ACCELERATED GROWTH OF

RENEWABLES AND GAS POWER CAN RAPIDLY CHANGE THE TRAJECTORY ON CLIMATE CHANGE

EXECUTIVE SUMMARY

Addressing climate change must be an urgent global priority, requiring global action, national commitments, and consistent policy and regulatory frameworks.

Too often, the dialog around climate change can be mired in defining and debating an ideal future state and the timeline by which society would achieve that end-state. In the meantime, insufficient global progress is being made with each passing day. Paraphrasing an old adage, "Perfection is the enemy of progress."

Decarbonization* of the power sector and electrification of energy-use sectors (e.g., transportation, industry and heat) as quickly as possible will have the most substantial impact on global carbon emissions. Based on our extensive analysis and unique experience across the breadth of the global power industry, **GE believes that accelerated and strategic deployment of renewables and gas power can change the trajectory for climate change, enabling substantive reductions in emissions quickly, while in parallel continuing to advance the technologies for low or near zero-carbon power generation.**

GE also believes that decarbonization actions will be determined locally, based on resource availability, policy, current infrastructure, and demand for power. There are many regions in which gas power can be a key enabler to further renewables penetration, specifically in regions with high current gas capacity and/or substantial dependence on coal. In those regions, gas power can serve as a backbone for greater renewables penetration and accelerate the retirement of coal assets, both of which will have significant positive impact on overall emissions.

Renewables are the fastest growing source of new power generation capacity and electricity. This dramatic growth has been propelled by a combination of factors including public awareness about climate change, steep cost declines, advances in wind and solar technologies, and favorable policies that incentivize investment in renewable technologies. Yet despite the progress, today wind and solar together account for just 8 percent of global electricity generation and with all renewables considered (predominantly hydropower) it grows to nearly 27 percent.[1]

To put the challenge of relying solely on increased deployment of wind and solar PV to combat climate change into perspective, in the International Energy Agency's (IEA) Stated Policies Scenario, their reference scenario, wind and solar account for nearly 75 percent of global net capacity additions between now and 2040. This results in more than a 3X increase in wind, and 6X increase in solar installed capacity. Despite the rapid growth and significant investment in wind and solar PV postulated in this scenario, their combined generation contribution only increases to 28 percent of the global total in 2040 and they are roughly on par with coal at 22 percent and gas power at 21 percent.[2]

GE believes that the accelerated and strategic deployment of renewables and gas power can change the trajectory for climate change

New sources of abundant and affordable natural gas have driven the economic shift of coal-to-gas switching in several regions. With less than half the CO_2 of coal generation, natural gas is contributing significantly to decarbonization in these regions. Yet globally, coal still accounts for nearly 40 percent of electricity generated and it is expected to remain the largest single source of electricity generation for decades to come unless significant changes in the power sector fuel mix occur.

Viewed separately, renewables and gas generation technologies each have merits and challenges as a means to address climate change and optimum solutions will differ regionally. Such solutions will depend upon factors such as fuel availability and security, land use constraints, renewable resource availability, and the emphasis a particular region is placing on climate change. Together, their complementary nature offers tremendous potential to address climate change with the speed and scale the world requires. Key attributes of these technologies are summarized on the following page.

**Decarbonization in this paper is intended to mean the reduction of carbon emissions on a kilogram per megawatt hour basis.*

EXECUTIVE SUMMARY

TABLE 1: The complementary attributes of renewables and gas power

	WIND, SOLAR & STORAGE	GAS POWER
FUEL	Limitless, free fuel that is variable	Flexible, dispatchable power whenever needed, utilizing abundant & affordable natural gas or LNG
CO_2	Carbon-free generation	Less than half the CO_2 of coal generation with a pathway to future conversion to low or near-zero carbon with hydrogen and Carbon Capture and Sequestration (CCS)
COST	Competitive Levelized Cost of Electricity (LCOE) with no lifecycle uncertainty (mostly CAPEX)	Competitive LCOE with lowest CAPEX, providing affordable, dependable capacity
DISPATCH	Dispatches first in merit order… extremely low variable cost	Most affordable dispatchable technology… fills supply/demand gap
PEAKING	Battery storage economical for short duration peaking needs (<8 hour, intraday shifting)	Gas economical for longer-duration peaking needs (day-to-day and weather-related extended periods)
CAPACITY FACTORS	25%–55% capacity factors based on resources (wind and solar often complementary)	Capable of >90% capacity factors when needed, runs less based on variable costs & renewables
LAND	Utilizes abundant land with good renewable resources (multi-purpose land use); Offshore wind is not land constrained	Very small physical footprint for dense urban areas with space constraints
HYBRID SOLUTIONS	Extends renewable energy to align with peak demand	Carbon-free spinning reserve peaking plants using onsite battery storage

Technologies other than wind, solar, battery storage and gas will contribute as well to the longer-term power mix, but **the focus of this whitepaper is to elevate the emphasis on renewables and gas power as an urgently needed solution to change the near-term trajectory on climate change.**

The power industry has a responsibility, and the technical capability to take significant steps to quickly reduce greenhouse gas emissions and help address climate change at scale. The solution for the power sector is not an either/or proposition between renewables and natural gas, but rather a multi-pronged approach to decarbonization with renewables and natural gas power at its core. GE as a company is uniquely positioned to play a role through its scale, breadth, and technological depth.

Attributes of renewables and gas power are complementary, making them a powerful combination to address climate change

We have been a key player in the power industry since its inception and have a suite of complementary renewable, gas-fired, nuclear, grid and digital technologies needed for the transformation to a decarbonized energy future. This industry experience coupled with technological know-how enables GE to help policy makers to make effective decisions that deliver the desired decarbonization results while avoiding unintended consequences.

FRAMING THE CLIMATE CHALLENGE

There is broad scientific consensus that the concentration of CO_2 in the atmosphere is increasing, that the increase is due primarily to anthropogenic (man-made) sources, and that the higher concentration is causing an increase in global average temperatures. Although other greenhouse gases (GHGs) including methane, nitrous oxide, and fluorinated gases are also contributing to the increase in global temperatures, CO_2 is the largest single contributor, accounting for more than 75 percent of all GHGs.

THE POWER INDUSTRY CAN'T DO IT ALONE: CROSS SECTOR SOLUTIONS NEEDED

Forty one percent (13.7 Gigatonnes or Gt) of the global CO_2 emissions from fuel combustion are attributable to the electricity and heat production sector. This is followed by the industry and transport sectors, with 26 percent and 25 percent respectively.[3] See Figure 1. Although there has been significant attention, and some progress addressing CO_2 emissions in the power sector, there has not been as much focus or progress in other sectors. As an example of non-power sector initiatives, GE supports the aviation industry's plan to achieve a net reduction in aviation CO_2 emissions of 50 percent by 2050, relative to 2005 levels. GE invests $1 billion annually to accelerate technology innovations needed to drive reduction in carbon emissions that help make flying increasingly sustainable.

If power sector CO_2 emissions could somehow be brought immediately to zero—an impossibility—that would not realize the COP 21 Paris Agreement goal of keeping the global average temperature increase to less than 2°C.

Emission reductions are needed across all sectors, but the power sector can and should make whatever reductions it can by deploying as much renewables as possible supported by a combination of coal-to-gas switching, deployment of new gas-fired power plants and efficiency upgrades to existing gas-fired plants.

