Estimated United States Transportation Energy Use 2005

United States

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Abstract

A flow chart depicting energy flow in the transportation sector of the United States economy in 2005 has been constructed from publicly available data and estimates of national energy use patterns. Approximately 31,000 trillion British Thermal Units (trBTUs) of energy were used throughout the United States in transportation activities. Vehicles used in these activities include automobiles, motorcycles, trucks, buses, airplanes, rail, and ships. The transportation sector is powered primarily by petroleum-derived fuels (gasoline, diesel and jet fuel). Biomass-derived fuels, electricity and natural gas-derived fuels are also used. The flow patterns represent a comprehensive systems view of energy used within the transportation sector.

Introduction

Lawrence Livermore National Laboratory (LLNL) has published flow charts (also referred to as “Sankey Diagrams”) of important national commodities since the early 1970s. The most widely recognized of these charts is the U.S. energy flow chart (http://flowcharts.llnl.gov). LLNL has also published charts depicting carbon (or carbon dioxide potential) flow and water flow at the national level as well as energy, carbon, and water flows at the international, state, municipal, and organizational (i.e. United States Air Force) level. Flow charts are valuable as single-page references that contain quantitative data about resource, commodity, and byproduct flows in a graphical form that also convey structural information about the system that manages those flows. The flowchart can be read “left-to-right”.

Energy taken from the environment is refined into transportation fuels. These fuels are distributed to vehicles, which convert the energy to propulsive work. That work is the fundamental service provided by the transportation sector.

This is the first presentation of detailed energy flow in the transportation sector of the United States economy. Data on transportation energy use is collected by the U.S. Department of Energy’s Energy Information Administration (U.S. EIA) and the Department of Transportation’s Bureau of Transportation Statistics (BTS). The primary data source for this report is Oak Ridge National Laboratory’s Transportation Energy Data Book (TEDB, 2010), which is based largely on BTS and EIA data. Where TEDB did not have enough detail, U.S. EIA’s Alternatives to Traditional Transportation Fuels (ATTF, 2008) served as a secondary reference. A handful of other statistics, as well as vehicle efficiencies and other conversion factors, were calculated from the other references listed in the bibliography. Because many transportation energy statistics are not published on an annual basis, this report is based on data for the year 2005, the most recent year for which a full accounting is possible.
This flow chart of transportation energy usage and explanations of the calculations and assumptions utilized can be found at: http://flowcharts.llnl.gov.
Estimated United States Transportation Energy Use in 2005
~31,000 Trillion BTU

Source: LLNL 2011. Data is based on DOE/ORNL-6985(2010), July 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. All quantities are rounded to 2 significant digits and annual flows of less than 0.0005 trBTU are not included. Totals may not equal sum of components due to independent rounding. LLNL-TR-513773
Analysis
This visualization of energy use in the transportation sector is based upon a “bottom-up” calculation of
energy consumption for civilian consumption. Specific energy flows for which data is available are listed
first, followed by flows and quantities which are calculated as residuals or summations. Every effort has
been made to logically group energy flows by sector and fuel.

Consumption of Refined Fuels:
Energy use in the transportation sector is based on the consumption of refined fuels. In many cases,
statistics for the consumption of these commodities in the transportation sector are readily available.

Electricity:

Electricity Production -> Automobiles
Light duty vehicles are reported to have consumed 3.6 million gasoline-equivalent gallons of Electricity
or 0.45 trBTUs in 2005 (ATTF: Table C5, 2010).1 Because light duty vehicles are not described in further
detail, the Electricity usage of 0.45 trBTUs by light duty vehicles is entirely attributed to Automobiles.

Electricity Production -> Medium & Heavy Trucks
In 2005, Electricity use by medium duty vehicles is reported as 44 thousand gasoline-equivalent gallons
or 0.0055 trBTUs and use by heavy duty vehicles (including buses) is reported as 1.6 million gasoline-
equivalent gallons or 0.20 trBTUs (ATTF: Table C5, 2010). As described below, Transit Buses used 530
thousand kilowatt hours of electricity, or 0.00069 trBTUs, in 2005 by another source (TEDB: Table A.3,
2010). The Electricity attributed to medium duty and heavy duty vehicles not used as fuel by Transit
Buses is attributed to Medium & Heavy Trucks, which is equivalent to 0.20 trBTUs of energy.

Electricity Production -> Transit Buses
The energy from Electricity Production used by Transit Buses is reported as 0.00069 trBTUs in 2005
(TEDB: Table A.3, 2010).

Electricity Production -> Pipeline
The pipeline sector consumes electricity at some pumping and compression stations. The energy from
Electricity Production used by Pipeline is calculated to be 27 trBTUs in 2005 (TEDB: Table A.11, 2010).2

Electricity Production -> Passenger Rail
The energy from Electricity Production used by Passenger Rail is calculated to be 66 trBTUs in 2005

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1Over 90% of the estimated number of electric vehicles in service in 2008 are “Low Speed Vehicles” (ATTF: Table
V5, 2010), which are assumed to fall in the class of Automobiles. As this flow is relatively small and the remainder
is not described in further detail, the usage of Electricity by light duty vehicles is entirely attributed to Automobiles.
2 Electricity usage by Pipeline reported is 240 trBTU (TEDB: Table 2.5, 2007) and 27.4 trBTU (TEDB: Table A.11,
2010). The data in Table A.11 is more detailed than the data in Table 2.5, therefore the Electricity usage by Pipeline
in 2005 is reported as 27.4 trBTU.
Ethanol:
Ethanol is consumed by vehicles either as E85 fuel (~85% ethanol, 15% gasoline) or as an oxygenated blending component (typically ~10%) of traditional gasoline. In this analysis, we have depicted the ethanol portion of E85 consumption as a direct flow from Ethanol to vehicles and we have depicted oxygenate consumption as a flow from Ethanol into the Gasoline fuel supply.

Ethanol -> Gasoline
Ethanol is used as a blending component in oxygenated gasoline by Automobiles and Light Trucks. The use of Ethanol in Gasoline is reported as 2.8 billion gasoline-equivalent gallons or 340 trBTUs in 2005 (TEDB: Table2.4, 2010).

