Petroleum

An Overview of Critical Factors for Energy Resources

Introduction

America generates energy from a number of sources. At its most basic level each source turns a turbine to generate electricity. That power is then fed into the electrical grid to be distributed to homes and businesses. America consumes 4 trillion kilowatt hours (kWh) of electricity per year. The energy mix to generate this electricity is a blend of public policy and private action. Petroleum is only used to generate 0.4 percent of America's electricity, but it is the primary resource used in the global transportation sector, and crude, refined, and petroleum derivatives are used in everything from gasoline to plastics and more, making it one of the most important resources in the world today.

Petroleum has been the backbone of the U.S. energy sector for decades. In 2020, the U.S. consumed 6.63 billion barrels for energy and other uses. Its versatility, ease of storage, and adaptability to the national and global energy market, make oil a key resource not only for energy, but for everyday household items.[1,2] This policy brief will outline eight key factors that shape the current and future utilization of petroleum for American energy needs. To help build a comprehensive picture of petroleum's energy outlook, this brief will examine its energy density, costs to generate energy, availability and reserves, land needed, overall safety record, climate impact, long-term impact, and potential limitations of the energy source.

Basics of Petroleum

The process of extracting oil is broken down into four key phases: exploration, development, production, and abandonment.[3] As a resource with a finite supply underground, the process involves both identifying and economically evaluating potential reserves.

Geophysical prospecting and exploratory drilling is first used to find rock formations with untapped oil reserves and identify wells that are economically recoverable to begin the well development process. During this process, wells are constructed to a beginning phase to determine if there is enough oil to warrant extraction. If significant reserves of hydrocarbons are found, wells are fully built and prepared for extraction. The extraction process entails pumping up oil or natural gas, separating out water, gas, liquids, and solids, and selling the products.[4] The final stage of the well-site process is abandonment. This occurs when the costs of extraction outweigh profit, or when the oil reserve has been completely depleted.

Petroleum products are primarily transported by pipelines, railcars, trucks, barges, and tanker ships. These transports take the petroleum products to refineries, manufacturers, power plants, gas stations, and other end users. Petroleum is used in virtually every industry in the world.

1. Density

Petroleum has one of the highest energy densities of all fossil fuels. A single barrel, which contains 42 gallons, of crude oil possesses an average of 5,691,000 Btu (1,667.87 kWh) of heat energy.[5] On a per-gallon basis, this would equal about 40 kWh of energy. Different types of crude oil and refined products vary in their energy density. Heating oil, which is derived from crude oil and has a lower viscosity as well as at least 15 to 500ppm (parts per million) of sulfur, contains 138,500 Btu (40.59 kWh) of heat energy per gallon.[6] Diesel fuel, mostly utilized to power trains, buses, boats, and other larger vehicles, contains 137,381 Btu (40.26 kWh) of heat energy per gallon.[7] Finally, a single gallon of gasoline sold in the United States (including the fuel ethanol content) contains 120,286 Btu (35.25 kWh) of heat energy.[8]

Petroleum is highly energy dense, and that has made it essential for the transportation sector and other heating uses. This heat energy potential also lends itself to generating electricity. When accounting for thermal efficiency and other factors, at utility scale electricity generation, it takes 0.08 gallons of petroleum liquids to produce one kilowatt hour, for a rate of 12.76 kWh/gallon.[9]

To picture the energy density of petroleum, consider how much petroleum it would take to power a modern house. The average U.S. household consumes 10,649 kWh of electricity per year. To run the average household on petroleum alone for one year, it would take 851.92 gallons of petroleum liquids.

2. Cost

Petroleum makes up less than one percent of U.S. electricity generation.[10] Given its low prominence for electricity, many studies and forecasts do not account for petroleum-based generation costs. Different types of oil derivatives are used for different types of generators and turbines. The average cost for petroleum liquids and petroleum coke to generate electricity is 26.58 cents per kWh in 2019.[11] While not a levelized cost of electricity, this figure represents the average cost to produce a kilowatt hour of power. Accounting for lifecycle costs, capital, fixed and variable costs, storage, and waste management, the per kWh cost is likely higher.

Most electricity is generated from other energy resources, and few states rely on petroleum for electricity. In Hawaii, however, over 66 percent of electricity is generated from petroleum-fired power plants. There, the cost of electricity per kWh runs as high as 40 cents.[12,13,14]

Overall, petroleum is primarily consumed by the transportation sector. The national average cost per gallon of gasoline is $3.145, while diesel fuel currently comes in at $3.324 per gallon.[15] In a year, the average household spends between $2,000 and $3,000 on gasoline for transportation, while heating oil averages between $1,000 and $2,000 per household for winter heat.[16,17] Limiting the analysis to electricity generation, the cost to power an average U.S. household for one year on petroleum alone would be an estimated $2,830.50.

