20% biodiesel, or B2 to B20.[23]

To view Hawaiian Electric's RPS reports submitted to the PUC which detail net electric generation quantities associated to biodiesel, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

For more information on underlying data and assumptions that EPA eGRID used to estimate plant nominal heat rates, visit the eGRID landing page on the EPA website (https://www.epa.gov/egrid).

For more information on underlying data and assumptions that SEDS used to estimate biodiesel consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

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[23] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.4 Coal

Energy flows that represent coal derive from the EIA’s Form EIA-923 Power Plant Operations Report and the EPA’s eGRID database.

No coal was directly consumed by the commercial, industrial, or residential sectors, nor any transportation sector.

Coal consumed by the electric power sector as represented in the flowchart was not represented by SEDS data since it included waste oils as part of the total. Rather, Form EIA-923’s published value for coal consumed for electric generation purposes were used. Thus, SEDS estimates were not used to represent coal, and the more precise estimate that was adopted into the flowchart was provided by Form EIA-923.

AES Hawaiʻi—the last coal plant in Hawaiʻi—was operational until its closure in September 2022. All electric generation energy flows are assumed to represent the AES Hawaiʻi coal plant.

Thermal electric generation losses from coal are estimated from the reported AES Hawaiʻi plant nominal heat rate published in the EPA’s eGRID database for AES Hawaiʻi. The plant nominal heat rate was used to calculate the thermal electric generation efficiency of coal.

For a detailed description of the methodology used and the associated calculations, refer to section 4.3.5.a.

Key Assumption(s):

- Coal is only consumed by the electric power sector and is representative of the AES Hawaiʻi electric generation plant.

Definition from EIA Glossary:

> **Coal**: A readily combustible black or brownish-black rock whose composition, including inherent moisture, consists of more than 50 percent by weight and more than 70 percent by volume of carbonaceous material. It is formed from plant remains that have been compacted, hardened, chemically altered, and metamorphosed by heat and pressure over geologic time.[24]

For more information on underlying data and assumptions that SEDS used to estimate coal consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_coal.pdf).

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[24] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.5 Distillate Fuel Oil (DFO)

Energy flows that represent DFO derive from SEDS, the EIA's Form EIA-923 Power Plant Operations Report, and the EPA's eGRID database.

No adjustments were made to SEDS estimates of DFO consumed directly by the commercial, industrial, and residential sectors.

DFO consumption by the commercial and residential sectors represent space heating, water heating, and cooking. DFO consumption by the industrial sector represents industrial space heating, refining, construction, and other industrial uses.

DFO consumed by the electric power sector was not represented by SEDS data. Rather, Form EIA-923's published value for DFO consumed for electric generation purposes were used.

DFO consumed by all transportation sectors is assumed to be entirely consumed as diesel fuel. SEDS reports DFO consumption by all transportation sectors as a single lumped value. The methodology used to allocate SEDS-reported DFO consumption to individual transportation sectors is outlined in section 4.3.5.a.

Key Assumption(s):

- All DFO consumed by all transportation sectors is consumed as diesel fuel.
- Allocation of DFO consumption to individual transportation sectors is accomplished by using separately reported DFO consumption statistics published by EIA.

Definition from EIA Glossary:

> **Distillate Fuel Oil (DFO)**: A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electric power generation.[25]

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[25] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

For more information on underlying data and assumptions that SEDS used to estimate DFO consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

3.1.6 Distributed Solar (i.e., Rooftop Solar)

Energy flows that represent the consumption of distributed solar derive from Hawaiian Electric's and KIUC's reported net electric generation from distributed solar.

Electricity generated from distributed solar is assumed to only be consumed by the residential sector and only inclusive of small-scale photovoltaic (PV) units. While the flowchart appears that distributed solar passes through the electric power sector (since all other utility electric production passes through the "electricity" category in the fuels column of the flowchart), this interpretation is false—all electric production deriving distributed solar is assumed to solely be consumed by the residential sector.

Distributed solar consumed by the residential sector as electricity was estimated by summing Hawaiian Electric and KIUC's reported net electric generation as seen in their RPS reports (represented as the category "Customer-Sited, Grid-Connected").[26] Since the metric reported in the RPS reports is net electric generation, no thermal generation losses are estimated.

Distributed solar was only calculated using the EDA since it does not represent thermal electric generation.

Key Assumption(s):

- All consumption of distributed solar occurs in the residential sector (assumption derived from SEDS documentation)
- Total distributed solar energy consumed by the residential sector in the form of electricity is derived by the net electric generation reported in Hawaiian Electric and KIUC's annual RPS reports under the category "Customer-Sited, Grid-Connected"
- No thermal electric generation losses are estimated

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[26] Hawaiian Electric and KIUC's reported net electric generation from distributed solar is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

Definitions from EIA Glossary:

- **Solar Energy**: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity.[27]
- **Small-scale solar**: Solar photovoltaic systems smaller than one megawatt, as measured in alternating current.[28]

To view Hawaiian Electric's and KIUC's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

For more information on underlying data and assumptions that SEDS used to estimate solar energy consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

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[27] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[28] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.7 Ethanol

Energy flows that represent the consumption of ethanol derive from SEDS estimates and Federal Highway Administration (FHWA) gasoline consumption statistics.

It is assumed that all ethanol is consumed by end use sectors as a blend of motor gasoline and ethanol—a product that is defined and observed in the flowchart as "gasoline".

The same proportions of motor gasoline derived to allocate motor gasoline to specific transportation sectors in section 4.3.4.b also apply to ethanol since the two resources are assumed to always be consumed together as "gasoline".

Key Assumption(s):

- All consumption of ethanol by end use sectors occurs as a motor gasoline-ethanol blend that is represented in the flowchart as "gasoline".
- The proportional distribution of ethanol to end use sectors is identical to motor gasoline since they are consumed together as blended "gasoline".

Definitions from EIA Glossary:

- **Ethanol**: A clear, colorless, flammable alcohol. Ethanol is typically produced biologically from biomass feedstocks such as agricultural crops and cellulosic residues from agricultural crops or wood. Ethanol can also be produced chemically from ethylene. [29]
- **Fuel ethanol (as represented in flowchart):** Ethyl alcohol for fuel use that is produced by the fermentation of sugars. Fuel ethanol is denatured with petroleum products (for example, natural gasoline) to render it unfit for human consumption. [30]

For more information on underlying data and assumptions that SEDS used to estimate ethanol consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

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[29] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[30] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.8 Geothermal

Energy flows in the flowchart that represent the consumption of geothermal derive from SEDS estimates and Hawaiian Electric reported net electric generation from geothermal. Geothermal energy is directly consumed by the electric power, commercial, and industrial sectors.

All geothermal energy is produced by the Puna Geothermal Venture power plant on Hawaiʻi Island and is consumed in the electric sector. Electricity generated is then supplied to electricity-consuming end use sectors.

To estimate geothermal electric generation, net electric generation from geothermal resources as reported in Hawaiian Electric's RPS report was used for the flowchart's two estimation methodologies.

Calculating geothermal electric generation using the EDA, total geothermal consumption by the electric power sector is set to Hawaiian Electric's reported net electric generation from geothermal and total electric generation delivered from the electric power sector is set to Hawaiian Electric's reported net electric generation from geothermal.[31] Thus, no thermal generation losses are estimated or are visually represented in the flowchart.

To derive geothermal electric generation using the GEA, total geothermal consumption by the electric power sector was estimated by adding Hawaiian Electric's net electric generation from geothermal to the thermal generation losses estimated to produce Hawaiian Electric's reported geothermal-related net electric generation. Thermal generation losses were estimated using a global average generation efficiency percentage of 12%. Refer to section 4.3.5.b for more information on how this assumption was made and to view a detailed description of the EDA and GEA methodologies used to estimate the electric power sector relating to geothermal.

Geothermal energy consumed directly by commercial[32] and industrial sectors represents geothermal resources used as direct heat or for heat pumps. See SEDS documentation for further reference.

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[31] Hawaiian Electric's reported net electric generation from geothermal is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

[32] Excluding combined heat-and-power plants and electricity-only plants.

Key Assumption(s):

- Net electric generation from geothermal resources defined in Hawaiian Electric's RPS report represents electricity delivered to end use sectors from geothermal-powered electric generation
- EDA to estimate the electric power sector
    - Both the inputs and outputs of the electric power sector (only pertaining to geothermal-fueled electric generation) are represented by Hawaiian Electric's reported net electric generation from geothermal resources. No thermal electric generation losses from geothermal are represented.
- GEA to estimate the electric power sector
    - Geothermal electric generation from the electric power sector is represented by Hawaiian Electric's reported geothermal net electric generation.
    - Geothermal inputs to the electric power sector are derived by back calculating the total energy inputs needed to produce Hawaiian Electric's reported net electric generation from geothermal
    - Derivation accomplished by using a 12% global average generation efficiency percentage for geothermal energy resources. See section 4.3.5.b for calculations.
    - This value is equal to Hawaiian Electric's geothermal net electric generation summed with estimated geothermal thermal electric generation losses from geothermal thermal electric generation.

Definition from EIA Glossary:

> **Geothermal energy:** Hot water or steam extracted from geothermal reservoirs in the earth's crust. Water or steam extracted from geothermal reservoirs can be used for geothermal heat pumps, water heating, or electricity generation. [33]

To view Hawaiian Electric's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

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[33] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

For more information on underlying data and assumptions that SEDS used to estimate geothermal energy consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

3.1.9 Hydroelectric (Hydro)

Energy flows that represent the consumption of hydroelectric power (i.e., electricity delivered from a hydroelectric energy resource) derive from Hawaiian Electric and KIUC reported net electric generation from hydroelectric power resources.

All hydroelectric energy is first consumed by the electric power sector to generate electricity, which is then delivered to electricity-consuming end use sectors.

Hydroelectric power consumed by end use sectors as electricity was estimated by summing Hawaiian Electric and KIUC's reported net electric generation as seen in their RPS reports (represented as the RPS category "Hydro").[34] Since the metric reported in the RPS reports is net electric generation of a renewable energy resource, no thermal generation losses are estimated. Hydroelectric power was only calculated using the EDA.

Key Assumption(s):

- Total hydroelectric power consumed by end use sectors in the form of electricity is derived by the net electric generation reported in Hawaiian Electric and KIUC's annual RPS reports under the category "Hydro".
- No thermal electric generation losses are estimated.
- All hydroelectric energy in Hawaiʻi is consumed by the electric power sector to produce electricity that is then delivered to end use sectors.

Definition from EIA Glossary:

> **Hydroelectric Power:** The use of flowing water to produce electrical energy. [35]

To view Hawaiian Electric's and KIUC's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

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[34] Hawaiian Electric's reported net electric generation from hydroelectric power is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

[35] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.10 Jet Fuel

Energy flows that represent jet fuel consumption are derived from SEDS estimates.

Jet fuel consumed by the originally defined, all-inclusive transportation sector represents both military and non-military uses. The jet fuel energy resource defined in the flowchart is representative of both kerosene-type jet fuel and naphtha-type jet fuel. It is assumed that 88% of jet fuel is consumed by the air transport sector (non-military uses largely representing commercial air travel) and the military transport sector consumes the remaining 12%. The methodology used to split the original jet fuel-to-transportation energy flow into separate transportation sectors is defined in section 4.3.4.c.

No jet fuel consumption occurs in the electric power, commercial, industrial, and residential sectors.

Key Assumption(s):

- All jet fuel consumed by the transportation sector (as appears in SEDS) is consumed in the air transport sector (non-military) and military transport sectors (as appears in flowchart)
- 88% of total jet fuel consumption in Hawaiʻi is by the air transport sector (non-military)
- 12% of total jet fuel consumption in Hawaiʻi is by the military transport sector

Definition from EIA Glossary:

> **Jet Fuel**: A refined petroleum product used in jet aircraft engines. It includes kerosene-type jet fuel and naphtha-type jet fuel.[36]

For more information on underlying data and assumptions that SEDS used to estimate jet fuel consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[36] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.11 Lubricants

Energy flows that represent the consumption of lubricants are derived from SEDS estimates.

No adjustments were made to SEDS estimates of lubricants consumed directly by the industrial sector.

Lubricants consumed by the originally defined, all-inclusive transportation sector are distributed proportionally to each transportation sector based on total non-lubricant fuel consumption. The method used to split the original lubricants-to-transportation energy flow into separate transportation sectors is defined in section 4.3.4.d.

No lubricant consumption occurs in the electric power, commercial, military transport, and residential sectors.

Key Assumption(s):

- All lubricants consumed for transportation uses (as appears in SEDS) are consumed by each transportation sector by the proportions derived from each transportation sector's non-lubricant fuel consumption totals.
- No lubricants are consumed by the military transport sector (assumption made due to lack of data).

Definition from EIA Glossary:

> **Lubricants**: Substances used to reduce friction between bearing surfaces or incorporated into other materials used as processing aids in the manufacture of other products, or used as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Lubricants include all grades of lubricating oils, from spindle oil to cylinder oil to those used in greases.[37]

For more information on underlying data and assumptions that SEDS used to estimate lubricant consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[37] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.12 Motor Gasoline

Energy flows that represent motor gasoline consumption are derived from SEDS estimates and FHWA gasoline consumption statistics.

SEDS estimates motor gasoline use based on two primary distinctions: highway use and non-highway use. Highway use of motor gasoline is assumed to be entirely allocated to the ground transport sector.

Highway use of motor gasoline does not include diesel fuels, which are represented by distillate fuel oils.

Non-highway use of motor gasoline is broken into separate categories of consumption which are split into commercial, industrial, air transport, ground transport, and marine transport sectors. No adjustments were made to SEDS estimates of motor gasoline consumed directly by the commercial and industrial sectors. Non-highway use of motor gasoline is split into air transport, ground transport, and marine transport sectors using FHWA data and a methodology that is defined in section 4.3.4.b.

No motor gasoline consumption occurs in the electric power or residential sectors.

It is assumed that the military transport sector consumes no motor gasoline since SEDS does not account for a separate military consumption value when calculating total motor gasoline consumption.

Additionally, it is assumed that end use sectors consume all motor gasoline as a consistent blend of motor gasoline and ethanol—a fuel that is defined and observed in the flowchart as “gasoline”.

The distribution methodology of motor gasoline consumed by end use sectors is detailed in section 4.3.4.b.

Key Assumption(s):

- All consumption of motor gasoline by end use sectors occurs as a motor gasoline-ethanol blend that is represented in the flowchart as "gasoline"
- All highway use of motor gasoline is assumed to represent the ground transport sector
- Non-highway use of motor gasoline is divided among reported consumption levels in the commercial, industrial, air transport, ground transport, and marine transport sectors
- Motor gasoline is not consumed in the military transport sector

Definition from EIA Glossary:

> **Motor Gasoline (finished)**: A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. motor gasoline includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline. Note: Volumetric data on blending components, such as oxygenates, are not counted in data on finished motor gasoline until the blending components are blended into the gasoline.[38]

For more information on underlying data and assumptions that SEDS used to estimate motor gasoline consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[38] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.13 Onshore Wind

Energy flows that represent wind energy consumption are derived from Hawaiian Electric's reported net electric generation from onshore wind resources. All onshore wind energy is initially consumed by the electric power sector to generate electricity, which is then delivered to electricity-consuming end use sectors.

All electricity generated from onshore wind is consumed within Hawaiian Electric jurisdictions. Thus, onshore wind energy consumed by end use sectors as electricity was estimated using Hawaiian Electric's reported net electric generation from onshore wind resources within their RPS report.[39]

Onshore wind was only calculated using the EDA. See section 2.2 for more information.

Key Assumption(s):

- Total wind energy consumed by end use sectors in the form of electricity is derived by the net electric generation reported in Hawaiian Electric's RPS report under the category "Wind"
- No thermal electric generation losses are estimated
- All wind energy in Hawaiʻi is consumed by the electric power sector to produce electricity delivered to end use sectors

Definitions from EIA Glossary:

> **Wind Energy:** Kinetic energy present in wind motion that can be converted to mechanical energy for driving pumps, mills, and electric power generators.[40]

To view Hawaiian Electric's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

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[39] Hawaiian Electric's reported net electric generation from onshore wind is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

[40] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.14 Propane

Energy flows that represent the consumption of propane are derived from SEDS estimates. No adjustments were made to SEDS estimates of propane consumed directly by the commercial, industrial, and residential sectors. Propane is not consumed in any transportation sector. SEDS assumes propane is not directly consumed by the electric power sector, but the small amount that is consumed by the electric power sector is already accounted for as waste oils.

SEDS accounts for propane in their hydrocarbon gas liquids (HGL) resource category which is inclusive of ethane, propane, normal butane, isobutane, and natural gasoline. Propane consumption in the commercial and residential sectors is used for water heating and cooking appliances. Propane consumption in the industrial sector is used to run construction equipment, power industrial cooking machinery, and refining.

Key Assumption(s):

- SEDS estimates adopted

Definition from EIA Glossary:

> **Propane**: A straight-chain saturated (paraffinic) hydrocarbon extracted from natural gas or refinery gas streams, which is gaseous at standard temperature and pressure. It is a colorless gas that boils at a temperature of -44 degrees Fahrenheit. It includes all products designated in ASTM Specification D1835 and Gas Processors Association specifications for commercial (HD-5) propane.[41]

For more information on underlying data and assumptions that SEDS used to estimate propane consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[41] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.15 Renewable Natural Gas (RNG)

Energy flows that represent the consumption of RNG are derived from RNG production levels reported by Hawaiʻi Gas.

RNG is derived from harnessed biogas at the Honouliuli Wastewater Treatment Plant.

It is assumed that all RNG is consumed by end use sectors as a blended fuel comprised of RNG and synthetic natural gas (SNG) that is represented in the flowchart as “natural gas”.

It is assumed that RNG is inclusive in SEDS’s originally defined resource category “supplemental gaseous fuels”.

See section 4.3.2 for more information on eliminating the double counting of supplemental gaseous fuels in SEDS data. Then see section 4.3.3 to view methodology for how a portion supplemental gaseous fuels were allocated to represent RNG.

RNG is consumed in the commercial, industrial, and residential sectors as the blended fuel “natural gas”. See section 3.2.4 for specific end uses of the blended fuel “natural gas”.

Key Assumption(s):

- RNG is consumed as a blended fuel and is represented in the flowchart as “natural gas”—a fuel that comprises both RNG and SNG
- Distribution of RNG to end use sectors is derived from the distribution percentages of the SEDS energy resource “supplemental gaseous fuels”

Definition from EIA Glossary:

- **Biogas**: A mixture of methane and other gases produced by decomposing matter in an oxygen-free (anaerobic) environment with the assistance of microbes. Biogas is typically produced at landfills and anaerobic digesters. [42]

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[42] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

- **Natural Gas**: A gaseous mixture of hydrocarbon compounds, the primary one being methane. [43]
- **Synthetic Natural Gas (SNG)**: A manufactured product, chemically similar in most respects to natural gas, resulting from the conversion or reforming of hydrocarbons that may easily be substituted for or interchanged with pipeline-quality natural gas. [44]

Definition from EPA:

> **Renewable Natural Gas (RNG)**: Renewable natural gas is a term used to describe biogas that has been upgraded for use in place of fossil natural gas. The biogas used to produce RNG comes from a variety of sources, including municipal solid waste landfills and anaerobic digester plants at water resource recovery facilities (wastewater treatment plants), livestock farms, food production facilities and organic waste management operations. RNG can be used locally at the site where the product is created, piped in a dedicated pipeline to an end user or injected into a natural gas transmission or distribution pipeline. [45]

For more information on underlying data and assumptions that SEDS used to estimate supplemental gaseous fuel consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

See section 1.4.2 for more information on reported levels of RNG production.