Ethanol -> Automobiles
In 2005, 37.8 million gasoline-equivalent gallons of E85 were consumed by light duty vehicles (ATTF: Table C5, 2010), 85% of which is Ethanol. This flow is split between Automobiles (33%) and Light Trucks (67%), based on the number of light duty vehicles in service in 2008 using E85 as a fuel (ATTF: Table V5, 2010). Therefore, the use of 10.7 million gasoline-equivalent gallons or 1.3 trBTUs of Ethanol is attributed to Automobiles.

Ethanol -> Light Trucks
In 2005, 37.8 million gasoline-equivalent gallons of E85 were consumed by light duty vehicles (ATTF: Table C5, 2010), 85% of which is Ethanol. This flow is split between Light Trucks (67%) and Automobiles (33%), based on the number of light duty vehicles in service in 2008 using E85 as a fuel (ATTF: Table V5, 2010.). Therefore, 21.7 million gasoline-equivalent gallons or 2.7 trBTUs of Ethanol is attributed to Light Trucks.

Ethanol -> Medium & Heavy Trucks
In 2005, 304 thousand gasoline-equivalent gallons of E85 were consumed by medium duty vehicles (ATTF: Table C5, 2010), 85% of which is Ethanol. The usage of Ethanol by medium duty vehicles is wholly attributed to Medium & Heavy Trucks. Therefore, 260 thousand gasoline-equivalent gallons or 0.032 trBTUs of Ethanol is used by Medium & Heavy Trucks.

Biodiesel:
Specific data on the use of Biodiesel by vehicle class could not be found. As a whole, Biodiesel use is reported as 92 million gasoline-equivalent gallons in 2005 (TEDB: Table 2.3, 2010). In this analysis, we have assumed that the consumption of Biodiesel follows the same pattern as the consumption of Diesel & Distillate Fuel Oil in Automobiles, Light Trucks, and Medium & Heavy Trucks.3

3 The use of Biodiesel is not attributed to any one class of transportation vehicle in the Transportation Energy Data Book (TEDB, 2010) or the Alternatives to Traditional Transportation Fuels report (ATTF, 2010), except for Transit Buses, for which Biodiesel is reported as first being used in 2006. Therefore, Biodiesel is assumed to be used by Automobiles, Light Trucks, and Medium & Heavy Trucks in the same fraction as these vehicles use Diesel & Distillate Fuel Oil.
Biodiesel -> Automobiles
The usage of Biodiesel by Automobiles is estimated as 0.011 of the total, the same ratio of Diesel & Distillate Fuel Oils used by Automobiles to the Diesel & Distillate Fuel Oils used by Automobiles, Light Trucks, and Medium & Heavy Trucks. Therefore the use of Biodiesel by Automobiles is estimated as 1.0 million gasoline-equivalent gallons or 0.12 trBTUs.

Biodiesel -> Light Trucks
The usage of Biodiesel by Light Trucks is estimated as 0.066 of the total, the ratio of Diesel & Distillate Fuel Oil used by Light Trucks to that used by Automobiles, Light Trucks, and Medium & Heavy Trucks. Therefore the use of Biodiesel by Light Trucks is estimated as 6.1 million gasoline-equivalent gallons or 0.76 trBTUs.

Biodiesel -> Medium & Heavy Trucks
The usage of Biodiesel by Medium & Heavy Trucks is estimated as 0.92 of the total, the ratio of Diesel & Distillate Fuel Oil used by Medium & Heavy Trucks to that used by Automobiles, Light Trucks, and Medium & Heavy Trucks. Therefore the Biodiesel by Medium & Heavy Trucks is estimated as 85 million gasoline-equivalent gallons or 11 trBTUs.

Hydrogen:

Hydrogen -> Automobiles
11 thousand gasoline-equivalent gallons of Hydrogen or 0.0014 trBTUs are reported as used in light duty vehicles (ATTF: Table C5, 2010). This flow of Hydrogen, 0.0014 trBTUs, is entirely attributed to Automobiles.

Hydrogen -> Transit Buses
14 thousand gasoline-equivalent gallons of Hydrogen or 0.0017 trBTUs are reported as consumed by heavy duty vehicles (ATTF: Table C5, 2010), which are assumed to be Transit Buses. Therefore, the flow from Hydrogen to Transit Buses is 0.0017 trBTUs.

CNG:

CNG -> Automobiles
In 2005, light duty vehicles consumed 29 million gasoline-equivalent gallon of CNG (ATTF: Table C5, 2010). Over 40% of the number of light duty vehicles in service in 2008 using CNG as a fuel were Automobiles in 2008 (ATTF: Table V5, 2010). Assuming this percentage of vehicles holds true in 2005, the usage of CNG by Automobiles is estimated as 40% of the total: 12 million gasoline-equivalent gallons or 1.4 trBTUs.

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4 Nearly 75% of the light duty vehicles in service in 2008 using Hydrogen as a fuel were Automobiles (ATTF: Table V5, 2010). As the remaining flow of energy (0.00035 trBTUs) is small, the entire 0.0014 trBTUs of Hydrogen usage is attributed to Automobiles.

5 As reported by the National Renewable Energy Laboratory (NREL, 2011), Transit Buses are one of the best early transportation applications for fuel cell technology. All of the active projects reported by this source utilizing Hydrogen as a fuel source are Transit Buses.
CNG -> Light Trucks
In 2005, light duty vehicles used 29 million gasoline-equivalent gallon of CNG (ATTF: Table C5, 2010). Nearly 60% of the number of light duty vehicles in service in 2008 using CNG as a fuel were light trucks, vans, or sport utility vehicles in 2008 (ATTF: Table V5, 2010), which are considered to be Light Trucks in this analysis. Assuming this percentage of vehicles holds true in 2005, the usage of CNG by Light Trucks is estimated as 60% of the total: 17 million gasoline-equivalent gallons or 2.2 trBTUs of CNG.

CNG -> Medium & Heavy Trucks
In 2005, CNG use by medium duty vehicles is reported as 19 million gasoline-equivalent gallons or 2.4 trBTUs and use by heavy duty vehicles is reported as 120 million gasoline-equivalent gallons or 15 trBTUs (ATTF: Table C5, 2010). As described below, Transit Buses used 15 trBTUs of CNG in 2005. The CNG fuel used by medium and heavy duty vehicles not consumed by Transit Buses (2.1 trBTUs) is attributed to Medium & Heavy Trucks.