Another method for reducing power sector emissions is through reduced electricity consumption. Demand-side energy efficiency is sometimes called the first fuel, or the fuel you don't need to use, and is often expressed in terms of electrical intensity. This metric is defined as the amount of electricity consumed per unit of gross domestic product (GDP), and it has been on a steady global decline for several decades due to things such as more efficient home appliances, LED light bulbs, and energy conservation measures.

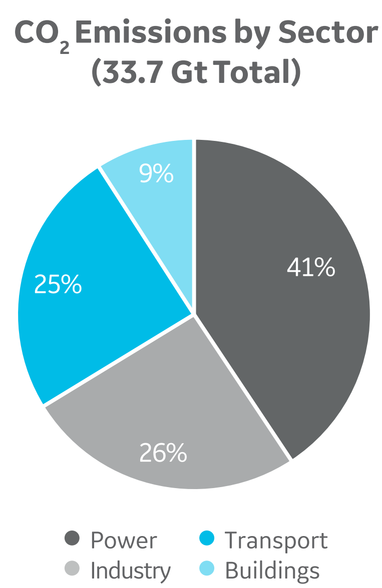


FIGURE 1: The power sector produces the largest amount of CO_2 emissions, but all sectors need to address CO_2 emissions.

Continuing these energy efficiency efforts will help to reduce the need for additional generation across the power sector. The "Future is Electric" scenario from the IEA's 2018 World Energy Outlook[4] postulates that widespread deployment of currently available technologies could take the proportion of electricity in final energy use from 19 percent to a maximum technical potential of around 65 percent. This would happen, for example, if heat pumps become widespread in industry and buildings, if electric vehicles (EVs) become the vehicle of choice, if induction stoves become the sole choice for cooking, and so on. The potential for higher electrification therefore is very large, even though around 35 percent of final consumption would still require other energy sources, including most shipping, aviation and certain industrial processes.

Electrification by itself will not deliver on sustainability goals. Although switching from combustion of fuels to electricity has clear environmental advantages at the point of use due to reduced emissions of local air pollutants, the overall environmental impact needs to be considered at the system level. **Simply shifting from tailpipe emissions from an internal combustion engine to smokestack emissions from a coal power plant providing electricity to an EV does not necessarily reduce, and in some locations could increase, system CO_2 emissions.** For electrification to be most effective at reducing CO_2 emissions there needs to be a concurrent shift in the makeup of the fuel sources of the power sector such as coal-to-gas switching immediately and continuing the pursuit of low or zero-carbon sources. This concurrent shift, combined with electrification, would then enable significant reductions across the largest CO_2 emitting sectors of the economy, namely power, transportation, and industry.

AFFORDABLE, RELIABLE AND SUSTAINABLE ENERGY IS A BASIC HUMAN RIGHT

Access to affordable, reliable, and sustainable energy is critical to growing economies and is fundamental to the quality of life in the modern world. According to the IEA, roughly 770 million people lack access to reliable electricity, and more than 2.6 billion do not have access to clean cooking fuel, relying primarily on biomass (wood, charcoal, dung, etc.). Universal access to modern energy by 2030, including electricity and clean cooking, is one of the key pillars of the United Nations' Sustainable Development Agenda (SDG 7).[5] See Figure 2.

In addition to the challenge of addressing basic energy access, the global middle class is now more than half of the world's total population—more than doubling since 2010—and is expected to reach 5.3 billion by 2030. Most of this growth is expected to occur in Asia.[6] The continent has some of the most densely populated cities in the world,

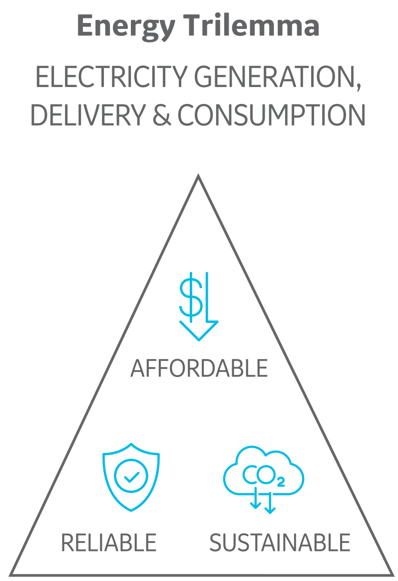


FIGURE 2: The energy trilemma is the challenge of providing affordable, reliable and sustainable energy.

and the power density of gas power makes it well suited to providing power at scale, in close proximity to demand. As people join the middle class, they purchase more energy intensive products such as air conditioners, refrigerators and other home appliances, thereby increasing electricity demand. The IEA projects that total electricity demand will rise globally by nearly 50 percent through 2040.[7]

The most effective way to ensure power system reliability and energy security is through a mix of generation sources. No single form of power generation is optimal in every situation or economy. For example: wind and solar are variable but consume no fuel and emit no CO_2; natural gas-fueled generation emits CO_2 but is dispatchable (i.e., has output that can be readily controlled between maximum rated capacity or decreased to zero) to help balance supply and demand; hydro power often requires dedicating significant amounts of land area but is zero-carbon, renewable and dispatchable, and can provide long-term, low-cost energy storage.

A mix of generation sources is the most effective way to provide system reliability and energy security

Renewable power is carbon-free, uses an infinite supply of free fuel that is not subject to price fluctuations, and produces very low cost electricity. These attributes make the deployment of renewables the core element in combatting climate change, leading to tremendous growth in capacity additions since the turn of the century—especially in wind and solar PV. This explosive growth has been driven primarily by reductions in cost, technology advancements to improve capacity factors, favorable policies and positive public sentiment around zero-carbon energy. In some locations with abundant wind and solar resources, renewable technologies have become cost-advantaged relative to thermal power generation on an LCOE basis. The biggest perceived drawback of wind and solar, the fact that they are variable, is mitigated by the fact that with modern weather forecasting methods they are largely predictable.

Despite massive renewables investment, coal generation is down only ~10% and gas generation is up ~33% through 2040.

Global installed capacity of renewables has grown from approximately 1 GW of solar PV and 17 GW of wind in 2000 to approximately 650 GW of each today.[8] 2019 was an unprecedented year for global renewable capacity orders, eclipsing the 200 GW mark for the first time.[9] The cumulative effect of nearly two decades of renewables orders growth resulted in 27 percent of global electricity supply coming from renewable sources in 2019.[10] This growth is expected to continue

