Naturgy Foundation

NATURAL GAS

in the New Energy World

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2021

VACLAV SMIL

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Preface

At the beginning of 2020 it seemed that the third decade of the 21st century will see the continuation and intensification of trends that have prevailed during the preceding two decades: economic globalization, expansion of trade, rapid advances in information and communication, unprecedented levels of international travel, gradual decarbonization of national economies led by solar and wind-powered electricity generation. The pandemic caused by SARS-CoV-2 appeared to change all of that, but closer looks reveal a more complicated pre-COVID-19 situation –as well as less dramatic eventual post-COVID-19 changes.

Economic globalization and trade were actually in retreat since the mid-2000s.[1] Pervasiveness of social media, high market shares held by a few major companies and concerns about dissemination of disinformation led to calls for increased regulation and accountability of the IT sector, both in Europe and in the US. The rapidly rising volume of international tourist travel created concerns about environmental degradation, reduced quality of life in places overrun by visitors and to the first moves to limit the excesses of what became known as over-tourism. And while the quest for accelerated decarbonization of the global energy supply has obviously been linked to rising concerns about global climate change, there is nothing new about the process itself.[2]

Histories of modern primary energy and electricity production present clear trends toward lower carbon intensity. Fuelwood was followed by coal, coal by crude oil and crude oil by natural gas, and as fossil-fueled electricity generation was augmented by hydro and nuclear generation and, most recently, by solar and wind-powered conversions. But the global pace of these transitions has been slow: half a century ago the world derived about 94% of its primary energy from fossil fuels, by 2020 the share was still about 85%, while 60% of the world's electricity was still generated in coal- and natural gas-fired stations (crude oil and refined fuels accounted for another 4% of the total).[3]

Modern primary energy and electricity production present clear trends toward lower carbon intensity.

Almost as soon as the pandemic began to unfold, we were told that it is a once-in-a-lifetime opportunity to transform the world in general (and the managing director of the International Monetary Fund was not alone in saying this), a providential point of departure for a rapid transition to non-carbon energy supply in particular: when the International Energy Agency (IEA) published its Energy Technology Perspectives in June 2020 it offered a radical scenario of major carbon emission reduction resulting from accelerated electrification of heating and transportation, and from large-scale production of low-carbon hydrogen and hydrogen-derived fuels.[4] A temporary drop in CO_2 emissions resulting from economic lockdowns in the spring months of 2020 was seen by an increasing number of commentators and governments as the beginning of complete decarbonization that would be accomplished in just three decades.[5] But there is little to celebrate, much to be concerned about, and wishful thinking should not be mistaken for realistic appraisals.

To begin with, the global decline in energy use has been far lower than initially assumed. The reduction will only slow down the build-up of atmospheric CO_2, it will not even interrupt it: by the end of November 2020 the atmospheric CO_2 level measured at Mauna Loa was 0.64% higher than in October 2019.[6] Short-term impact of COVID-19-induced restrictions cannot be distinguished from natural year-to-year variability of atmospheric CO_2 concentrations, and the net effect will be to slow down global warming by no more than 0.01oC!.[7]

And –setting aside the fact that this drop in energy use has imperiled the livelihood of hundreds of millions of people, disrupted food production and manufacturing and led to the collapse of many personal services–only a poor understanding of basic energy imperatives could lead to the unrealistic claims of an impending rapid downturn in global fossil fuel consumption. From the most pressing perspective, even exceptionally rapid and extensive expansion of solar and wind-powered generation (or the conversion of biomass to liquid biofuels) would do nothing to secure billions of pieces of personal protective equipment (PPE: masks, shields, gowns, boots) for COVID-beset hospitals and clinics.[8] Mass-scale production of PPE is dependent on the large-scale output of polymers, with some of the most important monomers based on light feedstocks separated from natural gas (ethane to produce ethylene) or derived from steam reforming of hydrocarbon petrochemical feedstocks (propylene).

When looking ahead it is imperative to separate what is possible in the high-income economies from what is required in low-income nations. Relatively rapid expansion of renewable electricity generation and the pursuit of higher energy efficiencies can (combined with stationary or declining populations) translate into a steady and significant rate of decarbonization in high-income economies. Even so, it will be impossible to displace all fossil fuels that are now required for heating, transportation and industrial uses by non-carbon alternatives for decades to come. In contrast, Asian and African consumption of fossil fuels is still rising and the developmental aspirations of low-income nations ensure that it will continue to increase in the foreseeable future even with accelerated expansion of renewable electricity generation and with the adoption of more efficient conversions. There are some indications that, after four decades of rapid economic development, China's CO_2 emissions might peak even before 2030, but they will certainly keep on rising in India, most of the Middle East and Africa.[9]

In the future, expanded consumption of natural gas can make as much of substantial difference in today's low-income countries as it has made in high-income nations: the fuel is perfectly suited to replace coal in electricity generation (one of the fuel's largest uses), to power new generation capacities that can operate with unequaled dispatchability and conversion efficiency, to be used more efficiently than any other fuel in a multitude of industrial process, and to provide (for a long time to come) an indispensable feedstock for syntheses of many essential chemicals.

Looking ahead requires at least the basic qualitative and quantitative understanding of what we are dealing with and where we are coming from. This is why –before addressing concerns about the fuel's environmental impacts and before examining its future– I will first outline the key properties and benefits of natural gas, its reserves and resources and, briefly, history of its extraction, transportation and consumption.

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Natural Gas

Natural gas is a collective name for a mixture of light hydrocarbons of the alkane series CnH_{2n+2}) dominated by its lightest constituent (methane, CH_4). Ethane (C_2H_6) makes up typically 2-7% by volume, propane (C_3H_8) up to 1.3% and butane (C_4H_{10}) and pentane (C_5H_{12}) may be present.[10]

C_2-C_5 compounds are known as natural gas liquids (NGL), with propane and butane often marketed in pressurized containers as liquid petroleum gases (LPG). Natural gas also contains traces of CO_2, H_2S, N_2, He and water vapor, but gas processing plants remove nearly all but traces of these compounds and elements before the methane-dominated gas is transported by pipelines.