CNG -> Transit Buses
Transit Buses used 120 million diesel-gallon equivalents of CNG in 2005 (TEDB: Table A.3, 2010). The CNG fuel use attributed to Transit Buses is equivalent to 15 trBTUs of energy.

Methanol:
Methanol -> Transit Buses
Transit Buses used 8.1 million gallons of methanol in 2005 (TEDB: Table A.3, 2010). This Methanol fuel use attributed to Transit Buses is equivalent to 0.52 trBTUs of energy.

LNG:
LNG -> Light Trucks
LNG use by light duty vehicles is reported as 59 thousand gasoline-equivalent gallons in 2005 (ATTF: Table C5, 2010). Assuming the usage of LNG is also dominated by pickup trucks in 2005, the entire LNG usage of 0.0074 trBTUs by light duty vehicles is attributed to Light Trucks.

LNG-> Medium & Heavy Trucks
In 2005, LNG use by medium duty vehicles is reported as 190 thousand gasoline-equivalent gallons or 0.024 trBTUs and use by heavy duty vehicles is reported as 22 million gasoline-equivalent gallons or 2.8 trBTUs (ATTF: Table C5, 2010). As described below, Transit Buses used 1.7 trBTUs of LNG in 2005 (TEDB: Table A.3, 2010). The LNG fuel use by medium and heavy duty vehicles not attributed to Transit Buses (1.1 trBTUs) is attributed to Medium & Heavy Trucks.

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6 The entire amount of LNG used by light duty vehicles in 2005 is attributed to Light Trucks in this analysis. As reported in the Alternatives to Traditional Transportation Fuels report, over 90% of the LNG-fueled light duty vehicles are pickup trucks (ATTF: Table V5, 2010). Because the LNG energy usage is relatively small (less than 0.01 trBTUs) and the vast majority is used by Light Trucks, the entire LNG fuel usage is attributed to Light Trucks.
**LNG -> Transit Buses**

Transit Buses used 18 million gallons of LNG in 2005 (TEDB: Table A.3, 2010). The LNG fuel use attributed to Transit Buses is calculated to be 1.7 trBTUs of energy.

**LPG:**

**LPG -> Light Trucks**

Light Trucks used 470 million gallons of LPG in 2005 (TEDB: Table A.5, 2010). The LPG fuel use attributed to Light Trucks is calculated to be 43 trBTUs of energy.

**LPG -> Medium & Heavy Trucks**

Medium & Heavy Trucks used 190 million gallons of LPG in 2005 (TEDB: Table A.6, 2010). The LPG fuel use attributed to Medium & Heavy Trucks is calculated to be 17 trBTUs of energy.

**LPG -> Transit Buses**

Transit Buses used 2.0 million gallons of LPG in 2005 (TEDB: Table A.3, 2010). The LPG fuel use attributed to Transit Buses is calculated to be 0.18 trBTUs of energy.

**Gasoline:**

**Gasoline -> Automobiles**

Automobiles used 52 billion gallons of gasoline, 25 billion gallons of oxygenated gasoline, and 1.9 million gallons of gasoline blended into E85 fuel in 2005 (TEDB: Tables 2.3 and A.1, 2010 and ATTF: Table C5, 2010). The Gasoline fuel use attributed to Automobiles is calculated to contain 9,500 trBTUs of energy including the ethanol blended as an oxygenate.

**Gasoline -> Motorcycles**

Motorcycles used 19 million gallons of Gasoline (TEDB: Table A.2, 2010). The Gasoline fuel use attributed to Motorcycles is calculated to contain 24 trBTUs of energy.

**Gasoline -> Light Trucks**

Light Trucks used 37 billion gallons of gasoline, 19 billion gallons of oxygenated gasoline, and 3.8 million gallons of gasoline blended into E85 fuel in 2005 (TEDB: Tables 2.3 and A.5, 2010 and ATTF: Table C5, 2010). The Gasoline fuel use attributed to Light Trucks is calculated to contain 6,900 trBTUs of energy including ethanol blended as an oxygenate.

**Gasoline -> Medium & Heavy Trucks**

Medium & Heavy Trucks used 4.1 billion gallons of gasoline and 46 thousand gallons of gasoline blended into E85 fuel in 2005 (TEDB: Table A.6, 2010 and ATTF: Table C5, 2010). The Gasoline fuel use attributed to Medium & Heavy Trucks is calculated to contain 510 trBTUs of energy.

**Gasoline -> Transit Buses**

Transit Buses used 1.0 million gallons of Gasoline in 2005 (TEDB: Table A.3, 2010). The Gasoline fuel use attributed to Transit Buses is calculated to contain 0.12 trBTUs of energy.
Gasoline -> Intercity & School Buses
Intercity & School Buses used 53 million gallons of Gasoline in 2005 (TEDB: Table A.4, 2010). The Gasoline fuel use attributed to Intercity & School Buses is calculated to contain 6.6 trBTUs of energy.

Gasoline -> General Aviation
General Aviation used 320 million gallons of aviation gasoline in 2005 (TEDB: Table A.7, 2010). While the actual formulation of aviation gasoline is different from gasoline used in Automobiles and Light Trucks, the energy content of the fuel is similar. Because of this, Aviation Gasoline is included on this flowchart as Gasoline. The Gasoline fuel use attributed to General Aviation is calculated to contain 39 trBTUs of energy.

Gasoline -> Recreational Boating
Recreational Boating used 1.6 billion gallons of Gasoline in 2005 (TEDB: Table A.10, 2010). The Gasoline fuel use attributed to Recreational Boating is calculated to contain 200 trBTUs of energy.

Jet Fuel:
Jet Fuel -> General Aviation
General Aviation used 1.5 billion gallons of Jet Fuel in 2005 (TEDB: Table A.7, 2010). The Jet Fuel use attributed to General Aviation is calculated to contain 200 trBTUs of energy.