CAPACITY ADDITIONS FORECAST AND RESULTING GENERATION EVOLUTION

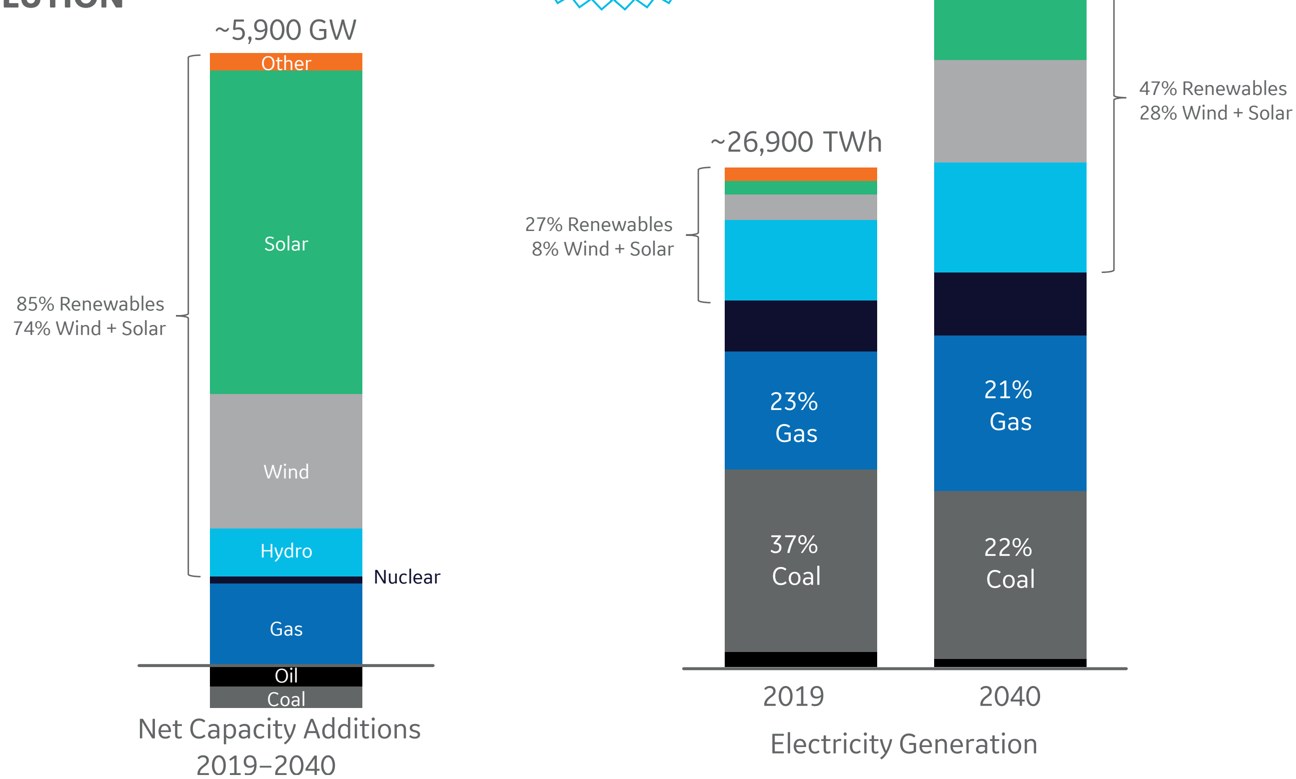


FIGURE 3: Net capacity additions and resulting change in electricity generation 2019 to 2040...despite aggressive renewables net additions, they are insufficient to result in a meaningful reduction in absolute global coal generation by 2040.

Source: IEA World Energy Outlook 2020 Stated Policies Scenario

LCOE reductions in wind and solar are expected to continue, driven by lower CAPEX and improved capacity factors

and accelerate, with solar PV capacity growing approximately 6X to more than 3,600 GW, and wind capacity more than 3X to 1,900 GW by 2040, according to the IEA's reference Stated Policies Scenario. An additional two decades of renewables growth will result in more than a 2.6X increase in electricity generation from renewable sources, accounting for 47 percent of the total global electricity supply in 2040.[11]

Yet despite wind and solar accounting for nearly 75% of global net capacity additions between now and 2040, the industry needs to do more to reduce global generation from coal to meet decarbonization goals. See Figure 3.

The cost drivers behind the rapid growth in renewables deployment are expected to continue. Figure 4 demonstrates how the LCOE of onshore wind and utility scale solar PV are expected to continue to drop between 2020 and 2040. As examples, the LCOE for onshore wind in Brazil is expected to drop 31 percent during this period and solar PV in Germany is expected to drop 50 percent. In fact, the average reduction in onshore wind LCOE for the five diverse countries shown is 32 percent, and for solar PV it is 49 percent.[12] A main driver for these reductions in LCOE is a reduction in CAPEX as supply chains benefit from increasing scale and an accelerating learning curve. A key outcome of the reduction in CAPEX is the ability to accelerate renewables deployment because a fixed amount of investment purchases more capacity.

Advances in technology have also contributed to the reduction in LCOE. Wind turbines are getting more efficient at low wind speeds. The towers are getting taller and blade diameters larger, enabling them to produce more energy from a given piece of land. Capacity factors are also improving, with new onshore wind farms now operating at up to 35 percent capacity factor and new offshore wind farms at up to 55 percent capacity factor.[13]

Offshore wind energy holds the promise of significant environmental and economic benefits. It is an abundant, low-carbon energy resource located close to major coastal load centers, and in many cases provides an alternative to long-distance transmission or development of electricity generation in these land-constrained regions. Moreover, offshore wind LCOE keeps dropping yearly, with GE's most efficient designs achieving a capacity factor of 63%.

Offshore wind is an affordable, renewable source of energy that can be deployed at a scale capable of providing as much capacity as thermal and nuclear power plants. The IEA has highlighted its almost limitless potential, and the Ocean Renewable Energy Action Coalition (OREAC) estimates the world can deploy 1.4TW by 2050.[14] Offshore wind is an undeniable pillar in the energy mix, a here-and-now technology contributing to decarbonization and limiting increases in global average temperatures.

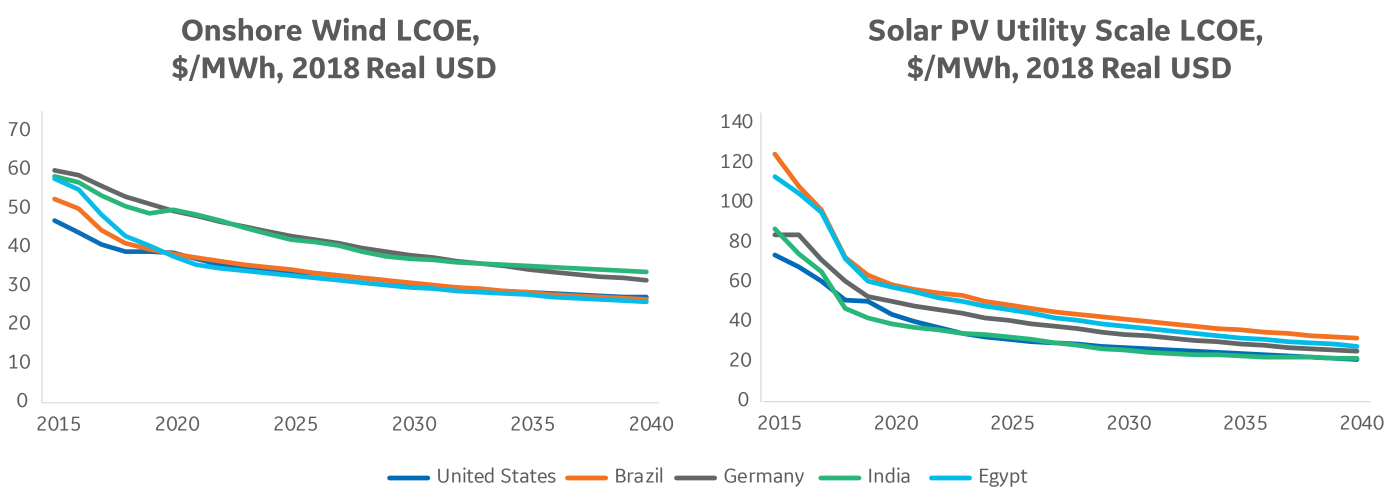


FIGURE 4: LCOE of Onshore Wind and Utility Scale Solar PV are expected to continue to drop.

