MONT 100N – Modeling the Environment
Chapter 3 Project
September 29, 2017

1 Background

To solidify your confidence in dealing with quantitative information, this chapter presents another project summarizing ideas developed in the previous two chapters, as well as a few data visualization topics that we have not mentioned before. The subject will be the whole U.S. energy economy in recent years.

Figure 1 shows energy production and end-use consumption data for all major sectors in the United States energy economy for the year 2010. Figure 2, given later, shows the analogous data for the year 2016. Similar diagrams have been produced each year by the Lawrence Livermore National Laboratory, using data provided by the Energy Information Administration, a division of the U.S. Department of Energy.

Reading the Charts

To read these diagrams, you will want to rotate the page or the screen by 90° clockwise, then follow the flow of energy by reading from left to right. On the far left are boxes representing the major energy sources labeled Solar, Nuclear, Hydro, Wind, etc. The 4 boxes towards the right (Residential, Commercial, Industrial, Transportation) are the four largest end-use sectors of energy consumption. Some of the basic source energy is first converted to electricity before it is transmitted to the four end-use sectors, as shown by the box labeled "Electricity Generation."[1] On the far right two boxes in the diagram indicate the total amount of energy that is lost or wasted ("Rejected Energy") and the amount that is used for its intended purpose ("Energy Services"). The "pipelines" joining the boxes represent how much energy originating in the box to the left was delivered to the box on the right. The numerical amounts are given as the numbers printed next to the pipelines in units to be discussed below.[2] The width of each energy flow (pipeline) is also in direct proportion to the amount of energy in that flow so you can judge the importance visually.

Units

The header on the top of the chart states that Net Primary Resource Consumption is approximately 98 Quads – this is energy-speak for 98 quadrillion BTUs. One quadrillion is 1×10^{15}. All energy measurements on the diagram have units of quadrillion British thermal units (BTU's), or "Quads" for short. One BTU is the quantity of heat needed to raise the temperature of 1 pound of water by 1° F at or near 39.2° F. Some approximate conversion factors are given below. In most cases,

[1] At the top of the diagram, you can also see that there is a very small amount of electric energy that was imported (mostly from hydroelectric plants in Canada). This is so small that it is essentially negligible in the big picture.

[2] The numbers aren't always near the source, so you may need to hunt for them!