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[43] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[44] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[45] See U.S. Environmental Protection Agency (https://www.epa.gov/lmop/renewable-natural-gas)

3.1.16 Residual Fuel Oil (RFO)

Energy flows that represent RFO are derived from SEDS, the EIA’s Form EIA-923 Power Plant Operations Report, and the EPA’s eGRID database.

No adjustments were made to SEDS estimates of RFO consumed directly by the industrial sector or for transportation uses. No RFO was directly consumed by the commercial and residential sectors.

RFO consumed by the electric power sector as represented in the flowchart was not represented by SEDS data. Rather, Form EIA-923’s published value for RFO consumed for electric generation purposes was used.

Electric net generation values reported in Hawaiian Electric and KIUC’s annual RPS reports were not used for estimating fossil thermal generation (unlike all renewable electric generation values represented in the flowchart) since all fossil energy resources were published as a single value in the RPS reports, not as separate resource categories.

RFO consumption by the industrial sector represents industrial space heating, refining, and other industrial uses.

RFO consumed by all transportation sectors is assumed to be entirely consumed by the marine transport sector as vessel bunkering fuel. SEDS reports RFO consumption by all transportation sectors as a single value, without indicating the proportions allocated to individual transportation sectors. The methodology used to allocate RFO consumption by all transportation sectors to solely the marine transport sector is outlined in section 4.3.4.

Key Assumption(s):

- RFO consumption by all transportation sectors (as reported by SEDS) is assumed to solely represent RFO consumed by the marine transport sector as vessel bunkering fuel.

Definition from EIA Glossary:

> **Residual Fuel Oil (RFO)**: A general classification for the heavier oils, known as No. 5 and No. 6 fuel oils, that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations. It conforms to ASTM Specifications D 396 and D 975 and Federal Specification VV-F-815C. No. 5, a residual fuel oil of medium viscosity, is also known as Navy Special and is defined in Military Specification MIL-F-859E, including Amendment 2 (NATO Symbol F-770). It is used in steam-powered vessels in government service and inshore powerplants. No. 6 fuel oil includes Bunker C fuel oil and is used for the production of electric power, space heating, vessel bunkering, and various industrial purposes.[46]

For more information on underlying data and assumptions that SEDS used to estimate RFO consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[46] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.17 Solar (i.e. Utility-Scale Solar)

Energy flows that represent the consumption of solar energy derive from Hawaiian Electric's and KIUC's reported net electric generation from utility-scale solar facilities. Solar energy (utility-scale) is consumed by the commercial, industrial, and residential sectors as electricity.

Total solar energy produced by utility-scale facilities then delivered as electricity to the commercial, industrial, and residential sectors was estimated by summing Hawaiian Electric and KIUC's reported net electric generation as seen in their RPS reports (represented as the category "Photovoltaic and Solar Thermal").[47]

Solar was only calculated using the EDA. See Section 2 for more information.

Key Assumption(s):

- Total utility-delivered solar energy consumed by end use sectors in the form of electricity is derived by the net electric generation reported in Hawaiian Electric and KIUC's annual RPS reports under the category "Photovoltaic and Solar Thermal"
- No thermal electric generation losses are estimated

Definitions from EIA Glossary:

- **Photovoltaic and solar thermal energy (as used at electric utilities):** Energy radiated by the sun as electromagnetic waves (electromagnetic radiation) that is converted at electric utilities into electricity by means of solar (photovoltaic) cells or concentrating (focusing) collectors. [48]
- **Solar Energy**: The radiant energy of the sun, which can be converted into other forms of energy, such as heat or electricity. [49]

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[47] Hawaiian Electric and KIUC's reported net electric generation from utility solar is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

[48] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[49] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

To view Hawaiian Electric's and KIUC's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

3.1.18 Still Gas

Energy flows that represent the consumption of still gas derive from SEDS's reported estimates.

Still gas is assumed to be only consumed by the industrial sector mainly for refining purposes.

Key Assumption(s):

- 7,965 billion Btus of still gas is consumed by the industrial sector as refinery fuel and intermediate products
- 4 billion Btus of still gas is consumed by the industrial sector not as refinery fuel or intermediate products

Definitions from EIA Glossary:

> **Still gas:** Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. The principal constituents are methane and ethane. May contain hydrogen and small/trace amounts of other gases. Still gas is typically consumed as refinery fuel or used as petrochemical feedstock. Still gas burned for refinery fuel may differ in composition from marketed still gas sold to other users. [50]

For more information on underlying data and assumptions that SEDS used to estimate supplemental gaseous fuel consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

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[50] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.19 Synthetic Natural Gas (SNG)

Energy flows that represent the consumption of SNG derive from SEDS estimates and Hawaiʻi Gas production reporting.

SNG is derived from naphtha which is a byproduct of local petroleum refining.

It is assumed that all SNG is consumed by end use sectors as a blended fuel comprised of SNG and RNG that is represented in the flowchart as “natural gas”.

It is assumed that SNG is counted within SEDS’s originally defined resource category “supplemental gaseous fuels”.

See section 4.3.2 for more information on eliminating the double counting of supplemental gaseous fuels in SEDS data. See section 4.3.3 for the methodology used to define the portion of supplemental gaseous fuels to be represented as SNG.

SNG is consumed in the commercial, industrial, and residential sectors as the blended fuel “natural gas”. See section 3.2.4 for specific end uses of the blended fuel “natural gas”.

Key Assumption(s):

- SNG is consumed as a blended fuel represented in the flowchart as “natural gas”—a fuel that comprises both RNG and SNG
- Distribution of SNG to end use sectors derives from the distribution percentages of the SEDS energy resource “supplemental gaseous fuels”

Definitions from EIA Glossary:

- **Natural Gas:** A gaseous mixture of hydrocarbon compounds, the primary one being methane. [51]
- **Synthetic Natural Gas (SNG):** A manufactured product, chemically similar in most respects to natural gas, resulting from the conversion or reforming of hydrocarbons that may easily be substituted for or interchanged with pipeline-quality natural gas. [52]

Definition from EPA:

> **Renewable Natural Gas (RNG):** Renewable natural gas is a term used to describe biogas that has been upgraded for use in place of fossil natural gas. The biogas used to produce RNG comes from a variety of sources, including municipal solid waste landfills and anaerobic digester plants at water resource recovery facilities (wastewater treatment plants), livestock farms, food production facilities and organic waste management operations. RNG can be used locally at the site where the product is created, piped in a dedicated pipeline to an end user or injected into a natural gas transmission or distribution pipeline. [53]

For more information on underlying data and assumptions that SEDS used to estimate supplemental gaseous fuel consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_petrol.pdf).

See section 1.4 for more information on reported levels of SNG production.

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[51] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[52] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[53] See U.S. Environmental Protection Agency (https://www.epa.gov/lmop/renewable-natural-gas)

3.1.20 Waste (i.e., Municipal Solid Waste)

Energy flows in the flowchart that represent the consumption of waste derive from SEDS estimates, Hawaiian Electric's reported net electric generation from waste, and estimated thermal generation losses calculated using plant nominal heat rates published in the EPA's eGRID database.

All electricity generated from waste is consumed by the Hawaiian Electric jurisdiction of Honolulu County and is produced by the H-Power municipal solid waste (MSW) plant. Electricity generated is then supplied to electricity-consuming end use sectors.

To estimate electric generation from waste, net electric generation from waste resources as reported in Hawaiian Electric's RPS report was used for the flowchart's two estimation methodologies.[54]

Calculating waste electric generation using the EDA, total waste consumption by the electric power sector is set to Hawaiian Electric's reported net electric generation from waste and total electric generation delivered from the electric power sector is set to Hawaiian Electric's reported net electric generation from waste. [55] Thus, no thermal electric generation losses are estimated or are visually represented in the flowchart.

To derive waste electric generation using the GEA, total waste consumption by the electric power sector was estimated by adding Hawaiian Electric's net electric generation from waste to the thermal electric generation losses estimated to produce Hawaiian Electric's reported waste-related net electric generation. Total thermal electricity generation losses were estimated using plant nominal heat rates published in the EPA's eGRID database.

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[54] Reported in Hawaiian Electric's RPS report under the resource category "biomass". In Hawaiian Electric and KIUC's RPS reports, the resource category "biomass" includes both municipal solid waste and wood. Both biomass energy resources are used in Hawaii to produce electricity, but since the only MSW plant in Hawaii is under Hawaiian Electric's jurisdiction and the only wood plant is under KIUC's jurisdiction, it is assumed that biomass in Hawaiian Electric's RPS report refers to MSW and biomass in KIUC's RPS report refers to wood.

[55] Hawaiian Electric's reported net electric generation from waste is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

Refer to section 4.3.5.a to view a detailed description of the two methodologies used to estimate the electric power sector relating to waste.

Key Assumption(s):

- Net electric generation from waste defined in Hawaiian Electric's RPS report represents electricity delivered to end use sectors from waste-powered electric generation
- EDA to estimate the electric power sector
    - Both the inputs and outputs of the electric power sector (only pertaining to waste-fueled electric generation) are represented by Hawaiian Electric's reported net electric generation from waste. No thermal electric generation losses from waste are represented.
- GEA to estimate the electric power sector
    - Waste electric generation from the electric power sector is represented by Hawaiian Electric's reported waste net electric generation.
    - Waste inputs to the electric power sector are derived by back calculating the total energy inputs needed to produce Hawaiian Electric's reported net electric generation from waste
        - Derivation accomplished by using EPA eGRID's plant nominal heat rates for waste resources
        - This value is equal to Hawaiian Electric's waste net electric generation summed with estimated waste thermal electric generation losses from waste thermal electric generation.
    - To calculate the thermal electric efficiency rate for waste electric generation, the plant nominal heat rate for H Power published in the EPA's eGRID database was used. See section 4.3.5.a for calculations.

Definition from EIA Glossary:

> **Municipal solid waste (MSW):** Garbage collected from municipalities or a similar customer base (including a mix of residential and commercial entities) consisting of biogenic and non-biogenic fractions that would typically be disposed of at a landfill or incinerated. Useful energy may be extracted from MSW either by capturing the heat produced by burning it to produce steam and electricity or by separating and processing the organic materials to produce higher-value fuels. [56]

To view Hawaiian Electric's RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

For more information on underlying data and assumptions that SEDS used to estimate waste energy consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

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[56] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.1.21 Wood

Energy flows that represent the consumption of wood derived from SEDS estimates, KIUC's reported net electric generation from wood, and estimated thermal generation losses calculated using plant nominal heat rates published in the EPA's eGRID database.

Wood energy is consumed by the electric power, commercial, industrial, and residential sectors.

All electricity generated from wood is consumed by the KIUC jurisdiction of Kauai County and is produced by the Mahipapa biomass plant. Electricity generated is then supplied to electricity-consuming end use sectors.

To estimate wood electric generation, net electric generation from wood resources as reported in KIUC's RPS report was used for the flowchart's two estimation methodologies.[57]

To calculate electric generation from wood using the EDA, total wood consumption by the electric power sector is set to KIUC's reported net electric generation from wood and total electric generation delivered from the electric power sector is set to KIUC's reported net electric generation from wood.[58] Thus, no thermal electric generation losses are estimated or are visually represented in the flowchart using the EDA.

To derive wood electric generation using the GEA, total wood consumption by the electric power sector was estimated by adding KIUC's net electric generation from wood to the thermal electric generation losses estimated to produce KIUC's reported wood-related net electric generation. Total thermal electricity generation losses were estimated using plant nominal heat rates published in the EPA's eGRID database.

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[57] Reported in KIUC's RPS report under the resource category "biomass". In Hawaiian Electric and KIUC's RPS reports, the resource category "biomass" includes both municipal solid waste and wood. Both biomass energy resources are used in Hawaii to produce electricity, but since the only MSW plant in Hawaii is under Hawaiian Electric's jurisdiction and the only wood plant is under KIUC's jurisdiction, it is assumed that biomass in Hawaiian Electric's RPS report refers to MSW and biomass in KIUC's RPS report refers to wood.

[58] KIUC's reported net electric generation from wood is published as MWh. To represent this value in the flowchart, MWh were converted into Btus using the conversion ratio of 1 MWh = 3.41214 million Btu. The final representation of the flowchart is reported in trillion Btus.

Refer to sections 4.3.5.a and 4.3.5.c to view a detailed description of the two methodologies used to estimate the electric power sector relating to wood.

Wood consumed by the commercial sector represents wood used for commercial purposes other than electric generation and combined heat-and-power plants.

Wood consumed by the industrial sector refers to wood used for manufacturing purposes (e.g., sawmills and planning mills, wood household furniture, paper mills, wet corn milling, raw cane sugar, etc.) and was originally measured by the North American Industry Classification System (NAICS). See SEDS documentation for further reference.

Wood consumed by the residential sector represents wood used for heating and cooking.

Key Assumption(s):

- Net electric generation from wood defined in KIUC's RPS report represents electricity delivered to end use sectors from wood-powered electric generation
- EDA to estimate the electric power sector
    - Both the inputs and outputs of the electric power sector (only pertaining to wood-fueled electric generation) are represented by KIUC's reported net electric generation from wood. No thermal electric generation losses from wood are represented using the EDA.
- GEA to estimate the electric power sector
    - Wood electric generation from the electric power sector is represented by KIUC's reported wood net electric generation.
    - Wood inputs to the electric power sector are derived by back calculating the total energy inputs needed to produce KIUC's reported net electric generation from wood
        - Derivation accomplished by using EPA eGRID's plant nominal heat rates for wood resources
        - Wood inputs to electric generation are equal to KIUC's wood net electric generation summed with estimated generation losses from wood thermal generation.
    - To calculate the thermal electric generation efficiency rate for wood, the plant nominal heat rate for Kauai Biomass Facility (name that appears in EPA eGRID) published in the EPA's eGRID database was used. See section 4.3.5.a for calculations.

Definitions from EIA Glossary:

- **Wood**: Wood and wood products, possibly including scrubs and branches, etc., bought or gathered, and used by direct combustion. [59]
- **Wood energy**: Wood and wood products used as fuel, including round wood (cord wood), limb wood, wood chips, bark, saw dust, forest residues, charcoal, pulp waste, and spent pulping liquor. [60]

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[59] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[60] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

To view KIUC’s RPS reports submitted to the PUC which detail net electric generation quantities, visit the RPS Annual Reports Docket 2007-0008 on the PUC website (https://puc.hawaii.gov/reports/energy-reports/renewable-portfolio-standards-rps-annual-reports/).

For more information on underlying data and assumptions that SEDS used to estimate wood energy consumption, visit the SEDS documentation published on the EIA website (https://www.eia.gov/state/seds/sep_use/notes/use_renew.pdf).

3.2 Products (second column of flowchart)

Products refer to what is consumed by end use sectors for energy-related activities. The products listed below are those that have not already been defined and included in section 3.1 as energy resources. Except for products listed as diesel, electricity, and gasoline, all products (second flowchart column) appear under the same name as when their energy flow is traced back to energy resources (first flowchart column).

3.2.1 Diesel

Distillate fuel oil (DFO) consumed by the ground, marine, and military transport sectors is assumed to be in the form of diesel fuel (the air transport sector representing civil and commercial aviation is not reported by EIA to consume DFO).

No adjustments were made to SEDS estimates of DFO consumed directly for transportation uses. However, the name of the product consumed by the transportation sectors mentioned prior was changed from DFO to "diesel". The flowchart indicates diesel as the product consumed by any transportation sector when SEDS reports DFO consumed for transportation uses.

Key Assumption(s):

- Any DFO indicated by SEDS to be consumed by any transportation sector is consumed as diesel fuel (the air transport sector does not consume DFO)

Definitions from EIA Glossary:

- **Distillate Fuel Oil (DFO):** A general classification for one of the petroleum fractions produced in conventional distillation operations. It includes diesel fuels and fuel oils. Products known as No. 1, No. 2, and No. 4 diesel fuel are used in on-highway diesel engines, such as those in trucks and automobiles, as well as off-highway engines, such as those in railroad locomotives and agricultural machinery. Products known as No. 1, No. 2, and No. 4 fuel oils are used primarily for space heating and electric power generation.[61]
- **Diesel Fuel**: A fuel composed of distillates obtained in petroleum refining operation or blends of such distillates with residual oil used in motor vehicles. The boiling point and specific gravity are higher for diesel fuels than for gasoline.[62]

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[61] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[62] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.2.2 Electricity

The generation of electricity from various energy resources is represented within the second column of the flowchart by the category “electricity”. Though electricity generation is not considered a “product” as per EIA’s definition of the term (in the case of the definition, “fuel” was used as a proxy for “product” since all other categories in the “products” columns are considered fuels or heat sources),[63] electricity delivered to end use sectors is represented in the flowchart in a similar way as are end use sectors’ direct consumption of other energy resources such as petroleum, natural gas, biodiesel, propane, etc. Thus, electricity is represented in the flowchart as a product flowing from the second column (product) to the third column (end use sector).

Electricity, represented in the flowchart as a product consumed by end use sectors, is representative of two types of electric generation:

- Distributed solar electric generation
- Electric power sector generation

On the right-hand side of the flowchart, the “Filtered Views” setting features two electric generation-related selections: “Electricity Generation” and “Electricity Delivered (RPS)”. The primary difference between the two is that “Electricity Generation” includes thermal generation losses in the flowchart and “Electricity Delivered (RPS)” does not include thermal generation losses in the flowchart. Thus, “Electricity Generation” depicts a more nuanced view of the electric power sector that includes generation efficiency and “Electricity Delivered (RPS)” depicts the distribution of kWh deliveries to end use sectors attributed to their resource origin. See Section 2 for more information.

When only viewing distributed solar electric generation (filter to “distributed solar” in the first column representing energy resources), no thermal electric generation losses are calculated, and only the residential sector is assumed to consume most of the electricity generated. A small amount of electricity generated from distributed solar is directed to the ground transport sector to represent electric vehicle (EV) charging that occurs at residencies.

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[63] **Fuel**: “Any material substance that can be consumed to supply heat or power. Included are petroleum, coal, and natural gas (the fossil fuels), and other consumable materials, such as uranium, biomass, and hydrogen.”

The electric power sector is the second element that comprises “electricity”. The electricity generated by the electric power sector can be thought of as the electricity that is delivered to end uses from commercial entities that comprise the statewide electricity grid.

The proportional distribution of electricity to end use sectors that is observed in the original SEDS database was used to allocate electricity consumption across the end use sectors seen in the flowchart. The proportional distributions of electricity to end use sectors that were used for the flowchart are included below, rounded to the nearest tenth of a percent.

- Electricity to commercial sector: 31.4%
- Electricity to industrial sector: 38.2%
- Electricity to residential sector: 30.4%

Representations in the flowchart of electricity being consumed by the ground transport sector (indicative of EV charging) redirect electricity from the commercial and residential sectors to the ground transport sector. It was assumed that SEDS included electricity consumed for electric vehicle charging within the commercial and residential sectors. See section 4.3.9 for more information on EV charging adjustments and associated methodologies.