Methane has only one obvious disadvantage: at ambient atmospheric pressure and temperature (25°C), its specific density is only 0.656 g/L and this means that its volumetric energy density is just 37.7 MJ/m^3 (higher heating value), with the actual rates for natural gases ranging between 33-42 MJ/m^3. These values are three orders of magnitude lower than the volumetric energy densities of refined liquid fuel (gasoline at 35 GJ/m^3, diesel fuel nearly 36.5 GJ/m^3). Obviously, this low energy density precludes any mass-scale above-ground storage of the fuel in tanks or the fuel's intercontinental shipping in gaseous state. The first challenge has been solved by large-scale underground storage (in depleted natural gas reservoirs, in porous aquifers and in salt caverns), the second one by liquefying the gas (at -162°C), raising the specific density to 428 kg/m^3 and volumetric energy density to about 21.4 GJ/m^3 or roughly 600 times the value for typical natural gas.[11]

The fuel's numerous advantages include high combustion efficiency, reliable and affordable transportation and distribution in pipelines, convenience and flexibility of use, low emissions, and abundant and reliable supply. Modern natural gas-fired heating furnaces have maximum efficiencies of 95-97%, combustion efficiency of natural gas in large heat-producing boilers used in many industries can exceed 85%, and the best combined-cycle gas turbines used in electricity generation now achieve overall efficiency approaching 65%, the rate unsurpassed by any other heat converter.[12] Long-distance transportation of compressed gas in pipelines is now done routinely on transcontinental scales, with the trunk lines connecting Western Siberia with Western Europe (>5,000 km) and Central Asia with Eastern China (about 6,000 km). Much like electricity grids, natural gas pipelines can be supplied and tapped continuously at variable rates, but they are superior energy carriers when compared to high-voltage long-distance transmission because their capacities are much higher.[13]

Convenience and flexibility of use are obvious. The fuel is almost instantly available by turning a knob, flipping a switch or setting a thermostat, and the reliability of its delivery via pipelines (and now among continents using tankers carrying liquefied gas) is very high. As a result, the fuel is widely used for residential, commercial and institutional heating, it provides process heat in industries ranging from steel and glass making to food preparation, and it has become a steadily more important choice for electricity generation. In addition, methane is currently an indispensable feedstock for the synthesis of ammonia and the two heavier alkanes, ethane and propane play the same role for the synthesis of leading plastics. Natural gas is thus the optimal fuel for densely inhabited urban areas that require seasonal heating, an efficient, reliable and clean choice for electricity generation and industrial process heat, and a critical feedstock for producing ammonia, plastics, methanol and hydrogen.

As for atmospheric emissions, natural gas is the only fuel whose combustion does not produce SO_2 (H_2S is removed form the raw gas before it enters a pipeline) and emits only a tiny amount of the smallest (diameter < 2.5 μm, PM2.5) particulate matter. This makes it an ideal fuel for electricity generation at sites near or within urban areas. As with all fossil fuels, combustion of natural gas generates CO_2 but per unit of energy methane has the lowest carbon intensity: complete combustion of bituminous coal generates 93-95 kg CO_2/GJ, the rate is mostly between 73-74 for refined liquid fuels and 56 kg CO_2/GJ for natural gas.[14]

Reliability of delivery is taken for granted both by industries and by households, and the risks of natural gas distribution have been minimized. US data show that accidental explosions and ignitions of natural gas cause two deaths a year, a minuscule share of the more than 160,000 deaths a year that are caused by unintended injuries.[15] The abundance of natural gas is best illustrated by the fact that its global supply has almost exactly quadrupled during the past 50 years and increased by nearly 75% during the first two decades of the 20th century. Europe's 2021 natural gas price spike was not caused by any looming physical shortages of the fuel but by an unpredictable concatenation of events including colder winter (hence a longer heating season), reduced wind electricity production and rising dependence on imports at a time when the global demand rebounded after the worst phase of Covid-driven economic restrictions. In fact, natural gas has been just one of many globally traded commodities that have seen such high price rises – but adequate investment in developing the existing reserves and expansion of the global market should bring the return to lower prices. On the other hand, lack of such investments, combined with premature closure of other fossil-fueled (or nuclear) capacities, might lead to even higher price spikes in the future. The lesson of 2021 is clear: energy transition must be guided by physical realities, not by arbitrary goals for years ending in zero.

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Reserves and Resources

Natural gas is abundant in the topmost layer of the Earth's crust and for decades its extraction tapped three major sources: gas associated with crude oil deposits; non-associated natural gas comes from hydrocarbon fields where CH_4 is combined with heavier alkanes (natural gas liquids); and non-associated gas from reservoirs containing more than 90% of methane (so-called dry gas). In recent decades increasing volumes of gas have been produced from nonconventional sources, above all from coal beds and from shales (by hydraulic fracturing). Commercialization of these sources has greatly increased the available resource base, and even larger volumes of the gas are trapped in methane hydrates (clathrates) that remain unavailable for practical extraction.

There is no reason to be concerned about the magnitude of global natural gas reserves, and even less about the ultimate resources. Gaseous methane (nearly pure or mixed with variable shares of other light alkanes) is present as associated gas in tens of thousands of oilfields, and there are thousands of fields producing non-associated gas. More than half of all production comes from giant fields, those containing more than 8.5 km^3 of recoverable gas, with 20 fields in super-giant category with recoverable reserves in excess of 850 km^3.[16]

Expanding scope and improving techniques of geophysical exploration have resulted in a steady rise of global natural gas reserves: they increased from just 10 Tm^3 in 1950 to 65 Tm^3 in 1974, the year when the world began to cope with the OPEC's quintupling of oil prices.[17] By 1980 the total reached about 73 Tm^3, a decade later it was just below 125 Tm^3 and by the century's end it was nearly 135 Tm^3. The new century saw an impressive increase of reserves to just over 170 Tm^3 by 2010 and to about 200 Tm^3 by 2020. In 1950 the US had more than half of the world's gas reserves, but subsequent discoveries in the USSR, Iran and Qatar had put those countries well ahead of the American total.

The largest Soviet discoveries took place during the 1960s and the early 1970s, with Urengoy (the world's second largest super-giant with 6,300 km^3 of recoverable reserves) first drilled in 1966.[18] By 2020 the countries of the former USSR held almost exactly a third of the world's natural gas reserves, with Russia having some 60% of the total and Turkmenistan most of the rest. Iran and Qatar rank second and third, both thanks largely to the split ownership of the world's largest (and offshore) natural gas field (reserves of 35.7 Tm^3) discovered in 1971 and known as South Pars in Iran and as the North Dome in Qatar. Iran owns just over 70% of the total of 35,000 km^3 of recoverable reserves.[19]

As is the case with nearly all mineral resources, global size distribution of natural gas fields is extremely skewed, with the ten largest fields containing about a third, and the top 20 more than two-fifths of all conventional gas. Iran and Russia harbor a third of all reserves (almost equally split), the top four countries (adding Qatar and Turkmenistan) have nearly 60% of global reserves, making this a higher concentration of mineral wealth than for crude oil (in 2019 Venezuela, Saudi Arabia, Canada and Iran held about 53% of global oil reserves). This highly skewed distribution also means that more than 80% of the world's 200+ nations either do not have domestic reserves large enough to satisfy potential demand or have no commercially viable reservoirs and must turn to imports if they want to enjoy the multiple benefits of the fuel.