Source: IHS Markit, Global Renewable Levelized Cost of Electricity Outlook Part 1, February 2020.

Strong grids and energy storage systems are key to compensating for the variable nature of wind and solar generation. Although in some locations wind and solar generation are complementary, i.e., solar generation is available during the day and wind generation is more prevalent at night, modern power systems must match supply and demand in real time and provide 24/7/365 reliability.

Very high penetration of renewables generation could lead to system instability if grid operators don't mitigate the variability of the resource via a combination of storage, complementary gas generation, demand side management, grid infrastructure investment, and other strategies.

Lithium-ion (Li-ion) battery energy storage system (BESS) technology has made great strides in CAPEX reductions resulting in the potential to significantly improve the dispatchability of wind and solar generation to provide required grid reliability.

The CAPEX of Li-ion batteries has come down substantially in recent years and this cost reduction trajectory is expected to continue. See Figure 5. Utility-scale battery systems have benefited from the massive build-up of battery capacity to support the electric vehicle market, and the CAPEX of a 4-hour BESS is expected to drop an additional 50 percent between 2020 and 2040.[15]

Li-ion battery storage has become an attractive and economical approach for intra-day (typically <8 hours) storage of renewables. Utility scale batteries are now being deployed to provide grid ancillary services and to defer transmission investments. The economics can be justified because in intra-day applications the battery charges and discharges, and creates value daily, or even multiple times within a day. The battery CAPEX for this intra-day shifting is therefore monetized over many charge/discharge cycles. Using batteries to shift energy from perhaps a weekend when the sun is shining but demand is low to a weekday when demand is higher will reduce the number of charge/discharge cycles over which to monetize the battery CAPEX. The relationship of CAPEX to the Levelized Cost of Storage (LCOS) is such that if the number of charge/discharge cycles is cut in half, the LCOS doubles. **Battery storage will not be competitive on an LCOS basis for durations greater than 8 hours until there is a significant technology breakthrough resulting in a reduction in cost.** Until a battery technology breakthrough occurs, gas power remains the most cost effective backup for large, multi-day shortfalls in the supply of renewable energy.

Batteries can also be deployed effectively in a hybrid power plant in which a BESS is integrated directly with one or more forms of power generation such as wind, solar, or a gas turbine power plant. This type of application leverages the best attributes of each technology and can help provide vital grid stability services such as frequency regulation, spinning reserve capacity, or black start capability, and several hybrid BESS systems are in operation today.

Battery storage has become economical for intra-day storage of renewables but not yet for longer periods

Gas plants are capable of compensating for long gaps in renewable production in ways that today's battery storage technology cannot

Battery Storage CAPEX, Li-ion 4 Hour $/kW, 2018 Real USD

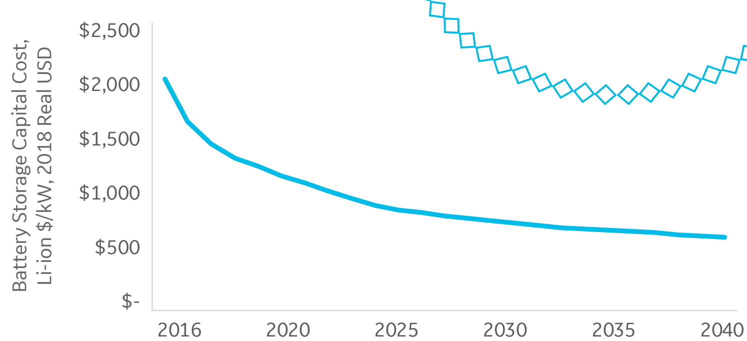


FIGURE 5: The CAPEX of Li-ion battery storage systems has dropped substantially and is expected to continue to drop. *Source: IHS Markit, US Battery Storage Capital and Levelized Cost Outlook, January 2020. ©2020 IHS Markit. All rights reserved. The use of this content was authorized in advance. Any further use or redistribution of this content is strictly prohibited without prior written permission by IHS Markit.*

COAL IS DOWN, BUT NOT OUT

As the international community moves toward a decarbonized future, the ideal generation mix will depend on an individual country's available fuel resources, its point in the journey to a decarbonized future, and the often-competing goals of providing reliable, affordable and sustainable energy to a growing population that aspires to improved standards of living.

Coal is the largest fuel source for electricity generation in the world today, accounting for 37 percent of the total.[16] Despite well publicized retirements of coal-fired capacity in the United States and Western Europe, **there are still more than 2,000 GW of coal power plants installed globally, making up nearly 30 percent of global installed capacity, and nearly 400 GW in the United States and Western Europe alone.** Approximately 1,400 GW of new coal-fired power plants have been put on order globally since the turn of the century, mostly in China during the 2000-2010 timeframe. In recent years there has been a dramatic slowdown in orders for new coal power plants due in large part to utilities responding to the negative public perception of coal, and reductions in available sources of finance from entities such as export credit agencies, pension funds, and private equity. Despite the retirements and recent orders slowdown, there remains a large installed base of coal power plants globally and it is expected that there will still be nearly 2,000 GW of coal plants in operation at the end of this decade.[17]

Global CO_2 emissions from coal power has been increasing for decades, but with a leveling off of coal power generation due to coal-to-gas switching, increased renewables generation, reduced operation and retirement of coal power plants, policy mandates, and the impact on demand due to the COVID-19 pandemic, global coal power CO_2 emissions likely have already reached their peak. Since 2010, coal power CO_2 emissions have come down more than 46 percent, and 31 percent in the USA and Europe, respectively. See Figure 6. These trends are expected to continue, and in the IEA's Stated Policies Scenario the USA's coal power CO_2 emissions come down 77 percent by 2030 relative to the 2010 baseline year and Europe's come down 74 percent.[18] Despite the gains in these regions, there is the potential to reduce coal power CO_2 emissions even further by running the installed gas power fleet more and strategic deployment of new gas power and renewables.

Coal in 2040: 22% of total global electricity and 68% of power sector CO_2

SOURCE: IEA WEO 2020

China and the rest of the world (ROW), however, have experienced increases in coal power CO_2 emissions since 2010. Coal power CO_2 emissions in China are up approximately 44 percent since 2010 and the ROW is up 27 percent. Coal power emissions are expected to level off in China and ROW near the end of this decade, leaving both with enormous potential to further reduce CO_2 emissions from coal.

Looking out a decade further, to 2040, coal power is expected to provide 22 percent of global electricity generation and be responsible for 68 percent (8.5 Gt) of power sector CO_2 emissions, according to the IEA.[19]

Emissions from coal at this level are inconsistent with achieving the goal of reducing global warming and more aggressive actions are needed, including deployment of carbon capture, utilization and storage (CCUS) at coal power plants, increased utilization of existing gas power, and increased deployment of new gas power and renewables.