Generation efficiency losses were calculated for all thermal electric generation resources. However, referring specifically to non-fossil thermal electric generation (biodiesel, geothermal, waste, and wood), two methodologies were used to represent electric generation. See Section 2 for a description of each of the methodologies relevant to biodiesel, geothermal, waste, and wood electric generation.

3.2.3 Gasoline

Motor gasoline and ethanol consumed by the commercial, industrial, air transport, ground transport, and marine transport sectors are assumed to be consumed in the form of a blended fuel are referred to in the flowchart as “gasoline”.

No adjustments were made to SEDS estimates of motor gasoline and ethanol consumed directly by the end use sectors indicated. However, the name of the fuel consumed by the end use sectors listed prior was changed from its respective motor gasoline/ethanol distinction to “gasoline”. This adjustment is how both motor gasoline and ethanol are accounted for in the flowchart.

It is assumed that the motor gasoline-ethanol blend ratio stays constant regardless of the end use sector the blended gasoline fuel is consumed by. The blend ratio was not precalculated, it was derived by the total consumption of motor gasoline and ethanol across end use sectors. Below is the distribution of blending components that comprise the fuel “gasoline” as seen in the flowchart, rounded to the nearest tenth of a percent:

- Motor gasoline: 92.6%
- Ethanol: 7.4%

Gasoline consumed by the commercial sector represents internal combustion engine vehicles.

Gasoline consumed by the industrial sector represents internal combustion engine vehicles used for construction and agriculture.

Gasoline consumed by any transportation sector represents any gasoline-powered airplane, boat, or vehicle with an internal combustion engine.

Key Assumption(s):

- All motor gasoline and ethanol indicated by SEDS to be consumed by any end use sector is consumed as a blended fuel to be referred to as “gasoline”
- The distribution of the blended fuel “gasoline” to end use sectors is determined by the distribution of motor gasoline to its end use sectors as reported by SEDS
- The gasoline blend between motor gasoline and ethanol components remains constant regardless of end use sector consumption

Definitions from EIA Glossary:

- **Motor Gasoline (finished)**: A complex mixture of relatively volatile hydrocarbons with or without small quantities of additives, blended to form a fuel suitable for use in spark-ignition engines. motor gasoline, as defined in ASTM Specification D 4814 or Federal Specification VV-G-1690C, is characterized as having a boiling range of 122 to 158 degrees Fahrenheit at the 10 percent recovery point to 365 to 374 degrees Fahrenheit at the 90 percent recovery point. motor gasoline includes conventional gasoline; all types of oxygenated gasoline, including gasohol; and reformulated gasoline, but excludes aviation gasoline. Note: Volumetric data on blending components, such as oxygenates, are not counted in data on finished motor gasoline until the blending components are blended into the gasoline. [64]
- **Ethanol**: A clear, colorless, flammable alcohol. Ethanol is typically produced biologically from biomass feedstocks such as agricultural crops and cellulosic residues from agricultural crops or wood. Ethanol can also be produced chemically from ethylene. [65]
- **Fuel ethanol (as represented in flowchart):** Ethyl alcohol for fuel use that is produced by the fermentation of sugars. Fuel ethanol is denatured with petroleum products (for example, natural gasoline) to render it unfit for human consumption. [66]

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[64] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[65] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[66] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.2.4 Natural Gas

The fuel “natural gas” consumed by the commercial, industrial, and residential sectors that is a comprised blend of both renewable natural gas (RNG), and synthetic natural gas (SNG) is referred to in the flowchart as “natural gas”.

This product is not to be confused with “still gas” which is consumed solely by the industrial sector as a refinery fuel.

RNG is derived from the Honouliuli Wastewater Treatment Plant Biogas Project. See section 3.1.15 for a full description of RNG.

SNG is derived from naphtha as part of the petroleum refining process. See section 3.1.19 for a full description of SNG.

Since no liquified natural gas (LNG) was reported by SEDS to have been imported to Hawaiʻi in 2022, it was assumed that the product that Hawaiʻi Gas (the sole distributer of natural gas products in Hawaiʻi) delivers to customers is a blend of both locally sourced RNG and SNG. Thus, “natural gas”—as represented the flowchart—does not refer to the commonly known energy resource LNG. “Natural gas” in the flowchart refers to the RNG-SNG blend that is delivered by Hawaiʻi Gas to its customers.

Total natural gas deliveries to end use sectors were estimated by using the SEDS category “supplemental gaseous fuels” (see section 4.3.2 for the methodology used undo the double-counted supplemental gaseous fuels category, and see section 4.3.3 for the methodology of how disaggregating supplemental gaseous fuels into RNG and SNG energy resources occurred).

It is assumed that the RNG-SNG blend ratio stays constant regardless of the end use sector the blended gasoline fuel is consumed by. The blend ratio was not precalculated, it was derived by the total consumption of RNG and SNG across end use sectors (originally reported as one category, supplemental gaseous fuels). Below is the distribution of blending components that comprise the fuel “natural gas” as seen in the flowchart, rounded to the nearest tenth of a percent:

- RNG: 1.1%
- SNG: 98.9%

Natural gas consumed by the commercial sector represents cooking ovens and water heaters.

Natural gas consumed by the industrial sector represents refining and food processing.

Natural gas consumed by any residential sector represents water heating and cooking stoves.

It is assumed that no natural gas is consumed in the transportation sector.

Key Assumption(s):

- All RNG and SNG indicated by SEDS to be consumed by any end use sector is consumed as a blended fuel to be referred to as "natural gas"
- The flowchart fuel "natural gas" is not inclusive of LNG. No LNG was imported to Hawaiʻi in 2022.
- The distribution of the blended fuel "natural gas" to end use sectors is determined by the distribution of the SEDS energy resource "supplemental gaseous fuels" to its end use sectors (the SEDS-defined energy resource that includes both RNG and SNG)
- The natural gas blend between RNG and SNG remains constant regardless of end use sector consumption

Definitions from EIA Glossary:

- **Natural Gas**: A gaseous mixture of hydrocarbon compounds, the primary one being methane. [67]
- **Synthetic Natural Gas (SNG)**: A manufactured product, chemically similar in most respects to natural gas, resulting from the conversion or reforming of hydrocarbons that may easily be substituted for or interchanged with pipeline-quality natural gas. [68]

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[67] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

[68] See EIA Glossary (https://www.eia.gov/tools/glossary/index.php)

3.3 End Uses (third column of flowchart)

The third column of the flowchart represents the end use sectors that consume the energy resources and products outlined in sections 3.1 and 3.2. The seven end use sectors that electricity and fuel consumption occur in are listed as follows:

- Commercial
- Industrial
- Residential
- Air Transport
- Ground Transport
- Marine Transport
- Military Transport

However, when viewing the end use column in the flowchart (third column from the left), an eighth category appears—generation losses. While generation losses appear to be represented as an end use sector in the flowchart, they are not. The flowchart category “generation losses” is a visual representation the energy lost in the electricity generation process.

A description of each of the seven end use sectors follows, along with a description of the visual representation of electric generation losses.

3.3.1 Commercial

The commercial sector represented by the flowchart is representative of the EIA's definition.[69] The primary entities that comprise the commercial sector are listed below:

- Service-providing facilities and equipment of businesses
- Federal, State, and local governments
- Other private and public organizations, such as religious, social, or fraternal groups
- Institutional living quarters[70]
- Sewage treatment facilities

See SEDS documentation for more information.

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[69] EIA definition of *commercial sector*: "An energy-consuming sector that consists of service-providing facilities and equipment of businesses; Federal, State, and local governments; and other private and public organizations, such as religious, social, or fraternal groups. The commercial sector includes institutional living quarters. It also includes sewage treatment facilities. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a wide variety of other equipment. Note: This sector includes generators that produce electricity and/or useful thermal output primarily to support the activities of the above-mentioned commercial establishments."

[70] EIA definition of *institutional living quarters*: "Space provided by a business or organization for long-term housing of individuals whose reason for shared residence is their association with the business or organization. Such quarters commonly have both individual and group living spaces, and the business or organization is responsible for some aspects of resident life beyond the simple provision of living quarters. Examples include prisons; nursing homes and other long-term medical care facilities; military barracks; college dormitories; and convents and monasteries."

3.3.2 Industrial

The industrial sector as represented by the flowchart is representative of the EIA's definition.[71] The primary entities that comprise the industrial sector are listed below:

- All facilities and equipment used for producing, processing, and assembling goods
- Agriculture
- Construction
- Fishing
- Forestry
- Hunting
- Manufacturing
- Mining
- Oil & gas extraction[72]

See SEDS documentation for more information.

3.3.3 Residential

The residential sector as represented by the flowchart is representative of the EIA's definition.[73] The primary entity that comprises the residential sector is listed below:

- Private households (excluding institutional living quarters)

See SEDS documentation for more information.

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[71] EIA definition of *industrial sector*: "An energy-consuming sector that consists of all facilities and equipment used for producing, processing, or assembling goods. The industrial sector encompasses the following types of activity manufacturing (NAICS codes 31-33); agriculture, forestry, fishing and hunting (NAICS code 11); mining, including oil and gas extraction (NAICS code 21); and construction (NAICS code 23). Overall energy use in this sector is largely for process heat and cooling and powering machinery, with lesser amounts used for facility heating, air conditioning, and lighting. Fossil fuels are also used as raw material inputs to manufactured products. Note: This sector includes generators that produce electricity and/or useful thermal output primarily to support the above-mentioned industrial activities. Various EIA programs differ in sectoral coverage."

[72] Not relevant to Hawaiʻi

[73] EIA definition of *residential sector*: "An energy-consuming sector that consists of living quarters for private households. Common uses of energy associated with this sector include space heating, water heating, air conditioning, lighting, refrigeration, cooking, and running a variety of other appliances. The residential sector excludes institutional living quarters. Note: Various EIA programs differ in sectoral coverage."

3.3.4 Air Transport

The air transport sector is one of the seven end use sectors for energy flows. Originally defined within SEDS' all-inclusive transportation sector, specific energy flows were identified to be represented as the air transport sector.

The air transport sector represents all commercial and civil aviation energy uses. No military-related energy consumption is represented by the air transport sector.

Technologies represented by the air transport sector include commercial jet airplanes, commercial aviation not powered by jet engine aircraft, other commercial aviation uses, civil aviation, and private aviation.

3.3.5 Ground Transport

The ground transport sector is one of the seven end use sectors for energy flows. Originally defined within SEDS' all-inclusive transportation sector, specific energy flows were identified to be represented as the ground transport sector.

The ground transport sector represents all commercial, industrial, and civil ground transportation energy uses. No military-related energy consumption is represented by the ground transport sector.

Technologies represented by the ground transport sector include private vehicles, commercial and industrial vehicles, other non-highway vehicles, buses, etc.

3.3.6 Marine Transport

The marine transport sector is one of the seven end use sectors for energy flows. Originally defined within SEDS' all-inclusive transportation sector, specific energy flows were identified to be represented as the marine transport sector.

The marine transport sector represents all commercial, industrial, and civil marine transportation energy uses. No military-related energy consumption is represented by the ground transport sector.

Technologies represented by the marine transport sector include large container ships, tanker ships, commercial vessels, private vessels, etc.

3.3.7 Military Transport

The military transport sector is one of the seven end use sectors for energy flows. Originally defined within SEDS' all-inclusive transportation sector, specific energy flows were identified to be represented as the military transport sector.

The military transport sector represents all transportation energy consumption relating to military uses. Such uses could be for air, ground, or marine purposes, but any military-related transportation energy consumption resides in the military transport sector.

Technologies represented by the military transport sector include jet engine-powered aircraft and diesel engine-powered ground transportation.

Marine transport for military uses is not included in the aggregation of the military transport sector since military/non-military consumption of vessel bunkering fuel is not documented in SEDS or other readily available public data sources. Vessel bunkering fuel is consumed for military purposes (e.g., various-sized warships), but a substantive and well-defensible estimation methodology could not be created from available public data sources. See section 4.3.4 for more information.

3.3.8 Generation Losses

While residing in the flowchart in the same column as the seven defined end use sectors, generation losses (as seen in the flowchart) are not a category to be interpreted as an end use sector.

Generation losses refer to the energy losses incurred in the generation of delivered electricity.

Generation losses were estimated using reported electric plant fuel consumption and plant nominal heat rates. See section 4.3.5 calculations and refer to Section 2 for descriptions of the two methodologies used to estimate generation losses.

3.4 Efficiency (fourth column of flowchart)

Inspired by Lawrence Livermore National Laboratory's (LLNL) energy flowcharts,[74] the last column in the flowchart is a representation of the amount of energy used to perform useful work (i.e., the accomplishment of an intended task resulting from energy consumption) in the seven end use sectors. The last column also provides an estimation of the amount of energy waste in the entire energy system. To this end, there are two efficiency categories represented in the flowchart:

- Energy Used
- Energy Wasted

In the LLNL energy flowcharts, *energy used* is represented as "energy services" and *energy wasted* is represented as "rejected energy". Energy services is defined by LLNL as "useful work output" and rejected energy is defined by LLNL as "waste heat transferred to the environment".[75] There is no energy consuming device with 100% efficiency; energy will always be wasted to some degree.

The energy efficiency is indicated by the ratio between the *energy used* and the *energy wasted*. A highly energy-efficient activity will have a larger *energy used* value relative to *energy wasted*, while a highly energy-inefficient activity will have a larger *energy wasted* value relative to *energy used*. This can be calculated within the seven end use sectors as well as for the entire energy system.

However, there are two sources of wasted energy: first, generation losses attributed to the amount of electricity delivered to an end use sector, and second, the amount of energy that is consumed by an end use sector that is not converted into useful work. Transmission and distribution losses are not represented.

Sections 3.4.1 and 3.4.2 describe both *energy used,* and *energy wasted*. Figure 5 illustrates the distinction between *energy used* and *energy wasted*.

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[74] See Energy Flow Charts, LLNL. https://gs.llnl.gov/energy-homeland-security/energy-security/energy-flow-charts

[75] See Energy Flow Charts, LLNL. https://gs.llnl.gov/energy-homeland-security/energy-security/energy-flow-charts

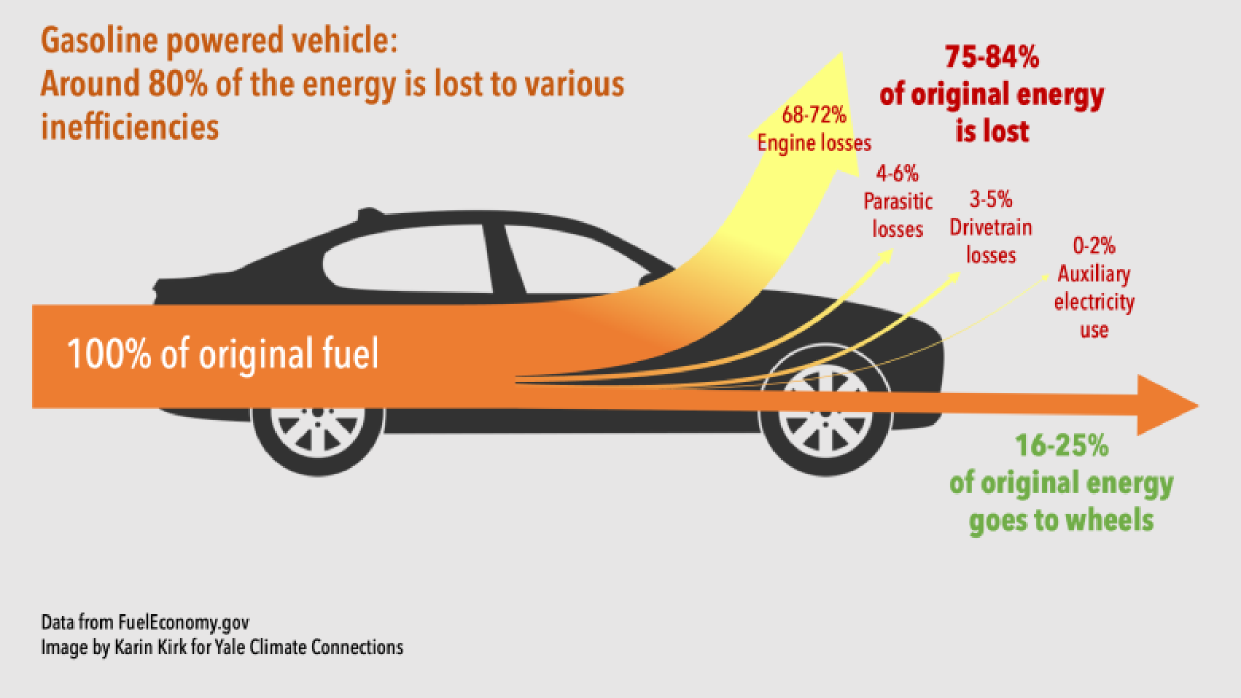

Figure 5 - Energy Efficiency of a Gasoline-Powered Vehicle

In terms of a vehicle powered by a gasoline internal combustion engine (ICE), gasoline is used to power the engine which, in turn, propels the vehicle forward. However, energy losses occur at various stages before the energy generated by the engine reaches the wheels. Energy losses occur as heat within the ICE, from the power train steering system, the drivetrain, and many other areas. The energy used to propel the car forward would be considered *energy used;* the energy lost in the stages before energy is delivered to the wheels would be considered *energy wasted*. Refer to Figure 5 for a visual example of the total energy efficiency of a gasoline-powered vehicle.[76]

Note: The visual represented as Figure 5 was not used to derive the end use efficiency of gasoline-powered ground transport. The methodology used to derive the flowchart's end use efficiency for gasoline-powered ground transport resides in section 4.3.8.

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[76] Kirk, Karin. (2024). Yale Climate Connections. https://yaleclimateconnections.org/2024/01/electric-vehicles-use-half-the-energy-of-gas-powered-vehicles/

3.4.1 Energy Used

The end use efficiency designation *energy used* is a representation of useful work output and is inspired by LLNL's efficiency designation "energy services".

Useful work output refers to energy after an energy conversion process (e.g., electricity powering a fan, gasoline powering a vehicle, propane powering a forklift, etc.) that can be harnessed to perform an intended task.

End use efficiency rates were derived from research and a series of assumptions found in section 4.3.8. For each end use sector, each product consumed was assigned an efficiency rate based on the technologies and consumption practices that are represented by each product.

Refer to section 4.3.8 for methodologies and assumptions made to derive the end use efficiency rates seen in the flowchart.

3.4.2 Energy Wasted

The end use efficiency designation *energy wasted* is a representation of energy consumed that is not transferred into useful work output and is inspired by LLNL's efficiency designation "rejected energy".

Energy wasted is predominantly in the form of heat that is transferred to the environment.[77] When an energy-consuming device within the seven end use sectors is operational, that device's energy efficiency is represented by the magnitude difference between *energy used* and *energy wasted*. A highly energy efficient activity will have a larger *energy used* value while a highly energy inefficient activity will have a larger *energy wasted* value.

End use efficiency rates were derived from research and a series of assumptions found in section 4.3.8. For each end use sector, each product consumed was assigned an efficiency rate based on the technologies and consumption practices that are represented by each product.

Refer to section 4.3.8 for methodologies and assumptions made to derive the end use efficiency rates seen in the flowchart.

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[77] Consistent with LLNL's definition of "rejected energy" which "ultimately takes the form of waste heat transferred to the environment". See LLNI Energy Flow Charts (https://gs.llnl.gov/energy-homeland-security/energy-security/energy-flow-charts).

Section 4 Methodologies

Sections 4.1 through 4.4 include processes of fetching, cleaning, and presenting the data used to construct the flowchart. All manual changes to the original SEDS data are included.