Jet Fuel -> Commercial Aircraft
Commercial Aircraft include commercial passenger carriers and air freight carriers, and the fuel use described in this flowchart encompasses domestic and international departures. Commercial Aircraft used 19 billion gallons of Jet Fuel in 2005 (TEDB: Table A.8, 2010). The Jet Fuel use attributed to Commercial Aircraft is calculated to contain 2,600 trBTUs of energy.

Diesel & Distillate Fuel Oil:
Diesel & Distillate Fuel Oil -> Automobiles
Automobiles used 390 million gallons of Diesel Fuel in 2005 (TEDB: Table A.1, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Automobiles is calculated to contain 54 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Light Trucks
Light Trucks used 2.4 billion gallons of Diesel Fuel in 2005 (TEDB: Table A.5, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Light Trucks is calculated to contain 330 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Medium & Heavy Trucks
Medium & Heavy Trucks used 33 billion gallons of Diesel Fuel in 2005 (TEDB: Table A.6, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Medium & Heavy Trucks is calculated to contain 4,600 trBTUs of energy.
Diesel & Distillate Fuel Oil -> Transit Buses
Transit Buses used 530 million gallons of Diesel Fuel in 2005 (TEDB: Table A.3, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Transit Buses is calculated to contain 74 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Intercity & School Buses
Intercity & School Buses used 690 million gallons of Diesel Fuel in 2005 (TEDB: Table A.4, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Intercity & School Buses is calculated to contain 96 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Passenger Rail
Passenger Rail used 140 million gallons of Diesel Fuel in 2005 (TEDB: Tables A.13-A.15, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Passenger Rail is calculated to contain 20 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Freight Rail
Freight Rail used 4.1 billion gallons of Diesel Fuel in 2005 (TEDB: Table A.12, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Freight Rail is calculated to contain 570 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Recreational Boating
Recreational Boating used 300 million gallons of Distillate Fuel Oil in 2005 (TEDB: Table A.10, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Recreational Boating is calculated to contain 42 trBTUs of energy.

Diesel & Distillate Fuel Oil -> Commercial Shipping
Commercial Shipping used 2.1 billion gallons of Distillate Fuel Oil in 2005 (TEDB: Table A.9, 2010). The Diesel & Distillate Fuel Oil fuel use attributed to Commercial Shipping is calculated to contain 290 trBTUs of energy.

Residual Fuel Oil:
Residual Fuel Oil -> Commercial Shipping
Commercial Shipping used 5.5 billion gallons of Residual Fuel Oil in 2005 during international as well as domestic departures (TEDB: Table A.9, 2010). The Residual Fuel Oil fuel use attributed to Commercial Shipping is calculated to contain 830 trBTUs of energy.

Refined Fuels Production:
The fuels described above are manufactured from energy resources present in the environment. In some cases (e.g. petroleum refining) entire industrial sectors exist primarily to support the production of transportation fuels. In other cases (e.g. electricity production) transportation consumes a small fraction of the sector’s output. In all cases, the quantities depicted here pertain only to the portion of fuel consumed by the transportation sector.

All transportation fuels depend on a chain of energy transformations beginning with resource extraction and ending with final fuel production. This analysis depicts that final step, and excludes all steps
upstream of manufacture. This choice in system boundaries creates some “overlap” with other energy flow chart analyses.

**Biomass Refining**
The biofuels sector is comprised of ethanol manufacturing and biodiesel manufacturing.

**Biomass Refining -> Ethanol**
The amount of Ethanol consumed by vehicles in 2005 is reported as 38 million gasoline-equivalent gallons of E85 of which 85% is Ethanol and 2.8 billion gasoline equivalent-gallons of Ethanol used in oxygenated gasoline in 2005 (TEDB Table 2.3, 2010). From these quantities, the energy from Biomass Refining transformed into Ethanol is calculated to be 350 trBTUs in 2005.

**Biomass Refining -> Biodiesel**
The amount of Biodiesel used as an alternative fuel in 2005 is reported as 92 million gasoline-equivalent gallons (TEDB Table 2.3, 2010). With 125,000 BTUs per gasoline-equivalent gallon, the energy from Biomass Refining transformed into Biodiesel is calculated to be 11 trBTUs in 2005.

**Natural Gas Refining**
Transportation fuels derived from natural gas include Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), methanol and hydrogen. Natural gas is also consumed directly at pipeline compression stations – after it has undergone processing but before it is packaged for consumption by other parts of the transportation sector.

**Natural Gas Refining -> Hydrogen**
The amount of Hydrogen used as an alternative fuel in 2005 is estimated as 25 thousand gasoline-equivalent gallons (TEDB Table 2.3, 2010). Most hydrogen is produced via the steam reforming of natural gas. The energy from Natural Gas Refining transformed into Hydrogen is calculated to be 0.0031 trBTUs.

**Natural Gas Refining -> CNG**
The amount of CNG used as an alternative fuel in 2005 is estimated as 170 million gasoline-equivalent gallons (TEDB Table 2.3, 2010). From this, the energy from Natural Gas Refining transformed into CNG is calculated to be 21 trBTUs in 2005.

**Natural Gas Refining -> Methanol**
The amount of Methanol used as an alternative fuel in 2005 is reported as 8.1 million gallons (TEDB: Table A.3, 2010). The energy from Natural Gas Refining transformed into Methanol is calculated to be 0.52 trBTUs in 2005.
Natural Gas Refining -> LNG
The amount of LNG used as an alternative fuel in 2005 is reported as 22 million gasoline-equivalent gallons (TEDB: Table 2.3, 2010). The energy from Natural Gas Refining transformed into LNG is calculated to be 2.8 trBTUs.

Natural Gas Refining -> Pipeline
Fuels are moved throughout the United States using pipelines. In 2005, the transportation of these fuels used 580 billion cubic feet of Natural Gas (600 trBTUs) and 2.6 billion kilowatt hours of electricity (24 trBTUs). The fuel from Natural Gas Refining attributed to transporting fuels by Pipeline is calculated to be 600 trBTUs of energy.

Petroleum Refining

Petroleum Refining -> LPG
The amount of LPG used in the transportation sector in 2005 is reported as 660 million gallons (TEDB: Tables A.3, A.5, and A.6, 2010). Therefore, the energy from Petroleum Refining transformed into LPG is calculated to be 60 tBTUs.