They can do so without worrying about the availability of future supply. During the past four decades global gas consumption rose 2.3-fold but the global reserve/production ratio fluctuated within a narrow band of 48-65 years (it was 50 years in 2019). This means that new discoveries and new recovery technique have kept up the pace with the increasing need to "translate" resources into commercially producible reserves. Of course, that could be affected by intra- and international conflicts, and by economic and political developments, but major users in North America, the EU, Japan and China have never experienced any protracted supply interruptions. Major natural gas discoveries made in 2019 show how widespread the successful search for new reserves has become. Their locations range from the Russian Arctic (Kara Sea) to the subtropical waters offshore Mauritania and Senegal, and from the much-disputed finds (Turkey, Cyprus, Greece) in the eastern Mediterranean to the latest additions to already gas-rich Malaysia and United Arab Emirates.

And there should be no concern about long-term availability of the fuel. The latest USGS assessment estimated that technically recoverable resources of conventional natural gas (excluding the United States) amount to about 159 Tm^3.[20] Beyond this are even more massive non-conventional sources of natural gas, above all in the reservoirs with poor permeability and low porosity (shale gas and tight gas), coal bed methane and methane hydrates (clathrates) below the sea floor. For example, the US Geological Survey puts the total undiscovered but technically recoverable resources of gas reserves in the Appalachian Basin at about 6 Tm^3 – and America's innovative pioneering post-2000 efforts to recover this gas in large volumes have shown that, at least as far as the US is concerned, extraction of these non-conventional resources has been successfully commercialized.[21] Methane hydrates present a much great extraction challenge, and they should be considered as the ultimate resource insurance, not as a near-term source of affordable gas.

Expanding scope and improving techniques of geophysical exploration have resulted in a steady rise of global natural gas reserves


LNG SOKOTO

Production, Transportation, Consumption

Unlike crude oil, whose commercial extraction led almost immediately to substantial international trade with the valuable liquid (and later also with individual refined products including gasoline, kerosene and diesel and bunker fuels), natural gas markets remained comparatively small and completely segregated during the first 100 years of the industry's development. Seamless steel pipes (first produced by Reinhard and Max Mannesmann in 1885) made it possible to build long-distance pipelines, but their cost, limited volumes of known gas reserves and inexpensive coal and oil supplies did not provide incentives for such projects. Similarly, the first patent for a liquefied natural gas (LNG) tanker was filed by Godfrey Cabot in 1915, but the absence of overseas markets (US was the only major user of gaseous fuel), high costs of such vessels and LNG facilities delayed the first (still very expensive) projects until the 1960s.[22]

Natural gas production is now a mature industry that relies on the sequence of advanced exploration, extraction, processing, transportation and conversion techniques to deliver, affordably and reliably, a large and increasing share of the world's primary energy. Advances in exploration have been based on better understanding of fundamental tectonic geology, on the deployment of new geophysical exploration methods and on increasingly more detailed 3D and 4D simulations of oil and gas reservoirs used to determine the best course of extraction. Transportation is now virtually unlimited as far as the length of pipelines is concerned (as inter-continental links between Siberia and Europe and long-distance intra-continental links between Western and Eastern Asia have become common). Similarly, LNG exports have evolved to become a truly global industry that now delivers half of all traded gas.

For decades, intercontinental LNG sales remained restricted to a relatively small number of long-term contracts (with Japan dominant by imported volume), but by the year 2000 nine countries (including Indonesia, Malaysia, Australia, and Qatar) joined the original two exporters (Algeria and the US) to ship LNG overseas, including (in the order of volumes sold) exports to France, Spain, Belgium and Italy.[23] These arrangements began to change thanks to several technical advances that introduced both larger and smaller innovations. The first decade of the 21st century saw the doubling of maximum LNG train sizes and a new design of large LNG tankers replaced large aluminum spheres (Kvaerner-Moss shells, covered with insulation and placed inside steel tanks) with a membrane design using thin stainless steel to make insulated tanks that fit into the vessel's inner hull.[23] As a result, after decades of minimal growth capacities of the largest LNG tankers increased to more than 250,000 m^3, with Qatargas Q-Max class carrying 267,000 m^3. In the opposite direction, small (even mini) LNG facilities are now available to energy users that are not connected to pipelines and that are too small to afford large regasification plants. The most obvious beneficiaries have been the island nations in Southeast Asia and in the Caribbean.[24]

Thanks to these advances, global LNG shipments reached 25% of all exported natural gas in 2008, and by 2020 the total annual export capacity reached nearly 500 Mt, with about a third of all sales imported on a spot or short-term basis, and the rest based on contracts lasting typically between 11-16 years. By 2020, 21 countries exported and 42 countries imported LNG whose shipments accounted for more than 49% of the globally traded gas.[25] Six hundred vessels (most of them less than 15 years old) carry the gas among continents, with Australia and Qatar being the largest exporters (each one shipping about 21% of the global total). United States rose rapidly to third place, followed by Malaysia, Nigeria and Russia (Arctic gas).

East Asia (Japan, China, South Korea and Taiwan) dominates the imports (buying half of the global volume), while Spain, France, UK and Italy are the largest buyers in Europe. Remarkably, this continuing LNG expansion has not changed the industry's excellent safety record. January 19, 2004 explosions at an LNG plant in Skikda in Algeria remain the only serious incident at a liquefaction facility (26 deaths, 74 injuries), and since the trade's beginning in 1964 there has been never any shipping accident that would have resulted in loss of life or cargo or in damage to port facilities.[26]

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USA

In 1900 natural gas supplied less than 3% of America's primary energy, the share reached 20% in 1951, it peaked at about 32% in 1970 and then, as the US conventional gas production stagnated (the output in 2010 was less than 1% above the 1970 volume!), it remained below 25%. This stagnation resulted not only in rising natural gas prices but in fears about the adequacy of future supply. In 2003 two experienced petroleum geologists published an assessment of North American natural gas market that had a single perfunctory reference to shale gas and concluded that the days of cheap gas are history, that additional LNG facilities are needed for increased imports but that it may not be possible to build them fast enough to prevent the rationing of available gas.[27] But just six years later the country surpassed Russian extraction to become, once again, the world's leading producer of natural gas. Moreover, by 2016 the country became an LNG exporter and by 2019 it sold 47.5 Gm^3, ahead of Russia but a distant third to Qatar and Australia. All of this happened because of the combination of horizontal drilling and high-volume hydraulic fracturing.

