Natural Gas

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. Natural gas is used to generate the largest share of America's electricity at 40.3 percent as of 2020. It is also used directly for heating, cooking, and many other energy needs beyond electricity.

This policy brief will outline eight key factors that shape the current and future utilization of natural gas for American energy needs. To help build a comprehensive picture of natural gas'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 Natural Gas

Natural gas has taken on a larger share of U.S. power in recent years. Since 2005, natural gas production has increased quickly due to advancements in horizontal drilling and hydraulic fracturing (or "fracking") techniques to locate and collect gas pockets in shale, sandstone, and several other previously inaccessible geologic formations.[1] Natural gas is composed primarily of methane, but can contain small amounts of liquids and other gases like carbon dioxide. Natural gas is generally classified by where it is found naturally. Conventional natural gas is located in large cracks or spaces between layers of rock, while unconventional natural gas is found in tiny pores in formations of some sedimentary rock.[2] Associated natural gas occurs within deposits of crude oil and can be extracted alongside oil. Renewable natural gas is derived from ongoing agriculture, landfills, waste treatment, and other organic waste from industrial processes.

Natural gas extraction and processing is similar to oil. Once a deposit has been located, gas is extracted by drilling vertically from the Earth's surface. Other methods to extract harder to reach gas include hydraulic fracturing, horizontal drilling, and acidizing.[3] Fracking utilizes a mixture of chemicals, water, and sand to break apart rock to release trapped pockets of gas that are in smaller pores in the rock.[4] Horizontal drilling can increase the area that a single gas well can access without drilling from multiple sites on the surface.[5] Acidizing helps break down rock and other materials that inhibit a gas well's productivity, and gains access to gas in harder to reach rock pores and smaller pockets.[6] Gathering lines are used to collect the natural gas from the drilling site for transportation to processing facilities. Once all gas has been extracted from wells, the site is either abandoned or utilized for underground storage.

Renewable natural gas (RNG) is also a source of energy. RNG is a usable biofuel generated as a byproduct by decomposing organic materials, wastewater, agricultural processes, dairy manure, and food and green waste.[7] RNG is a form of biogas that requires its sources to be gathered and placed in a digester, where the material can further decompose and the resulting methane can be collected.[8] Gas is then lightly refined to meet purity standards and can be utilized for heating, vehicle fuel, electricity generation, and other energy needs. Because of the massive amounts of natural biogas from a variety of sources, methane capture from renewable gas sources can eventually turn natural gas into a truly renewable energy source, separating it from the traditional exhaustible fossil reserves.

Natural gas composition does come with slight regional variation. Natural gas can have large percentage of hydrocarbons making it energy dense, but which can be removed and sold as a separate energy source or chemicals to serve other industrial needs.[9] Small-scale cleaning of natural gas as it is being extracted allows for it to be cleanly burned for energy and the simplistic chemical makeup of natural gas creates a plethora of uses for natural gas.

1. Density

Natural gas is a hydrocarbon containing significant heat potential. The energy density of natural gas is estimated to be around 0.264 kWh/ft^3 to 0.651 kWh/ft^3 (900-2,200 btu per cubic foot).[10] Due to natural gas containing between 70-90 percent methane, along with smaller amounts of ethane, butane, and propane, natural gas is extremely pure and does not require an extensive refining process, making it highly efficient in combustion.[11] Over 11.62 trillion cubic feet of natural gas was used to generate 1.617 trillion kWh – or over 40 percent – of electricity in the United States last year. In 2020, accounting for all generation and inefficiencies, it took 7.43 cubic feet of natural gas on average to generate one kWh of electricity.[12] Natural gas is more efficient for heating and cooking, where less energy is lost relative to electricity generation.

To picture the energy density of natural gas, consider how much natural gas it would take to power a modern house. The average U.S. household consumes 10,649 kWh of electricity per year. To run an average household on natural gas alone for one year, it would take 79,122 cubic feet of gas.

2. Cost

Natural gas is extremely cost-effective for utility-scale energy generation. Advancements in hydraulic fracturing have made it economical to extract large volumes of natural gas, greatly expanding supply and lowering costs. The levelized cost of electricity for producing a kWh of electricity from a new combined cycle natural gas plant in 2026 is 3.45 cents per kWh.[13] [14] A gas-fired power plant's average energy efficiency comes in at 42 percent.[15] In a combined-cycle natural gas power plant, which account for over 50 percent of plants, electricity generation can peak at almost 60 percent efficiency.[16] At 3.45 cents per kWh, by 2026 it would cost $367.39 per year to power the average U.S. household with natural gas.

