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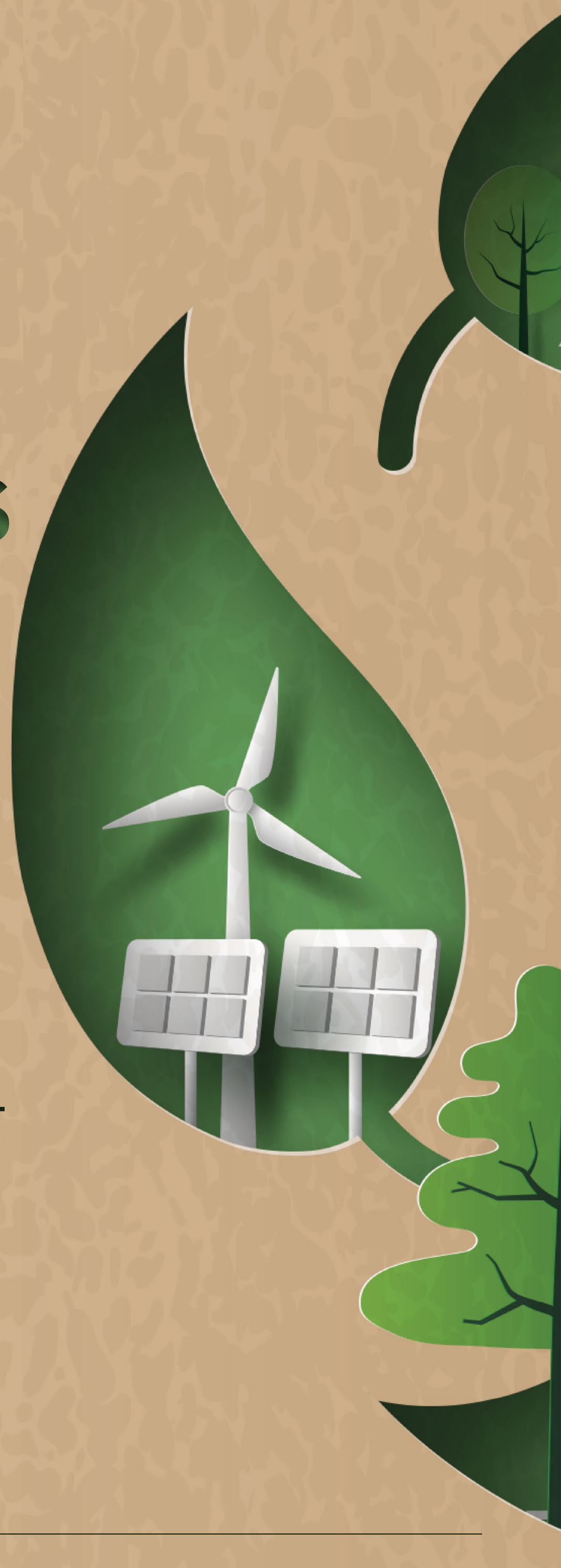


The US national security and economy depend on reliable and long-term access to abundant energy sources. Historically, the US has benefited from easy access to energy resources, including coal, oil, gas, wind, solar, and hydro power. Access to energy resources includes oil importation. Events in the 1970s demonstrated that a lack of self-reliance could lead to vulnerabilities. As a result, the US endeavored to achieve "energy independence," to become a net exporter of energy resources. For the US, that goal was first achieved in 2020.

Energy independence is a noble goal, but it does not eliminate vulnerabilities. Malicious actors, cyberattacks on energy infrastructure, turbulence from climate change, an aging electrical grid, and unsecured supply chains pose threats to America's competitive edge and economic wellbeing. Sudden increases in the price of energy could destabilize the population by making essential goods and services unaffordable. Residential heating and air conditioning, transportation, and commercial real estate rely on cheap energy sources. Industry depends on large supplies of energy, because, for example, manufacturing typically involves massive consumption of energy. The military requires prodigious supplies of energy in the form of jet fuel, gasoline, and nuclear power—for wartime and peacetime operations. The supply of energy resources is important, but its distribution is also essential to the population, the economy, and the military. Even when sources of energy are based on indigenous domestic supplies, disruptions can occur that put America's national security and economy at risk.

