The Global Energy Landscape

There are few things more complex than global energy supply and consumption. In fact, the global energy landscape is a prime example of a complex system: each of the components in the system may have been carefully designed, but the connections and interrelations between components – an example within this system is the power grid – emerged without a central plan; the very essence of complexity. The interdependencies of networks, regulatory issues, and types of energy supply and demand all add to the dizzying complexity of the entire system.

Technologies will continue to emerge and evolve, but the only constant is that they are all subject to the laws of thermodynamics. Table 1 is a work-in-progress resource that depicts the landscape in terms of various energy components.

Table 1. Advantages and Drawbacks of Different Energy Sources

Type of Energy	Pros	Cons
Petroleum	Low cost. Infrastructure and technology are mature.	High environmental burden including climate change, spills are catastrophic.
Coal	Low cost. Infrastructure and technology are mature.	High environmental burden including climate change, mountain top blasting scars landscape, burning coal significantly worsens air quality
Natural Gas	Abundant domestically, lower GHG emissions, potential bridge to future energy systems (e.g., hydrogen (H_2)).	Methane leakage incurs high GHG emissions, water quality deteriorates from fracking, seismic activity.
Nuclear	Low GHG emissions.	Waste management, accidents are catastrophic.
Hydropower	Low GHG emissions.	Negative social and environmental effects of dams, drought can limit supply.
Biomass	Renewable carbon lessens GHG emissions.	Conventional agriculture consumes fertilizer which leads to GHG emissions and run-off.
Geothermal	Low GHG emissions.	Viability depends on region, limited application in densely populated areas because of land requirement.
Wind	Low GHG emissions.	Biodiversity impacts (e.g., avian mortality), intermittency.
Solar (PV)	Low GHG emissions.	Requires large land footprint, intermittency.
Hydrogen	High energy density.	High costs of transport, infrastructure immature.

GHG = greenhouse gas
PV = photovoltaic
EV = electric vehicle

The energy sources in Table 1 are used to produce electricity, transportation fuels, and in the case of natural gas (NG) and petroleum in particular, as raw materials in chemical processes that make plastics and other products. Figure 1 illustrates the 2020 energy landscape from energy sources to uses. In 2020, the United States consumed 72 quads (quadrillion BTUs) of fossil fuels, mainly petroleum and natural gas.