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2020

Both of these are old techniques that have been improving for decades, and today's practices of combined horizontal drilling and hydraulic fractioning had their beginning in US government-funded research that began during the late 1970s to boost the recovery of natural gas from non-conventional resources, above all from the country's abundant shales.[28] Commercial breakthrough based on these advances, and on the deployment of a cheaper fracking liquid, was achieved first during the late 1990s by George P. Mitchell's company (Mitchell Energy & Development) in the Barnett shale in Texas. By 2009 it became clear that the world's largest super-giant natural gas field is not in the Middle East or Siberia but in the Marcellus shale in Appalachia, extending from New York state to Alabama.[29]

In the year 2000 shale gas supplied just 1.6% of the total US production (and hydraulic fracturing of conventional and non-conventional deposits produced less than 30% of the total), in 2010 shale gas accounted for about 22% and in 2019 it reached 68% of the total, with hydraulic fracturing responsible for 80% of all US gas extraction.[30] This rapid ascendance of a new energy resource lifted the nation's gas production by 52% between 2010 and 2019 when natural gas supplied 32% of the country's primary energy, second only to crude oil (37%) and well ahead of coal and renewables (11% each). As a result, wellhead and city gate prices declined from their peaks, as did the prices of commercial deliveries, US pipeline exports expanded more than 15-fold during the first two decades of the 21st century, and LNG export grew more than 100-fold since their inception in 2014.[31]

Europe

European energy supply was dominated by coal (widely used to produce town gas in many larger cities of the continent) until after WW II. Only a few countries (Romania, Italy, Austria) had small natural gas fields and the continent's aggregate gas output was negligible. In the absence of major natural gas reserves the UK and France resorted in 1964 to the world's first, and expensive, imports of liquefied natural gas from the first high-capacity liquefaction plant in Arzew, Algeria, and in 1969 came the first exports from Libya to Spain. Large-scale conversions of household heating and industrial processes to natural gas began only after the discoveries of the Groningen field in the Netherlands (drilled in 1959, first production in 1963) and of major fields in the British and Norwegian sectors of the North Sea (the line between the sectors was drawn in 1965).[32]

The British West Sole field came firstin 1965, gas was brought on shore in 1967 and the program to convert residential uses to natural gas was completed in 1976. The Norwegian Frigg gas field was drilled in 1971, and reserves of the super-giant Troll were assessed at 1.3 trillion m^3 in 1979 (its gas reached EU only in

1996). Norway eventually made substantial natural gas discoveries also in the Barents Sea (Snøvhit in 1984) and in the Norwegian Sea above the 62nd parallel (Ormen Lange in 1997 in deep water). Undersea pipelines were laid under the North Sea not only to Norway, Scotland and England but also directly to Denmark, Germany, Belgium and France. As the largest fields were mostly or completely in the Norwegian sector, the country became Europe's leading natural gas exporter.

The next major developments that changed the European natural gas market for decades to come came during the 1980s when the USSR completed trunk lines of unprecedented lengths and capacity to link super-giant fields in Western Siberia with Eastern, Central and Western Europe.[33] These mass-scale exports began even as the USSR was consuming rising volumes of the gas domestically. A dense northern and central European network of natural gas pipelines was extended southward to Italy, France, Spain and Portugal, and then came the African connections delivering the gas from Algeria's super-giant Hassi R'Mel field: first (1983) the Trans-Med Pipeline to Sicily via Tunisia, in 1996 the Maghreb-Europe Pipeline via Morocco crossing the Strait of Gibraltar to Spain, in 2004 the GreenStream line from Libya to Sicily, in 2020 the Medgaz line across the Mediterranean to Almeria.[34]

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Undersea pipelines now also extend from Russia, the NordStream 1 from Vyborg near Sankt Peterburg under the Baltic Sea to Greifswald in northern Germany was completed in 2011, and the line's doubling (NordStream 2) was halted in December 2019 and a year later the fate of this nearly-finished link remains uncertain.[35] The latest addition is the TurkStream that takes the Russian gas under the Black sea from the Krasnodar region to the coast of Turkey's European territory. The continent's natural gas transportation network thus extends from the North Sea to Andalusia and Sicily, and from Ireland to the Urals, and it is now connected to northern Africa, Siberia and Central Asia. The extent, density and cost of this enormous infrastructure that was built over more than half a century and that has become indispensable to maintain the continent's high standard of living makes it clear that the reliance on natural gas is here to stay for decades to come.

The production of the Groningen field and some older North Sea fields has been declining, and some fields (including Norway's giant Frigg) were decommissioned as the continent's natural gas production peaked and then ebbed. In 2019 Europe's extraction was 30% below its peak output (in 2004), and the respective declines were 67% for the Netherlands (peak already in 1977) an 65% for the UK (peak output in the year 2000). Inevitably, European gas imports have been rising, with Russia becoming a steadily more important supplier.[36] And yet even this enormous infrastructure capable to deliver on the order of 250 Gm^3 of natural gas a year has not been enough, and the continent is now one of the leading destinations of expanded LNG shipments. In 1999 five European countries, led by France and Spain, were importing less than 30 billion m^3 of gas as LNG, two decades later 15 countries (with import volumes still led by France and Spain) were buying about 120 billion m^3 and that year also saw new contracts for additional LNG shipments to Spain, Greece and Poland.[37]

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Asia

The first well-documented commercial use of natural gas was about 500 years ago in China's Sichuan province where the wells were made by percussion drills, gas was transported in bamboo pipes and used to evaporate brines. But, leaving the Asian part of Russia aside, the continent became the fuel's major user only during the past 40 years. Two decades of Japan's most rapid economic expansion (1955-1975) were energized by rising imports of crude oil and coal; China's and India's modernization depended overwhelmingly on domestic coal; and despite its enormous gas resources the Middle East relied primarily on its abundant crude production.

As oil prices quintupled during the 1970s, major Middle Eastern producers began to turn to natural gas, and since 1980 Saudi consumption has increased 12-fold and in the UAE nearly 20-fold. In 2014 the IEA concluded that the region's demand for natural gas will exceed its production by 2019. That did not happen despite the demand rising higher than predicted, and the region, besides continuing as a major exporter of LNG, now derives just over 50% of its primary energy from gas –but future growth rates are likely to be slower than most envisaged by most forecasts.[38]

Japan began its LNG imports from Alaska in 1969, during the 1970s it added gas from Brunei and Indonesia, it doubled the purchased volume during the 1980s and (adding purchases from Malaysia and Australia) again during the 1990s (adding Qatari gas) to about 100 billion m^3 in the year 2000, and in 2019 it was the world's largest LNG importer (ahead of China). As a result, LNG's share in the country's primary energy consumption rose gradually from about 13% in the year 2000 to 21% by 2020.[39]

At the beginning of the 21st century, China was the world's only major economy without significant reliance on the fuel as its consumption was equal to only about a quarter of the Japanese annual use. That changed thanks to the combination of aggressive domestic exploration and extraction, construction of high-capacity pipelines delivering gas from the Central Asia and Russia and the development of the world's largest LNG import facilities. Even so, Chinese primary energy consumption remains dominated by coal and in 2020 natural gas supplied less than 10% of the total demand: clearly, the country has a long way to go to reach a natural gas share comparable to the levels prevailing in other large, modern economies. India's share (at about 6% in 2020) is even lower and hence the potential for future imports is even higher.