3. Availability and Reserves

Oil has been extracted for over 160 years by drilling and tapping into large subsurface reserves. Today, oil remains available and accessible through reliance on efficient methods of extraction. As a nonrenewable resource, estimates vary on how much crude oil remains in the ground. Many countries calculate reserves differently, while energy companies use the reserves-to-production ratio to determine their own oil reserves at each year's end.[18]

At the end of 2018, BP estimated there to be 1.7297 trillion barrels of crude oil remaining on the planet.[19] In 2019, U.S. proved reserves were projected to be 47.1 billion barrels, primarily concentrated in Texas, while Alaska reported the largest increase in proven reserves that year.[20] Reserves can increase because the availability of oil take cost into consideration. When new technology or practices make it economical to access more remote oil, reserves can increase; while eventually it will not make economic sense to extract the last remnants of oil. Technology can also help map and identify previously unknown supply or the extent of favorable geologic formations and reserves in a given location.

In terms of the accessibility of crude oil reserves, the Arctic is now considered to be the last major frontier for oil reserves and has already begun to produce large volumes of oil.[21] Fracking technology and other intensive processes to get at hard to reach oil has allowed oil production to boom in recent years, and projections indicate that global oil reserves are adequate to satisfy demand at least through 2050.[22] With the rise in alternative energy options, energy storage developments, hybrid and electric vehicles, and other innovations, oil demand may marginally decline, which would further extend the longevity of global reserves.

4. Land Required

In order to utilize petroleum, either for electricity generation or other energy needs, oil must be extracted, refined, transported, and stored. The total energy footprint adds up quickly when factoring in the size of the oil field, number of oil wells, refining facilities, and the transport methods.

Well-site acreages vary, with the average size of a well pad being 3.5 acres while in use.[23] Due to horizontal drilling and hydraulic fracturing technology, a single well pad can host several drill sites spanning outward in all directions, with a 12 acre well pad reaching up to 2,560 acres of horizontal space below the surface.[24,25] Innovations in recent years have reduced the amount of land that is needed for standard oil-producing facilities.

The total footprint is more than simply drilling sites, it also includes facilities and supporting infrastructure. As of 2019, there were 1,090 petroleum power plants used to generate electricity in the United States.[26] Adding in an estimated 639,000 acres for conventional wells, 536,000 acres for fracked wells, 236,000 acres for America's 129 operable refineries, and around 2 million acres for pipeline easements, petroleum's total acreage amounts to 3.55 million acres.[27,28]

While petroleum is overwhelmingly used for transportation, manufacturing, and other products, less than one percent was used for electricity.[29] The multi-million acre footprint is relatively small considering the outsized role petroleum plays in the U.S. and global economy for energy, manufacturing, transportation, recreation, medicine, and many other purposes.[30]

It is estimated that petroleum sent for electricity generation is only 0.57 percent of total petroleum extracted and consumed in the U.S.[31,32] If we were to take this proportion of land, the footprint for electricity generation alone would be an estimated 20,235 acres. With petroleum generating 17 billion kWh of electricity in 2020, this would result in 840,128.49 kWh/acre.[33]

To power a single average U.S. household's electricity needs with petroleum alone for one year, it would take up approximately 0.013 acres (51.3 square meters).

5. Safety

Despite thorough safety procedures, oil development still poses legitimate health and safety risks to industry and supply chain workers as well as the general public. In terms of the global energy supply, oil contributes to between 18.43 and 36 total deaths per TWh (1 billion kWh).[34,35,36] These worldwide statistics account for deaths from extraction sites, transportation, refinery and facility accidents, and end-use impacts like pollution and emissions. While accidents and incidents do occur on oil rigs and elsewhere, respiratory complications are a significant cause of fatality globally. Moreover, fatality statistics are skewed by developing countries and those with lower engineering and regulatory standards, as demonstrated by the difference between Organization for Economic Co-operation and Development (OECD) countries versus non OECD countries. Among OECD countries, which include the U.S. and 37 other nations, only 179 severe accidents resulting in five or more deaths in the oil industry occurred between 1970 to 2008.[37]

Due to increased regulation and advancements in technology that allow for less intrusive oil exploration and refinement, the rate of fatalities has fallen in recent years, yet in the nine years from 2008 to 2017, 1,566 workers died in the U.S. oil and gas industry.[38,39] These are attributable to vehicle accidents, being struck-by/caught-in/caught-between equipment, explosions, fires, falls, confined spaces, and chemical exposures for workers. Beyond these fatality risks are those to the general public from fires, spills, and air or water pollution.