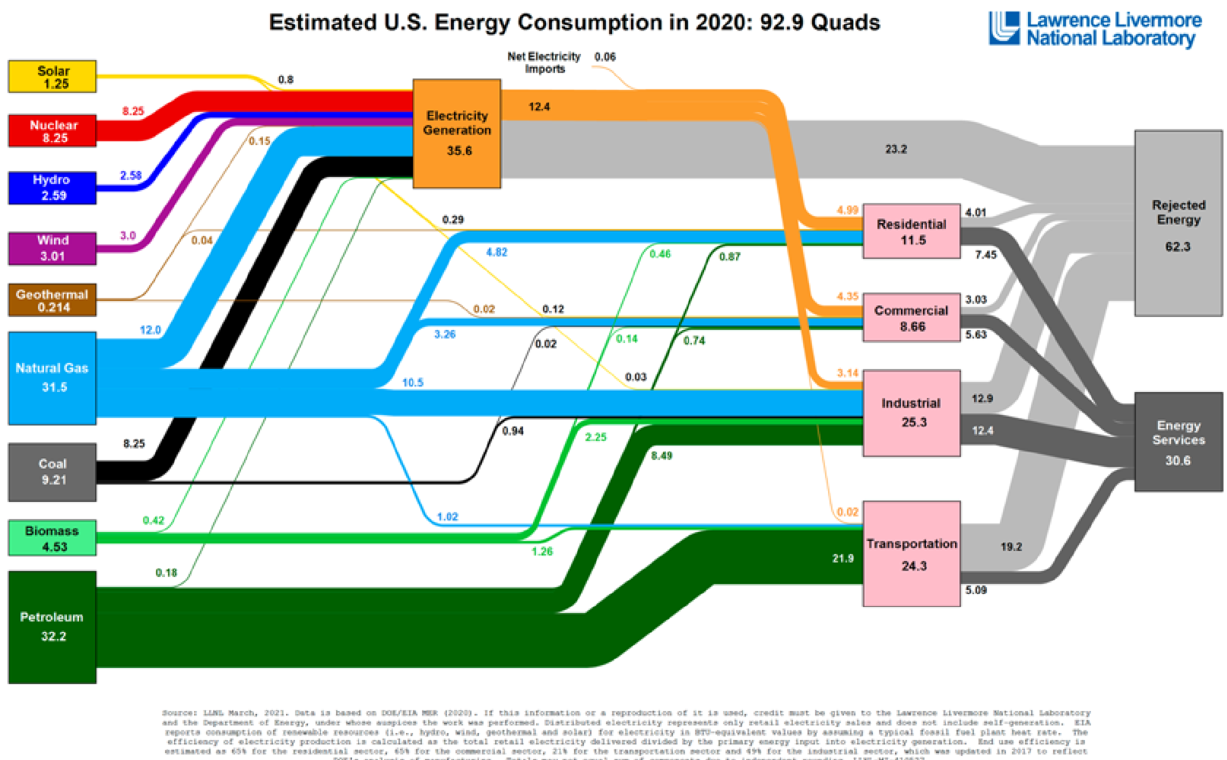

Figure 1: Estimated energy consumption in the U.S. during 2020: 92.9 quads (equivalent to 97 trillion megajoules). Lawrence Livermore National Laboratory.

Figure 1 shows that electricity and transportation are the two major consumers of fossil energy. This is a massively complex problem, and only a few major points are made in the comments that follow.

Figure 2 depicts life-cycle energy and environmental effects of electricity production from different sources. Figure 2a shows the amount of fossil fuels in megajoules (MJ) consumed to produce one MJ of electricity. This includes the entirety of fossil fuels consumed in electricity production from coal mining, for example, to use of electricity at a wall outlet. Per MJ of electricity produced from different sources, renewable energy technologies require very little consumption of fossil fuels. It is also important to consider how much water (in liters (L)) is consumed to produce one MJ of electricity. Producing electricity from fossil fuels is water efficient, particularly in the case of natural gas (NG) (Figure 2b). Reducing emissions of greenhouse gases (GHG) that cause global warming is critical. Evaluating electricity generation options on the amount of GHG emissions, reported as grams of carbon dioxide equivalents in Figure 2c, is therefore essential. Carbon dioxide equivalent emissions include emissions of carbon dioxide and two other GHGs: methane and nitrous oxide, which are approximately 30 and 300 times more potent GHGs than carbon dioxide, respectively. Producing electricity from renewable energy emits dramatically lower amounts of GHGs than producing it from fossil fuels.

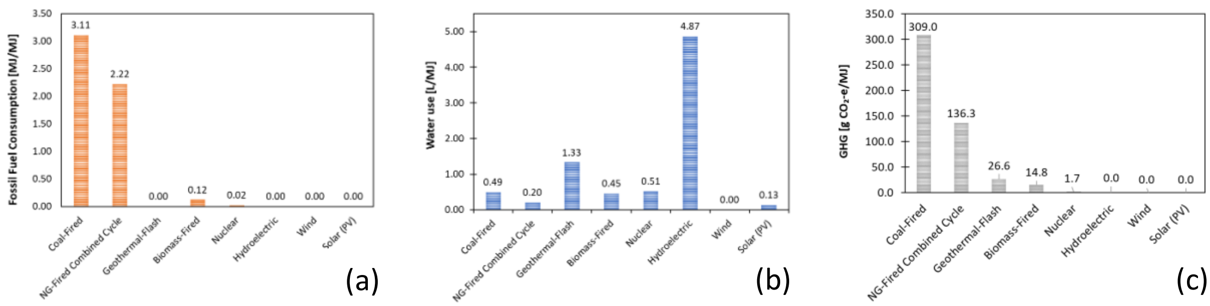

Figure 2: Life-cycle (a) fossil fuel consumption [MJ/MJ electricity] (b) water consumption [gal/MJ electricity] and (c) greenhouse gas emissions [g CO_2e/MJ electricity] for electricity production [Greenhouse gases, Regulated Emissions and Energy use in Technologies (GREET) model, greet.es.anl.gov].