3. Availability and Reserves

Traditionally understood as a nonrenewable resource, existing recoverable natural gas reserves in the U.S. amount to 2.867 quadrillion cubic feet.[17] At the current extraction rate, the U.S. holds an estimated 84-year supply of proven and unproven natural gas reserves.[18] Advancements in fracking within the last decade have expanded access to previously unreachable reserves, so improvements in technology could further lower costs for natural gas exploration and extraction, providing physical or economic access to previously unreachable potential reserves.[19] Globally, there is an estimated 7.257 quadrillion cubic feet of proven reserves.[20]

Added to the reserves in the ground, there is an abundant source of methane at the surface generated by human activity and natural processes. This renewable sources of methane has the potential to redefine natural gas from an exhaustible fossil resource to a renewable resource. Out of the U.S. agricultural sector's total emissions, methane comprises over 36 percent.[21] Expanding natural gas collection to include large amounts of RNG can further increase its availability, making the total reserves a combination of the in-ground supply plus continuously generated flow from agriculture, waste management, and methane capture projects. Overall, alongside technological improvements and strong supply, natural gas – or methane – will continue to be available for energy needs for decades.

4. Land Required

The land required for natural gas includes well pads for extraction, pipelines for transport, facilities for refining, and power plants for electricity generation.[22] Calculating the land use density can be measured by the total power generated divided by the acreage of power plants themselves, or by the total sum of infrastructure. As of 2019, there were 1,899 natural gas power plants in the U.S.[23] The Natural Gas Supply Association states that power plants utilize between 20 and 40 acres each, making the total power plant footprint an estimated 56,970 acres. In terms of the land taken up for extraction, a single pad takes up about 3.7 acres during production.[24] However, including the pipelines that are utilized to transport natural gas, the acreage increases sizably. A total of 319,223 miles of pipeline are used to gather and transport natural gas nationwide, accounting for a large majority of acreage taken up by the industry.[25]

The total acreage taken up by natural gas drilling operations, pipeline easements, and power plants amounts to an estimated 4.457 million acres.[26] Of this, transportation and transmission are considerable land uses in the form of utility corridors and easements. With natural gas providing 1.617 trillion kWh, that means it can produce over 362,721 kWh per acre. Natural gas is both energy dense as a resource at the generation site and spatially efficiency due to fracking and horizontal drilling. The inclusion of renewable natural gas does not require additional land, as it implicates concurrent land uses. For RNG, existing sources including farms, wastewater treatment plants, animal waste ponds, and landfills can all be fitted with methane capture technology.

Because of how efficiently natural gas burns, measuring the footprint of power plants alone would mean to power the average U.S. home, 0.00038 acres (or 1.21 square meters) of land would be needed. Accounting for all accompanying space and infrastructure, it would take 0.029 acres (or 117 square meters) to power an average U.S. household.

5. Safety

Natural gas workers face various risks while working with volatile and flammable methane. While fatalities have trended downward in the industry, natural gas extraction still leads to occasional fatalities. The most recent data from the U.S. Centers for Disease Control and Prevention indicates the total number of deaths in the U.S. for 2017 oil and gas exaction combined was 69 fatalities, with multiple-fatality accidents reaching record lows.[27] Most fatalities occur to younger workers, which coincide with a reliance on smaller contractors to man offshore rigs and a lack of trained safety professionals at every site.[28]

When calculating the overall safety record, externalities are also calculated, to include respiratory issues caused from emissions. The worldwide death rate attributable to natural gas is between 2.8 and 4 deaths per terawatt hour (1,000,000,000 kWh).[29] [30]

Strong regulations and innovative technologies in the U.S. keep fatalities and accidents in the nation's natural gas industry far lower than other countries, including cleaner burns and reduced emissions. Nevertheless, due to natural gas primarily being composed of methane, a colorless and odorless gas that is extremely flammable, it poses both an emissions and fire threat when methane leaks.[31] Large-scale methane leaks can also displace breathable oxygen in confined spaces and can cause breathing problems, light-headedness, and other temporary health problems.[32]

Using global data, if natural gas was used exclusively to power an average U.S. household, the casualty rate for a full year would be between 0.0000298 and 0.000042596. While the U.S. safety record is far stronger, at this rate, over 33,000 homes would be powered before a single global death is attributable to natural gas.

6. Climate Impact

Natural gas is the cleanest burning of all fossil fuels, resulting in fewer carbon emissions and other air pollutants. More specifically, one million btus (293.07 kWh) of natural gas produces 117 pounds of carbon dioxide.[33, 34] In terms of emissions generated during the combustion process, natural gas emits between 0.399 and 0.91 pounds CO_2/kWh, the lowest of all non-renewable resources, including biofuels. The largest emissions threat from natural gas comes from leaks of non-combusted methane into the atmosphere.[35] This can come from natural geological sources, leaks from pipelines, leaks from generation facilities, agriculture, or organic decomposition from landfill and other waste disposal sites.