Petroleum Refining -> Gasoline
The amount of Gasoline used in 2005 is reported as 95 billion gallons: 93 billion gallons as gasoline, 5.7 million gallons as the gasoline portion of E85, and 44 billion gallons as oxygenated gasoline—also referred to as gasohol (TEDB: Tables 2.3 and Appendix A, 2010). Therefore, the energy from Petroleum Refining transformed into Gasoline is calculated to be 17,000 trBTUs including the gasoline portion of E85 (TEDB, 2008).

Petroleum Refining -> Jet Fuel
The amount of Jet Fuel used in 2005 is reported as 21 billion gallons (TEDB: Tables A.7 and A.8, 2010). The energy from Petroleum Refining transformed into Jet Fuel is calculated to be 2,800 trBTUs in 2005 (TEDB, 2010).

Petroleum Refining -> Diesel & Distillate Fuel Oils
The amount of Diesel & Distillate Fuel Oils used in 2005 is reported as 44 billion gallons (TEDB: Tables A.1, A.3-A.6, A.9-A.10, A.12-A.13, and A.15, 2010). The energy from Petroleum Refining transformed into Diesel & Distillate Fuel Oils is calculated to be 6,000 trBTUs in 2005 (TEDB, 2010).

Petroleum Refining -> Residual Fuel Oil
The amount of Residual Fuel Oil used in 2005 is reported as 5.5 billion gallons (TEDB: Tables A.9, 2010). The energy from Petroleum Refining transformed into Residual Fuel Oil is calculated to be 830 trBTUs in 2005 (TEDB, 2010).
**Energy Disposition:**

**Energy Services**
This value is estimated as the sum of all propulsive and other useful work from transportation activities including *Automobiles, Motorcycles, Light Trucks, Medium & Heavy Trucks, Transit Buses, Intercity & School Buses, Pipeline, General Aviation, Commercial Aircraft, Passenger Rail, Freight Rail, Recreational Boating*, and *Commercial Shipping*.

**Rejected Energy**
Rejected energy represents the energy consumed by the transportation sector, which is not converted to propulsive or other useful work. This is the sum of all *Rejected Energy* from all transportation activities including *Automobiles, Motorcycles, Light Trucks, Medium & Heavy Trucks, Transit Buses, Intercity & School Buses, Pipeline, General Aviation, Commercial Aircraft, Passenger Rail, Freight Rail, Recreational Boating*, and *Commercial Shipping*.

**Energy Services**
Energy services in the transportation sector can be approximated by the sum of propulsive work (the mechanical work required to overcome aerodynamic drag, rolling resistance and vehicle inertia) and other useful work (minimum work required to run auxiliary and accessory loads in vehicles). In this analysis, we have assumed that all auxiliary and accessory services are delivered at 50% efficiency (i.e. 50% of energy delivered to auxiliary and accessory loads is a service, while the remainder is rejected).

*Automobiles -> Energy Services*
Energy use by *Automobiles* for combined city and highway driving has been estimated using the following percentages: 70 - 72% to engine losses, 3% to standby or idling, 5 - 6% to accessories, 8 - 10% to aerodynamic drag, 5 - 6% to rolling resistance, 5 - 6% to drivetrain losses, and 4 - 5% to braking (Fuel Economy, 2011). Defining useful energy to include the energy necessary to overcome aerodynamic drag, rolling resistance, braking, and half of the energy used by accessories, using the average percentages of the provided ranges, 22% of the total energy is attributed to *Energy Services*. Therefore, the flow from *Automobiles* to *Energy Services* is calculated as 2,100 trBTUs.

*Motorcycles -> Energy Services*
The energy efficiency of *Motorcycles* powered by gasoline is reported to be 15% (Chiu, 1999). Therefore, the flow from *Motorcycles* to *Energy Services* is calculated as 15% of the energy from *Motorcycles*, or 3.5 trBTUs.

*Light Trucks -> Energy Services*
The energy efficiency of *Light Trucks* is estimated by assuming the percent of useful work accomplished by *Light Trucks* is equivalent to that of *Automobiles*. Therefore, the total energy efficiency for *Light Trucks* is 22% and the flow from *Light Trucks* to *Energy Services* is calculated as 22% of the energy from *Light Trucks*, or 1,600 trBTUs.
Medium & Heavy Trucks -> Energy Services

Energy use by Medium & Heavy Trucks is estimated using the following percentages: 60% to engine losses, 21% to aerodynamic drag, 13% to rolling resistance, 4% to auxiliary losses, and 2% to drivetrain (US CCTP, 2003). Defining useful energy services as the energy needed to overcome the aerodynamic drag, rolling resistance, half the auxiliary losses, and drivetrain, the percentage of useful energy for Medium & Heavy Trucks is 38%. Therefore, the flow from Medium & Heavy Trucks to Energy Services is calculated to be 1,900 trBTUs.

Transit Buses -> Energy Services

The energy use by different functions in Transit Buses has been analyzed as a function of speed ranging from 20 – 50 miles per hour (mph) (Delorme, 2010). For this analysis, the energy usage by Transit Buses is calculated for a speed of 20 mph, assumed to be representative of average operating conditions. At a speed of 20 mph, 61% of the energy is consumed by engine losses, 20.5% by accessories, 1.8% by transmission, 0.1% by axles, 14.4% by rolling resistance, and 2.2% by aerodynamic drag. The energy efficiency of Transit Buses is estimated by summing the contributions from rolling resistance, aerodynamic drag, and half of the accessories for a total of 27%. Therefore, the flow from Transit Buses to Energy Services is calculated to be 25 trBTUs.

Intercity & School Buses -> Energy Services

For this analysis, the energy efficiency for Intercity & School Buses is estimated by using the energy distribution calculated for Transit Buses at a speed of 20 mph for School Buses and 50 mph for Intercity Buses (Delorme, 2010). Similar to Transit Buses, the Energy Services for School Buses traveling at an average of 20 mph is estimated to be 27%. The total energy used by School Buses is 73 trBTUs, therefore the flow from School Buses to Energy Services is calculated to be 20 trBTUs.