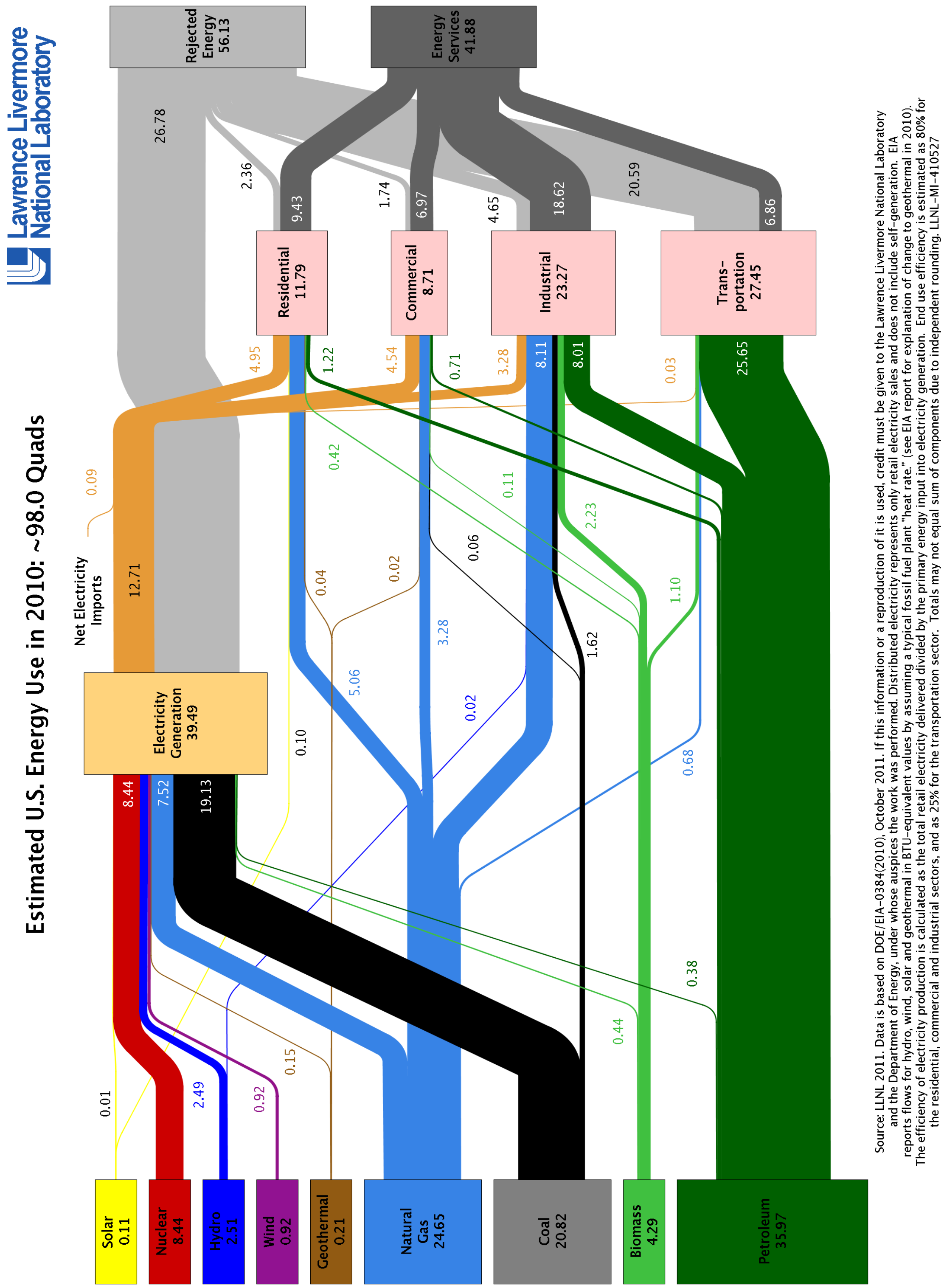

Figure 1: The U.S. energy sector in 2010.

Table 1: Energy content of various fuels.

Fuel	Equivalent (BTU)
1 ton coal	$21,400,000$
1 barrel (42 gal.) oil	$5,800,00$
1 cubic foot natural gas	1000
1 kilowatt − hour electricity	$3,400$

the numbers on the chart have been rounded to 1 decimal place (tenth of a Quad). Because of this rounding, the total Quads listed next to each production sector and end-use sector might not exactly equal the sum of the individual components.

2 Questions

(A) Rank the energy sources from highest to lowest in Quads and compute the percentage each accounts for in the total U.S. energy sector. Construct a *pie chart* representing this information. (You can do this in Excel, for instance, or construct the pie chart by hand.)

(B) Using Table 1, determine the answers to the following.

  (1) What is the equivalent amount of petroleum used in 2010 in units of barrels?

  (2) What is the equivalent amount of natural gas used in 2010 in cubic feet?

(C) Construct a table showing the total natural gas energy used by each of the four end-use sectors. Note that some of the natural gas is used for Electricity Generation, and that electricity is then used in the end-use sectors. In other words, do not miss the portion of the end-use sectors that use natural gas by way of electricity generated by burning gas. (How will you account for the fact that only a part of the Electricity Generation is done by burning natural gas?)

(D) Which of the energy sources are based on "fossil fuels?" Which of the energy sources are "renewable energy" sources? What percentage of the total energy produced is accounted for by renewables?

(E) **Analysis of the Electricity Generation sector.** Many sources of energy flow into the electric power sector, which then distributes electricity to the end-use sectors. Petroleum, coal, natural gas and biomass are burned in conventional power plants to produce heat to boil water. The steam from the boiling water spins turbines which then produce electricity. Nuclear fuels can be used to produce electricity in much the same way: nuclear reactions in power plants make the heat which boils the water which spins the turbines which produces the electricity. Other sorts of energy are also used to generate electricity. Both conventional-electric and nuclear-electric power plants have the property that a large amount of the fuel energy is lost in the process of making electricity and then more is lost during transmission along electrical lines.