Methane is four times more effective at trapping radiation in the atmosphere and has more than 30 times the warming power of carbon dioxide over 100 years, despite having a shorter lifespan than CO_2 in the atmosphere.[36] The greatest source of methane leaks are from unsecured natural gas storage and transportation containers, abandoned natural gas sites, animal waste from large-scale agricultural operations, and emissions from landfills as waste decomposes.[37] Further developing renewable natural gas will help reduce the carbon impact of other industries, especially the U.S. agriculture industry which totaled 629 million metric tons of emissions in 2019.[38] Regulations, methane capture technology integration, and continued monitoring for methane leaks in oil and gas facilities can help cut overall methane emissions.

Another environmental impact is not of natural gas itself, but the overall process of extracting it. Some documented cases exist of groundwater contamination, low-magnitude often undetectable seismic activity, and leaked or improper disposal of wastewater and fluid byproducts.[39] The heavy water-use intensity is also relevant to conservation efforts varying by region and climate.

To power a single average U.S. household for a year on natural gas alone, a total of between 4,248 and 9,690 pounds of CO_2 emissions would be generated.

7. Long-Term Impact

The downsides of natural gas utilization as an energy source mainly deal with the potential of methane storage and transport structures to leak. Fortunately, natural gas pipelines have an effective rate of over 99.999 percent, leaking far less than a thousandth of a percent of methane transported.[40] Data trends also indicate that methane emissions have declined despite significant increases in volumes transported, miles of pipeline added, and compressor stations added. Proper closure of abandoned wells and secure storage will also be critical to reducing emissions longterm.

Furthermore, weather patterns have a large impact on the short-term natural gas market, as colder winters mean an uptick in natural gas consumption.[41] This is relevant in the U.S. as well as import/export markets for natural gas. As regional climates vary in the future, more or less cold weather and natural gas demand may arise. Only 40 percent of all natural gas consumption is in electricity generation, with the majority of natural gas currently being used to heat buildings, cook food, and generate heat for industry processes.[42]

Outside of power generation, one considerable factor that will determine natural gas longevity is flaring and venting of natural gas during the extraction process.[43] Flaring is when natural gas is burned at the end of a well's vent to relieve the pressure that comes with extracting large amounts of reactive gases deep in the Earth. Flaring during natural gas extraction naturally produces emissions as long as the flow of gas is being extracted. Venting is a similar safety procedure that releases the pressure built up by the extraction of natural gas. However, venting directly releases non-combusted methane, carbon dioxide, volatile organic compounds (VOCs), sulphur compounds, and gas impurities, which are all extremely harmful to the atmosphere.[44]

Renewable natural gas has the potential to capture many of the emissions that would otherwise negatively impact the atmosphere and climate, while still being useable fuel. Without capturing these emissions, and while continuing to vent and flare high pressure sites, not only is the atmosphere impacted, but economic product is lost. Finding a way to maintain workplace safety, while not dispersing these gases that could ultimately be used is the largest barrier to natural gas production long term.

8. Limitations

Outside of being a nonrenewable resource, natural gas also requires considerable storage capacity.[45] Combining new capture programs only expands the quantity needed to be safely transported and stored. Natural gas has also been labeled a "bridge fuel" as industries transfer over to cleaner energy sources and make cleaner energy more viable for large-scale energy producers and consumers.[46] An implied limitation is that it is viewed as a bridge and not long-lasting source. This makes investment in technology that utilizes natural gas difficult, as longterm investment in a mid-term solution does not make economic sense. Transitioning large vehicle fleets to run on natural gas is difficult because of the predominant system of gasoline and diesel-powered vehicles.

Other limitations center on the extraction process. Fracking methods have raised questions on the extent to which long-term fracking operations impact seismic activity in particular areas and on the sustainability of using large amounts of water for fracking activities in arid areas.[47] Current limits to large-scale harvesting of renewable natural gas are mostly limited to regulatory bias, but also include technological needs.[48] Three-fourths of all domestic renewable natural gas is used by the transportation sector, despite RNG's potential as a source of utilities.[49] Natural gas's limitations overall stem from its quick rise to prominence this past decade and the subsequent regulatory, technological, and environmental oversights that comes with such a large industry growing so quickly.

Conclusion

The U.S. natural gas market has grown from an afterthought industry to supplying over a third of all the United States's energy needs in a little over 10 years. Overall, natural gas is highly energy dense, low cost, widely available, and with a relatively small footprint and fatality record. This versatility, efficiency, and low climate impact has placed natural gas at the center of American energy, and few factors indicate it will be displaced in the coming decade.

The movement towards cleaner burning energy sources and net zero carbon emissions puts natural gas in a unique position to serve as a long-term energy source providing support for development of technological advancements in renewable energy. Renewable natural gas especially has the potential to become a more reliable source of energy, due to the biogas being given off in both rural and urban areas. Technological innovation and investment in methane capture will not only limit the impact of traditional natural gas, but expand the supply of renewable natural gas, both limiting climate impact and providing energy.

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