At a speed of 50 mph, 59% of the energy in Intercity Buses is consumed by engine losses, 8% by accessories, 1.1% by transmission, 1.0% by axles, 16% by rolling resistance, and 15% by aerodynamic drag. The energy efficiency of Intercity Buses is estimated by summing the contributions from rolling resistance, aerodynamic drag, and half of the energy used by accessories for a total of 35%. The total energy used by Intercity Buses is 30 trBTUs, therefore the flow from Intercity Buses to Energy Services is calculated as 10 trBTUs.

The total flow from Intercity & School Buses to Energy Services is the sum of these two flows for a weighted average of 29% energy efficiency, or 30 trBTUs.

Pipeline -> Energy Services

The energy service provided by the Pipeline sector is equal to the work done overcoming fluid friction within the pipelines. The energy efficiency in Pipeline is estimated to be 30%, about the efficiency of a compressor powered by a natural gas engine (Leslie, 2009). Therefore, the flow from Pipeline to Energy Services is calculated as 30% of the energy from Pipeline, or 190 trBTUs.
General Aviation -> Energy Services
The most efficient aircraft have a thermal efficiency of 55 - 60% and propulsive efficiency of 65 - 70% (Schafer, 2009). A separate source finds the thermal efficiency of small aircraft to be 30% (Paulus, 2003). Because the fleet of aircraft used in General Aviation is assumed to have lower efficiencies than the most efficient aircraft, the overall energy efficiency is estimated using 40% thermal efficiency (between the thermal efficiencies of the two sources) and 60% propulsive efficiency or 40% x 60%, for an overall efficiency of 24%. Therefore, the flow from General Aviation to Energy Services is calculated to be 58 trBTUs.

Commercial Aircraft -> Energy Services
The most efficient aircraft have a thermal efficiency of 55 - 60% and propulsive efficiency of 65 - 70% (Schafer, 2009). To take into account less efficient aircraft, the efficiencies for Commercial Aircraft are estimated using the percentages at the low end of the ranges or 55% x 65%, for an overall efficiency of 36%. Therefore, the flow from Commercial Aircraft to Energy Services is calculated to be 930 trBTUs.

Passenger Rail -> Energy Services
The energy efficiency for Passenger Rail varies significantly for trains fueled by diesel fuel or electricity; both fuels are used in significant amounts. Passenger Rail electric engines used 66 trBTUs of energy as electricity in 2005, which are 65% efficient (Lindgreen, 2005). Passenger Rail diesel engines used 20 trBTUs of energy as diesel fuel in 2005, the efficiency of which are assumed to be equivalent to Freight Rail at 30% (Lindgreen, 2005). The overall energy efficiency in Passenger Rail is calculated to be 57% from a weighted average. Therefore, the flow from Passenger Rail to Energy Services is calculated to be 49 trBTUs.

Freight Rail -> Energy Services
The energy efficiency of Freight Rail using diesel engines is estimated to be 30% (Lindgreen, 2005). Therefore, the flow from Freight Rail to Energy Services is calculated to be 170 trBTUs.

Recreational Boating -> Energy Services
The propulsive coefficient of marine pleasure craft is reported as 66% and the thermal efficiency of marine gasoline engines is reported to be between 25 - 35% (AEA, 2008). The energy efficiency of Recreational Boating is estimated to be 66% x 30%, for an overall efficiency of 20%. Therefore, the flow from Recreational Boating to Energy Services is calculated to be 49 trBTUs.

Commercial Shipping -> Energy Services
The propulsive coefficient (ratio of the effective power to the power measured at the thrust block) of merchant ships is reported as ranging between 60 - 70% (Barrass, 2004). The thermal efficiency of marine diesel engines is reported to be 45% (Rowen, 2008). Therefore, the energy efficiency of Commercial Shipping is estimated to be 65% x 45%, for an overall efficiency of 29%. Therefore, the flow from Commercial Shipping to Energy Services is calculated to be 330 trBTUs.
Rejected Energy
Energy rejected from the transportation sector includes all of the energy rejected (usually as waste heat or drivetrain losses) from the operation of vehicles and their accessories. This analysis also includes the energy rejected as waste heat or materials from the final manufacturing step in the fuels production supply chains.

Automobiles -> Rejected Energy
As described above, Automobiles are estimated to have an efficiency of 22%. Therefore, the flow from Automobiles to Rejected Energy is calculated as 78% of the energy from Automobiles, or 7,500 trBTUs.

Motorcycles -> Rejected Energy
As described above, Motorcycles are estimated to have an efficiency of 15%. Therefore, the flow from Motorcycles to Rejected Energy is calculated as 85% of the energy from Motorcycles, or 20 trBTUs.

Light Trucks -> Rejected Energy
As described above, Light Trucks are estimated to have an efficiency of 22%. Therefore, the flow from Light Trucks to Rejected Energy is calculated as 78% of the energy from Light Trucks, or 5,700 trBTUs.

Medium & Heavy Trucks -> Rejected Energy
As described above, Medium & Heavy Trucks are estimated to have an efficiency of 38%. Therefore, the energy flow from Medium & Heavy Trucks to Rejected Energy is calculated as 62% of the energy from Medium & Heavy Trucks, or 3,200 trBTUs.

Transit Buses -> Rejected Energy
As described above, Transit Buses are estimated to have an efficiency of 27%. Therefore, the energy flow from Transit Buses to Rejected Energy is calculated as 73% of the energy from Transit Buses, or 67 trBTUs.

Intercity & School Buses -> Rejected Energy
As described above, Intercity & School Buses are estimated to have a weighted energy efficiency of 29%. Therefore, the energy flow from Intercity & School Buses to Rejected Energy is calculated as 71% of the energy from Intercity & School Buses, or 73 trBTUs.

Pipeline -> Rejected Energy
As described above, Pipeline is estimated to have an efficiency of 30%. Therefore, the flow from Pipeline to Rejected Energy is calculated as 70% of the energy from Pipeline, or 440 trBTUs.

General Aviation -> Rejected Energy
As described above, General Aviation is estimated to have an efficiency of 24%. Therefore, the flow from General Aviation to Rejected Energy is calculated as 76% of the energy from General Aviation, or 180 trBTUs.
Commercial Aircraft -> Rejected Energy
As described above, Commercial Aircraft are estimated to have an energy efficiency of 36%. Therefore, the flow from Commercial Aircraft to Rejected Energy is calculated as 64% of the energy from Commercial Aircraft, or 1,700 trBTUs.