Evaluations of energy use in transportation highlight similar patterns. Figure 3 breaks down fossil fuel consumption for different fuel-vehicle types commonly used in transportation on a MJ consumed per mile driven basis. These fuel cycle in these results covers the full supply chains of energy production (e.g., from oil extraction to refining to fueling at a gas station pump). The vehicle cycle covers the production of the car using the fuel, whether it is a conventional car with an internal combustion engine running on gasoline or an electric vehicle powered by a battery. Of transportation options, gasoline-powered internal combustion engine vehicles consume the most fossil fuel energy per mile. Other technologies, including electric vehicles, also use large amounts of fossil fuels throughout their supply chain, including in electricity production – which is still dominated by fossil fuels - and the manufacturing of vehicles. It should be noted that negative social and environmental effects arise from mining for battery components including cobalt, nickel, and lithium. Fossil energy consumption in electric vehicle manufacturing is dominated by natural gas (57%). While hydrogen is considered an emerging low-carbon fuel, the technology used to make it today generally consumes large amounts of natural gas. Accordingly, in Figure 3, hydrogen-based transportation technologies consume more fossil fuel than electric vehicles. Yet, we need to produce hydrogen from fossil fuels now to establish the foundational infrastructure and experience with the technology necessary for using hydrogen at a large scale when it is cost effectively produced from electrolysis.

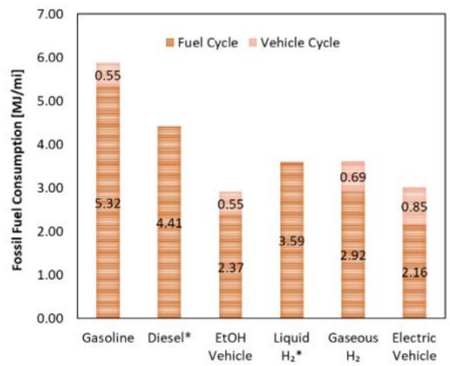

Figure 3: Fossil fuel consumption (MJ/mi) for different fuel-vehicle combinations. National average grid mix assumed for provision of electricity for electric vehicles. *denotes vehicle cycle results are unavailable in the GREET model.

The Energy Transition

The consumption of fossil fuels must decrease to achieve GHG mitigation goals. The transition away from fossil fuels is far from simple. If we decelerate their use too quickly, the development of the technology we need for net zero energy systems could be stymied. This is especially true because of inadequate investments in renewables and in so-called "transition fossil fuels", such as liquefied natural gas.[1] In addition, the United States is dependent upon unstable international supply chains for key metals (e.g., cobalt, iridium) used in emerging, low-carbon energy sources. If the U.S. stops developing its fossil fuel resources, the energy transition could become reliant on fossil fuels or metals provided by unstable autocratic nations or regions with lower environmental protections. This situation could disrupt supply chains. If energy costs skyrocket as a result, as some[1] envision, the general public may turn against decarbonization. It is imperative that the United States develop concrete strategies to use fossil fuels as a bridge to a low-carbon energy future. This will require investments in fossil fuel infrastructure that reduce its GHG emissions (e.g., from leaking natural gas distribution systems), oil spills, and other negative environmental effects. The path to decarbonization also requires investment in uses of fossil fuels that de-risk the low-carbon energy sources of the future, including hydrogen produced from electrolysis.

References: 1. Hydrocarbons, The energy shock. The Economist. October 15, 2021.