POWER SECTOR COAL EMISSIONS TRAJECTORY

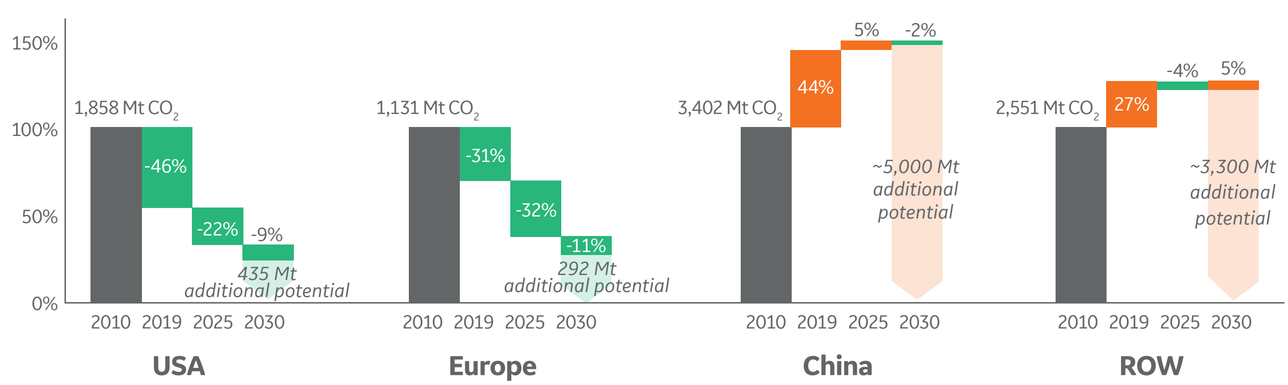


FIGURE 6: The USA and Europe are on a trajectory to reduce coal power CO_2 emissions significantly through retirements and decreased operation, but there is an opportunity for further reductions. China and ROW are still on a trajectory of increasing coal power emissions and need to reverse course. *Source: IEA World Energy Outlook 2020 Stated Policies Scenario*

The world is better served by accelerating renewables deployment, running existing gas plants more, and adding new gas capacity as the industry reduces coal generation

A POWERFUL COMBINATION – RENEWABLES PLUS GAS-FIRED POWER

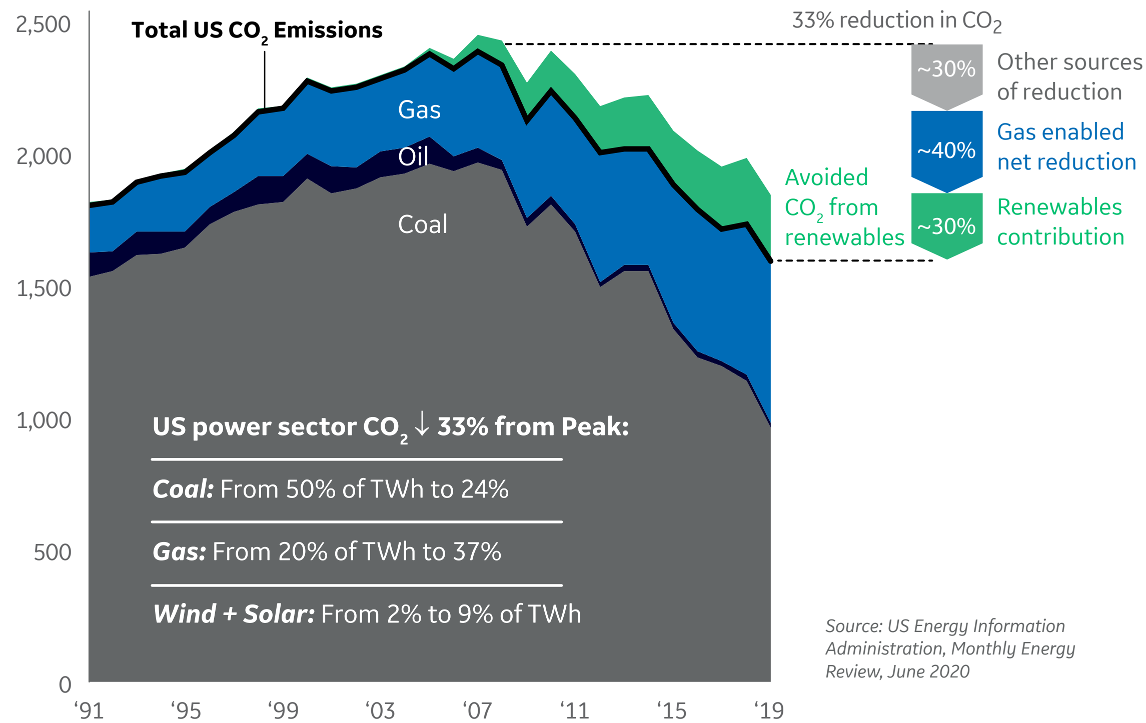
GE believes in and promotes additional renewables capacity, augmented where needed with natural gas generation to provide system flexibility and dependable capacity, as the most effective near-term action to decarbonize the energy sector. Despite the massive deployment of wind and solar capacity in recent years, increases are not occurring at the pace or scale needed to decarbonize the electricity sector and meet the goals of the Paris Agreement. According to the IEA, given the time it takes to build up new renewables and to implement energy efficiency improvements, coal-to-gas switching represents a potential quick win for emissions reductions. There is potential in today's power sector to immediately reduce up to 1.2 Gt/yr of CO_2 emissions by running existing gas-fired plants harder and reducing coal use commensurately. There is additional opportunity to reduce coal emissions by retiring existing coal-fired capacity and replacing it with new, high efficiency combined cycle capacity. Doing so would almost immediately bring down global power sector emissions by 10 percent and total energy-related CO_2 emissions by 4 percent.[20]

Given the time it takes to deploy new renewables and to implement energy efficiency improvements, coal-to-gas switching represents a potential quick win for emissions reductions.