Global trends

The record shows that natural gas has been gaining higher market shares (displacing crude oil and coal) at a slower rate than the previous two major fuel substitutions, coal displacing wood, and crude oil displacing coal.[40] Coal replacing wood reached the 5% share of the global supply around 1840, it captured 25% of the market by 1875 and 33% by 1885. Starting in 1840 it took 35 years to reach 25% and 45 years to attain 33%. Crude oil reached 5% of the global market in 1915 and it took 40 years to get to 25% and 50 years to reach 33% of the global supply, not much slower than coal. Natural gas reached 5% of the global primary energy supply in 1930, 20% 40 years later –but in 2020, 90 years after capturing 5%, it was still a shade below 25%.

There are obvious reasons for this relatively slow market penetration. Liquid fuels refined from crude oil are significantly more energy dense than coal (42 GJ/t for crude oil, 20-25 GJ/t for bituminous coal), and this high energy density makes for easy portability and assures their dominance of transportation markets, and for stationary combustion their storage is more convenient and their conversion efficiency is higher. In comparison, natural gas has much lower energy density (1/1,000 at atmospheric temperature and normal pressure, or just around 35 MJ/L) that makes its uses less flexible, and until the advent of inexpensive LNG exports it could not be widely traded on the global market.

This has changed recently.[41] In 2000 about 20% of all consumed gas was from imports by 44 countries, with 16 countries exporting the fuel by pipelines and 11 by LNG tankers. By 2020 about 25% of all gas consumed worldwide was from imports by more than 60 countries, with 25 countries exporting fuel by pipelines and 20 by LNG tankers. This, combined with the continuing retreat from coal in Europe and in North America, and with the plans for a further large-scale increase of gas consumption in Asia and Africa, means that the 25% mark might be reached in the near future.

What happened to those roughly 4 trillion cubic meters consumed worldwide in 2019 before COVID-19 reduced the 2020 levels of primary energy use? World energy balances, tracing the flows of fuels and primary electricity from production to final consumption, indicate that electricity generation has been the single largest use (close to 30% of the total).[42] Adding the gas destined for combined heat and power plants would raise this total to nearly 40%. Gas directly used for space heating (produced by centralized heat plants, common in Europe and China, and by gas furnaces in houses and apartments and in public and commercial buildings) claims almost a quarter of all uses, industries consume nearly 20% and about 6% of the final consumption are non-energy uses.

Moving away from coal-fired to natural gas-fired electricity generation has brought three key advantages: near-elimination of particulate and sulfurous emissions; lower rates of CO_2 generation per unit of energy; and, reinforcing the second advantage, unrivaled efficiency of fuel conversion. The convenience and reliability of natural gas combustion are particularly welcome for space heating by residential, commercial and institutional users as indoor temperatures are effortlessly controlled by pre-set thermostats. Similarly, natural gas provides an excellent source of process heat in industries ranging from glass making to food processing, and it is also a dominant source of process heat for direct reduction of iron, the only relatively large-scale commercial alternative to blast furnaces, and blast-furnace smelting (fueled primarily by coke derived from coal) has been made more efficient by injections of natural gas.

Transportation is the only major economic sector where natural gas is not a leading source of primary energy supply (only about 3% of the global natural gas consumption is claimed by this sector). The fuel has been widely used to power its own distribution by long-distance pipelines (using gas turbines in compressor stations along their routes) but its low energy density makes it unsuitable for flying and shipping, with LNG now being introduced as a possible practical choice for long-distance trucking. The importance of non-energy uses of natural gas is far higher than their relatively small share of final consumption.

Without the synthesis of ammonia, the starting compound for production of nitrogenous fertilizers, we could feed no more than half of today's population of nearly 8 billion people because even the most intensive recycling of organic wastes could not supply enough nitrogen for the world's high-yielding staple crops (rice, wheat, corn) and for nitrogen-intensive cultivation of vegetables.[43] The Haber-Bosch process of ammonia production relies on natural gas both as an affordable source of hydrogen and an excellent fuel to energize the high-pressure, high-temperature synthesis. While there are other ways to synthesize ammonia, none is as economical, and none has been deployed at an even remotely similar scale, as using methane both as a feedstock and as a fuel to energize the synthesis.

The world now produces annually around 300 million tons of plastic materials and their production depends heavily on two hydrocarbons commonly present in natural gas: on ethane, the most voluminous component of natural gas liquids, and on propane.[44] These monomers are used for the production of the three dominant plastic polymers, polyethylene, polypropylene and polyvinylchloride whose annual output now accounts for about 60% of the global demand for synthetic materials. Methane is the most important starting material for the synthesis of methanol (methyl alcohol) which, in turn, is a key feedstock used to make formaldehyde, acetic acid and other intermediates used in the production of resins, plastics, paints, adhesives and silicones.

Finally, roughly half of all hydrogen is now produced by the steam reforming of methane ($CH_4 + H_2O \rightarrow CO + 3H_2$), with the rest coming mostly from steam-reforming of liquid hydrocarbons and coal. Hydrogen is indispensable in crude oil refining, it is required for many chemical syntheses (methanol, polymers, solvents, pharmaceuticals), and its industrial uses range from glass-making to food processing. Hydrogen production by electrolysis of water, using inexpensive hydroelectricity, is limited, and the production of "green" hydrogen driven by electricity generated by photovoltaics or wind is in the earliest stages of commercialization.[45]

As expected, national energy balances show various departures from the global pattern. The US breakdown for 2019 was not that different from the global mean: 36% to generate electricity, 33% for industrial uses, 27% for residential and commercial heating and 3% for transportation.[46] The Spanish breakdown is quite different, with industry claiming two-thirds, electricity generation only about 11% and residential and commercial uses about 16%[47]. And in Germany less than 15% of gas is used for electricity generation, industry consumes more than a third of the total and space heating nearly half of it.[48]

Natural gas provides an excellent source of process heat in industries

Decarbonization and Methane Leakage

At the beginning of the second decade of the 21st century there was a widespread conviction that natural gas is the best fuel to provide the bridge between the fossil fuel era and the new energy epoch relying on conversion of renewable flows. This sentiment was perhaps best expressed in the title of the 2013 IEA's report on Golden Rules for the Golden Age of Gas.[49] But soon after that report was published new studies about excessive leakage of methane appeared to put these expectations in question, and hence it is essential to explain the process of natural gas-driven decarbonization of global energy and assess the degree to which this shift might be affected by the leakages of methane along the gas supply chain.