Environmentally, the largest risks from oil production stem from spills of crude oil in transit, while the actual drilling for oil can cause seismic activity that can harm local wildlife, spills of crude oil, hydraulic pump water, and chemicals used for refinement and drilling can impact large ecosystems.[40] Overall, oil spills have become less frequent, but incidents from pipelines and ocean rigs continue to pose human and environmental risks.[41]

To power a single average U.S. household on electricity from petroleum alone, there would be fewer than an estimated 0.00019 fatalities.[42] This would mean that over 5,000 homes could be powered before a single death is attributable to petroleum.[43]

6. Climate Impact

The process of extracting, transporting, refining, distributing, and burning petroleum products for energy and consumer needs account for a majority of U.S. and worldwide emissions. In 2020, an estimated 45 percent of all U.S. emissions derived from the use of petroleum, concentrated mainly in the transportation sector followed by industrial uses and finally residential and commercial.[44,45]

Emissions occur when petroleum products are burned, either in vehicle combustion engines or at power plants. When consuming fuel, diesel and heating oil emit 161.3 pounds/million Btu (249.65g CO_2 /kWh), while gasoline without ethanol emits 157.2 pounds/million Btu (243.3g CO_2 /kWh).[46] These emission rates are the isolated instances solely of burning the fuel. To generate electricity, calculated emissions include extraction, transportation, and other factors as well as fuel combustion. On a lifecycle basis, electricity generation from petroleum ranges from 510 to 1,170g CO_2 /kWh with median emission estimate of 800g CO_2 /kWh.[47]

Lifecycle emissions accounting for all stages of development have changed over time, as technology and practices change. Fracking is a carbon intensive process, but leads to greater yield, while offshore rigs can lead to methane leaks (around 0.3 percent of production).[48] Overall, the emissions generated from petroleum greatly contribute to greenhouse gases in the atmosphere, and spills and leaks can impact wildlife and ecologically sensitive areas. Petroleum currently supports most of the transportation sector and very little electricity generation. As technology advances in competing alternative energy areas, it is likely that petroleum will begin to marginally decline in its use and proportionately decline in emissions.

To power an average U.S. household for a year on petroleum-based electricity alone, the estimated quantity of emissions would be 18,781.62 pounds of CO_2.

7. Long-Term Impact

The longer-term impacts of oil production include land uses and restoration of depleted oil fields, safe disposal of offshore rigs, and atmospheric emissions from continued use of petroleum. While there are clear challenges for some of these issues, others represent potential solutions in themselves.

Depleted oil fields offer the potential to serve as natural storage facilities, where product can be pumped back into a subsurface void. This can make use of natural storage capacity, saving costs and potential emissions from building additional storage facilities.[49] At the same time, abandoned oil fields have the potential to leak potent greenhouse gases like methane that can also cause wildfires and other disasters if ignited.[50] Securing orphaned oil fields to limit methane leaks and restoring the areas to their natural state could not only open up more potential agricultural land, but also could reduce air pollution and begin to restore the surrounding areas water quality.[51] For depleted reserves and decommissioned well pads, restoration and revegetation are key issues. An estimated 430,000 sites across the U.S. are poised to be environmentally restored, covering more than two million acres, including service roads, storage areas, and fluid tanks.[52]

In terms of decommissioning offshore rigs, deconstructing can cost between $500,000 and $4 million.[53] However, numerous alternative uses for offshore rigs have made decommissioning them more affordable and environmentally friendly.[54] Rigs that meet certain criteria can be overturned and made into artificial reefs, boosting local fisheries and contributing to the local economy by offering tourist dives, places for research, and supporting local marine life.[55] Partnerships with shoreline states have made removal of rigs cheaper, more environmentally friendly, and less risky than deconstructing the whole rig.

8. Limitations

The largest limitations for oil as an energy source are market volatility, shifting regulatory regimes, and climate focus. These each impact supply, demand, and favorability of petroleum.

The recent fracking boom of the last decade introduced record low oil prices that also increased the worldwide supply.[56] However, large shifts in both price and demand could mean that as alternative energy sources are developed further, consumers could opt for a more stable and predictable energy source.[57] Market volatility can arise due to technological advancements, economic boom or decline, conflict, or cartel behavior. Many of these limitations are subject to foreign governments and markets. Within the U.S., a vast supply of petroleum can help support smooth markets, even as global markets fluctuate, but regulatory changes can impact this. From federal land permits for new exploration and production to pipelines being approved or denied, petroleum is largely impacted by government action.

The future limitations of oil will largely be determined by government and consumer preferences for energy with a climate focus in mind. Petroleum is one of the most used natural resources, so it will be developed for decades to come, but its use as an energy sources may wane as innovative technologies and alternative energy sources become widespread.

Conclusion

Oil and its products have fueled the transportation sector since the beginning of the 20th Century. The continued reliance on oil for powering vehicles of all kinds speaks to the energy source's high versatility and ease of transportation and storage. Whether for electricity or a wide range of other energy and commercial uses, petroleum is highly energy dense, relatively low cost, widely available and with moderate footprint and safety record. Its carbon dioxide emissions and the risk of spills are primary challenges, as well as potential conversion of land for short-term and permanent easements. The challenges for the further utilization of petroleum continue to take shape, as improvements in renewable energy sources and energy storage challenge crude products like diesel, gasoline, and heating oil. While oil reserves are still substantial worldwide, petroleum continues to have emissions, regulatory, public opinion, and market drawbacks that present limitations on its future as a widespread energy source.

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