(1) The 2010 diagram indicates that the electric power sector converted various energies to 39.49 Quads of electrical energy. What were the top two sources of energy for the electric power sector?

(2) How many Quads of electricity were successfully distributed from power plants, and how many Quads were lost at the power plants?

(3) The *efficiency* of an energy system is defined as the percentage of the total energy used for the intended purpose. Determine the efficiency of the U.S. electric power sector, using your previous answers and ignoring losses after distribution.

(4) Natural gas contributed 7.52 Quads of energy to the electric power sector. How many Quads of that contribution were immediately lost by the electric power sector? Explain any assumptions you are making.

(5) Give two practical reasons why so little electricity is distributed to the transportation sector.[3]

(F) Make a pie chart illustrating the *five* largest energy forms used in the Residential sector and the percentages they account for in the Residential sector.

(G) **The Industrial sector.** The Industrial sector includes manufacturing industries, mining, construction, agriculture, fisheries and forestry.

(1) The industrial sector consumed 23.27 Quads through *six* forms of energy.[4] Draw a bar chart to illustrate the number of Quads used for each of those six form of energy. Label each bar with its energy name and amount.

(2) Natural gas energy is directly consumed by the Industrial sector through the burning of natural gas. But the Industrial sector also consumes natural gas energy indirectly by using distributed electricity. Compute the total Quads of natural gas energy consumed by the industrial sector. Ignore energy losses.

(H) **Petroleum and Transportation.**

(1) The transportation sector is primarily fed by the energy derived from Petroleum, with small contributions from Biomass, Natural gas, and Electricity. What percent of the

[3] There is *some* electric power used for transportation, though. The Amtrak Northeast Corridor passenger rail lines between Boston and Washington, DC use electric power, for instance.

[4] You will need to look carefully to find them all, but they are there!

total Petroleum energy is consumed by the transportation sector? You can ignore the small amount of oil energy that is first converted to electricity.

(2) What percent of the energy consumed by the transportation sector was wasted in 2010? Consider all forms of energy.

(3) Multiply the percentages found in the last two parts to find the percentage of all Petroleum energy that was wasted by the transportation sector. How many barrels of oil is that? How many gallons?

(I) **Heating homes.** Most homes and apartments today are heated with electricity or natural gas. (The exception to this general rule comes in New England, where many homes are still heated by burning oil.) Electric heaters are 100% efficient because all of the energy that goes into the heaters is turned into heat (the intended purpose). Natural gas furnaces vary considerably in how efficiently they burn gas. The most efficient ones turn about 95% of the gas energy into heat (the intended purpose); the other 5% of the gas energy is wasted through the furnace exhaust. Comparing the numbers (100% versus 95%), one could argue that electric heaters are slightly better than even the most efficient gas furnaces. Explain what is wrong with this argument, using numbers to support your answer.

(J) **Electric power again.**

(1) Some of the electricity generated by the Electricity Generation sector was successfully distributed to users, but much was lost in the system (see question (E)). Some of the electricity that is distributed to the Residential, Commercial, Industrial, and Transportation sectors is further wasted (i.e. lost). Compute the total amount of electricity that is wasted after it is transported to these 3 sectors.

(2) Determine the total amount of electric energy that is distributed and then used, and the total amount that is wasted, for the U.S. electric power system.

(3) In your answer to part (2) you were making a certain proportionality assumption about the end-use sectors. Explain.

(K) Based on the 2010 data, if you were asked to recommend *two aspects* of the U.S. energy economy where changes might increase total efficiency most, what would they be? What sorts of changes would be necessary? Would they be matters of better technology, changes in attitudes of people, etc.?

(L) Now consider the diagram for 2016.

(1) What major changes do you see between 2010 and 2016? What accounts for those changes? (If you need to look up information to answer this by all means go ahead. But, as always, document your sources!)