Evolution of human energy use has been one of steady decarbonization, of shifting the ratios of carbon and hydrogen. Wood dominated energy supply for millennia. Its carbon content is around 50% (the actual range is narrow, within 46-55%) and it contains only about 5% hydrogen. Bituminous coal has about 65% carbon and 5% hydrogen, and hence the atomic H:C ratio of wood is about 1.4 and of bituminous coal around 1.0. But because a large share of wood's hydrogen is never oxidized (because hydroxyl radicals escape in early stages of combustion) the effective H:C ratio of wood is usually less than 0.5 and replacing wood by coal results in producing lower CO_2 emissions per unit of energy.[50]

The atomic H:C ratio of refined liquid fuels is 1.8 (86% carbon and 13% hydrogen), nearly twice as high as bituminous coal, and further decarbonization is achieved by burning CH_4 whose atomic H:C ratio is obviously 4.0. On this basis natural gas would be an uncontested choice for a relatively rapid decarbonization, particularly by replacing coal in electricity generation. In the US this transition has been unfolding for two decades. Between 2000 to 2005 additions of gas-fueled capacity reached nearly 192 GW as the fuel replaced coal as the source of baseload power, and between 2012 and 2030 US utilities will reduce coal-fired capacity by about 115 GW, more than a third of the former peak rating.[51] But new measurements of methane leakages accompanying the production and processing of natural gas suggested that this carbon advantage is not only weakened but could be even fully eliminated due to the uncontrolled emissions of this powerful greenhouse gas whose atmospheric concentration is currently around two-and-half times greater than pre-industrial levels and is increasing steadily.

Even seemingly small methane leakages (on the order of 2-4% of the produced gas) would negate the benefits of lower CO_2 emissions because methane is a far more potent greenhouse gas than CO_2: its global warming potential is 84-87 times higher over the period of 20 years and at 28-36 higher over a century) and its excessive leakage would detract from the fuel's advantages.[52] Estimates of methane emissions are subject to a high degree of uncertainty, but the most recent comprehensive examination of the global methane budget suggests that during the decade of 2008–2017 they averaged 576 (550–594) Mt/year, with 40% from natural source and 60% attributed to human activity.[53] Agriculture (enteric fermentation of ruminant animals, emissions from rice fields) is the largest anthropogenic source, and the oil and gas industry contributed about 80 (72-97) Mt/year.

In 2019 the IEA estimate put the industry's global methane emissions at 82 Mt, split between oil and gas extraction, processing and transportation.[54] Methane emissions from the industry can be deliberate (venting the gas for safety reasons or when there is no commercial outlet for it) and accidental (faulty equipment, leaking valves, wells and pipelines). Assessing methane leakages on national scales has been quite challenging, but several older US studies came up with losses equal to small shares of the produced gas. But in 2018 a study of the US oil and natural gas supply chain (using ground-based measurements, validated by airborne observations and scaled up nationally) estimated total methane emissions to be about 60% higher than the previous inventory by the Environmental Protection Agency, equivalent to 2.3% of gross U.S. gas production.[55]

Almost instantly, natural gas acquired a very black reputation. Headlines tagged it as not so natural, worse for the planet than coal, hurting the climate, making global warming worse –and Bill McKibben concluded, using the phrasing befitting the leading climate catastrophist in the US, that turning from coal to natural gas is "as if we proudly announced that we kicked our Oxycontin habit by taking up heroin instead."[56] Without any doubt, methane leakages during extraction, processing and transportation do diminish the overall beneficial impact of using more natural gas– but they do not erase it, and they can be substantially reduced.

In its detailed 2019 assessment of lifecycle emissions resulting from natural gas and coal supply, the IEA concluded that "over 98% of gas consumed today has a lower lifecycle emissions intensity than coal when used for power or heat." Switching to gas brings declines averaging 33% per unit of heat used in industry and buildings, and 50% when generating electricity. Moreover, IEA's 2020 assessment found that about three-quarters of today's methane emissions from oil and gas industry can be controlled by deploying known technical fixes.[57] And, most significantly, IEA's presentation of global marginal methane abatement cost curves shows that about 40% of those emissions could be avoided at no net cost because the captured gas can be readily, and often easily, sold for profit!

Consequently, relatively high methane leakage is not an unavoidable consequence of natural gas extraction, processing and distribution but a failure resulting from the lack of proper management (losing a valuable resource that should be prevented from escaping and should instead be sold for profit), absence of stringent regulations (compare methane leakage from Western Canada's natural gas extraction with Turkmenistan, where giant plumes of leaking methane are visible from satellites), and insufficient deployment of well-known technical solutions.[58]

New means help in identifying a problem, many well-established procedures can control the losses. Satellite observations provide near-instant information about methane leaks and make it possible to undertake any needed action without delay but, so far, the read-outs have a considerable range of uncertainty (better sensors are coming) and apply only to large emitting sources. Drones now offer a highly accurate and inexpensive means of regular on-site (and along a pipeline route) monitoring. Methane leaks have many causes

IEA's 2020 assessment found that about three-quarters of today's methane emissions from oil and gas industry can be controlled by deploying known technical fixes.

and there are many commensurate technical fixes ranging from proper pipe connections to valve and pump replacements.[59] Results of these improvements could be impressive and the IEA's 2020 conclusion (that even with low gas prices in an oversupplied market, reducing methane leakages in the oil and gas industry is still one of the least-cost options for cutting down greenhouse gas emissions) became even more valid in 2021 when natural gas prices rose around the world.

There is no justification for demonizing natural gas as a fuel choice worse than coal. Proper regulations concerning methane leakage and diligent deployment of highly cost-effective means of emission reduction can keep the overall losses well below the rate at which the lower carbon intensity of gas would be greatly reduced or even eliminated by excessive methane emissions. Although available controls can be highly effective, some losses along the natural gas supply chain are inevitable. Even the most efficacious drugs have undesirable side effects, even the best technical fixes have downsides. To think that the supposedly greenest alternatives, PV and wind turbines, make no fossil fuel footprints and bring only benefits is to ignore well-known realities.[60] So is the uninformed judgment about the evils of natural gas: it is not a perfect choice (nothing is) but its benefits decisively surpass its drawbacks and they could be raised even further.

Looking Ahead

The 2020 pandemic interrupted years of continuous expansion of the world's natural gas industry, with 2019 setting yet another record growth rate at 2.3% a year, and a record addition of LNG capacities. Pandemic-driven lockdowns and slow-downs had the worst impact on energy uses in several sectors of transportation (aviation kerosene, car gasoline and diesel), while the primary uses of natural gas (electricity generation, industrial production and space heating) were much less affected and hence the overall consumption decline will be limited to less than 5% of the 2019 record level. There is no reason to foresee any dramatic departures from the pre-2020 trend in the post-pandemic world. Eventual retreat of the second (winter in the Northern hemisphere) COVID-19 wave and the progressing vaccination will support market recovery but it is unlikely that the rebound will set a new demand record: that is more likely to happen in 2022 or 2023.

The longer-term outlook will not be constrained either by available reserves of natural gas (abundant resources ensure that technically recoverable reserves could supply the growing global demand for many decades to come) or by the lack of requisite infrastructures (as new distribution lines and liquefaction and storage facilities can now be built in record time). The LNG market will be the strongest indicator of the future course. The global LNG network has become essential for balancing the markets and providing both flexibility of choices and security of deliveries. This market will see further structural changes both because a large share of longer-term delivery contracts will expire during the first half of the 2020s and because new liquefaction capacities will keep coming on-line.