Being a net exporter of energy resources does not mean that the US does not depend on imports. A major complication is that oil must be refined, and there are different types of oil for different kinds of refineries. The United States imports certain types of oil for which it has refinery capacity and capabilities and exports other types of oil for refining elsewhere. Should imports be disrupted, the US would confront supply deficiencies because current exports could not be converted quickly to domestic use. Moreover, domestic supplies of oil are limited.

Distribution requirements cause other vulnerabilities. Oil and gas pipelines can be sabotaged through physical and cyberattacks. Power grids for electricity distribution require maintenance and are vulnerable to weather or other disruptions.

In addition to threats from geopolitical adversaries, whether wartime or gray zone, there is also a competition for resources. Supply and demand are typically in a very delicate balance globally, and nations need and want access to sufficient energy resources. Any disruption can lead to a scramble and competition for resources globally. This scenario occurred in 2022 due to the reduction and redirection of supplies of oil and gas from Russia.

There are multiple other competitions that take place with respect to energy. In wartime, a typical target of an adversary's infrastructure and warfighting capabilities involves local energy supplies. There is also a competition for affordable energy, as oil-rich states benefit from high oil prices, whereas major consuming nations benefit from low prices. Today, there is even competition for the installation of renewable energy resources, as there is increasing global interest in reducing atmospheric carbon emissions and thus reducing or eliminating the use of fossil fuels.

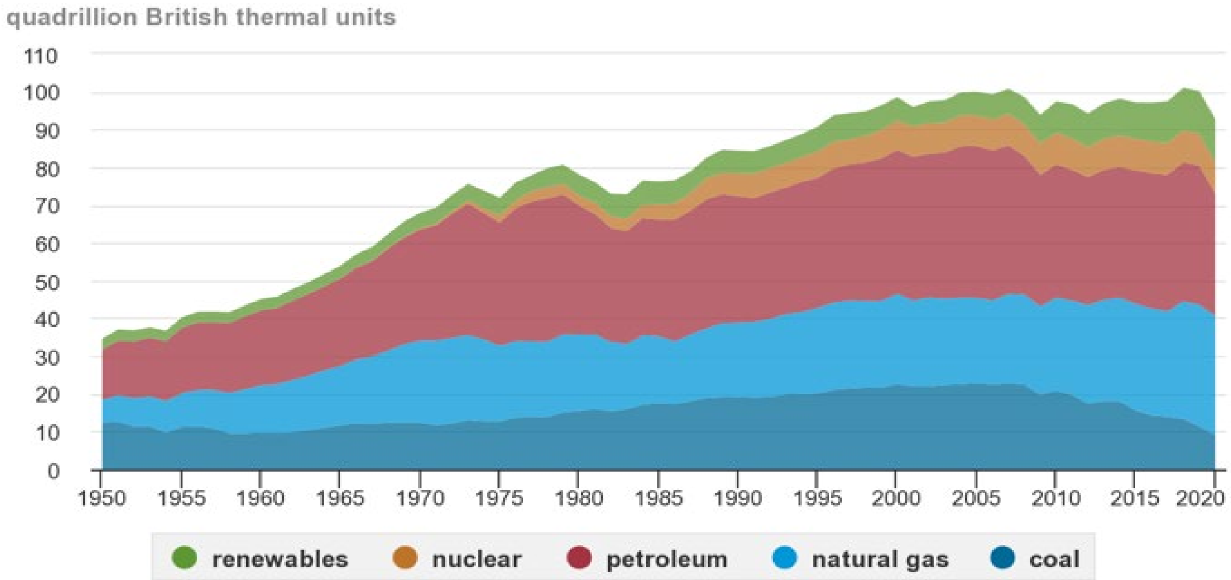
Because energy is so important to prosperity and security, the overarching requirement is for reliable access to energy resources. This necessitates sources of energy, production, and distribution, with reserve capacity in all areas. Even then, vigilance is required in recognizing potential threats, both natural and deliberate. This sets up a relentless pursuit of a competitive advantage in access to sources, production, and distribution of energy for the US population, industry, and military needs.

