Coal

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. Coal was used to generate 19.3 percent of America's electricity in 2020. It is also used directly for industrial processes and other energy needs beyond electricity.

The utilization of coal as an energy source in the U.S. has rapidly declined in recent years. Whereas coal was once the primary energy source for the transportation, industrial, residential, and commercial sectors, its primary use today is electricity generation. This policy brief will outline eight key factors that shape the current and future utilization of coal for American energy needs. To help build a comprehensive picture of coal'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 Coal

Coal is extracted from underground and surface-level mines across the United States. The type of mining utilized for coal varies depending by region. In Appalachia, most coal mines are underground or strip mines, as coal deposits are buried beneath mountains or can be exposed by removing the top of a mountain.[1] In the Midwest and Western states, surface area strip mining is more common due to the flat topography.[2] Miners extract the coal and use heavy machinery to transport resources to the surface. The large amounts of waste extracted alongside coal, called a spoil, are formed into large piles outside the coal mine.[3]

There are four distinct types or *ranks* of coal depending on its age, hardness, and depth, which implicate the amount of carbon the coal contains and the subsequent amount of heat energy the coal can produce.[4] Anthracite coal is found deepest and usually has an over 87 percent carbon content makeup with the highest heating value per ton.[5] Bituminous coal is found just above that and has a carbon makeup between 77-87 percent. Bituminous coal is extremely common, making up over 50 percent of all coal U.S. production.[6] Sub-Bituminous coal is shallower, containing anywhere from 71-77 percent carbon, but still contains substantial amounts of oxygen and hydrogen that limit its energy potential.[7] Lignite is closest to the surface and has the least energy efficiency of coal, with a carbon content ranging from 60-70 percent.[8]

1. Density

Energy density is the heat potential of burning a single unit of the fuel. The energy density of coal largely depends on the coal's rank and carbon percentage. For example, anthracite having the largest percentage of carbon contains 3.8 kWh/lb to 4.4 kWh/lb of energy (between 13,000 btu/lb and 15,000 btu/lb of heat energy).[9,10] However, due to anthracite's rarity in the U.S., it only accounts for less than one percent of all coal utilized nationwide. Bituminous coal, which accounts for over half of all coal consumed in the U.S., has a density range of 3.2 kWh/lb to 3.8 kWh/lb (11,000 btu/lb to 15,000 btu/lb) depending on the deposits methods of classifications.[11]

Sub-bituminous coal makes up most of the coal deposits west of the Mississippi River and has a density ranging from 2.5 kWh/lb to 3.8 kWh/lb (8,500 btu/lb to 13,000 btu/lb) and is also widely used for electricity generation in the U.S.[12] Finally, lignite contains 1.2 kWh/lb to 2.4 kWh/lb (4,000 btu/lb to 8,300 btu/lb) depending on the amount of moisture still present in it.[13] Lignite is also utilized primarily for power generation.

Accounting for all ranks and the average thermal efficiency of plant during process of generating electricity, the national average amount of coal used to generate one kWh in the U.S. in 2020 was 1.13 pounds[14] for an overall real-world energy density of 0.88 kWh/lb.

To picture the energy density of coal, consider how much coal 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 coal for one year using the national average for all ranks and plants, it would take 12,033 pounds of coal.

2. Cost

The purely economic cost of producing energy using coal is extremely affordable. The capital costs for a coal combustion turbine ranges from $500 to $1,000 per kW and the subsequent operating costs for the turbine are only 0.02 to 0.04 $/kWh.[15] Ultimately, overall costs depend on the efficiency of the power plant. Traditional coal-fire plants are around 33 percent efficient, while newer supercritical coal plants achieve up to 44 percent efficiency. The next generation of ultra-supercritical coal plants may reach 50 percent efficiency, potentially costing more for capital but converting a higher percentage of coal's dense energy potential into electricity.

Factoring in capital costs, fixed operations and maintenance (O&M) costs, variable costs that include O&M and fuel costs, financing costs, an assumed utilization rate for each plant type, and waste management and storage, the total cost on a lifetime basis is estimated. Accordingly, the leveled cost of electricity and storage outlook for ultra-supercritical coal is projected to be 7.28 cents per kWh.[16,17]

To power the average U.S. household on coal alone could cost an estimated $775.25 each year.