SOURCE: IEA SPECIAL REPORT, THE ROLE OF GAS IN TODAY'S ENERGY TRANSITIONS, JULY 2019

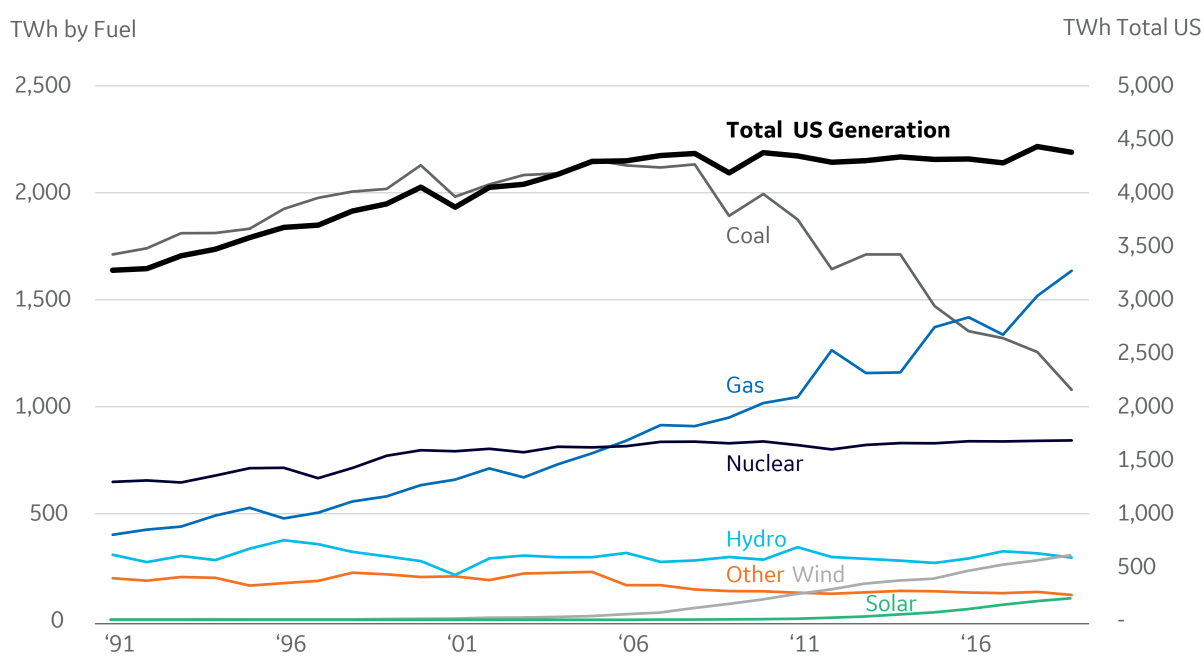
The United States is a powerful example of the pace and scale that renewables and gas power can lead to decarbonization of a power sector that was heavily dependent on coal. Since the peak in 2007, power sector CO_2 emissions in the United States have dropped 33 percent while total electricity generation remained fairly constant at approximately 4,300 TWh. During this time, coal generation dropped roughly in half, from 50 percent to 24 percent, while gas generation increased from 20 percent to 37 percent, and wind and solar grew from less than 1 percent to 9 percent.[21] The emissions reduction attributed to coal-to-gas switching was greater than that from any other fuel source. See Figure 7 on the following page.

US POWER SECTOR CO2 (Million Metric Tons)



Source: US Energy Information Administration, Monthly Energy Review, June 2020

US ELECTRICITY GENERATION BY FUEL



Source: GE Gas Power Global Power Outlook 2020

FIGURE 7: Coal-to-gas switching is contributing more to power sector carbon reduction in the US than any other generation technology.

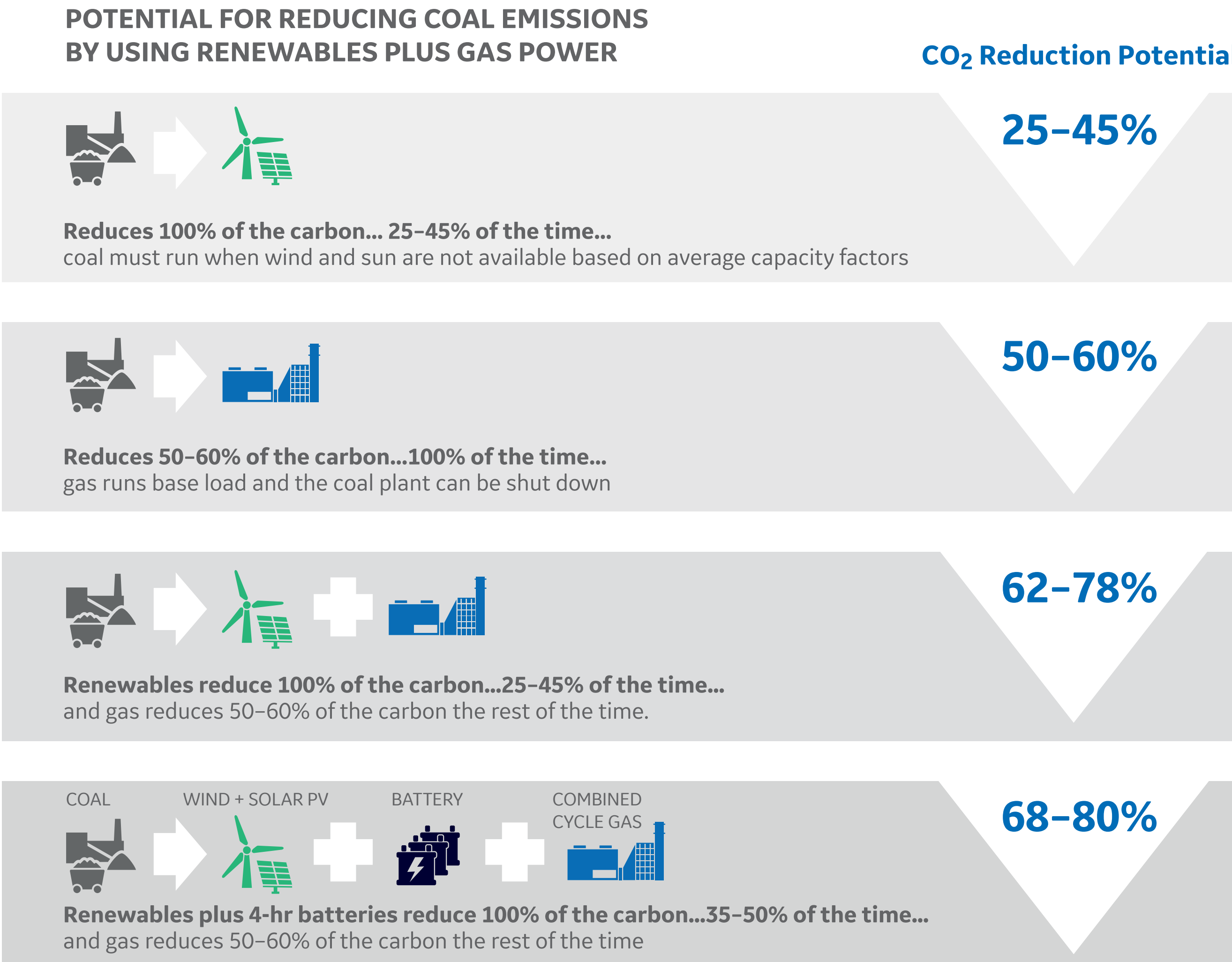


FIGURE 8: Replacing baseload coal with a combination of renewables and gas yields the quickest carbon reduction at scale. Note that CAPEX and required land are not addressed in the above analysis.

On a global scale, replacing coal with a combination of variable renewables and batteries plus dispatchable gas yields greater carbon reduction than renewables alone. An analysis done by GE and summarized in Figure 8 considers the real-time balancing of power supply and demand using a hypothetical base loaded coal plant as an example.

Because of the variable nature of wind and solar energy, and lower capacity factors for these technologies, a direct replacement of coal with wind and solar would eliminate approximately 25–45 percent of the coal CO_2 emissions. That said, the coal plant would still need to provide energy, and thereby emit CO_2, when wind and solar are not available.

Replacing the coal plant with base load natural gas alone would reduce CO_2 emissions by approximately 50–60 percent for 100 percent of the time due to the lower CO_2 intensity of natural gas.

Replacing the coal plant with a complementary mix of wind and solar plus natural gas, however, enables the wind and solar to provide zero-carbon energy whenever they are available, with combined cycle gas turbine plants making up any remaining energy needs. This results in approximately a 62–78 percent reduction in overall system CO_2.