4.1 Fetching raw data

Data collection was done both automatically and manually depending on the data source. For SEDS data, a script was written in the Python programming language to scrape the publicly available EIA API. For all remaining data sources, individual data points were manually extracted from various databases, tables, and publications. A summary of sources is included in Table 2.

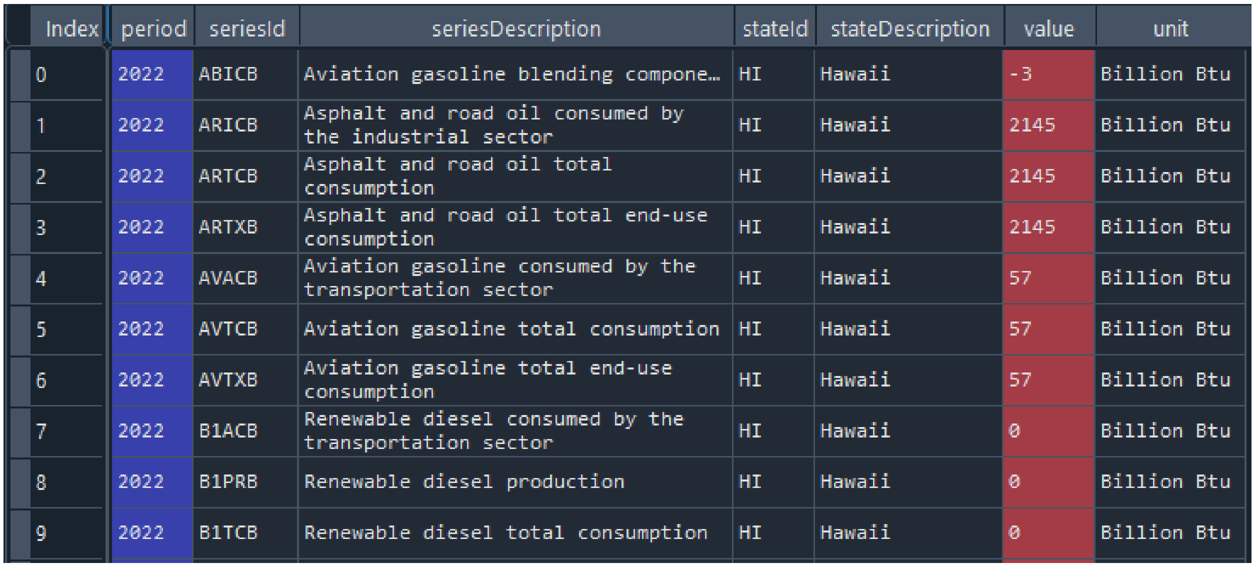
Table 2 - Data source descriptions

Source	Data	Table(s)	Description	Use
U.S. Energy Information Administration (EIA)	SEDS	n/a	Energy flows listed in “Billion Btus” for Hawai‘i	Baseline energy flows
	EIA-821	Sales of Distillate Fuel Oil by End Use	Portions of DFO used in transportation sub-categories	Teasing apart DFO transportation consumption into sub-sectors
	EIA-923	Monthly Generation and Fuel Consumption	Total biodiesel used for electricity generation in “Billion Btus”	Redirecting a portion of biodiesel energy flows into electricity generation
U.S. Environmental Protection Agency (EPA)	eGRID	Plant Year 2022	Plant nominal heat rates	Recalculating electricity generation efficiency percentages for energy resources
Federal Highway Administration (FHWA)	Highway Statistics Series	MF-21, MF-24	Portions of gasoline used in transportation sub-categories	Teasing apart gasoline and ethanol transportation consumption into sub-sectors
Hawai‘i Public Utilities Commission (PUC)	Annual RPS Reports	Docket No. 2007-0008	Renewable energy generation by resource	Defining amount of electricity generated by various energy resources
	Gas Utility Renewable Energy Reports	HRS § 269-45	Total therms of RNG and SNG product produced for use within Hawai‘i	Teasing apart the SEDS energy resource category “supplemental gaseous fuels” into RNG and SNG
Hawai‘i State Energy Office (HSEO)	PATHWAYS Transportation Model	PATHWAYS Energy Demands	Electricity demand in MMBtu for electric ground transportation	Redirecting electricity energy flows to account for electric vehicle energy demand

4.2 Identifying relevant energy flows in SEDS data set

One of the main challenges when navigating the raw SEDS data is determining which categories are inclusive of others. For each end use, energy flows were back calculated to the various energy resources to identify the categories that are not inclusive of any other categories. This was important to ensure that resources were not being double counted anywhere in the flowchart.

Once the raw SEDS data was fetched from the EIA API, the data frame was then filtered to the year 2022, the state of Hawai‘i, and the “billion Btu” unit of measure. This left a 289x7 data frame, the first ten rows appearing below in Figure 6.

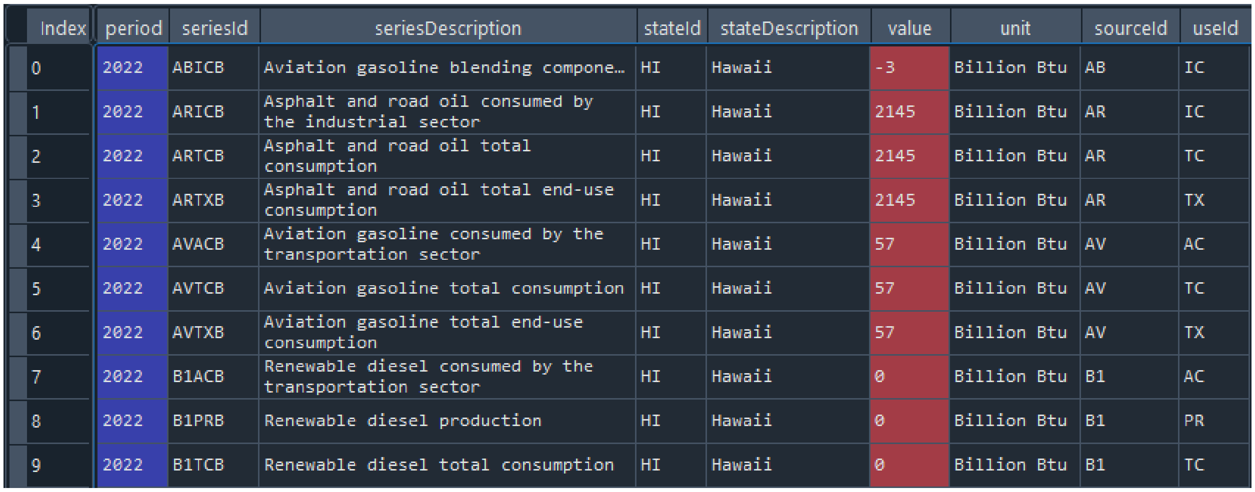


Index	period	seriesId	seriesDescription	stateId	stateDescription	value	unit
0	2022	ABICB	Aviation gasoline blending compone…	HI	Hawaii	-3	Billion Btu
1	2022	ARICB	Asphalt and road oil consumed by the industrial sector	HI	Hawaii	2145	Billion Btu
2	2022	ARTCB	Asphalt and road oil total consumption	HI	Hawaii	2145	Billion Btu
3	2022	ARTXB	Asphalt and road oil total end-use consumption	HI	Hawaii	2145	Billion Btu
4	2022	AVACB	Aviation gasoline consumed by the transportation sector	HI	Hawaii	57	Billion Btu
5	2022	AVTCB	Aviation gasoline total consumption	HI	Hawaii	57	Billion Btu
6	2022	AVTXB	Aviation gasoline total end-use consumption	HI	Hawaii	57	Billion Btu
7	2022	B1ACB	Renewable diesel consumed by the transportation sector	HI	Hawaii	0	Billion Btu
8	2022	B1PRB	Renewable diesel production	HI	Hawaii	0	Billion Btu
9	2022	B1TCB	Renewable diesel total consumption	HI	Hawaii	0	Billion Btu

Figure 6 - Data cleaning checkpoint 1

The next data cleaning step was splitting the “seriesId” column into its component IDs (first two letters representing the energy resource, next two letters representing the energy end use sector, and the last letter representing the unit of measurement). Since all other units of measurement other than “Billion Btu” have been filtered out, only the first 4 letters of the “seriesId” column are of interest.

After creating two new columns named “sourceId” and “useId”, a data frame of dimensions 289x9 was left, the first ten rows appearing on the next page in Figure 7.



Index	period	seriesId	seriesDescription	stateId	stateDescription	value	unit	sourceId	useId
0	2022	ABICB	Aviation gasoline blending compone…	HI	Hawaii	-3	Billion Btu	AB	IC
1	2022	ARICB	Asphalt and road oil consumed by the industrial sector	HI	Hawaii	2145	Billion Btu	AR	IC
2	2022	ARTCB	Asphalt and road oil total consumption	HI	Hawaii	2145	Billion Btu	AR	TC
3	2022	ARTXB	Asphalt and road oil total end-use consumption	HI	Hawaii	2145	Billion Btu	AR	TX
4	2022	AVACB	Aviation gasoline consumed by the transportation sector	HI	Hawaii	57	Billion Btu	AV	AC
5	2022	AVTCB	Aviation gasoline total consumption	HI	Hawaii	57	Billion Btu	AV	TC
6	2022	AVTXB	Aviation gasoline total end-use consumption	HI	Hawaii	57	Billion Btu	AV	TX
7	2022	B1ACB	Renewable diesel consumed by the transportation sector	HI	Hawaii	0	Billion Btu	B1	AC
8	2022	B1PRB	Renewable diesel production	HI	Hawaii	0	Billion Btu	B1	PR
9	2022	B1TCB	Renewable diesel total consumption	HI	Hawaii	0	Billion Btu	B1	TC

Figure 7 - Data cleaning checkpoint 2

The “sourceId”, “useId”, “seriesId”, and “value” columns were used to filter the energy flows to only the categories necessary for the analysis. The categories that were excluded from the analysis in the following order:

- “useId”: 'PR', 'SC', 'TC', 'TX'
- “sourceId”: 'BF', 'DK', 'HL', 'MG', 'P1', 'P5', 'PA', 'PE', 'PM', 'RE', 'SF'[78], 'TE', 'TN', 'WW'
- “seriesId”: 'BDFDB', ‘DFACB’, 'DFASB', 'DFICB', 'ESISB', 'ESRFB', 'NGISB', ‘OPACB’, 'PQISB', 'RFISB', 'WDRSB', 'WDRXB'
- “value”: numbers less than or equal to zero

After all filters were applied, a data frame of dimensions 52x9 remained, the first ten rows appearing in Figure 8.

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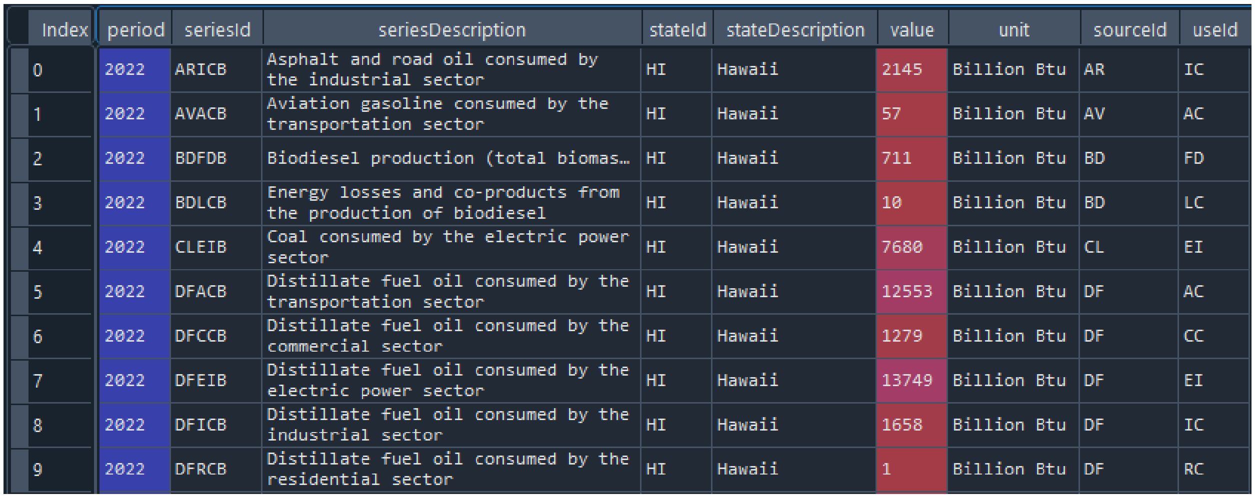
[78] Supplemental gaseous fuels (“sourceId” of ‘SF’) were removed in data cleaning, but their energy flow values were stored in the data cleaning Python3 script before being filtered out. Supplemental gaseous fuels are double counted in the ‘natural gas’ category seen in “sourceId”. ‘Supplemental gaseous fuels’ energy flows were added back in manually after their value was subtracted from the ‘natural gas’ energy flows. It is not necessary to filter out ‘supplemental gaseous fuels’ at this stage of data cleaning if their energy flow values are subtracted from ‘natural gas’ energy flows.



Index	period	seriesId	seriesDescription	stateId	stateDescription	value	unit	sourceId	useId
0	2022	ARICB	Asphalt and road oil consumed by the industrial sector	HI	Hawaii	2145	Billion Btu	AR	IC
1	2022	AVACB	Aviation gasoline consumed by the transportation sector	HI	Hawaii	57	Billion Btu	AV	AC
2	2022	BDFDB	Biodiesel production (total biomas…	HI	Hawaii	711	Billion Btu	BD	FD
3	2022	BDLCB	Energy losses and co-products from the production of biodiesel	HI	Hawaii	10	Billion Btu	BD	LC
4	2022	CLEIB	Coal consumed by the electric power sector	HI	Hawaii	7680	Billion Btu	CL	EI
5	2022	DFACB	Distillate fuel oil consumed by the transportation sector	HI	Hawaii	12553	Billion Btu	DF	AC
6	2022	DFCCB	Distillate fuel oil consumed by the commercial sector	HI	Hawaii	1279	Billion Btu	DF	CC
7	2022	DFEIB	Distillate fuel oil consumed by the electric power sector	HI	Hawaii	13749	Billion Btu	DF	EI
8	2022	DFICB	Distillate fuel oil consumed by the industrial sector	HI	Hawaii	1658	Billion Btu	DF	IC
9	2022	DFRCB	Distillate fuel oil consumed by the residential sector	HI	Hawaii	1	Billion Btu	DF	RC

Figure 8 - Data cleaning checkpoint 3

To further clean the raw SEDS data, each “sourceId” and “useId” was mapped to the category’s full name. Each mapping is represented on the next two pages in Table 3 and Table 4.

Table 3 - Mapping energy resources with their Source IDs

Source Name (as appears in SEDS)	Source IDs	Petroleum (T/F)	Fossil (T/F)
Asphalt & Road Oil	‘AR’	True	True
Aviation Gasoline	‘AV’	True	True
Biodiesel	'BD'	False	False
Coal	'CL'	False	True
Distillate Fuel Oil	'DF', 'DM'	True	True
Ethanol	'EM'	False	False
Electricity[79]	'ES', 'LO'	n/a	n/a
Geothermal	'GE'	False	False
Hydroelectric	'HY'	False	False
Jet Fuel	'JF'	True	True
Lubricants	'LU'	True	True
Motor Gasoline	'MM'	True	True
Natural Gas	'NG', 'SG'	False	True
Onshore Wind	'WY'	False	False
Other Petroleum Products	'OP'	True	True
Propane	'PQ'	True	True
Residual Fuel Oil	'RF'	True	True
Solar	'SO'	False	False
Unfinished Oils	'UO'	True	True
Waste	'WS'	False	False
Wood	'WD'	False	False

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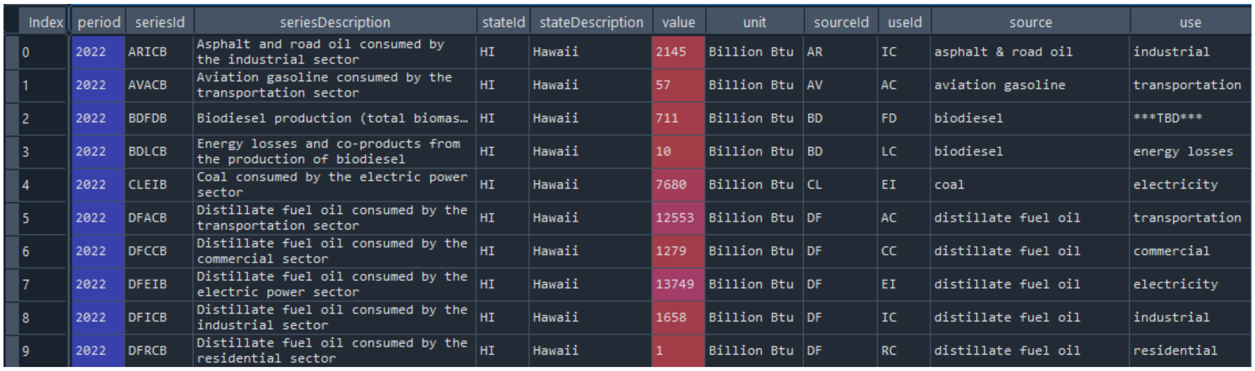
[79] Regarding the two listed Source IDs for Electricity, ‘ES’ refers to electricity delivered to end uses and ‘LO’ refers to the energy generation and distribution losses associated to the amount of electricity delivered to end uses.

Table 4 - Mapping energy use sectors with their Use IDs

Use Name (as appears in SEDS)	Use ID
Commercial	'CC'
Industrial	'IC', 'IS', 'RF'
Residential	'RC', 'RS', 'RX'
Transportation	'AC'
Electricity Generation	'EG', 'EI'
Energy Losses	'LC'

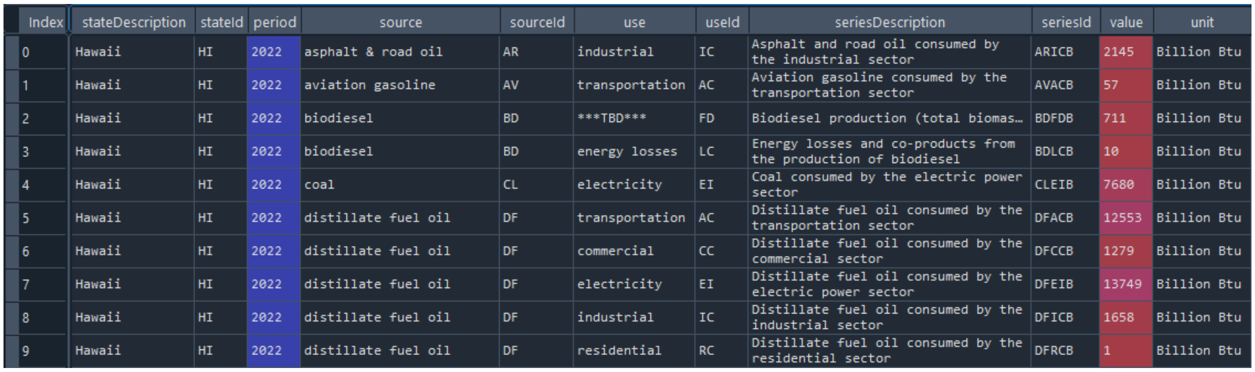
The names of each source and use where included in the new data frame columns "source" and "use" when their associated ID were mapped. After mapping "sourceId" and "useId" columns to their category names, a data frame of dimensions 52x11 remained, the first ten rows appearing below in Figure 9.