3. Availability and Reserves

Coal is readily available in several large deposits within the U.S., making it cost effective to identify and retrieve, and explaining its high importance throughout U.S. energy history. Coal deposits are located throughout the United States, with particular reserves in Wyoming and the Appalachian region of Kentucky, West Virginia, and Pennsylvania; with additional smaller deposits in southern Illinois and across the country in varied ranks.[18] U.S. coal is plentiful and accessible either by surface mining or by underground mining, and reserves are in no danger of being exhausted.[19] The demonstrated reserves in the U.S. amount to over 946 trillion pounds.[20]

Based on 2019 coal production data, the amount of coal that is left within the United States is projected to last about 357 years, with reserves in mines that are currently operating projected to last another 20 years.[21] Overall, the U.S. contains the largest reserves of coal in the world, and the ease of mining makes its future utilization for energy production feasible. Outside of the United States, there remains an estimated 1.14 trillion short tons (2.28 quadrillion pounds) in coal reserves.[22]

4. Land Required

The overall foot print to generate electricity from coal includes, coal mines, transportation, refineries, power plants, and waste repositories that all take up physical space. Coal mines require large areas to operate, taking up considerable acreage. Mining operations require the large-scale movement of earth, construction of mine shafts and tunnels, waste heaps, and open pits.[23] Additionally, mine remediation is both a long-term and expensive process once the mine has been depleted and could require additional land usage.[24]

Coal's footprint has shrunk considerably in the last few years alone. Even since 2015, coal production has slowed, power plants have shuttered, and coal's share of the energy mix has declined by nearly half. As of 2019, there were 308 coal-fired power plants, estimated to use 19 acres per MW.[25,26] Accounting for coal mining operations, coal's share of transportation by rail, and waste sites, the total acreage adds up to 600,000.[27] Inclusion of power plants adds another estimated 50,000 acres. Using the total 650,000 acres of land[28] and the 774 billion kWh generated in 2020, the overall footprint of coal is 1,190,769.23 kWh/acre.

Factoring in all the land from mines to power plants, transportation, and waste disposal, to power a single average American home for a year, coal infrastructure would require 0.0089 acres (or 36.02 square meters).

5. Safety

This brief examines coal's overall safety record in terms of injuries and deaths to workers and surrounding communities. Deaths in the coal industry reached an all-time low in 2020, with only twenty-nine fatalities out of 63,612 U.S. coal miners.[29] The latest injury data from 2017 showed 4,035 non-fatal accidents in the 1,216 then-active U.S. coal mines.[30] The overall trend of deaths and injuries in the U.S. coal industry demonstrates a decline. These trends are in part attributable to higher safety standards and use of technology, but also against the backdrop of a waning industry, which is closing mines and power plants every year.

Outside of the U.S., the worldwide rate of deaths directly or indirectly attributable to the coal industry per terawatt hour stands near 100, which is largely skewed by China.[31] For the U.S. this number is estimated up to 10 human casualties per terawatt hour (1 billion kWh), and accounts for mortality attributed not only to mining and transport, but pollution-induced respiratory complications.[32] Of note, these statistics are 10 years old, and during this window technological innovations have likely made marginal reductions in the fatality rate of coal within the U.S.[33,34,35]

Safety incidents can also impact the surrounding environment and local wildlife. Large-scale mines severely alter the surrounding environment and can render land barren if proper remediation methods are not undertaken once a mine has been exhausted.[36] Coal mining exposes several toxic pollutants to the environment and atmosphere that can adversely affect human health. For example, sulfur dioxide and nitrogen oxide can both cause lung cancer, nitrogen oxide weakens the human immune system, and sulfur dioxide can burn the skin and cause eye irritation.[37] Finally, mercury exposed during the coal mining process can kill local wildlife and contaminate the environment due to the toxicity of both its vapor and liquid forms.[38] In the U.S. health and safety standards largely require these pollutants to be scrubbed, captured, or mitigated.

The number of casualties associated with powering a single average American home with coal for a full year would be under 0.000106. At this rate, over 9,400 homes would be powered before there was a death attributable to the coal industry.