Sources of Energy

To a limited extent, energy resources are fungible. Natural gas can be used in place of gasoline derived from oil; solar power can generate electricity in place of fossil fuel power plants. For resilient and stable access to energy resources, it is advisable to have a mix of available energy sources. We begin by considering the current mix of sources for US energy consumption.

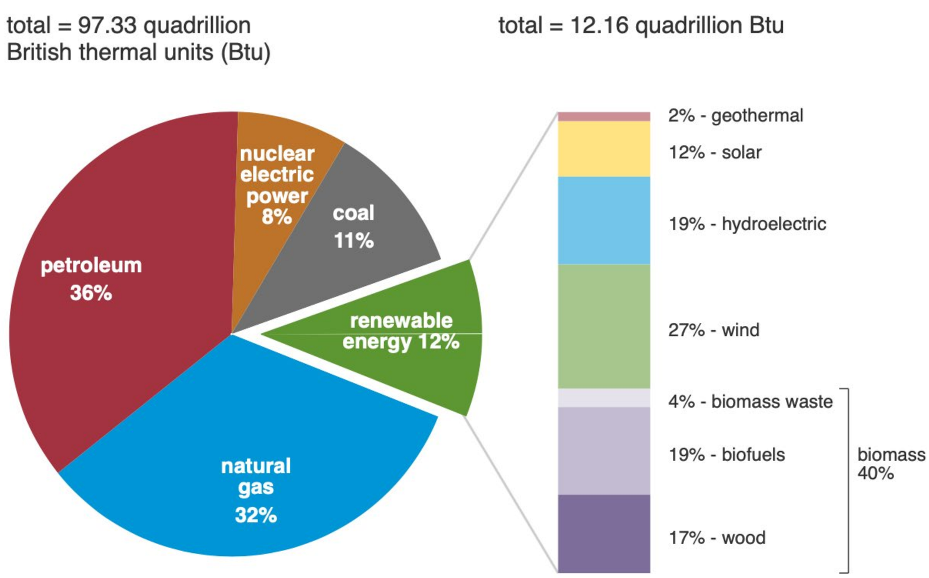
Petroleum, natural gas, and coal (fossil fuels) provide for the majority of the US power needs: 79%, as shown in Figure 1. Renewables account for 12% of US energy consumption, which includes wind, solar, hydroelectric, geothermal, and biomass sources. Nuclear energy comes in third after fossil fuels and renewables, contributing 8% to the total domestic energy portfolio.[1]

Figure 1. US Primary Energy Consumption by Major Sources, 1950-2020



Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3, April 2021, preliminary data for 2020
Note: Petroleum is petroleum products excluding biofuels, which are included in renewables.

Figure 2. US Primary Energy Consumption by Energy Source, 2021



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2022, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

From https://www.eia.gov/energyexplained/us-energy-facts/.

Measured in "quads" representing the equivalent of a quadrillion British thermal units (Btu), total US consumption is a little less than 100 quads per year, which is roughly one-sixth of worldwide consumption. In the US, roughly a third comes from petroleum, a third from natural gas, and 11% of energy production from coal. Roughly 3.2 quads come from wind turbines, and 1.5 quads from solar.[2] Biofuels (including ethanol from corn) contribute less than a quad.[3] Thus, wind, solar, and biofuels are still relatively minor sources. The US continues to increase renewables while generally decreasing reliance on coal, although the use of coal in the US increased in 2021.

Today, and for some years to come, oil and gas will remain the predominant sources of energy in the US. The US produces around 11 million barrels of crude oil per day, which is supplemented with hydrocarbon gas liquids and biofuels to effectively produce 18.6 million barrels per day in 2021. (Hydrocarbon gas liquids come from both natural gas and from the process of refining crude oil.) Consumption stood at around 19.9 million barrels per day in 2021, with the difference made up in imports.[4] Oil consumption in 2021 accounted for 31.3 quads of energy in the US.