Passenger Rail -> Rejected Energy
As described above, Passenger Rail is estimated to have a weighted energy efficiency of 57%. Therefore, the flow from Passenger Rail to Rejected Energy is calculated as 43% of the energy from Passenger Rail, or 37 trBTUs.

Freight Rail -> Rejected Energy
As described above, Freight Rail is estimated to have an energy efficiency of 30%. Therefore, the flow from Freight Rail to Rejected Energy is 70% of the energy from Freight Rail, or 400 trBTUs.

Recreational Boating -> Rejected Energy
As described above, Recreational Boating is estimated to have an energy efficiency of 20%. The flow from Recreational Boating to Rejected Energy is calculated as 80% of the energy from Recreational Boating, or 200 trBTUs.

Commercial Shipping -> Rejected Energy
As described above, Commercial Shipping is estimated to have an energy efficiency of 29%. The flow from Commercial Shipping to Rejected Energy is calculated as 71% of the energy from Commercial Shipping, or 800 trBTUs.

Electricity Production -> Rejected Energy
Electricity Production efficiency ranges from 33-52% and electricity delivery losses are estimated at 8% of generated electricity. From these values, the total efficiency of Electricity Production is estimated to be 32%. Therefore, as 94 trBTUs of electricity are used by the transportation sector, the total energy required to produce this amount of electricity is 94 trBTUs / 32%, or 290 trBTUs. Therefore, the energy flow from Electricity to Rejected Energy is calculated as 290 – 94 trBTUs, or 200 trBTUs.

Biomass Refining -> Rejected Energy
The processing of Ethanol by dry mill from corn uses 202,000 BTUs per gallon: 153,000 BTUs present in corn and 49,000 BTUs used to convert the corn into Ethanol (PennState, 2009; Rowlett, 2001; Shapouri, 2002). This process produces one gallon of Ethanol containing 76,000 BTUs using a dry mill (Shapouri, 2002; TEDB, 2010). Therefore, the processing of ethanol is estimated to be 38% efficient.

In comparison, 390,000 BTUs of energy are consumed during the processing of one gallon of Biodiesel from soybeans: 350,000 BTUs present in soybeans (Mourad, 2011; Conley, 2006), 23,200 BTUs in
soybean crushing, and 18,800 BTUs in Biodiesel conversion (Pradhan, 2009).\(^7\) The product, 1 gallon of Biodiesel, contains 120,000 BTUs (TEDB, 2010). Biodiesel processing is estimated to be 31% efficient.

Given the useful energy of 350 trBTUs in ethanol and 11 trBTUs in biodiesel, the Rejected Energy from Biomass Refining is calculated as \((350 / 38\% - 350)\) or 571 trBTUs from ethanol conversion and \((11 / 31\% - 11)\) or 24 trBTUs from biodiesel conversion. The total flow from Biomass Refining to Rejected Energy is the sum of these two flows, 590 trBTUs.

**Natural Gas Refining -> Rejected Energy**

In 2007, the processing of natural gas in North America was estimated as 97.2% efficient (CEC, 2007). Natural gas liquefaction and compression incur additional losses, as do the production of hydrogen or methanol from natural gas. However, because 96% of natural gas use in transportation consumes gas directly from the pipelines, those processing losses are negligible. Therefore, the energy flow from Natural Gas Refining to Rejected Energy is calculated as 2.8% of the total energy, 18 trBTUs.

**Petroleum Refining -> Rejected Energy**

Using a top-down approach, the efficiency of Petroleum Refining is calculated using the energy and material inputs and outputs. The inputs in Petroleum Refining for the transportation sector are estimated to be 27,000 trBTUs in 2005: 25,000 trBTUs of crude oil (Refinery Receipts, 2010), 100 trBTUs of electricity, 600 trBTUs of natural gas, 1,200 trBTUs of still gas, 450 trBTUs of petroleum coke, and 50 trBTUs of steam (U.S. EIA, 2010). The products have energy contents of 25,000 trBTUs. From this calculation, the Petroleum Refining process is estimated to be 91% efficient. Using the bottom-up approach to calculating energy present in petroleum products used in the transportation sector in 2005, the total energy flow to products is 27,000 trBTUs. Therefore, the energy flow from Petroleum Refining to Rejected Energy is calculated from \(27,000 / 91.5\% - 27,000\), or 2,500 trBTUs.

**Fuel production Sector:**

**Electricity Production:**

Electricity Production represents the sum of electricity used by Automobiles, Medium & Heavy Trucks, Transit Buses, Pipeline, and Passenger Rail and the energy rejected in producing this electricity. The total energy flow through Electricity Production in 2005 is 290 trBTUs.

**Biomass Refining:**

Biomass Refining represents the energy delivered to Automobiles, Light Trucks, Medium & Heavy Trucks, and Transit Buses via ethanol fuel (E85), biodiesel and ethanol blended into gasoline. It also includes the energy rejected in the manufacture of those fuels. The total energy flow through Biomass Refining in 2005 is therefore 950 trBTUs.

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\(^7\) These calculations do not remove the energy associated with making co-products including soybean meal and crude glycerin. Removing the energy associated with making these products would greatly increase the efficiency of this Biomass Refining of Biodiesel.
Natural Gas Refining:
Natural Gas Refining represents the fuel and energy used to produce Hydrogen, Compressed Natural Gas (CNG), Methanol, Liquefied Natural Gas (LNG), along with the natural gas used in Pipeline activities in the transportation sector and the energy rejected in producing these products. In 2005, 23 billion cubic feet of natural gas (24 trBTUs) were used to power vehicles, while 580 billion cubic feet (600 trBTUs) were used to power compression stations in the natural gas transmission and distribution systems (NGCEU, 2011), and 18 trBTUs were rejected, for a total of 640 trBTUs.

Petroleum Refining:
Petroleum Refining represents the fuel and energy used to produce Liquefied Petroleum Gas (LPG), Gasoline, Jet Fuel, Diesel & Distillate Fuel Oil, and Residual Fuel Oil for the transportation sector. It also includes the 2,500 trBTUs rejected in the manufacturing of these fuels. The energy flow through Petroleum Refining in 2005 is therefore 29,000 trBTUs.