6. Climate Impact

Because the carbon content of coal is the primary factor that determines its energy density, coal is generally associated with CO_2 emissions. Burning coal to generate electricity also releases several other emissions, as well as heavy metals, arsenic, and volatile organic compounds (VOCs).[39] In 2019, coal generated 2.21 pounds/kWh of carbon dioxide emissions on average and generated a total of 947,891 million kWh of electricity.[40]

Subsequently, the total carbon dioxide emissions from the 2,098,000 pounds of coal used for electricity generation in the same year was 952 million metric tons.[41,42] This does not account for emissions from coal for uses beyond electricity generation, like heat generation and industrial processes. Anthracite, bituminous, sub-bituminous, and lignite all produce differing levels of emissions and have different temperatures at which volatiles are released during the combustion process. Overall, coal's total emissions make it a high-emitting energy source, and its emissions are increasingly seen as more of a cumulative health, safety, and environmental cost. While coal itself emits these substances when burned, the process to combust coal is highly controlled and atmospheric emissions per kWh have fallen in recent decades. Technologies like coal scrubbers, filters, and pollution mitigation have helped to reduce the particulate matter pollutants and other emissions like sulfur dioxide and nitrogen oxide emitted into the atmosphere, even while CO_2 remains common.[43,44]

In order to fulfill the energy needs of the average U.S. household, 23,534 pounds of carbon dioxide emissions would be emitted in one year.

7. Long-Term Impact

Long term coal mining has several effects on both the landscape and on waste disposal. Long-term impact also varies depending on the type of coal mining that is carried out. For instance, strip mines displace large amounts of topsoil, which can severely inhibit restoration efforts as vegetation needs topsoil in order to grow.[45] Additional soil erosion concerns exist, and metallic dust from waste heaps can linger long after mining operations have ceased, causing additional problems for vegetation growth.[46] This damage to the environment means high remediation costs for the restoration of large open pit mines and many companies do not have the funds to fully clean up waste piles and larger-scale mines.[47]

Most coal mine cleanup funds come from the Abandoned Mine Land Fund (AML), an industry-funded initiative that is used to secure, clean up, and restore mine sites.[48] However, as coal has become less popular as an energy source in the United States, the AML's budget has been severely reduced in recent years, limiting the ability of many companies to clean up their mines and creating additional financial difficulties when coal companies declare bankruptcy.[49] The longer term health effects of coal ash – a mixture of byproducts from the burning of coal – is the single biggest long-term threat to environmental and human health.[50] Coal ash's mixture of heavy metals, chemicals, and other coal byproducts can cause multiple types of cancer, developmental problems, mental health problems, and can prevent vegetation from growing as it smothers small shrubs and trees.[51]

8. Limitations

The largest limitation of coal as an energy source is its impact on the climate through atmospheric emissions of carbon dioxide. Cleaner burning natural gas, as well as renewable alternative energy sources have slowly taken coal's place in the U.S. energy market due to the large amount of pollutants that coal releases when burned.[52] Coal emits the largest amount of carbon dioxide per kWh of all fossil fuels, which inherently limits its use in widespread energy generation in a climate-conscious world.[53] This makes coal's greatest limitation political in nature.

Additionally, when not appropriately scrubbed and filtered, coal produces both nitrous oxide and sulfur dioxide, two gases that mix together in the atmosphere and produce acid rain. Acid rain can erode crucial infrastructure, stunt vegetation growth, and damage entire ecosystems.[54] A combination of investors choosing to back cleaner burning fossil fuels, increasing regulations to combat climate change, and pressure from environmental campaigners have made coal energy more politically difficult to support and finance.[55]

Conclusion

Coal has been the standard source of energy for the United States and the world since the Industrial Revolution. The progression of science and technology has brought about new energy sources as competition, leading to innovations in cleaner coal and improved efficiency while also supplanting coal's place in the energy mix. Coal itself remains highly energy dense, relatively low cost, and widely available. Accounting for its easy access and energy potential, along with a century of infrastructure already built for it, coal can continue to supply energy in the United States.

Coal reserves have the capability to supply the U.S. energy grid for hundreds of years, and while coal itself is a high emitter of carbon dioxide and other harmful gases and particulates, scrubbers and filters are increasingly capable of limiting the negative outputs. This means that the future of coal is largely dependent on technological innovations that can neutralize its impact. While enormous amounts of energy will be needed in the coming energy revolution, coal may still have a prominent role in providing the power for massive industrial, mining, and building processes.

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[12] *Supra* notes 9 and 10.

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