Replacing the coal plant with a complementary mix of wind, solar, and 4-hour batteries, plus natural gas enables the wind and solar to provide zero-carbon energy for 35–50 percent of the time, with combined cycle gas turbine plants making up any remaining energy needs. This maximizes the energy from the renewables sources and results in approximately a 68–80 percent reduction in overall system CO_2.[22]

GAS POWER ENABLES MORE RENEWABLES

Natural gas-fired power generation is flexible and dispatchable. Plants can come online quickly, adjust power output level, and turn down to a very low output level to balance supply and demand as needed. They can deliver more power or less as supply and demand for electricity vary throughout the day, over the course of a week or month, and seasonally—whenever required. This flexibility is especially important to maintain grid stability as more non-dispatchable wind and solar resources are deployed.

Gas-fired power plants are available regardless of the time of day or weather conditions, providing dependable capacity as long as needed, whether for minutes, hours, days or weeks at a time. Wind and solar power are available when the wind is blowing or the sun is shining. The availability of the wind and solar resources does not always coincide with demand. Because electricity supply and demand must always be in balance, renewables require dispatchable backup power such as natural gas power plants or batteries to ensure system reliability. The Dependable Capacity metric shown in Figure 9 has been developed by GE to illustrate the ability of a technology to reliably produce electricity during summer or winter daytime and nighttime peaks considering nameplate capacity, degradation due to ambient temperature effects, and the coincidence of a renewable generation source to peak demand. The values shown are global averages.

Average Dependable Capacity

Gas	84%
Coal	78%
Nuclear	92%
Hydro	63%
Wind	14% Onshore, 27% Offshore
Solar	20–40%

FIGURE 9: Average dependable capacity of various generation technologies.[23]

Nuclear remains an important part of the power generation landscape and is contributing to the transition to cleaner energy as the most dependable source of CO_2-free power. Today nuclear power delivers approximately 10% of the world's electricity with more than 400 GW in the global installed base. While there are plans to phase out nuclear power in some countries, forecasts show around 10 GW/yr of future demand for new nuclear plants although the timing is uncertain.

Typical CAPEX Cost $/kW

Gas – CC	~$700–$1,200
Coal	~$5,000
Nuclear	~$8,000
OnshoreWind	~$1,500
Solar PV	~$1,250
Battery	~$1,200/kW (4-hour)

FIGURE 10: Gas power is the lowest cost generation technology on a $/kw basis.[24]

Gas power is affordable due to its low CAPEX requirements and the availability of abundant, cost competitive natural gas. In fact, it is currently the lowest cost generation technology on a $/kW basis. This is especially important when access to capital is constrained or project financing is required. See Figure 10.

Gas can provide affordable baseload power in developing, high-growth regions, and then transition to economic and complementary cyclic or peaking power as needed to accommodate future renewables growth.

Gas power is affordable, efficient and dispatchable as a means to complement renewables, with less than 50% of the CO_2 emissions compared to coal

LAND USE IS AN IMPORTANT FACTOR

Modern society requires vast amounts of electricity to function, and one of the greatest challenges we face today is providing electricity that is affordable, reliable and sustainable on a planet with a growing population that requires more land. **Land is an increasingly scarce global resource that is subject to competing pressures from agriculture, human settlement, and energy development. Renewables sources such as wind and solar PV are less power dense than natural gas power,** meaning that they require more land per unit of installed generating capacity or unit of electricity produced.

The low power density of wind, solar PV and battery storage is not an impediment in parts of the world where land is plentiful and the demand for electricity is in relatively close proximity to the renewable supply. Where this is not the case, there can be a conflict between electricity production and other land uses. Using the United States as an example, the relatively densely populated east and west coasts make locating utility scale onshore wind farms a challenge, but in the less populated central plains (e.g., Iowa) this is less of an issue. Similarly, solar PV can be located in the desert southwest (e.g., Arizona) where the solar resource is abundant and vast tracts of land are available with little or no competing uses. In both examples the transmission of the electricity from where it is generated to where it is consumed needs to be considered and new infrastructure such as high-voltage direct current transmission lines may be required.

Offshore wind has the potential to address land use challenges in some regions. A recent analysis by the IEA examined the technical potential of all marine areas within 300 kilometers of shore using the newest turbine designs. Tapping just the most attractive sites in near-shore shallow waters could provide nearly 36,000 TWh of electricity, nearly 90 percent of the total global electricity demand expected in 2040. Realizing this potential, however, will require trillions in investment dollars, careful planning, efficient supply chains, and transmission infrastructure capable of bringing the electricity onshore.[25]

Significantly less space is required for gas-fired generation, enabling natural gas power plants to be deployed closer to demand centers and possibly avoiding the need for an investment in transmission infrastructure. Figure 11 demonstrates the amount of land needed to provide 1,000 MW of power generation capacity using different technologies.[26]

Available land could become a barrier to a 100 percent renewable power sector in certain locations, particularly major cities, and will become increasingly challenging as the world's population grows. A more practical approach is to strategically deploy a combination of wind, solar PV, batteries and natural gas-fired power plants that enable decarbonization at a pace and scale greater than can be achieved by renewables alone, while minimizing the amount of valuable land required.