The US Strategic Petroleum Reserve (SPR) holds at maximum about 750 million barrels of oil,[5] which is a roughly 40-day supply for the US, or 100 days of imports at current rates. It is useful for wartime supplies, but also can be used to stabilize prices to absorb or make up for over- and under- capacity of the world's supplies. It is being drawn down in 2022 at a rate of a million barrels a day to make up for reduced Russian supplies of oil.

Natural gas production in the US in 2021 was a total of 34.5 trillion cubic feet (TCF),[6] of which the US consumed 30.3 TCF[7] and exported the remainder. Natural gas contributed 31.3 quads to US needs in 2021; coal contributed 10.5 quads.[8]

Petroleum products (which technically include both liquid oil products as well as natural gas) are uniquely important due to their high energy content per unit weight and volume. The military is vitally dependent on refined oil products and uses large quantities of natural gas. For certain military uses, it would be hard to replace petrochemicals with any other form of energy production. Aircraft, for example, need jet fuel for long-duration or high-velocity flights. Armored vehicles typically need diesel fuel to generate sufficient power. Many naval vessels rely on petrochemicals for propulsion.

Accordingly, for now and for the foreseeable future, the US requires a stable supply of petrochemicals. Our dependence arises both from common usage of oil and gas for residential, industrial, transportation, and other common uses, as well as from the military's need for large energy supplies. Total US consumption of energy is not expected to decrease, nor should it. This begs the question: to what extent should US energy supply be based on oil and gas, and are alternatives required?

The fact that the US is a net exporter of energy belies the observation that domestic oil and gas are increasingly difficult to extract. Today, oil and gas are found in abundance in the Middle East and other parts of the world but are highly concentrated in small pockets.

Uneven Distribution

The fact that fossil fuels are not evenly distributed throughout the world makes for a complicated marketplace with inequalities in competition. Moreover, production and demand are in close balance at any given time, mediated by prices. Excess production, or excess production capacity, requires excess infrastructure and is thus inefficient. Over production capacity suppresses prices which is not favored by the relatively few producers. The other problem is that as time goes on, oil and gas that is easy to recover has already been recovered. While there is plenty left, that which is left becomes more difficult to extract. New technologies enhance the ability to recover more difficult petrochemical sources, but also require significant investment.

Oil is concentrated into thousands of oil fields scattered throughout the world. Roughly 500 "giant" and 40 or so "super-giant" oil fields each contain over a half a billion barrels of ultimately recoverable liquid oil (5 billion, in the case of super-giant fields).[9] The largest, the Ghawar field, is in Saudi Arabia, is said to have contained nearly 100 billion barrels of liquid oil when first tapped in 1951, now contains an estimated 58 billion barrels equivalent, and continues to produce nearly four-million barrels of oil per day.[10] Most of the other giant fields, such as Prudhoe Bay in the north slope of Alaska, produce a few hundred thousand barrels per day. Thus, most fields produce a small fraction of the world's consumption of nearly 100 million

barrels per day. The giant fields and super-giant fields provide for 60% of the world's total consumption.[11]

If one looks at "proven reserves," and divides by current consumption rates, the world will run out of oil and gas in 47 years. The same computation for US proven reserves versus US consumption results in about 5 years of oil and 15 years of natural gas remaining.[12,13] In the US, the primary sources of oil and gas come from the north slope of Alaska containing the Prudhoe Bay fields, the East Texas Oil Field, and the West Texas "Permian Basin" fields. There are many other smaller sources, such as fracking in Pennsylvania and West Virginia, and many other potential sources, such as oil shale of western Colorado (which has seen multiple boom and bust cycles, due to the lack of profitability of oil extraction).