Index	period	seriesId	seriesDescription	stateId	stateDescription	value	unit	sourceId	useId	source	use
0	2022	ARICB	Asphalt and road oil consumed by the industrial sector	HI	Hawaii	2145	Billion Btu	AR	IC	asphalt & road oil	industrial
1	2022	AVACB	Aviation gasoline consumed by the transportation sector	HI	Hawaii	57	Billion Btu	AV	AC	aviation gasoline	transportation
2	2022	BDFDB	Biodiesel production (total biomas…	HI	Hawaii	711	Billion Btu	BD	FD	biodiesel	***TBD***
3	2022	BDLCB	Energy losses and co-products from the production of biodiesel	HI	Hawaii	10	Billion Btu	BD	LC	biodiesel	energy losses
4	2022	CLEIB	Coal consumed by the electric power sector	HI	Hawaii	7680	Billion Btu	CL	EI	coal	electricity
5	2022	DFACB	Distillate fuel oil consumed by the transportation sector	HI	Hawaii	12553	Billion Btu	DF	AC	distillate fuel oil	transportation
6	2022	DFCCB	Distillate fuel oil consumed by the commercial sector	HI	Hawaii	1279	Billion Btu	DF	CC	distillate fuel oil	commercial
7	2022	DFEIB	Distillate fuel oil consumed by the electric power sector	HI	Hawaii	13749	Billion Btu	DF	EI	distillate fuel oil	electricity
8	2022	DFICB	Distillate fuel oil consumed by the industrial sector	HI	Hawaii	1658	Billion Btu	DF	IC	distillate fuel oil	industrial
9	2022	DFRCB	Distillate fuel oil consumed by the residential sector	HI	Hawaii	1	Billion Btu	DF	RC	distillate fuel oil	residential

Figure 9 - Data cleaning checkpoint 4

After reordering the data frame columns for visual appeal, the final cleaned data frame was of dimensions 52x11, the first ten rows appearing on the next page in Figure 10.



Index	stateDescription	stateId	period	source	sourceId	use	useId	seriesDescription	seriesId	value	unit
0	Hawaii	HI	2022	asphalt & road oil	AR	industrial	IC	Asphalt and road oil consumed by the industrial sector	ARICB	2145	Billion Btu
1	Hawaii	HI	2022	aviation gasoline	AV	transportation	AC	Aviation gasoline consumed by the transportation sector	AVACB	57	Billion Btu
2	Hawaii	HI	2022	biodiesel	BD	***TBD***	FD	Biodiesel production (total biomas…	BDFDB	711	Billion Btu
3	Hawaii	HI	2022	biodiesel	BD	energy losses	LC	Energy losses and co-products from the production of biodiesel	BDLCB	10	Billion Btu
4	Hawaii	HI	2022	coal	CL	electricity	EI	Coal consumed by the electric power sector	CLEIB	7680	Billion Btu
5	Hawaii	HI	2022	distillate fuel oil	DF	transportation	AC	Distillate fuel oil consumed by the transportation sector	DFACB	12553	Billion Btu
6	Hawaii	HI	2022	distillate fuel oil	DF	commercial	CC	Distillate fuel oil consumed by the commercial sector	DFCCB	1279	Billion Btu
7	Hawaii	HI	2022	distillate fuel oil	DF	electricity	EI	Distillate fuel oil consumed by the electric power sector	DFEIB	13749	Billion Btu
8	Hawaii	HI	2022	distillate fuel oil	DF	industrial	IC	Distillate fuel oil consumed by the industrial sector	DFICB	1658	Billion Btu
9	Hawaii	HI	2022	distillate fuel oil	DF	residential	RC	Distillate fuel oil consumed by the residential sector	DFRCB	1	Billion Btu

Figure 10 - Data cleaning checkpoint 5

What follows in section 4.3 are the manual adjustments to the energy flows in the SEDS data that is represented in the data frame seen above in Figure 10. Taking a closer look and incorporating local knowledge of the Hawaiʻi energy system, some edge cases were found not to be represented in the SEDS data set. Section 4.3 identifies each of these major adjustments that were made to the SEDS data set to properly represent the holistic energy system in Hawaiʻi.

4.3 Manual adjustments to energy flows

Note: In the following sub-sections of section 4.3, the term “energy flows” refers to the quantity of energy (represented as billion Btus) moving left-to-right from one column category to another.

4.3.1 Biodiesel consumption adjustments

The flowchart assumes that biodiesel is consumed by both the electric power sector and the ground transport sector.

Hawaiian Electric’s RPS report provided the electric generation value, EPA eGRID data informed biodiesel’s electric generation efficiency percentage (when accounting for electric generation using the Generation Efficiency Approach (GEA)), and SEDS informed the ground transport consumption value. In addition to this information, further assumptions were needed to derive the biodiesel information represented in the flowchart.

SEDS originally published under the assumption that all biodiesel consumption in Hawaiʻi is directed to transportation uses (e.g., 739 billion Btus in 2022). For the flowchart, it is then assumed that the only specific transportation sector to consume biodiesel is ground transport (refer to section 3.1.3). However, Form EIA-923 indicates that biodiesel is also used for electric generation. To account for biodiesel being consumed for electric generation, the following methodology was used to redirect the proper amount of biodiesel from the ground transport sector to the electric power sector.

Since all resource-specific electric generation values were set to the published MWh values in Hawaiian Electric’s and KIUC’s RPS reports, biodiesel-related electric generation in 2022 was reported at 63,144 MWh (216 billion Btus).

Thus, using the Electricity Delivered Approach (EDA), total biodiesel consumption for electricity generation was 216 billion Btus (see section 2.2 for more information).

When calculating biodiesel consumption for electricity generation using the GEA, one additional step was taken. When applying the 36% electric generation efficiency for biodiesel (see section 4.3.5 for methodology), the total consumption of biodiesel for electric generation was calculated to be 598 billion Btus. In other words, 598 billion Btus of biodiesel were consumed to produce 216 billion Btus of electricity, resulting in an electric generation loss of 383 billion Btus. Thus, when using the GEA methodology, total biodiesel consumption for electricity generation is 598 billion Btus.

To estimate biodiesel consumption by the ground transport sector, SEDS data had to be analyzed further after calculating consumption by the electric power sector derived above.

The value that SEDS publishes for biodiesel consumed by the ground transport sector is 739 billion Btus. However, based on the assumption found in the SEDS documentation, this value is inclusive of biodiesel consumed as products by all sectors (i.e., the electric power and ground transport sectors) and is inclusive of generation losses.

To estimate biodiesel consumption by the ground transport sector, two energy flows were added together:

- Total biodiesel consumption as reported by SEDS (739 billion Btus), minus biodiesel consumed by the electric power sector as reported by Form EIA-923 (553 billion Btus)
    - The 553 billion Btus of biodiesel consumed by the electric power sector as reported by EIA's Form EIA-923 is not to be confused by the GEA-calculated 598 billion Btus of biodiesel consumed for electricity generation. The 553 billion Btus is a value published by EIA (not seen in flowchart) and the 598 billion Btus derived using the GEA (leveraging PUC RPS reports and EPA eGRID data). Despite the GEA consumption value of 598 billion Btus being used in the flowchart, the SEDS consumption value of 553 billion Btus was subtracted from the SEDS's total consumption value of 739 billion Btus to keep the underlying data sources the same.
    - Value calculated to be 186 billion Btus
- Biofuels product supplied (seen as the only relevant sub-category that derives the "Other Petroleum Resources" category) consumed for transportation uses as reported by SEDS (434 billion Btus)
    - SEDS's error category (see SEDS documentation for more information)

When added together, total biodiesel consumed by the ground transport sector is 620 billion Btus.

To verify this calculation, the estimated biodiesel consumption in ground transportation by SEDS is used. SEDS assumed that biodiesel consumption for transportation uses equates to 5% of diesel consumed for transportation uses (12,553 billion Btus). Using this assumption, 628 billion Btus of biodiesel should be consumed in the ground transport sector (12,553 billion Btus multiplied by 0.05). This difference between this value and the value calculated above is negligible, thus, validating the methodology.

SEDS documentation states that biofuel products supplied is a resource category "that is not reconcilable with EIA's collected survey data and includes supply of biodiesel, renewable diesel, and other biofuels (such as B100 biodiesel and R100 renewable diesel fuel) that are not reported as inputs on EIA surveys."[80] As stated in SEDS documentation, this error category is not to be interpreted as biofuel consumption. Biofuels product supplied is used as a proxy for fuel consumption to account for shortcomings in reporting. As stated in the previous paragraph, adding the 186 billion Btus of biodiesel consumed by ground transport to the 434 billion Btus of biofuels product supplied consumed by the ground transport sector reconciles the assumption made by SEDS that total biodiesel consumption by the ground transport sector equates to 5% of diesel consumption by the ground transport sector.[81]

The manual redirection of energy flows is summarized below in four steps.

1. Identified total biodiesel consumption across the electric power sector and transportation uses to be 739 billion Btus from SEDS data
2. Initialized new biodiesel consumption values for the electric power sector based on electric generation methodology
    a. Biodiesel to electric power sector from RPS report data
        i. EDA: 216 billion Btus
        ii. GEA: 598 billion Btus
3. Recalculated a new biodiesel consumption value for the ground transport sector from SEDS biodiesel consumption data and Form EIA-923 biofuels product supplied data
    a. Biodiesel to ground transport: 620 billion Btus

There are two key assumptions that underly this manual redirection of biodiesel energy flows:

- SEDS grouped all biodiesel consumption into a single use category (transportation); another EIA data source consistent with SEDS (Form EIA-923) reports biodiesel being used for electricity generation
- The remaining balance of biodiesel not used for electricity generation was used by the ground transport sector in addition to biofuels product supplied
    - Validated by SEDS's assumption that total biodiesel consumption for transportation purposes is 5% that of total diesel consumption for transportation purposes

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[80] See page 96 of SEDS documentation, "Biofuels (excluding fuel ethanol) product supplied". https://www.eia.gov/state/seds/sep_use/notes/use_technotes.pdf

[81] Actual statewide biodiesel consumption may differ.

4.3.2 Adjusting for double-counted supplemental gaseous fuels

Supplemental gaseous fuels are double-counted in the SEDS data. Aside from being represented as its own energy flow under the name “supplemental gaseous fuels”, the same energy flow is counted within the resource category “natural gas”. There are many energy resources that comprise the supplemental gaseous fuels category, but only two are relevant to Hawaiʻi: renewable natural gas (RNG) and synthetic natural gas (SNG). Thus, both RNG and SNG must be subtracted from the energy resource category “natural gas” to avoid being double-counted.

RNG and SNG are consumed together as a single gas product which is represented in the SEDS database as “natural gas”. [82] The other relevant resource categories that “natural gas” could include are liquified natural gas (LNG) and propane. However, no LNG is consumed within Hawaiʻi in 2022 according to SEDS. Additionally, propane is not included in the RNG-SNG blended gas since it is already accounted for in the energy resource category “propane”. Thus, it is assumed that the “natural gas” resource category that is seen in the SEDS data set for is representative of only RNG and SNG. “Natural gas” is seen in the second column of the flowchart as the energy product consumed by end use sectors.

Below summarizes the methodology for how “supplemental gaseous resources” energy flows were subtracted from “natural gas” energy flows to avoid being double-counted. See section 4.3.3 for more information on how RNG and SNG were later derived from the “supplemental gaseous fuels” energy flows.

Once “supplemental gaseous fuels” were subtracted from “natural gas” in the commercial and residential sectors, the remaining values were reassigned from being classified as “natural gas” to being classified as SNG. This assumption is made for 2022 since RNG production is known and SNG production is not publicly available.

Important to note is that the new SNG flows to the commercial and residential sectors that were derived from the remaining “natural gas” after supplemental gaseous fuels were subtracted are not the final SNG flows as seen in the flowchart. Once the supplemental gaseous fuels resource category are later split into separate RNG and SNG energy resources as described in section 4.3.3, the SNG values that are represented in the flowchart will be the sum of both SNG consumption values described (the leftover value of “natural gas” after subtracting supplemental gaseous fuels, and the SNG portion of supplemental gaseous fuels).

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[82] See Hawaii Gas (https://www.hawaiigas.com/clean-energy/decarbonization)

Once “supplemental gaseous fuels” were subtracted from “natural gas” in the industrial sector, a remainder of 4 billion Btus of natural gas was left. However, this remaining 4 billion Btus of “natural gas” is already accounted for as the “still gas” energy resource. Thus, this energy flow is deleted.

After “supplemental gaseous fuels” are separated from “natural gas”, “supplemental gaseous fuels” are teased apart into its relevant energy resources of RNG and SNG (described in section 4.3.3).

The methodology to remove double counted supplemental gaseous fuels from the natural gas energy flows is described below in three steps.

1. Collect energy flow values of supplemental gaseous fuels delivered to each end use category.
2. Identify all natural gas energy flows to end use categories.
3. For each end use category, subtract the energy flow of supplemental gaseous fuels to the end use category from the energy flow of natural gas to the end use category. Any remainder within the commercial and residential sectors is assumed to be SNG. Any remainder within the industrial sector is already accounted for as still gas and is deleted.

Refer to Table 5 for the manual changes in energy flow values. The column “Adjusted Value” are the energy flow values that do not include any double counted energy flows.

Table 5 - Removing double counted supplemental gaseous fuels counted as natural gas (billion Btus)

Resource	End use Sector	Original Energy Flows (billion Btus)	Adjusted Energy Flow (billion Btus)
Supplemental Gaseous Fuels **(to be broken into RNG and SNG later as described in section 4.3.3)**	Commercial	1,990	
	Industrial	79	
	Residential	517	
Natural Gas **(original SEDS resource category which included double-counted supplemental gaseous fuels)**	Commercial	2,113	0
	Industrial	83	0
	Residential	549	0
SNG **(leftover “natural gas” value after supplemental gaseous fuels are excluded—not final values seen in flowchart)**	Commercial	n/a	123
	Industrial	n/a	0 (remainder of 4 is deleted since it is already counted as still gas)
	Residential	n/a	32

4.3.3 Deriving RNG and SNG energy flows from supplemental gaseous fuels

After extracting supplemental gaseous fuels from SEDS’ energy resource category “natural gas”[83] so that supplemental gaseous fuels are not double counted, what is left are synthetic natural gas (SNG) energy flows to the commercial and residential sectors, and supplemental gaseous fuel energy flows to the commercial, industrial, and residential sectors. See section 4.3.2 for how these values were calculated.

Among many feedstocks listed in the EIA’s definition of “supplemental gaseous fuels”,[84] two listed were relevant to Hawaiʻi: RNG[85] and SNG. RNG is produced by harnessing biogas[86] at the Honouliuli Wastewater Treatment Plant. The final RNG product is delivered in the form of biomethane. SNG is produced in Hawaiʻi from naphtha, considered a byproduct in the refining process.

To determine the proportions of RNG and SNG within the “supplemental gaseous fuels” value, the 2022 Annual Renewable Energy Report delivered by Hawaiʻi Gas to the Hawaiʻi Public Utilities Commission (PUC) was referenced, as described in section 1.4.2. The 2022 Annual Renewable Energy Report includes the following regarding RNG production:

- The Honouliuli Wastewater Treatment Plant Biogas Project upgrades 288,734 therms of biogas to biomethane (i.e., RNG).

Converting 288,734 therms into billion Btus, total RNG production is estimated at 28.87 billion Btus in 2022.[87]

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[83] The SEDS energy resource category “natural gas” is inclusive of both RNG and SNG along with an assumed 4 billion Btus of still gas consumed in the industrial sector.

[84] “Any gaseous substance introduced into or commingled with natural gas that increased the volume available for disposition. Such substances include, but are not limited to, propane-air, refinery gas, coke-oven gas, still gas, manufactured gas, biomass gas, or air or inerts added for Btu stabilization.” See EIA Glossary for definition. https://www.eia.gov/tools/glossary/index.php?id=Supplemental%20gas

[85] The official feedstock that was listed in the EIA’s definition of “supplemental gaseous fuels” was “biomass gas”, which is inclusive of RNG. For simplicity, RNG is the energy resource that was stated.

[86] Biogas feedstock used for RNG production consists of carbon dioxide, biomethane, water, and hydrogen sulfide according to the landing page published by Hawaii Gas that describes the RNG production operation. See landing page on the Hawaii Gas website. https://www.hawaiigas.com/sustainability/renewable-natural-gas#:~:text=Hawai'i%20Gas%20pioneered%20capturing,equal%20to%20400%20cars%20yearly.

[87] Multiply therms by 0.0001 to convert to billion Btus

Table 6 shows the derivation of RNG and SNG energy flows. Since RNG energy flows are reported and the total amount of natural gas product is reported, the remaining natural gas product after subtracting RNG is assumed to be SNG. These percentages are shown in the "Percent of Original SEDS Energy Flow" column. The "Original SEDS Energy Flow" and "Percent of Original SEDS Energy Flow" columns were multiplied together to derive the preliminary energy flow seen in the "Energy Flow" column. See Table 6 below.

Table 6 – Derivation of RNG and SNG energy flows

Original SEDS Resource	End use Sector	Original SEDS Energy Flow	Flowchart Resource	Percent of Original SEDS Energy Flow	Energy Flow
Natural Gas (leftover "natural gas" after subtracting supplemental gaseous fuels)	Commercial	123	SNG	100%	123
	Residential	32	SNG	100%	32
Supplemental Gaseous Fuels	Commercial	1990	RNG	1.1165%	22.22
			SNG	98.8835%	1967.78
	Industrial	79	RNG	1.1165%	0.88
			SNG	98.8835%	78.12
	Residential	517	RNG	1.1165%	5.77
			SNG	98.8835%	511.23

Lastly, SNG flows within end use sectors must be summed together. In particular, Table 6 indicates two separate SNG energy flows each for the commercial and residential sector: one that represents the existing leftover "natural gas" once supplemental gaseous fuels were excluded, and one that is derived from the splitting of supplemental gaseous fuels into separate RNG and SNG energy resources. These two SNG energy flows are added together to derive the final flowchart energy flow. See Table 7 on the following page.

Table 7 – Derivation of end use sector consumption of natural gas product comprised of RNG and SNG

Flowchart Product (product that is consumed by end use sector)	End use Sector	Flowchart Resource	Energy Flow for Resource to End use Sector (billion Btus)	Energy Flow for Product to End use Sector (billion Btus)	Total Natural Gas Product Consumed (billion Btus)
Natural Gas	Commercial	RNG	22.22	2,113	2,741
		SNG	2,090.78		
	Industrial	RNG	0.88	79	
		SNG	78.12		
	Residential	RNG	5.77	549	
		SNG	543.23		

All RNG and SNG (represented as product “natural gas”) are assumed to be blended and consumed by end use sectors with the same universal composition proportions. Natural gas is then consumed by the various end use sectors.