(2) Is the U.S. energy economy more or less efficient in 2016 than it was in 2010? Explain the criteria you are using to derive your answer.

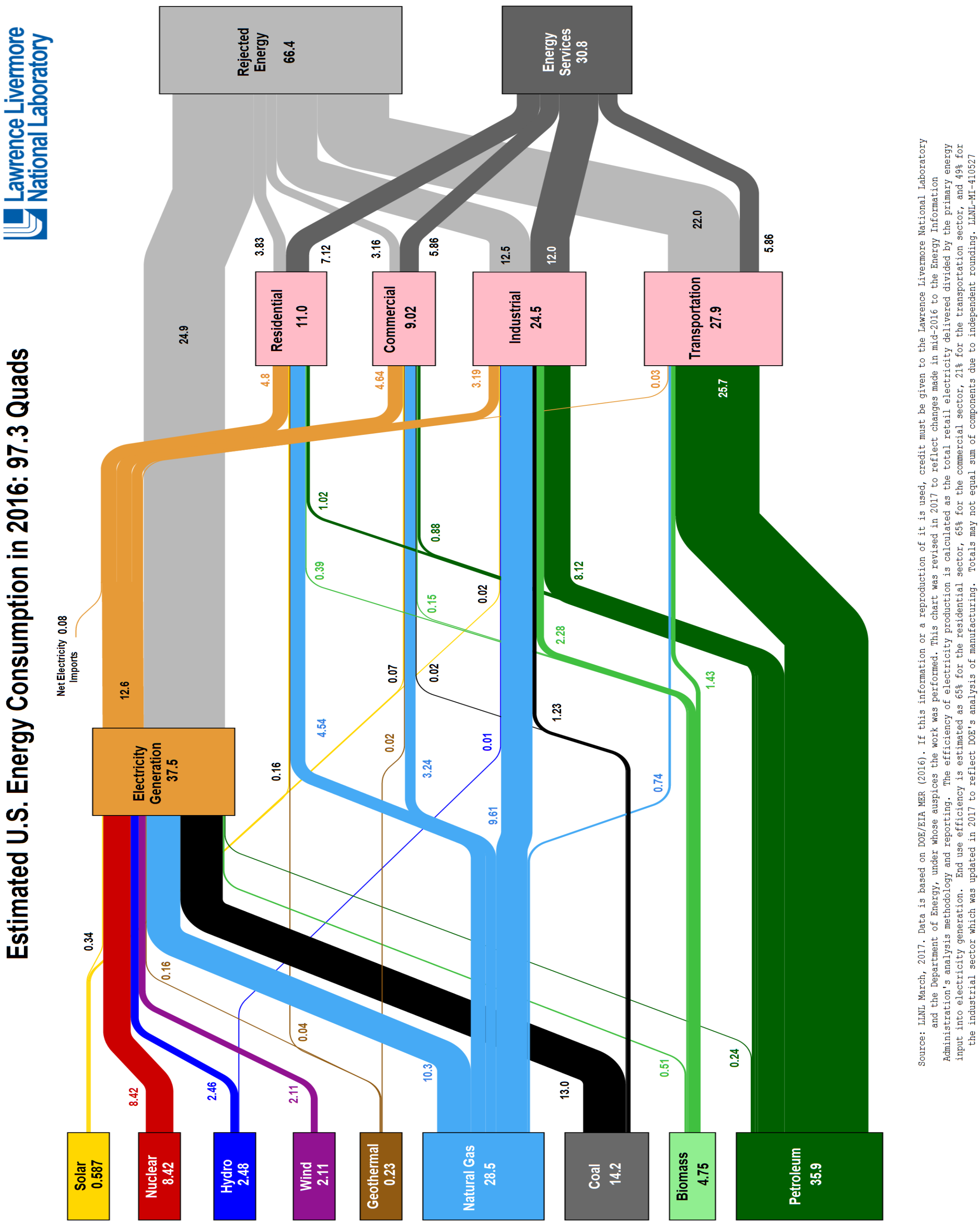

Figure 2: The U.S. energy sector in 2016.