However, computations of years remaining are naive for multiple reasons: For one thing, proven reserves can rise or fall over time, depending on the price of oil and gas and the development of new recovery technologies. New discoveries are made all the time. Proven reserves do not fully account for abundant oil shale, tar sands, and other sources that can provide oil and gas using advanced technologies, and "unproven reserves." Fracking, when performed safely and responsibly, can free up natural gas supplies that are not envisioned in the simple computation. Natural gas can be used in place of oil for many purposes, but in many places is "flared" (i.e., burned on the spot) because it is not profitable to capture and distribute. These amounts are often not included in proven reserves.

Nonetheless, at this point, total oil and gas supplies are limited. For the US to maintain its rate of energy use, and continue to depend on oil and gas, there will need to be new supplies soon. There could be new domestic discoveries, but it is likely that much will have to come from imports. Most of the rest of the world's oil is in oil fields located in the Middle East, namely Saudi Arabia, Iran, Iraq, and United Arab Emirates. There are other super-giant and major fields in Mexico, Venezuela, Brazil, Russia, and Kazakhstan, as well as that which remains in the US. With more than 90% of the world's supply (along with the US), these nations have outsized influence due to the concentration of oil reserves and super-giant fields in their territorial borders. There will be a competition for access to these resources.

Possible Future Sources

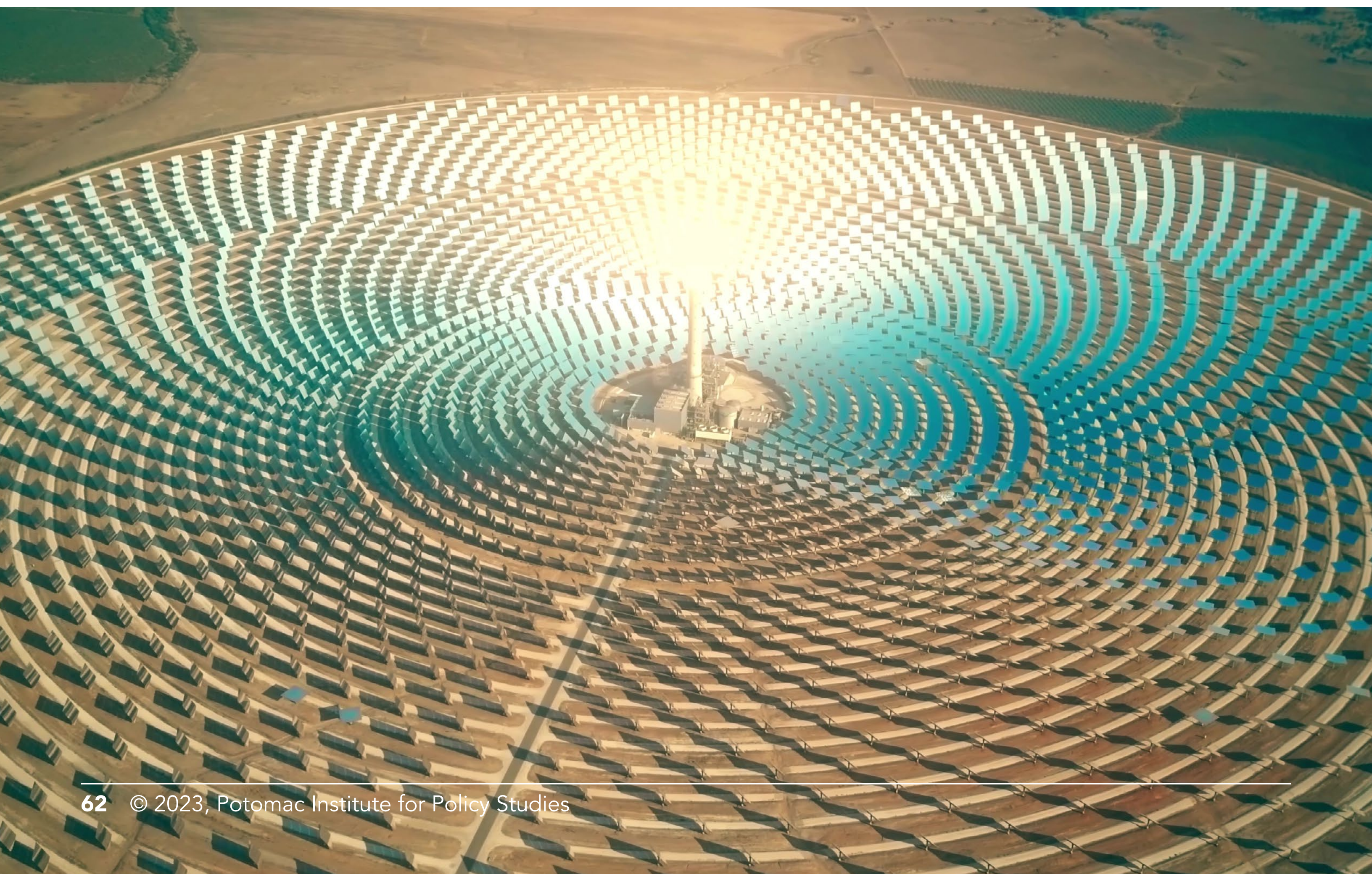
The issue becomes: Is there a way to reduce dependence on oil and gas, in whole or in part, to ensure that there are sufficient supplies for uses that require them? The concern over greenhouse gas emissions and global climate change only adds considerable additional pressure to the interest in new supplies (but only for renewables.)