The methodology of distributing energy flows from the “supplemental gaseous fuels” SEDS resource category into separate RNG and SNG energy resource categories is summarized below:

1. Fetched total energy flows for the SEDS energy resource “supplemental gaseous fuels”
2. Fetched total RNG production from the Hawaiʻi Gas Annual Renewable Energy Report delivered to the PUC. Convert the reported value from therms to billion Btus.
3. Subtracted RNG production energy flows (in billion Btus) from the total energy flows of “supplemental gaseous fuels” and assign the remainder to represent SNG.
4. Distribute to end use sectors consumed as the blended product “natural gas”
5. Confirmed two newly calculated energy flows:
    a. RNG-to-Natural Gas: 28.87 billion Btus
    b. SNG-to-Natural Gas: 2,712.13 billion Btus

This methodology to derive RNG and SNG energy flows relies on two key assumptions.

- The SEDS energy resource “supplemental gaseous fuels” is representative of both RNG and SNG (there are more categories included, but RNG and SNG are the only ones relevant to natural gas consumption in Hawaiʻi)
- After subtracting derived RNG energy flows from “supplemental gaseous fuels”, the remainder is assumed to be SNG

4.3.4 Deriving air, ground, marine, and military transport sectors

SEDS data aggregates all transportation sector consumption (air, ground, marine, military, etc.) into a single transportation sector value. To estimate the energy flow values for each of the transportation end use sectors, data published by both the EIA and Federal Highway Administration (FHWA)—part of the U.S. Department of Transportation (DOT)—helped construct an array of assumptions to distribute energy flows into each transportation sector.

The transportation end use sectors are defined as such:

- Air Transport: Commercial and civilian aviation (airlines, cargo, private, charter, etc.)
- Ground Transport (personal vehicles, public transportation, etc.)
- Marine Transport (large ships, commercial vessels, private vessels, etc.)
- Military Transport (diesel-powered vehicles and jet fuel-powered aircraft)
    - Excludes RFO (e.g., vessel bunkering fuel) used to power large ships (see section 3.3.7 for more information)

The first round of classifying energy resources to their associated transportation sector is based on the assumptions listed below in Table 8. These energy resources are to have only a single transportation use within a single transportation sector.

Table 8 – Transportation sector energy resource allocation (single sector delivery)

Source	Transportation Sector	Reasoning
Aviation Gasoline	Air Transport	Fuel type specific to small-sized airplanes.
Biodiesel	Ground Transport	Biodiesel not consumed for electricity generation is assumed to be consumed for ground transportation[88, 89]
Residual Fuel Oil	Marine Transport	Fuel type specific to large ships. No substantive public data to split RFO into military/non-military uses, so all RFO was assumed to be consumed for non-military purposes.

The remaining energy resources are used for transportation in various ways, requiring additional analysis to properly allocate their energy flows to the appropriate transportation

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[88] See Pacific Biodiesel's landing page, "Where to Buy Biodiesel". https://biodiesel.com/where-to-buy-biodiesel/

[89] See the U.S. Department of Energy's landing page mapping biodiesel fueling station in the United States and Canada. https://afdc.energy.gov/fuels/biodiesel-locations#/find/nearest?fuel=BD&location=hawaii

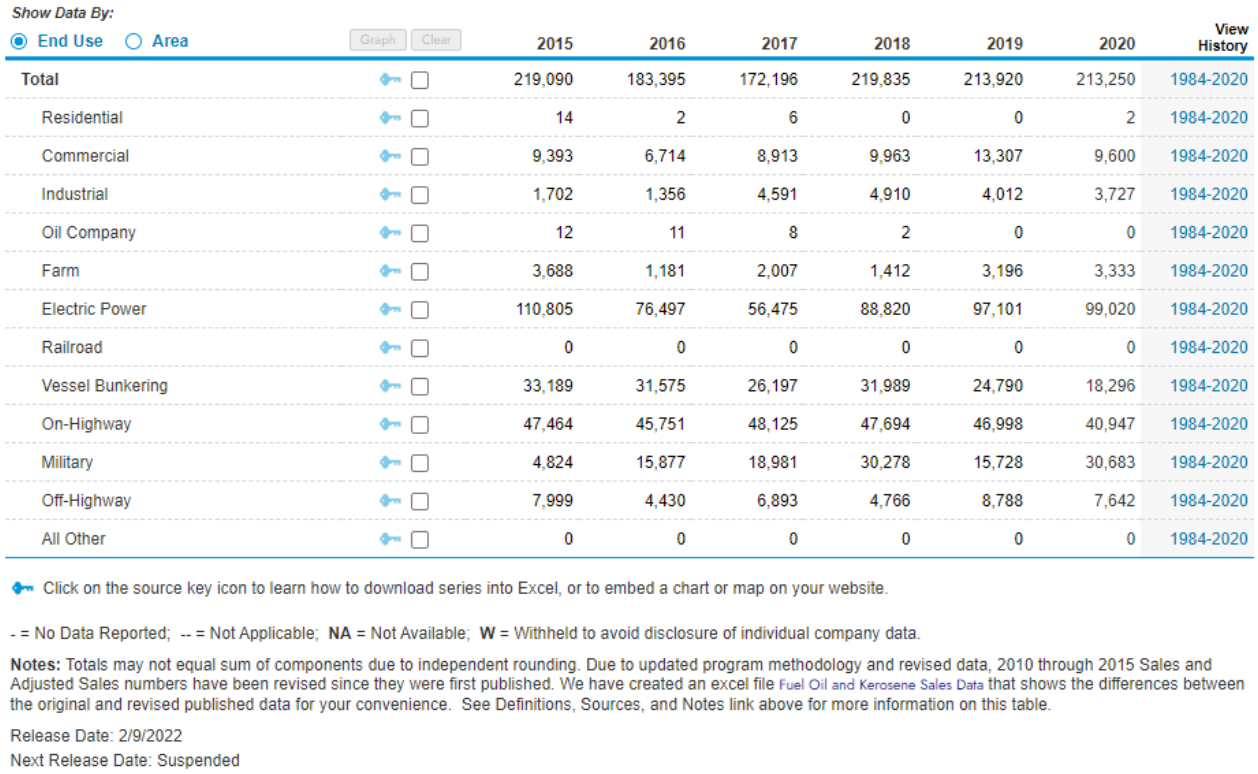
sectors. Table 9 lists the relevant transportation sector for each remaining transportation-related energy resource.

Table 9 – Transportation sector energy resource allocation (multiple sub-sector deliveries)

Resource	Fuel	Relevant Transportation Sectors (proportional allocation described in methodology)
Distillate Fuel Oil	Diesel	Ground Transport, Marine Transport, Military Transport
Ethanol	Gasoline	Air Transport, Ground Transport, Military Transport
Motor Gasoline		
Jet Fuel	Jet Fuel	Air Transport, Military Transport
Lubricants	Lubricants	Ground, Marine, Military

4.3.4.a Allocation of distillate fuel oil (DFO)

Distributing DFO energy flows to its estimated transportation sectors was accomplished using information provided by Form EIA-821 table “Sales of Distillate Fuel Oil by End Use” described in section 1.1.2 (the table). See a screenshot of the table below as Figure 11.



Show Data By:
● **End Use** ○ **Area**

		2015	2016	2017	2018	2019	2020	View History
Total	☐	219,090	183,395	172,196	219,835	213,920	213,250	1984-2020
Residential	☐	14	2	6	0	0	2	1984-2020
Commercial	☐	9,393	6,714	8,913	9,963	13,307	9,600	1984-2020
Industrial	☐	1,702	1,356	4,591	4,910	4,012	3,727	1984-2020
Oil Company	☐	12	11	8	2	0	0	1984-2020
Farm	☐	3,688	1,181	2,007	1,412	3,196	3,333	1984-2020
Electric Power	☐	110,805	76,497	56,475	88,820	97,101	99,020	1984-2020
Railroad	☐	0	0	0	0	0	0	1984-2020
Vessel Bunkering	☐	33,189	31,575	26,197	31,989	24,790	18,296	1984-2020
On-Highway	☐	47,464	45,751	48,125	47,694	46,998	40,947	1984-2020
Military	☐	4,824	15,877	18,981	30,278	15,728	30,683	1984-2020
Off-Highway	☐	7,999	4,430	6,893	4,766	8,788	7,642	1984-2020
All Other	☐	0	0	0	0	0	0	1984-2020

Click on the source key icon to learn how to download series into Excel, or to embed a chart or map on your website.

- = No Data Reported; -- = Not Applicable; **NA** = Not Available; **W** = Withheld to avoid disclosure of individual company data.

Notes: Totals may not equal sum of components due to independent rounding. Due to updated program methodology and revised data, 2010 through 2015 Sales and Adjusted Sales numbers have been revised since they were first published. We have created an excel file Fuel Oil and Kerosene Sales Data that shows the differences between the original and revised published data for your convenience. See Definitions, Sources, and Notes link above for more information on this table.

Release Date: 2/9/2022
Next Release Date: Suspended

Figure 11 - Sales of distillate fuel oil by end use (EIA)

The values in Figure 11 that were used to distribute DFO into its transportation sectors were from the year 2019 (most recent year reported that was not skewed by the COVID-19 pandemic) and are listed on the following page in Table 10.[90]

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[90] See EIA, Sales of Distillate Fuel Oil by End Use. https://www.eia.gov/dnav/pet/pet_cons_821dst_dcu_SHI_a.htm

Table 10 – Transportation sector distillate fuel oil (DFO) allocation

Form EIA-821 Transportation Category	Transportation Sector	DFO Retail Deliveries (thousand gallons)[91]	DFO Percentage	Adjusted Energy Flows (billion Btu)
On-Highway	**Ground Transport**	55,786	57.9%	7,271.57
Off-Highway				
Vessel Bunkering	**Marine Transport**	24,790	25.7%	3,231.32
Military	**Military Transport**	15,728	16.3%	2,050.11
Total	**n/a**	**96,304**	**100%**	**12,553**

Using the percentages derived in Table 10, DFO energy flows directed into the all-inclusive transportation sector were reclassified as their specific transportation sector (e.g., ground, marine, or military). Each transportation sector percentage was multiplied by the original total energy flow from DFO into transportation—12,553 billion Btus—to derive the adjusted energy flow values seen in Table 10.

Lastly, it is assumed that all DFO consumed by any transportation sector is consumed as diesel. Thus, “diesel” is the product consumed by the transportation end use sectors as seen in the flowchart.

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[91] From Figure 11 - Sales of distillate fuel oil by end use (EIA)

4.3.4.b Allocation of gasoline

Both motor gasoline and ethanol were treated similarly when redirecting energy flows into their transportation sectors. The foundational assumption for the redirection of motor gasoline and ethanol energy flows is that they are both blended into a single product to be known henceforth as "gasoline", as seen in the flowchart. When the two resources are combined, their proportional breakdown is observed as 92.61% motor gasoline and 7.39% ethanol (as calculated from SEDS). It is assumed that no matter the end use sector (which includes commercial, industrial, residential, and all transportation sectors), the same blend percentage is distributed and consumed.

To distribute gasoline (the assumed blended product that comprises 92.61% motor gasoline and 7.39% ethanol) into the transportation end use sectors, the MF-21 and MF-24 tables[92] within the Highway Statistics Series data source were used—published by the FHWA as described in section 1.3.1.[93]

Table 11 – Transportation sector percent derivation for gasoline

Transportation Sector	FHWA Data Source	Consumption (Thousand gallons)	Consumption Percent[94]	Transportation Sector Percent [95]
Air Transport	MF-24 Total Gasoline (Non-highway aviation)	222	0.05%	0.05%
Ground Transport	MF-21 Total Gasoline (Highway)	385,688	90.57%	99.67%
	MF-24 Total Gasoline, less Total Gasoline (Non-highway aviation & non-highway boating)	38,766	9.10%	
Marine Transport	MF-24 Total Gasoline (Non-highway boating)	1,163	0.27%	0.27%
Total	**n/a**	**425,839**	**100%**	**100%**

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[92] See MF-24, Highway Statistics Series 2022, Federal Highway Administration. https://www.fhwa.dot.gov/policyinformation/statistics/2022/mf24.cfm

[93] See Highway Statistics Series 2022, Federal Highway Administration. https://www.fhwa.dot.gov/policyinformation/statistics/2022/

[94] Might not add up to 100% due to independent rounding.

[95] Might not add up to 100% due to independent rounding.

The Table 11 column “Transportation Sector Percent” houses the percentages used to distribute gasoline into transportation end use sectors. These percentages were then applied to the total gasoline-to-transportation energy flows to calculate adjusted energy flows. Such calculations are seen in Table 12.

Table 12 - Transportation sector gasoline allocation

Resource	Transportation Sector	Transportation Sector Percent[96]	Original Energy Flows (billion Btu)	Adjusted Energy Flows (billion Btu)
Ethanol	Air Transport	0.05%	3,431	1.79
	Ground Transport	99.67%		3,419.84
	Marine Transport	0.27%		9.37
Motor Gasoline	Air Transport	0.05%	43,056	22.45
	Ground Transport	99.67%		42,915.96
	Marine Transport	0.27%		117.59
Total	**n/a**	**n/a**	**46,487**	**46,487**

The newly calculated energy flows seen in the Table 12 column “Adjusted Energy Flows (billion Btu)” were adopted and appear in the flowchart.

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[96] From Table 11 – Transportation sector percent derivation for gasoline. Might not add up to 100% due to independent rounding.

4.3.4.c Allocation of jet fuel

Jet fuel energy flows were distributed between both the air transport and military transport end use sectors. “Air transport” refers specifically to commercial and private aviation while “military transport” refers to all methods of transportation (air, ground, and marine) used by the military.

SEDS only reports jet fuel consumption by the transportation sector at large and does not indicate specific sectors. Based on the Hawaiʻi Department of Business, Economic Development & Tourism’s (DBEDT) 2007 estimation[97] of commercial/civilian versus military jet fuel consumption, it was assumed that 88% of total jet fuel consumption attributes to the commercial/civilian sub-sector and 12% relates to military consumption. HSEO has not been able to locate any public data source that indicates the distribution of jet fuel between commercial/civilian and military sub-sectors for 2022 or any years since 2007, so the 88%/12% respective distribution percentages were adopted. Table 13 on the following page calculates the adjusted energy flows for jet fuel into both commercial/civilian air transport and military transport sectors.

Table 13 – Transportation sector jet fuel allocation

Resource	Original Energy Flows (billion Btu)	Transportation Sector	Transportation Sector Percent[98]	Adjusted Energy Flows (billion Btu)
Jet Fuel	88,250	Air Transport	88%	77,660
		Military	12%	10,590
Total	**88,250**	**n/a**	**100%**	**88,250**

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[97] Most recent year of reported jet fuel consumption that indicated military consumption.

[98] Percent values assumed based on Hawaii Department of Business, Economic Development & Tourism’s (DBEDT) 2007 reported fuel consumption by transportation sector.

4.3.4.d Allocation of lubricants

Lubricants were assumed to be distributed across air, ground, and marine transport sectors based on the percentage of total energy flows each represents after aviation gasoline, biodiesel, RFO, DFO, motor gasoline, ethanol, and jet fuel have been allocated to their respective transportation sectors. Calculating the redistribution of lubricant energy flows is seen below in Table 14. Due to a lack of data availability, the assumption was made that no lubricants were consumed by the military transport sector.

Table 14 - Transportation sector lubricants allocation

Resource	Transportation Sector	Cumulative Sector Original Energy Flows (billion Btu)	Transportation Sector Percent[99]	Original Energy Flows (billion Btu)	Adjusted Energy Flows (billion Btu)
Lubricants	Air Transport	88,331.23	54.54%	336	183.25
	Ground Transport	53.755.41	37.71%		126.71
	Marine Transport	11,048.28	7.75%		26.04
Total	**n/a**	**153,134.92**	**100%**	**336**	**336**

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[99] Might not add up to 100% due to independent rounding.

4.3.4.e Summary

The methodology of distributing energy flows from a single transportation end use sector (as published by SEDS) into specific sectors representing air, ground, marine, and military transport is summarized below:

1. Identified SEDS energy flows consumed for transportation uses.
2. Redirected energy flows for aviation gasoline to the air transport sector, biodiesel to the ground transport sector, and RFO to the marine transport sector.
3. Redirected energy flows for DFO consumed for transportation uses into ground, marine, and military sectors based on the EIA's Form EIA-821.
4. Redirected energy flows for gasoline (comprises energy flows from both motor gasoline and ethanol) consumed for transportation uses into air, ground, and marine sectors based on the FHWA's data source "Highway Statistics Series".
5. Redirected energy flows for jet fuel consumed for transportation uses into air and military sectors based on an assumed percentage assigned for commercial/civilian aviation versus military.
6. Redirected energy flows for lubricants consumed for transportation uses into air, ground, and marine sectors based the proportion of total energy flows into each sector.

This methodology relies on six key assumptions to note.

- All aviation gasoline consumed for transportation uses is consumed by the air transport sector.
- Jet fuel is consumed both by the air transport (commercial/civilian) and military transport sectors at respective 88% and 12% proportions.
- All biodiesel consumed for transportation uses is consumed in pure form within the ground transport sector.
- All RFO consumed for transportation uses is consumed by the marine transport sector.
    - Lack of available public data restricts the creation of a defensible assumption directing likely RFO energy flows to the military transport sector (e.g., vessel bunkering fuel for ships)
- Both motor gasoline and ethanol consumed for transportation uses comprise a blended fuel referred to as "gasoline". When gasoline is consumed by different transportation sectors, the proportion of motor gasoline and ethanol stays constant.
- Lubricants are distributed to transportation sectors based on the proportion of total energy flows into each transportation sector.

4.3.5 Deriving electric generation efficiency rates

SEDS publishes values for total electricity delivered to end use sectors, total energy consumed for electric generation, and total electric generation efficiency losses linked to each sector's electricity deliveries. However, SEDS reports electric generation losses only as lump-sum totals for each end use sector—unassociated to specific electric generation resources. Since different methods of electric generation are more efficient than others, electric generation losses must be recalculated and associated to their respective resource. Transmission and distribution losses are not represented in the flowchart.

Electric generation efficiency is defined for the flowchart as the ratio of energy delivered to end use sectors in the form of electricity, to the total energy supplied by an energy resource to create that specified amount of electricity. To calculate electric generation losses for different energy resources, the EPA's eGRID database was used to derive electric generation efficiency percentages (see section 1.2).

Two methodologies were used to estimate electric generation losses: EDA and GEA (see Section 2). The EDA assumes that all electric generation efficiency percentages are 100% since the EDA assumes energy inputs to electric generation are equal to the energy delivered to end use sectors as electricity. All renewable energy resources used for electric generation were estimated using EDA. Fossil fuel electric generation resources were not estimated using EDA. See Table 15.

The GEA is applied to select renewable energy resources in addition to all fossil resources used for electric generation. Since all fossil resources used for electric generation incur thermal generation losses in their production of electricity, generation losses must be linked to the electric generation output of fossil resources. Additionally, the select renewable energy resources that are estimated using both EDA and GEA (biodiesel, geothermal, waste, and wood) also incur thermal generation losses in their production of electricity. These select renewable energy resources can either be represented in the flowchart by the EDA or GEA (flowchart setting "Generation Methodology" on right-hand side of the flowchart. All thermal electric generation losses are estimated using nominal heat rates published in the EPA's eGRID database, except for geothermal which used a global average. See Table 16.

Table 15 and Table 16 on the following pages list all electric generation efficiency percentages used for each methodology and notes on how they were derived. See Table 15 for EDA efficiency percentages and Table 16 for GEA efficiency percentages. In the sub-sections that follow, sections 4.3.5.a (biodiesel, coal, DFO, RFO, waste, and wood) and 4.3.5.b (geothermal) describe thermal generation resources and section 4.3.5.c describes non-thermal generation resources.