Conclusion

The flow chart described in this report is a compact depiction of the national energy use in the transportation sector in 2005. This diagram is available at: http://flowcharts.llnl.gov
References


Appendix

Conversions used (TEDB, 2010):

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>BTUs/Gallon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline-equivalent</td>
<td>125,000</td>
<td>BTUs/gasoline equivalent gallon</td>
</tr>
<tr>
<td>Diesel-equivalent</td>
<td>138,700</td>
<td>BTUs/diesel-equivalent gallon</td>
</tr>
<tr>
<td>Ethanol</td>
<td>75,700</td>
<td>BTUs/gallon of ethanol</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>117,100</td>
<td>BTUs/gallon of biodiesel</td>
</tr>
<tr>
<td>Methanol</td>
<td>64,600</td>
<td>BTUs/gallon of methanol</td>
</tr>
<tr>
<td>Natural Gas</td>
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<td>BTUs/cubic foot of natural gas</td>
</tr>
<tr>
<td>LNG</td>
<td>90,800</td>
<td>BTUs/gallon of LNG</td>
</tr>
<tr>
<td>LPG</td>
<td>91,300</td>
<td>BTUs/gallon of LPG</td>
</tr>
<tr>
<td>Gasoline</td>
<td>125,000</td>
<td>BTUs/gallon of gasoline</td>
</tr>
<tr>
<td>Gasohol</td>
<td>120,900</td>
<td>BTUs/gallon of gasohol</td>
</tr>
<tr>
<td>Aviation Gasoline</td>
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<td>BTUs/gallon of aviation gasoline</td>
</tr>
<tr>
<td>Jet Fuel</td>
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<td>BTUs/gallon of jet fuel</td>
</tr>
<tr>
<td>Diesel Fuel</td>
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<td>BTUs/gallon of diesel fuel</td>
</tr>
<tr>
<td>Distillate Fuel Oil</td>
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<td>BTUs/gallon of distillate fuel oil</td>
</tr>
<tr>
<td>Residual Fuel Oil</td>
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<td>BTUs/gallon of residual fuel oil</td>
</tr>
<tr>
<td>Electricity</td>
<td>10,339</td>
<td>BTUs/kWh</td>
</tr>
</tbody>
</table>

Glossary

Fuels:

*Ethanol:* Ethanol is refined from Biomass. This fuel represents the Ethanol in E85 used by Automobiles, Light Trucks, and Medium & Heavy Trucks and Ethanol used as a blending component in Gasoline.

*Biodiesel:* Biodiesel is produced from Biomass Refining and is used by Automobiles, Light Trucks, and Transit Buses.
Hydrogen:
In 2005, Hydrogen was produced by steam-reforming of natural gas. Hydrogen is used to fuel Automobiles and Transit Buses.

Compressed Natural Gas (CNG):
CNG is refined and compressed from Natural Gas and is used by Automobiles, Light Trucks, Medium & Heavy Trucks, and Transit Buses.

Methanol:
Methanol is refined from Natural Gas and is used by Transit Buses.

Liquefied Natural Gas (LNG):
LNG is refined from Natural Gas and is used by Light Trucks, Medium & Heavy Trucks, and Transit Buses.

Liquefied Petroleum Gas (LPG):
LPG is refined from Petroleum and is used by Light Trucks, Medium & Heavy Trucks, and Transit Buses.

Gasoline:
Gasoline is refined from Petroleum and is used by Automobiles, Motorcycles, Light Trucks, Medium/Heavy Trucks, Transit Buses, Intercity & School Buses, General Aviation, and Recreational Boating.

Jet Fuel:
Jet Fuel is refined from Petroleum and is used by General Aviation and Commercial Aircraft.

Diesel & Distillate Fuel Oils:
Diesel & Distillate Fuel Oils are refined from Petroleum and are used by Automobiles, Light Trucks, Medium & Heavy Trucks, Transit Buses, Intercity & School Buses, Passenger Rail, Freight Rail, Recreational Boating, and Commercial Shipping.

Residual Fuel Oil:
Residual Fuel Oil is refined from Petroleum and is used by Commercial Shipping.

Energy Use:

Light-duty vehicles
Light duty vehicles include motorcycles, automobiles, and light trucks.

Automobiles
The energy used by Automobiles is calculated as the sum of flows from Electricity Production, Ethanol, Biodiesel, Hydrogen, CNG, LNG, LPG, Gasoline, and Diesel & Distillate Fuel Oils.

Motorcycles
The energy used by Motorcycles is equal to the flow from Gasoline.
Light trucks
The energy used by Light Trucks is calculated as the sum of flows from Ethanol, Gasoline, and Diesel & Distillate Fuel Oils.

Medium & Heavy Trucks
The energy used by Medium & Heavy Trucks is calculated as the sum of flows from Gasoline and Diesel & Distillate Fuel Oils.

Transit Buses
The energy used by Transit Buses is calculated as the sum of flows from Electricity Production, CNG, Methanol, LNG, LPG, Gasoline, and Diesel & Distillate Fuel Oils.

Intercity & School Buses
The energy used by Intercity & School Buses is calculated as the sum of flows from Gasoline and Diesel & Distillate Fuel Oils.

Pipeline
The energy used by Pipeline is calculated as the sum of flows from Electricity Production and Natural Gas Refining.

General Aviation
The energy used by General Aviation is calculated as the sum of flows from Gasoline and Jet Fuel.

Commercial Aircraft
The energy used by Commercial Aircraft is equal to the flow from Jet Fuel and includes activities for domestic and all international air carriers.

Passenger Rail:
The energy used by Passenger Rail is equal to the flow from Diesel & Distillate Fuel Oils and includes both transit, intercity, and commuter rail operations.

Freight Rail:
The energy used by Freight Rail is equal to the flow from Diesel & Distillate Fuel Oils.

Recreational Boating:
The energy used by Recreational Boating is calculated as the sum of flows from Gasoline and Diesel & Distillate Fuel Oils.

Commercial Shipping:
The energy used by CommercialShipping, also referred to as Vessel Bunkering, is calculated as the sum of flows from Diesel & Distillate Fuel Oils and Residual Fuel Oil and includes fuel use for both domestic and international activities.