Significant headroom is available for expanding the use of solar production of electricity in the US. The current installed base is around 100 Gigawatts (GWs), which generates 1.5 quads per year.[14] An optimistic Department of Energy study posits 1,000 GWs installed by 2035,[15] which might generate 15 quads per year. However, many issues would need to be resolved, including storage and distribution.

Similarly, wind energy production offers enormous potential, from the current installed base of 135 GWs,[16] which produced a little less than 10% of all electric power generated in the US in 2021.[17] One vision predicts wind providing 35% of US electricity needs by 2050.[18] Wind generators operate at night as well as day, which is a big advantage. However, they rely on a smart grid, as most of the US production is in the Midwest (and some offshore), and so must be distributed. As demand increases for electric power, it is possible that wind turbines could supply much of the increase. Storage is a problem for wind power as well as solar, as total electrical power generation becomes more dependent on sources that can be episodic. A robust distribution system with spare capacity can lessen storage needs.

Nuclear power accounts for about 20% of all electricity generation in the US. There are 93 reactors in 55 plants throughout the US, down from a peak of 104 reactors in 2012.[19] The reactors are old, and many are operating past their expected life span. Significant research is ongoing on the design and construction of new forms of nuclear power plants,[20] which would provide greater safety and higher returns on investment (as nuclear power plants are very expensive and take a long time to build).

Perhaps the best prospects for increased nuclear power generation is through development of "small modular reactors" (SMRs).[21] The Department of Energy sponsors an advanced R&D program on the development of SMRs, and



considers them a key to the US energy future.[22] Each SMR would produce a few tens or hundreds of megawatts, and so hundreds or thousands would be envisioned to contribute to a percentage of the million megawatts of electricity generation capacity of the US. Although there is an aversion to the expansion of nuclear power, there are those who believe that the time for nuclear power dominance has come, especially for SMRs.[23]

US road, rail, and boat transportation accounts for around 20 quads of annual energy consumption in the US (down from around 24 quads in 2015).[24] Air transportation consumes only around one quad. If all transportation other than air could be converted to electric vehicle power, then it would be easy to replace the power generation from non-fossil fuel sources (such as wind, solar, or nuclear, feeding into electrical grids for onboard storage or immediate consumption).

Notably, the military uses small nuclear power plants for energy production, particularly for aircraft carriers and submarines. We might ask whether the military could eliminate its dependence on petrochemicals by converting to all-nuclear power production. But concepts for nuclear-powered aircraft are distant dreams. Nuclear power plants for armored vehicles are undoubtedly a bad idea.