Table 15 - Electric generation efficiency percentages (Electricity Delivered Approach)

Generation Category	Resource	Electric Generation Efficiency	Notes
Renewable	**Biodiesel**	100%	Assumed to be 100% following EDA methodology, using net electric generation values from RPS reports as the total amount of electricity delivered from each energy resource. See section 4.3.5.c.
	Distributed Solar		
	Geothermal		
	Hydro		
	Onshore Wind		
	Solar		
	Waste		
	Wood		
Fossil	**Coal**	-	Not estimated using EDA methodology.
	Distillate Fuel Oil (DFO)	-	Not estimated using EDA methodology.
	Residual Fuel Oil (RFO)	-	Not estimated using EDA methodology.

Table 16 – Electric generation efficiency percentages (Generation Efficiency Approach)

Generation Category	Resource	Resource Electricity Generation Efficiency	Notes
Renewable	**Biodiesel**	36%	Weighted average efficiency of all biodiesel plants based on annual net generation. See section 4.3.5.a.
	Distributed Solar	-	Not estimated using GEA methodology. See section 4.3.5.c.
	Geothermal	12%	Global average electric generation efficiency percentage.[100] See section 4.3.5.b.
	Hydro	-	Not estimated using GEA methodology. See section 4.3.5.c.
	Onshore Wind	-	Not estimated using GEA methodology. See section 4.3.5.c.
	Solar	-	Not estimated using GEA methodology. See section 4.3.5.c.
	Waste	18%	Efficiency of the only waste plant (H Power) in 2022. See section 4.3.5.a.
	Wood	23%	Efficiency of the only wood plant (Biomass to Energy Facility, Kauai) in 2021.[101] See section 4.3.5.a.
Fossil	**Coal**	31%	Efficiency of the only coal plant (AES Hawaiʻi) in 2022.[102] See section 4.3.5.a.
	Distillate Fuel Oil (DFO)	34%	Weighted average efficiency of all DFO plants (excluding Biomass to Energy Facility, Kauai) based on annual net generation. See section 4.3.5.a.
	Residual Fuel Oil (RFO)	34%	Weighted average efficiency of all RFO plants based on annual net generation. See section 4.3.5.a.

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[100] Fridriksson, Merino, Orucu, and Audinet (2017). https://documents1.worldbank.org/curated/en/875761592973336676/pdf/Greenhouse-Gas-Emissions-from-Geothermal-Power-Production.pdf

[101] EPA eGRID has not published a plant nominal heat rate (Btu/kWh) for Kauai's biomass plant for 2022 (appears in eGRID as "Biomass to Energy Facility, Kauai"). Most recent plant nominal heat rate that can be used is from 2021.

[102] Coal electricity generation at AES Hawaii was not operational throughout the entirety of 2022 (closing September 1, 2022).

4.3.5.a Thermal electric generation efficiency (excluding geothermal)

To calculate the electric generation efficiency percentage for thermal generation resources[103] (all except for geothermal), the EPA eGRID database was used to fetch plant nominal heat rates (Btu/kWh), which were then used to derive electric generation efficiency percentages.

To obtain an electric generation efficiency percentage from a plant nominal heat rate, the following unit conversion equation was used.

$$Thermal\ Generation\ Efficiency\ Percent = \frac{3{,}412.14\ \left(\frac{Btu}{kWh}\right)}{Plant\ Nominal\ Heat\ Rate\ \left(\frac{Btu}{kWh}\right)} \times 100$$

Table 17 lists heat rates by generation plant, grouped by resource. Each resource's electric generation efficiency percentage then was derived by averaging the efficiency percentage of each plant, weighted by each plant's net generation.

For biodiesel, waste, and wood, the total amount of electricity generated from each resource was known (via RPS report data) and the total fuel input was unknown. However, for coal, DFO, and RFO, the total fuel input was known (via SEDS data) and the total electricity generated from each resource was unknown. With each resource's electric generation efficiency percentage (derived from EPA eGRID data), resource estimates were constructed for every electric generation resource for both fuel input and electric output. These values were used to represent the GEA methodology in the flowchart.

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[103] In addition to fossil electric generation, includes electric generation from renewable energy resources whose electric generation efficiency was calculated using the GEA methodology. See Table 15.

Table 17 – Derivation of thermal generation efficiency percentages (except geothermal)

Resource	Plant (as appears in EPA eGRID)	Plant Nominal Heat Rate (Btu/kWh)	Plant Efficiency	Net Generation (MWh)[104]	Weighted Average Electric Generation Efficiency
Biodiesel	HNL Emergency Power Facility	9,439.822	36.15%	1,346	36%
	Schofield Generating Station	9,434.062	36.17%	14,908	
Coal	AES Hawaiʻi	10,945.161	31.17%	647,758	31%
Distillate Fuel Oil (DFO)	Campbell Industrial Park	16,473.046	20.71%	102,544	34%
	Hana Substation	11,116.505	30.79%	103	
	Kanoelehua	26,193.286	13.03%	2,949	
	Keahole	10,155.975	33.60%	285,372	
	Maalaea	9,307.278	36.66%	671,617	
	Miki Basin	10,112.561	33.74%	36,176	
	Palaau Power Hybrid	10,076.632	33.96%	31,723	
	Port Allen (HI)	9,888.966	34.50%	41,834	
	Puna	12,870.901	26.51%	61,898	
	Waimea	10,584.270	32.24%	2,136	
Residual Fuel Oil (RFO)	Kahe Generating Station	10,720.330	31.83%	2,505,746	34%
	Kahului	14,970.991	22.79%	159,024	

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[104] For plants listed in Table 17 that trace plant electricity net generation to multiple energy resources (e.g., AES Hawaii traces some net generation to both coal and oil), only the electricity net generation associated to the defined energy resource were included.

Resource	Plant (as appears in EPA eGRID)	Plant Nominal Heat Rate (Btu/kWh)	Plant Efficiency	Net Generation (MWh)[104]	Weighted Average Electric Generation Efficiency
	Kalaeloa Cogen Plant	7,641.277	44.65%	1,219,989	
	W H Hill	13,402.672	25.46%	170,026	
	Waiau Generating Station	11,627.339	29.35%	1,219,989	
Waste	H Power	19,474.376	17.52%	164,612	18%
Wood[105]	Biomass to Energy Facility, Kauai	14,894.688	22.91%	48,425	23%

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[105] EPA eGRID has not published a plant nominal heat rate (Btu/kWh) for Kauai's biomass plant for 2022 (appears in eGRID as "Biomass to Energy Facility, Kauai"). Most recent plant nominal heat rate that can be used is from 2021.

4.3.5.b Thermal electric generation efficiency (only geothermal)

To calculate the electric generation efficiency percentage for geothermal, the global average geothermal electric generation efficiency of 12% was assumed.[106] Due to the lack of a published heat rate for the Puna Geothermal Venture (PGV) plant in eGRID, a plant-specific electric generation efficiency percentage could not be estimated.

The main difference between the interpretation of thermal electric generation from geothermal when compared to other thermal generation resources such as petroleum, biodiesel, or waste is that geothermal is a heat input and the latter is a fuel input. Both use heat to create mechanical energy, which is then converted to electricity.

Despite this characterization of geothermal, it is represented with electric generation losses for a single reason:

- **Active generation, not passive generation** – Geothermal electric generation requires active operations managed by people and is not a generation mechanism that is relatively passive (e.g., solar, wind, etc.). In this respect, a geothermal plant operates in a similar manner to coal, petroleum, biodiesel, or waste.

Geothermal is represented in the flowchart by both the EDA (no generation losses) and the GEA (generation losses) methodologies. While not perfect, representations of geothermal electric generation, the EDA methodology groups geothermal with other renewable energy generation methods, while the GEA methodology groups geothermal with other thermal electric generation methods.

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[106] Zarrouk and Moon (2014). https://www.sciencedirect.com/science/article/abs/pii/S0375650513001120?via%3Dihub

4.3.5.c Non-thermal electric generation efficiency

For non-thermal renewable electric generation resources—distributed solar, hydro, onshore wind, and solar—the assumed electric generation efficiency percentage is 100%, since each of these electric generation resources were only estimated using the EDA methodology.

The remaining renewable electric generation resources—biodiesel, geothermal, waste, and wood—are represented as having a 100% electric generation efficiency percentage with the EDA and represented as having a non-100% electric generation efficiency percentage with the GEA (to represent thermal generation losses).

4.3.5.d Summary

The methodology for recalculating electric generation losses based on generation efficiency percentages is summarized in the steps below:

1. Identify electric generation resources that incur thermal generation losses in the electric generation process
2. Calculate the electric generation efficiency percentage for each resource
    a. Geothermal is represented differently than the other thermal electric generation resources. See sections 4.3.5.a and 4.3.5.b.
3. Use the GEA methodology to estimate the electric generation losses for each resource identified in step 1.

Key assumptions adopted to recalculate electricity generation losses for the GEA methodology:

- Electric generation efficiency percentages for each energy resource were derived using an average of resource-related plant electric generation efficiencies, weighted on net electric generation. These electric generation efficiency percentages were largely derived from plant nominal heat rates from the eGRID database.
- Geothermal electric generation efficiency percent set to global average of 12%. See section 4.3.5.b.

4.3.6 Identifying distributed vs. utility solar generation in original SEDS data set

SEDS did not specify separate utility-scale and distributed solar energy resource categories. To see both resources clearly in the flowchart, the RPS reports collected by the PUC were used to determine energy flows for solar-related resources.

The solar energy resources (utility-scale and residential rooftop) as seen in the flowchart (just like all other renewable energy resources used for electric generation) were derived from the RPS reports collected by the PUC (see section 1.4.1 for data source and see sections 2.2, 3.1.6, and 3.1.17 for more information regarding the representation of distributed solar (residential rooftop) and solar (utility-scale) in the flowchart.

4.3.7 Adjusting for select renewable energy resources that are directly consumed by end use sectors in SEDS

SEDS energy flows for geothermal, hydroelectric (hydro), waste, and wood originally were not entirely directed through electric power sector (appears as “electricity” in second column of the flowchart) before being delivered as electricity to end use sectors. Some portions of their energy resource supply were consumed by end use sectors without having been first converted into electricity by the electric power sector. However, upon analysis of these four energy resources, assumptions were made after reviewing the SEDS documentation that led to the decision to keep some energy flows and to exclude others.

The following sections 4.3.7.a through 4.3.7.d refer to the relational energy flows of energy resources being directly consumed by end use sectors (anything but the electric power sector), as originally defined in the SEDS data set. The amount of energy that the electric power sector consumes from each of these resources to generate electricity is determined by the RPS reports, not SEDS (see Section 2 for methodologies). However, some of the energy flows for each of the following energy resources were representative of electric generation. Thus, those energy flows had to be identified and excluded from the flowchart.

4.3.7.a Geothermal

In the original SEDS data set, geothermal energy flows were directed into the electric power sector along with the commercial and industrial end use sectors. The energy flows of geothermal energy consumed directly by the commercial and industrial sectors were kept due to their consumption of energy at non-electric power sector facilities not used for electric generation, but as direct heat or from heat pumps. See section 3.1.8.

4.3.7.b Hydroelectric (hydro)

In the original SEDS data set, hydro energy flows were directed into the electric power sector along with industrial end use sector. It was assumed that despite these hydro energy flows being directed into the industrial sector, since the hydro energy resource is representative of hydroelectric power, all energy flows relating to hydro would be directed through the electric power sector. Thus, any hydro energy flows to the commercial, industrial, or residential sector, or any transportation sector would be excluded. See section 3.1.9.

4.3.7.c Waste

In the original SEDS data set, waste energy flows were directed into the electric power sector along with the commercial end use sector. It was assumed that despite these waste energy flows being directed into the commercial sector, all waste consumption was for the use of electric generation. Thus, any waste energy flows to the commercial, industrial, or residential sector, or any transportation sector would be excluded. See section 3.1.20.

4.3.7.d Wood

In the original SEDS data set, wood energy flows were directed into the electric power sector along with the commercial, industrial, and residential end use sectors. Energy flows of wood energy consumed directly by the commercial, industrial, and residential sectors were kept due to their consumption of heat energy at non-electric power sector facilities not used for electric generation. See section 3.1.21.

4.3.8 Deriving energy efficiency rates for end use sectors

The energy flowcharts published by Lawrence Livermore National Laboratory (LLNL)[107] used as inspiration for this project calculate end use energy efficiency by a percentage unique to each end use sector. While this can be effective for measuring the energy system in its totality, this methodology cannot be used to measure individual energy flows that specify a single energy resource or product being consumed by a specific end use sector. For example, the energy efficiency of an internal combustion engine (ICE) vehicle varies from that of an electric vehicle (EV)—an electric vehicle is much more efficient at translating input energy toward moving the vehicle forward. In this example, energy efficiency is described in terms of the portion of energy consumed that is translated to useful mechanical work (see section 3.4).

Energy that is converted to useful mechanical work is defined as “energy used” (LLNL defined this category as “energy services”).

Energy that is not converted to useful mechanical work is defined as “energy wasted” (LLNL defined this category as “rejected energy”). Energy wasted consists of two primary components: losses from electric generation and end use energy efficiency losses.

To account for differences in end use efficiencies within end use sectors, efficiency rates were based on product consumed (e.g., ground transport end use sector has a different energy efficiency percentage for energy flows whose input fuel is electricity compared to gasoline).

Table 18 defines each end use sector’s end use efficiencies based on product consumed. For each product-to-end use energy flow, the associated end use efficiency percentage in Table 18 was applied.

Finally, this is a simplified estimation of end use energy efficiency. Many other variables influence end use efficiency, but this methodology was adopted for its simplicity and reproducibility across sectors.

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[107] See LLNL Energy Flowcharts (https://flowcharts.llnl.gov/)

Table 18 – End use energy efficiencies by product (use Cite IDs to view citation in Table 20)

End use Sector	Product	End use Efficiency	Description/Primary Technologies	Methodology	Cite ID[108]
Air Transport	Aviation Gasoline	34.0%	Piston engine aircraft	Thermal efficiency of a piston engine aircraft engine	18.1
	Gasoline	34.0%	Piston engine aircraft	Thermal efficiency of a piston engine aircraft engine	18.2
	Jet Fuel	19.4%	Jet engine aircraft	Thermal efficiency of gas turbine aircraft engines	18.3
	Lubricants	0%	n/a	Assumed: product is not consumed as energy.	18.4
Commercial	Distillate Fuel Oil	85.0%	Water heating	Thermal efficiency of a light diesel boiler	18.5
	Electricity	73.7%	Linear fluorescent lighting, space cooling, ventilation	See Appendix B.	18.6
	Gasoline	20.5%	Internal combustion engine vehicles	Midpoint of the range (16-25%) of the percentage of energy consumed by a gasoline engine-powered vehicle that translates to mechanical work propelling the vehicle forward (accounting for thermal engine losses, auxiliary electrical losses, parasitic losses, drivetrain losses, and idle losses).	18.7
	Geothermal	0%	Direct heat, heat pumps	Assumed: product is consumed as heat and therefore no longer usable energy.	18.8
	Natural Gas	65.0%	Natural gas cooking oven, water heating	Average between the midpoint of the thermal efficiency range (40-50%) of a gas stove (45%) and thermal efficiency of a natural gas water heater (85%).	18.9
	Propane	66.3%	LPG water heating, LPG cooking range oven	The average between the midpoint of the thermal efficiency range (80-95%) of a propane water heater (87.5%) and the midpoint of the thermal efficiency range (40-50%) of a gas stove (45%).	18.10
	Wood	78.0%	Wood stove	Average energy efficiency (HHV) of a wood stove (considering both catalytic and non-catalytic)	18.11
Ground Transport	Biodiesel	46.0%	Internal combustion engine vehicles	Thermal efficiency of a diesel engine (assuming 100% biodiesel fuel substitution in ICE)	18.12
	Distillate Fuel Oil	46.0%	Internal combustion engine vehicles	Thermal efficiency of a diesel engine	18.13

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[108] Index for full table of citations (“Cite IDs”) in Appendix A.

End use Sector	Product	End use Efficiency	Description/Primary Technologies	Methodology	Cite ID[108]
	Electricity	77.0%	Electric vehicles	Percent of electrical energy converted to mechanical work propelling the vehicle forward. Note: This efficiency percentage can fluctuate depending on drive cycle and if energy recaptured from regenerative breaking is counted.	18.14
	Gasoline	20.5%	Internal combustion engine vehicles	Midpoint of the range (16-25%) of the percentage of energy consumed by a gasoline engine-powered vehicle that translates to mechanical work propelling the vehicle forward (accounting for thermal engine losses, auxiliary electrical losses, parasitic losses, drivetrain losses, and idle losses).	18.15
	Lubricants	0%	n/a	Assumed; product is not consumed as energy.	18.16
Industrial	Asphalt & Road Oil	90.5%	Construction	Midpoint of the range (86.6-94.3%) of overall refinery efficiency. This was assumed to represent the refining of heavy oils such as bitumen to be used for road paving.	18.17
	Distillate Fuel Oil	68.3%	Refining, construction	Average of midpoint of the range (86.6-94.3%) of overall refinery efficiency (90.5%) and thermal efficiency of a diesel engine (46%).	18.18
	Electricity	72.9%	Food, agriculture, construction	See Appendix B.	18.19
	Gasoline	20.5%	Construction, agriculture	Midpoint of the range (16-25%) of the percentage of energy consumed by a gasoline engine-powered vehicle that translates to mechanical work propelling the vehicle forward (accounting for thermal engine losses, auxiliary electrical losses, parasitic losses, drivetrain losses, and idle losses).	18.20
	Geothermal	0%	Direct heat, heat pumps	Assumed; product is consumed as heat and therefore no longer usable energy.	18.21
	Lubricants	0%	n/a	Assumed: product is not consumed as energy.	18.22
	Natural Gas	65.0%	Refining, food	Energy efficiency duplicated from commercial and residential sectors due to lack of clarity regarding dominant technologies used.	18.23
	Still Gas	90.5%	Refining	Midpoint of the range (86.6-94.3%) of overall refinery efficiency. This was assumed to represent the refining of heavy oils such as bitumen to be used for road paving.	18.24
	Propane	45.0%	Construction, food, refining	Net thermal efficiency of an LPG-powered stoichiometric engine.	18.25
	Residual Fuel Oil	90.5%	Refining	Midpoint of the range (86.6-94.3%) of overall refinery efficiency.	18.26

End use Sector	Product	End use Efficiency	Description/Primary Technologies	Methodology	Cite ID[108]
	Wood	78.0%	Wood stove	Average energy efficiency (HHV) of a wood stove (considering both catalytic and non-catalytic)	18.27
Marine Transport	Distillate Fuel Oil	46.0%	Diesel engine used in smaller watercraft	Thermal efficiency of a diesel engine	18.28
	Gasoline	27.5%	Gasoline four-stroke engine used for smaller watercraft	Midpoint of the range (25-30%) of the thermal efficiency of a gasoline four-stroke engine.	18.29
	Lubricants	0%	n/a	Assumed: product is not consumed as energy.	18.30
	Residual Fuel Oil	42.5%	Two-stroke and four-stroke diesel engines used in large ships	Midpoint of the thermal efficiency of a two-stroke diesel engine (50%) and the thermal efficiency of a four-stroke diesel engine (35%)	18.31
Military Transport	Distillate Fuel Oil	46.0%	n/a	Thermal efficiency of a diesel engine	18.32
	Jet Fuel	19.4%	Jet engine aircraft	Thermal efficiency of gas turbine aircraft engines	18.33
	Lubricants	0%	n/a	Assumed: product is not consumed as energy.	18.34
Residential	Distillate Fuel Oil	40.0%	n/a	Thermal efficiency of a diesel generator	18.35
	Electricity	77.5%	Space cooling, water heating, lighting	See Appendix B.	18.36
	Natural Gas	65.0%	Water heating, cooking stove	The average between the thermal efficiency of a natural gas water heater (85%) and the midpoint of the range (40-50%) of the thermal efficiency of a gas stove (45%).	18.37
	Propane	66.3%	Water heating, cooking stove	The average between the midpoint of the range (80-95%) of the efficiency of a propane water heater (87.5%) and the midpoint of the range (40-50%) of the thermal efficiency of a gas stove (45%).	18.38
	Wood	78.0%	Wood stove	Average energy efficiency (HHV) of a wood stove (considering both catalytic and non-catalytic)	18.39
Generation Losses	Electricity	0.0%	Electric generation losses	Losses from electric generation. Since used energy in the electric generation process is represented as electricity delivered to end use sectors, generation losses are counted as wasted energy.	18.40

4.3.9 Electric vehicle charging adjustments

SEDS does not indicate electricity being consumed by the ground transport sector. To account for electric-powered transportation that exists in Hawaiʻi in the form of personal vehicles and public transportation, the PATHWAYS model developed by the Hawaiʻi State Energy Office (HSEO) (refer to section 1.5.1) was used to estimate a total electricity consumption value for ground transport sector.[109]

Upon fetching the data in the Excel Worksheet named "PATHWAYS Energy Demands", the following filters were applied to locate the necessary energy estimates:

- Scenario: "Reference"
- Timestamp: "2022"
- Sector: "Transportation"
- Final Fuel: "Electricity"

After verifying that all elements in the "subsector" column indicated ground transportation (the sub-sector "Transportation Other" is assumed to be ground transportation), the remining values listed in the "energy_demand" column were summed to 812 billion Btus.