Russia, with its plentiful resources, has particularly bold plans of quintupling its LNG supply to Asia by 2035 (with up to 70% of these exports shipped via the Arctic route) and to capture a fifth of the global market.[61] Russia is also pushing another high-capacity natural gas pipeline (Power of Siberia-2) to China, while the Chinese expectations are for a nearly doubled demand by 2035, and India plans to surpass China as the world's largest market for residential LPG even as it keeps extending its deliveries of pipeline gas.[62] But the future of natural gas must be judged by demand, not by the promises of expanded supply, and China's post-1980 development is a perfect indicator of potential energy demand among more than 7 billion people in low- and middle-income countries.

Annual per capita supply of primary energy now averages 135 GJ in the EU, 150 GJ in Japan, and 250 GJ in North America and Australia, and nearly 100 GJ in China –but we must remember that in 2021 half of humanity lives in countries whose annual per capita primary energy supply is less than 50 GJ and 40% of the world's population (3.1 billion people) use less than 25 GJ a year per capita, the rate achieved in Germany or France by 1860.[63] Obviously, these populations have no hope to enjoy a dignified standard of living without multiplying their current energy supply– much as China has done since embarking on its economic modernization.

China's rise –accompanied by improved nutrition, higher incomes and mass-scale construction of modern infrastructure– was made possible by unprecedented quantities materials whose production depends on high inputs of fossil fuels. China's quadrupling of economic production in a single generation has not been based on wind and solar electricity but on fossil carbon: since 1990 the country had nearly quadrupled its coal extraction, increased its oil consumption nearly ten-fold and its natural gas combustion almost 20-fold.[64] This has boosted per capita energy supply for its 1.4 billion people almost four-fold and this means that if 3.1 billion people in today's underdeveloped nations were to accomplish only half of what China has their total demand for fossil carbon would be larger than China's post-1990 increment!

A more specific, sectoral, look shows that there are three major reasons why both affluent and modernizing countries –even as they strive to increase the share of renewable energies in their primary energy consumption– will have either to keep natural gas as a major component of their primary energy supply or to increase its consumption. The first demand is for further replacement of coal-fired electricity generation by gas-fired turbines (shifting from the most carbon-intensive to a significantly less carbon-intensive mode) and for new gas-fired capacities to complement rising shares of renewables.

This is an apposite place to address the claim (now frequently repeated) about the cost advantage of renewable electricity generation. The latest IEA's review of renewable generation concluded that "solar PV and onshore wind are already the cheapest ways of adding new electricity-generating plants in most countries today," while Greentech Media (published by Wood Mackenzie) claimed the renewables "may be able to out-compete gas-fired plants virtually everywhere on a levelized cost basis by the year 2023."[65] The latter claim may be somewhat exaggerated –the US estimates of total levelized cost ($/MWh) for new capacities entering service in 2025 are 36.6 for combined cycle generation, 34.1 for offshore wind and 30.4 for solar PV– but, more importantly, it relies on comparing two incomparable modes of electricity generation.[66]

Renewables are, obviously, non-dispatchable unless further investments are made into overcoming this critical shortcoming. Non-dispatchable renewables can keep on expanding while taking the advantage of existing dispatchable modes of generation, but in a largely (and obviously even more so in a purely) renewable system they would have to be backed-up by unprecedented levels of storage or HV transmission. In reliably sunny or very windy places such back-ups might be relatively limited. But reliable electricity supply for billions of people living in monsoonal Asia (and particularly for tens of millions living in the continent's still growing megacities) would require back-ups on scales several orders of magnitude larger than today's largest battery storages because frequent typhoons may shut down, or severely restrict, PV and wind generation commonly for up to several days.[67] The same is, of course, true (albeit to a lesser extent) in all cloudy, colder higher-latitude regions of North America and Eurasia. While renewable generation may be interrupted for many hours or even days, and while standard (even if gas-fired) central power plants may take several hours to get fully on-line, gas turbines can reach their full capacity within minutes.[68]

The second reason is the need for seasonal heating. About 600 million people in Europe (including Ukraine and Russia), and at least another 250 million people in North America and Japan have to heat their houses for periods ranging from a few weeks to as many as seven months.[69] There is no shortage of alternative heating methods (ranging from heat pumps to geothermal installations) but we have no other option that could provide an equally affordable and reliable near-term replacement of effortless heat production by burning natural gas in high-efficiency gas furnaces. Replacing these extensive infrastructures (gas storages, distribution pipelines, furnaces) serving hundreds of millions of customers by direct electric heating (backed-up by sufficient storage) or by heat pumps powered by renewably-generated electricity (again, with adequate storage) will be a prolonged and expensive undertaking.[70]

The third reason is the need for natural gas to energize many industrial processes and to produce hard-to-replace feedstock for making essential materials and compounds. As already stressed, we do not currently have any commercially available alternatives that could produce annually hundreds of millions of tons of ammonia without natural gas. These needs will be particularly large in Africa and where industrial production in general and ammonia synthesis in particular should keep rising for decades to come. The continent already relies on food imports, it will add one billion people by 2050 and, obviously, it will not be able to feed itself without much increased synthesis of ammonia![71]

In addition, much of today's hydrogen and methanol production also depends on natural gas. Alternatives to all of these production techniques are available, but given the scale of global demand it would be naïve to expect that they could completely displace natural gas in a matter of two or three decades. A closer look at the particulars of recent "green" hydrogen promises (using renewably-generated electricity for the decomposition of water) shows how uncertain they remain. The EU is now "Going Climate-neutral by 2050" and the official roadmap envisages gross energy consumption falling by nearly 30%, while other published scenarios envisage declines anywhere between 18-60%.[72] Which one will it be in 2050: reducing the demand by 60% with hydrogen supplying just 4% of the new total (European Climate Foundation scenario), or reducing the demand by less than 30% but hydrogen providing nearly a quarter of all primary supply (Joint Research Center scenario)? The first outcome would require less than 7 million tons of renewable hydrogen a year, the other one about 70 Mt, more than today's global output.

We have no other option that could provide an equally affordable and reliable near-term replacement of effortless heat production by burning natural gas in high-efficiency gas furnaces.

More than a three-fold difference in projected savings and an order of magnitude difference in future hydrogen supply make it clear that, as yet, there is no clear, technically firmed-up decarbonization path ahead. All recent scenarios for 2050 are just more or less plausible stories driven more by politics than by realistically appraised technical capabilities, and only if the EU pursues a more aggressive course of decarbonization for at least a decade or so will we be able to say what might actually be possible by 2050. That is why any talk of natural gas as the soon-to-be enormous stranded asset, of "pushing out gas completely" and of disparaging it as a very short bridge between coal and renewables might be widely off the mark. Any realistic appraisal of future developments that takes into account the existing roles of natural gas in the global energy systems and our technical capabilities to displace it in its key markets by renewable electricity or by "green" hydrogen must conclude that there is no rational scenario that would relegate the fuel to only a negligible role or make it completely a relic of the past by 2050.