Each of these enhancements (wind, solar, nuclear) as well as any others will require significant investment, not just in the production infrastructure, but also in distribution and control systems, and eventually an electric storage infrastructure. Return on investment computations depend heavily on the future cost of energy, which in turn depends on the price of a barrel of oil.

Exotic Sources to Reduce Competition for Energy

A variety of more exotic energy sources might become available in the future. Some involve oil and gas from new sources, which would nonetheless relieve pressure on the competition for resources by providing large new reservoirs of energy supplies. In all cases, the new sources envision near-infinite supplies that could supply energy globally.

Potentially abundant supplies of natural gas are available, albeit difficult to extract, and creating greenhouse gas emissions. The frozen methane hydrates in the deep ocean fuse ice and natural gas into formations that exist under high pressure, but with deep sea mining techniques could be used to extract gas.[25] Separately, there is concern that global warming could cause a tipping point with existing methane hydrates, causing the uncontrolled release of methane into the environment, over a period of centuries or millennia.[26] So it would behoove the world to secure the resource before they melt.

The other suggestion is that the mantle of the Earth, located below the Earth's crust and typically 100 kilometers below the surface, is replete with methane, according to models of chemical processes.[27] It might be possible to tap into these supplies, which might be viewed as essentially infinite, although bore holes have rarely descended beyond 10 kilometers. Locations where the crust is thin, however, might provide locations where large supplies of methane could be extracted. Whether this is advisable or feasible is problematic.

Even more exotic is the idea of retrieving methane from outer planets and their moons, such as from Saturn's moon Titan. Note that bringing resources back to Earth is "downhill" relative to the sun's gravity well. We would also want to bring new supplies of oxygen to Earth.

Eventually, controlled fusion reactors might be able to supply power to electrical grids. International programs for the development of controlled fusion continue, and progress continues to be made. Practical power plants, however, remain many years, and perhaps decades, hence.

A less dangerous way to obtain energy might be to use giant solar cells in space, to beam energy to Earth. The concept of space-based solar power has been around for a long time, but only recently have practical experiments been conducted.[28] A major impediment is the cost of getting material into space from the Earth.

Summary

Necessity might drive invention in one or more of these directions, or in other directions. The world has had the luxury, as well as the consequences, of abundant fossil fuel resources over the past couple centuries. This will continue, but extraction will be increasingly difficult and costly, and will likely still be competitive as resources are unevenly distributed. Further, dislocations due to global climate change may also force the more aggressive pursuit of alternatives.

Energy resources are so vital to national economies and security that the competition for energy may be central to most other competitions. International investments into resources may be driven by a need to secure future sources of energy. Resources that depend on energy include food from agriculture products, and industrial production capacity, and residential resources for heating and cooling.

In the near term, it is a safe prediction that oil and gas will remain the predominant sources, and that most supplies will come from a handful of countries that have remaining easily available resources. Thus, a competition for resources will continue, and success depends on either being one of the handful of countries, economic dominance, or military might.

The approach is not sustainable long term. Military conflicts are likely to occur in the interim over energy supplies, which could include kinetic wars as in Ukraine, and cyber wars to disrupt or divert supplies. They can also engender investment wars, as oil companies and nations vie for the rights to emplace infrastructure in territories that are not traditionally under their own control. Until inexhaustible supplies are found and secured, the competition for energy and especially for oil and gas will become an increasing driver of human activity.

So, what should the US do to prevail in the competition for energy resources? The answer is undoubtedly "all of the above." That is, the nation needs to be strong militarily, economically, and politically, to secure domestic sources and maintain access to foreign sources. The US needs a diversity of sources of energy, to include current fossil fuels and other energy sources derived from domestic supplies, supply chains from overseas sources, and future sources, all including wind, solar, nuclear, renewables, and more exotic sources. Reports of recent improvements in controlled fusion, and other potential inexhaustible supplies, provide for a hopeful future, but cannot be relied upon in the short term. One of the keys will be continued R&D and investments in demonstration and pilot plants. The US has the ability to lead in respect to R&D, and thus could control not only its own destiny, but the destiny of the world in access to energy sources.

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