It was assumed that 90% of EV charging occurred at residences (residential sector) and 10% of EV charging occurred at commercial locations (commercial sector). Thus, these energy flows must be diverted from residential and commercial sectors and into the ground transport sector. It is important to note that this is merely a redirection of existing energy flows from both residential and commercial sectors into ground transport—not an additional electricity demand load.

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[109] To download the Hawaii PATHWAYS model results from the HSEO's 2023 Decarbonization Report that were used to estimate electric ground transportation energy consumption for the flowchart, visit the report's landing page on HSEO's website. https://energy.hawaii.gov/what-we-do/clean-energy-vision/decarbonization-strategy/decarbonization-report-development-assumptions-and-methods/

However, difficulties arise when attributing electricity consumption within the commercial and residential sectors to the energy resources that originally derived the electricity consumed. Such attribution of original electric generation resources is dependent on variable indicators such as time of day, distributed solar market saturation, and distributed storage (at-home batteries connected to rooftop solar) market saturation, among many others.

For instance, electric consumption for EV charging predominantly occurs overnight at owner's homes.[110] An EV owner charging overnight at home would more likely be consuming majority-fossil-derived grid electricity to charge their vehicle, unless they had an onsite rooftop solar unit with connected onsite battery storage.

The original iteration of the flowchart project indicated three EV charging scenarios to account for these various nuances: proportional, grid electricity focus, and rooftop solar focus, described in Table 19. Depending on the scenario selected in the flowchart, the portfolio of electric generation resources changes along with their associated magnitude. However, after creating such EV charging scenarios, only the proportional scenario was included in the final flowchart, as the grid electricity focus and rooftop solar focus scenarios could potentially under-represent or over-represent the effects of distributed energy resources on EV charging, respectively.

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[110] Powell, et al. Nature Energy. (https://www.nature.com/articles/s41560-022-01105-7)

Table 20 – Electric vehicle (EV) charging scenario descriptions

End use Sector	**Proportion**	**Scenario**	**Description**
Residential	90%	Proportional[111]	Electricity sourced proportionally from all electricity generation resources delivered to the residential end use sector (includes distributed rooftop solar)
		Grid Electricity Focus	Electricity sourced proportionally from grid electricity resources delivered to the residential end use sector (excludes distributed rooftop solar)
		Rooftop Solar Focus	Electricity 100% sourced from distributed rooftop solar from the residential end use sector
Commercial	10%	All scenarios	Electricity sourced proportionally across commercial end use sector electricity generation resources
Total	**100%**		

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[111] Only scenario that made the final flowchart publication

4.4 Constructing Sankey flow chart in Tableau Desktop

The interactive flowchart was constructed using Tableau Desktop and is simultaneously on Tableau Public for viewing. Tableau was chosen to create the flowchart due to its ability to create an interface where a user can select different combinations of filters to allow for a dynamic (rather than static) representation of the data. Also, various features within Tableau (e.g., calculated fields, table calculations, sets, parameters, hierarchies, and polygons) were used to create the visualization in a straightforward manner that aligned well with the data architecture.

For more information about the Tableau data visualization software, visit the Tableau website (https://www.tableau.com/).

Section 5 Appendices

Appendix A. End use energy efficiencies by product (citations)

Table 21 – End use efficiencies by product (citations for Table 18 – End use energy efficiencies by product)

Cite ID	Source(s)	URL(s)
18.1	Saavy Aviation Maintenance Management, Inc.	https://www.youtube.com/watch?v=OVA-jeE0i0w#:~:text=It's%20a%20painful%20truth%20that%20our%20piston,Aviation%20offers%20Professional%20Maintenance%20Services%20to%20owners
18.2	Saavy Aviation Maintenance Management, Inc.	https://www.youtube.com/watch?v=OVA-jeE0i0w#:~:text=It's%20a%20painful%20truth%20that%20our%20piston,Aviation%20offers%20Professional%20Maintenance%20Services%20to%20owners
18.3	Akdeniz, Balli, Caliskan (2022)	https://www.sciencedirect.com/science/article/abs/pii/S0016236122010225
18.4	Assumed value. No citation needed.	Assumed value. No citation needed.
18.5	EPCB Boiler	https://www.epcbboiler.com/which-fuel-is-best-for-boilers.html#:~:text=(4)%20The%20thermal%20efficiency%20of,85%25=8670%20kcal/kg.
18.6	See Appendix B.	See Appendix B.
18.7	FuelEconomy.gov (Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy)	https://www.fueleconomy.gov/feg/atv.shtml
18.8	Assumed value. No citation needed.	Assumed value. No citation needed.
18.9	Zhang, Wang, Wang, Zhang, and Wang (2023); EPCB Boiler	https://www.sciencedirect.com/science/article/abs/pii/S037877882300614X#:~:text=Meanwhile%2C%20the%20consumption%20of%20pipeline,15%5D%2C%20%5B16%5D https://www.epcbboiler.com/which-fuel-is-best-for-boilers.html#:~:text=(4)%20The%20thermal%20efficiency%20of,85%25=8670%20kcal/kg
18.10	Zhang, Wang, Wang, Zhang, and Wang (2023); Water Heaters Now	https://www.sciencedirect.com/science/article/abs/pii/S037877882300614X#:~:text=Meanwhile%2C%20the%20consumption%20of%20pipeline,15%5D%2C%20%5B16%5D

Cite ID	Source(s)	URL(s)
		https://www.waterheatersnow.com/blog/how-much-propane-does-a-tankless-water-heater-use#:~:text=On%20average%2C%20propane%2Dpowered%20units,and%20a%20reduced%20carbon%20footprint
18.11	Environmental Protection Agency (EPA)	https://www.epa.gov/burnwise/frequent-questions-about-wood-burning-appliances
18.12	Tank Transport Trader	https://tanktransport.com/2024/04/diesel-engine-thermal-efficiency/
18.13	Tank Transport Trader	https://tanktransport.com/2024/04/diesel-engine-thermal-efficiency/
18.14	FuelEconomy.gov (Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy)	https://www.fueleconomy.gov/feg/evtech.shtml
18.15	FuelEconomy.gov (Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy)	https://www.fueleconomy.gov/feg/atv.shtml
18.16	Assumed value. No citation needed.	Assumed value. No citation needed.
18.17	Foreman, Divita, Han, Cai, Elgowainy, and Wang (2014)	https://pubs.acs.org/doi/10.1021/es501035a
18.18	Foreman, Divita, Han, Cai, Elgowainy, and Wang (2014); Tank Transport Trader	https://pubs.acs.org/doi/10.1021/es501035a https://tanktransport.com/2024/04/diesel-engine-thermal-efficiency/
18.19	See Appendix B.	See Appendix B.
18.20	FuelEconomy.gov (Office of Energy Efficiency & Renewable	https://www.fueleconomy.gov/feg/atv.shtml

Cite ID	Source(s)	URL(s)
	Energy, U.S. Department of Energy)	
18.21	Assumed value. No citation needed.	Assumed value. No citation needed.
18.22	Assumed value. No citation needed.	Assumed value. No citation needed.
18.23	See 18.9 & 18.37	See 18.9 & 18.37
18.24	Foreman, Divita, Han, Cai, Elgowainy, and Wang (2014)	https://pubs.acs.org/doi/10.1021/es501035a
18.25	Splitter, Boronat, Chuahy, and Storey (2020)	https://www.osti.gov/servlets/purl/1669762
18.26	Foreman, Divita, Han, Cai, Elgowainy, and Wang (2014)	https://pubs.acs.org/doi/10.1021/es501035a
18.27	Environmental Protection Agency (EPA)	https://www.epa.gov/burnwise/frequent-questions-about-wood-burning-appliances
18.28	Tank Transport Trader	https://tanktransport.com/2024/04/diesel-engine-thermal-efficiency/
18.29	BoatTest.com	https://boattest.com/article/maximize-your-fuel-economy-part-i-outboards#:~:text=Typically%2C%20gasoline%20four%2Dstroke%20engine%20efficiency%20is%20about,process%20no%20matter%20whose%20engine%20it%20is
18.30	Assumed value. No citation needed.	Assumed value. No citation needed.
18.31	Appropedia	https://www.appropedia.org/2-stroke_Diesel_engine#:~:text=Unlike%204%2Dstroke%20diesel%20engines,appropriate%20technology%202%2Dstroke%20engines

Cite ID	Source(s)	URL(s)
18.32	Tank Transport Trader	https://tanktransport.com/2024/04/diesel-engine-thermal-efficiency/
18.33	Akdeniz, Balli, Caliskan (2022)	https://www.sciencedirect.com/science/article/abs/pii/S0016236122010225
18.34	Assumed value. No citation needed.	Assumed value. No citation needed.
18.35	General Power	https://www.genpowerusa.com/blog/diesel-generator-vs-gas-generator-which-is-more-efficient/#:~:text=How%20Efficient%20are%20Diesel%20Generators?,deciding%20which%20generator%20to%20buy
18.36	See Appendix B.	See Appendix B.
18.37	EPCB Boiler; Zhang, Wang, Wang, Zhang, and Wang (2023)	https://www.epcbboiler.com/which-fuel-is-best-for-boilers.html#:~:text=(4)%20The%20thermal%20efficiency%20of,85%25=8670%20kcal/kg. https://www.sciencedirect.com/science/article/abs/pii/S037877882300614X#:~:text=Meanwhile%2C%20the%20consumption%20of%20pipeline,15%5D%2C%20%5B16%5D
18.38	Water Heaters Now; Zhang, Wang, Wang, Zhang, and Wang (2023)	https://www.waterheatersnow.com/blog/how-much-propane-does-a-tankless-water-heater-use#:~:text=On%20average%2C%20propane%2Dpowered%20units,and%20a%20reduced%20carbon%20footprint https://www.sciencedirect.com/science/article/abs/pii/S037877882300614X#:~:text=Meanwhile%2C%20the%20consumption%20of%20pipeline,15%5D%2C%20%5B16%5D
18.39	Environmental Protection Agency (EPA)	https://www.epa.gov/burnwise/frequent-questions-about-wood-burning-appliances
18.40	n/a	n/a

Appendix B. Deriving end use sector efficiency percentages for electricity consumption

Table 22 - Deriving end use sector efficiency percentages for electricity consumption

Source	Sector	Category	Weight[112]	Technology	Efficiency	Cite ID	Weighted Efficiency
Electricity	Commercial[113]	Lighting	45%	LED, incandescent and CFL bulbs	65.0%	21.1	73.7%
		Air conditioning	34%	Reciprocating compressor	80.0%	21.2	
		Ventilation	20%	Backward-inclined centrifugal fan	86.0%	21.3	
	Industrial[114]	Food	44%	Electric forklift	90.0%	21.4	72.9%
		Agriculture	35%	Electric tractor	77.0%	21.5	
		Construction	21%	Electric excavator	30.0%	21.6	
	Residential[115]	Air conditioning	39%	Reciprocating compressor	80.0%	21.7	77.5%
		Water heating	34%	Electric resistance water heater	82.5%	21.8	
		Lighting	26%	LED, incandescent and CFL bulbs	70.0%	21.9	

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[112] May not sum to 100% for individual end use sectors due to independent rounding.

[113] Commercial consumption categories were derived from *Table 3.1.4* in the U.S. Department of Energy's "2011 Buildings Energy Data Book". Excluding space heating (assumed irrelevant to Hawaii), the top three commercial consumption categories were fetched, and their associated weights were derived from the total percent values that they comprise. See *Figure 2* in the Environmental and Energy Study Institute's (EESI) "Fact Sheet | Energy Efficiency Standards for Appliances, Lighting, and Equipment (2017)". https://www.eesi.org/papers/view/fact-sheet-energy-efficiency-standards-for-appliances-lighting-and-equipmen

[114] Industrial consumption categories were derived from HSEO PATHWAYS Study results table. Excluding the consumption category "Other", the top three consumption industrial consumption categories were fetched (assuming "Reference" scenario, 2022, filtered to Oahu since it comprises most of the state's energy demand), and their associated weights were derived from the total MMBtu values that they comprise.

[115] Residential consumption categories were derived from *Table 2.1.5* in the U.S. Department of Energy's "2011 Buildings Energy Data Book". Excluding space heating (assumed irrelevant to Hawaii), the top three residential consumption categories were fetched, and their associated weights were derived from the total percent values that they comprise. See *Figure 1* in the Environmental and Energy Study Institute's (EESI) "Fact Sheet | Energy Efficiency Standards for Appliances, Lighting, and Equipment (2017)". https://www.eesi.org/papers/view/fact-sheet-energy-efficiency-standards-for-appliances-lighting-and-equipmen

Table 23 - Energy efficiency of lighting in commercial sector

Predominant Bulb Type in Home	Energy Efficiency[116]	Percent of U.S. Commercial Buildings[117]	Weighted Average Energy Efficiency
LED	90%	44%	65%
Compact Fluorescent (CFL)	85%	19%	
Incandescent	10%	19%	
Halogen	15%	9%	
High-Intensity Discharge (HID)	70%	4%	
Misc.[118]	54%	5%	

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[116] For LED, CFL, and Incandescent, see GE Lighting (https://www.gelighting.com/inform/guide-energy-efficient-light-bulbs). For Halogen, see midpoint of 10-20% energy efficiency range published by Displays2Go (https://www.displays2go.com/Article/LED-Halogen-Bulbs-A-Bigger-Difference-Than-You-Might-Think-69). For High-Intensity Discharge (HID), see portion of energy emitted from HID bulb that is not infrared published by Stouch Lighting (https://www.stouchlighting.com/blog/lighting-comparison-led-versus-hid).

[117] EIA (https://www.eia.gov/todayinenergy/detail.php?id=49816)

[118] Unaccounted remaining 5%. Assumed to be average of LED, CFL, incandescent, halogen, and HID bulbs (54%).

Table 24 - Energy efficiency of lighting in residential sector

Predominant Bulb Type in Home	Energy Efficiency[119]	Percent of U.S. Homes[120]	Weighted Average Energy Efficiency
LED	90%	47%	70%
No Predominant Bulb Type[121]	62%	26%	
Incandescent or Halogen[122]	10%	15%	
Compact Fluorescent (CFL)	85%	12%	

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[119] GE Lighting (https://www.gelighting.com/inform/guide-energy-efficient-light-bulbs)

[120] EIA (https://www.eia.gov/todayinenergy/detail.php?id=51858)

[121] Energy efficiency of “No Predominant Bulb Type” in Table 23 is derived from an equally weighted average of the energy efficiencies of LED, incandescent/halogen, and CFL lightbulbs weighted by percent of homes.

[122] Energy efficiency of “Incandescent or Halogen” predominant bulb type in Table 23 is representative of only incandescent.

Table 25 - Deriving end use sector efficiency percentages for electricity consumption (citations from Table 21)

Cite ID	Methodology	Source	URL
21.1	See Table 22	See Table 22	See Table 22
21.2	Midpoint of the range (70-90%) of isentropic efficiency for a reciprocating compressor often used in air conditioning systems (80%).	Islam, M. Rafiqul. Reservoir Development. (2021).	https://www.sciencedirect.com/topics/engineering/compressor-efficiency#:~:text=For%20vapor%20cycle%20refrigeration%20of,as%20the%20practical%20compressor%20efficiency.
21.3	Average of efficiencies of backward-inclined centrifugal fans (86%): flat blade (82%), curved blade (86%), and airfoil (90%).	Aerovent Industrial Ventilation Systems	https://www.aerovent.com/wp-content/uploads/sites/2/2021/12/Fan-Performance-Characteristics-of-Centrifugal-Fans-FE-2400.pdf
21.4	Electric forklift that uses a lithium-ion battery chosen as a proxy for all electric powered food equipment. Due to lack of clarity of how this	Advanced Manufacturing (2024)	https://www.advancedmanufacturing.org/leadership-innovation/zero-emission-forklifts/article_566f1348-3180-11ef-92ee-cf94b94934aa.html#:~:text=New%2C%20lead%2Dacid%20batteries%20top,also%20reduces%20your%20utility%20bill.
21.5	Electric tractor energy efficiency rate. Chosen as proxy for all electric powered agricultural equipment.	Monarch Tractor (2023)	https://www.monarchtractor.com/blog/cost-to-charge-ev#:~:text=Fuel%20Efficiency,operating%20costs%20and%20carbon%20footprint.
21.6	Electric excavator energy efficiency rate. Since 50% of CO_2 emissions within the construction sector are from excavators, the energy efficiency of the entire sector is modeled from this dominant technology.	Construction Briefing (2023)	https://www.constructionbriefing.com/news/danfoss-qa-technology-to-reduce-excavator-energy-consumption/8026765.article
21.7	Midpoint of the range (70-90%) of isentropic efficiency for a reciprocating compressor often used in air conditioning systems (80%).	Islam, M. Rafiqul. Reservoir Development. (2021).	https://doi.org/10.1016/B978-0-12-820053-7.00004-4
21.8	Derived from multiplying energy factor values by 100 to arrive at an estimated energy efficiency percentage. Energy factor is an "efficiency ratio of the energy supplied in heated water divided by the energy input to the water heater, and is based on recovery efficiency, standby losses, and cycling losses". Derived by taking the average of the range (70-95%) of the converted energy factors (82.5%).	College of Earth and Mineral Sciences, Penn State University	https://www.e-education.psu.edu/egee102/node/2009#:~:text=EF%20is%20an%20efficiency%20ratio,ranging%20from%200.7%20and%200.95
21.9	See Table 23	See Table 23	See Table 23