This conclusion has not changed because of the recently announced decarbonization goals aimed at keeping the future increase of global temperature below 2°C or even below 1.5°C. Global warming presents an unprecedented challenge because the quest for decarbonization of the world's energy supply cannot succeed without legally binding participation of all major greenhouse gas emitters. I find it puzzling that so many people keep referring to the 2015 Paris accord as a major step in that direction. On its first page the final statement acknowledges that the effort "requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response" –but on the fourth page it

***Notes with concern* that the estimated aggregate greenhouse gas emission levels in 2025 and 2030 resulting from the intended nationally determined contributions do not fall within least-cost 2°C scenarios but rather lead to a projected level of 55 gigatonnes in 2030.**[73]

To emphasize the magnitude of the gap between intentions and realities, the projected emissions of 55 Gt in 2030 would be nearly 50% above the 2018 level! This might have been a case of exaggerated expectations, but there is no doubt that an even more extraordinary effort would be needed to keep the emissions below the level compatible with the acceptable level of future warming. Demands by activists and statements agreed after all-night negotiations of political leaders are one thing, technical capabilities and economic realities quite another. On the long road to complete decarbonization natural gas remains –when properly produced, transported and distributed– the least carbon-intensive fuel and this advantage is strengthened by its high conversion efficiencies.

These realities are implicitly recognized by all realistic forecasts of future energy use that are periodically prepared by international organizations or by energy companies.[74] Those who have never seen any of these efforts and who might think that EXXON's outlook is vastly different from the projections by the IEA will be disappointed. EXXON has the global primary energy demand in 2040 at 712 EJ, IEA at 718 (compared to about 600 EJ in 2020).[75] As always, I prefer to see any long-term forecasts only as indicators of major trends. Long-term forecasts always have such large margins of uncertainty that it is best to avoid quoting specific numbers and consult them only to get the feel for basic trends.

In that sense, the outlook is clear: natural gas will continue to be a major source of energy on the global as well as on the European level. Whatever the specific totals of primary energy demand might be, natural gas will either maintain its relative position (supplying no less than the quarter of the overall consumption which would require a steady slow growth of its extraction) or it may (by displacing coal in electricity generation even faster than anticipated and by making greater inroads in industrial uses) slightly increase its share of global supply. Looking at the relative trends, IEA's latest Stated Policies Scenariosees the global gas consumption in 2040 nearly 28% above the 2019 level, while Exxon forecasts an even higher increase of about 36%. And even if the IEA's Sustainable Development Scenario were to become a new reality (highly unlikely given its relatively rapid reduction of fossil carbon combustion), global supply of natural gas in 2040 would only be about 13% below the 2019 level (the production would remain about as large as it was in 2015). Expected shares for Europe are similarly stable. The IEA's Stated Policies Scenario has gas at 24% in 2019, 25% in 2030 and 24% in 2040, while the Sustainable Development Scenario envisages only a slow decline to 24% in 2030 and 19% in 2040.

Not surprisingly, even the European Council meeting in December 2020 had to acknowledge (while raising the 2030 target for the reduction of greenhouse gas emissions) that the member states have a right "to decide on their energy mix and to choose the most appropriate technologies to achieve collectively the 2030 climate target, including transitional technologies such as gas."[75] This might be clumsy wording (natural gas is a fuel, not a technology) but the meaning is clear: even deliberately promoted and administratively accelerated decarbonization will not be possible without relying on natural gas.

Actual shares presented in the Going Climate-Neutral by 2050 document envisage natural gas supplying about 20% of EU's gross inland energy consumption in 2030, and about 18% in the baseline case in 2050.[76] Even if the emissions were kept well below the level compatible with the increase of less than 2oC, natural gas would still provide about 8% of Europe's energy in 2050, and only in the least likely scenario of virtually eliminating all fossil carbon by 2050 would its contribution fall below 5% of the total. How unlikely that development is, and how committed the EU's largest economy, and the leader in decarbonization, remains to natural gas is demonstrated by the unfolding saga of the Nord Stream 2 project.

Despite the latest US legislation imposing additional US sanctions, pipe-laying work on Nord Stream 2 restarted in German waters in December 2020, and the state of Mecklenburg-West Pomerania (Chancellor Merkel's home district) is preparing new legal protection of the project.[77] The second Nord Stream link would double the capacity of the Russia-Germany under-sea pipeline to 110 billion m^3 a year, and according to Gazprom, "thanks to the materials, technologies, and solutions used in the project, the gas pipeline is expected to operate flawlessly for at least 50 years."[78] Clearly, under any realistic scenarios of gradual decarbonization, natural gas will remain one of the pillars of global, and European, energy supply during the next generation and the only uncertainty is how the fuel's long-term future will unfold.

On the long road to complete decarbonization natural gas remains –when properly produced, transported and distributed– the least carbon-intensive fuel and this advantage is strengthened by its high conversion efficiencies.

The extremes are easy to describe. **On one hand a slow and steady growth to reach new absolute demand highs (perhaps as much a third above the recent level, and with a slight increase of its relative share in the overall energy supply) before starting a gradual retreat –on the other a rapidly declining demand in response to aggressive, and effective, policies of accelerated decarbonization. The actual outcome remains unpredictable, but the preponderance of historical evidence and technical, infrastructural and economic imperatives do not indicate that neither the 2020s nor the 2030s are the last decades of natural gas as an essential component of modern energy supply.**

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See also: Climate Action Tracker **Countries | Climate Action Tracker**

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a major typhoon would shut down wind and solar generation. The largest battery storage in 2021 is the Florida Power and Light Manatee project rated at 900 MWh which means that the Tokyo storage would have to be three orders of magnitude larger, a difference that technical advances are unlikely to bridge in a couple of decades.

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In total, the US has only 12% of non-dispatchable (wind and solar) installed capacity, the German share in 2019 was 50.3%.

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Heating & Cooling Degree Days - Free Worldwide Data Calculation.

[70] Converting a single-family house near Madrid (1,400 degree-heating days, 2,900 hours of annual sunshine) to solar heating is a very different challenge than converting a similar house in central Canada: although relatively sunny (2,300 hours), the region has 5,000 degree-heating days, and PV as the only heat source (or as the only source of electricity for a heat pump) would require winter storage for up to three or four consecutively overcast days.

[71] Greatly improving Africa's domestic food supply is clearly an urgent matter, not one that can wait until we get green hydrogen for Haber-Bosch synthesis capable of producing tens of millions of tons of ammonia a year. Reliable and affordable food supply in sub-Saharan countries would also go some way to reduce illegal immigration to the EU.

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