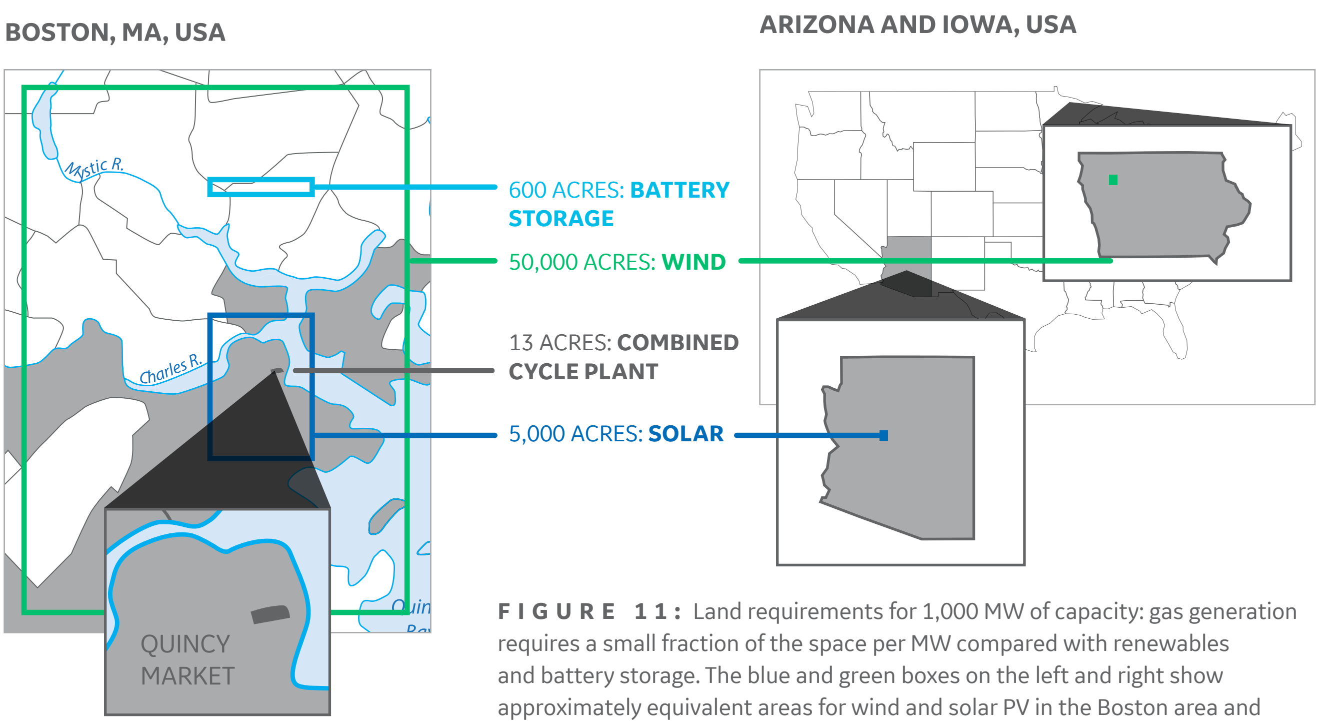


FIGURE 11: Land requirements for 1,000 MW of capacity: gas generation requires a small fraction of the space per MW compared with renewables and battery storage. The blue and green boxes on the left and right show approximately equivalent areas for wind and solar PV in the Boston area and less populated regions.

Gas power can be deployed quickly and at scale

NATURAL GAS IS ABUNDANT, AVAILABLE AND AFFORDABLE

Natural gas availability has increased dramatically with the advent of new methods for oil & gas production and a sharp increase in global gas liquefaction and regasification capacity. **The IEA projects that global natural gas production could increase nearly 30 percent by 2040 from 2019 levels and that USA wholesale prices remain below $4.20 ($2019) throughout the period.[27]**

According to IHS Markit, 2019 was a record year for global liquefied natural gas (LNG) on several fronts. Arguably, the most important of these is the amount of liquefaction capacity that was sanctioned in 2019, reaching a Final Investment Decision (FID). 70.4 Mtpa (millions of tons per annum) reached FID compared to the prior all-time high of 20 Mtpa in 2005. Most of this new liquefaction capacity will be in the US, Russia and Mozambique. Similarly, a record 38.8 Mtpa of new liquefaction capacity reached commercial operation in 2019, an increase of nearly 10 percent in global capacity.[28] In fact, the IEA expects globally traded LNG to grow nearly 80 percent by 2040.[29]

At the onset of 2020, the International Gas Union reported that there were 120 Mtpa of regasification capacity under construction, which will add about 15 percent to global capacity. When these facilities become operational, the number of countries with regasification capacity will exceed 42.[30]

The result of the new gas production methods and expansion of both liquefaction and regasification capacity is a natural gas fuel resource that is expected to be available at relatively low and stable prices for the foreseeable future.

Globally traded LNG is expected to grow nearly 80% by 2040.

SOURCE: IEA WEO 2020

RENEWABLES AND GAS POWER CAN BE DEPLOYED QUICKLY

The key to combatting climate change in the power sector is to make significant changes to the generation mix toward renewables and gas power quickly and at scale. **Natural gas power plants can be deployed more quickly than any other form of dispatchable, utility scale power.** A trailer mounted aeroderivative gas power plant rated at 30 MW can be deployed anywhere in the world in a manner of weeks to months to address emergency needs. Simple cycle gas power plants can be in commercial operation 6–12 months after notice to proceed is received. Combined cycle power plants rated at 1GW or more take 24–36 months to be brought into commercial operation. Wind and solar power can also be deployed quickly, typically generating power in as little as 6–12 months from notice to proceed.

These short deployment times mean that renewables and gas can be contributing to CO_2 reductions quickly and at scale, while generating revenue, and less capital is tied up during the construction phase of a project.

GAS TURBINES HAVE A PATHWAY TO LOW OR ZERO-CARBON EMISSIONS

Existing and future gas power plants can be decarbonized and avoid CO_2 "lock-in" by using hydrogen as a fuel or employing carbon capture

Natural gas-fired combined cycle power plants are the lowest emitting fossil fuel power plants, whether measured based on CO_2, SO_x, NO_x, particulate matter, or mercury. Going forward, however, there will be a need to reduce CO_2 emissions further and there is a concern that deploying new gas generation capacity will "lock in" CO_2 emissions for the lifetime of the power plant. Gas turbines currently in operation or yet to be deployed have a pathway to enabling decarbonization and avoiding lock in of CO_2 through utilization of hydrogen as a fuel or through carbon capture technologies. See Figure 12.

One method to reduce CO_2 emissions from gas turbines is to mix hydrogen with natural gas. "Green" hydrogen, which generates no carbon emissions, is produced by electrolyzing water using renewable energy as the energy source. The hydrogen produced in this manner serves effectively as an energy storage mechanism enabling the renewable energy to be stored in the form of hydrogen for later use in a gas turbine.

Gas turbines have been running for decades on high hydrogen/ low Btu gases. State-of-the-art HA gas turbines are currently capable of burning up to 50 percent hydrogen by volume when blended with natural gas, and work is underway to develop capability for 100 percent hydrogen in these machines by the end of the decade. It should be noted that mixing hydrogen and natural gas at a 50/50 volume ratio does not result in a 50 percent reduction in CO_2 emissions. In fact, because of the lower density and lower specific energy of hydrogen, a 50/50 mixture of hydrogen and natural gas by volume only reduces CO_2 emissions by approximately 25 percent relative to a gas turbine without hydrogen blended with natural gas. To achieve a 50 percent reduction in CO_2 would require approximately a 75/25 hydrogen/natural gas mixture by volume.[31]

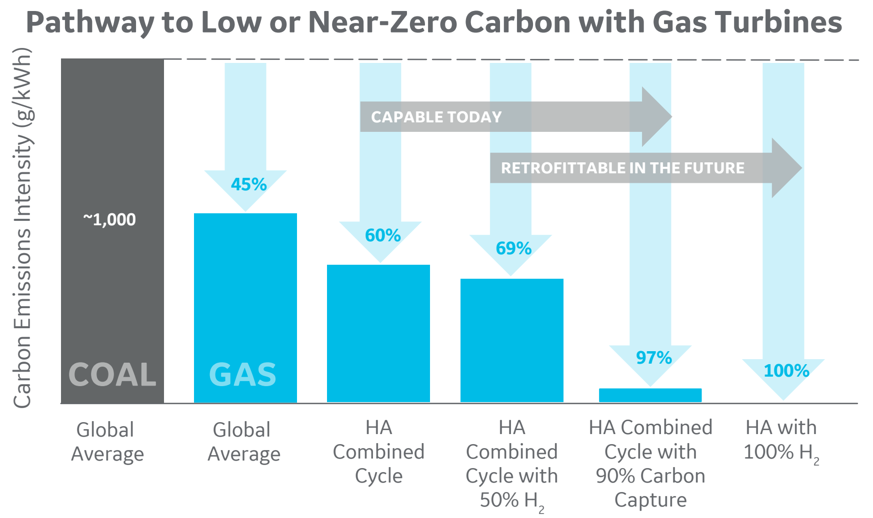


FIGURE 12: Gas turbine decarbonization opportunity

A potential benefit of using hydrogen as a fuel in gas turbines, either as a blend with natural gas or at 100 percent hydrogen, is that it can be accomplished either as a new build or on a retrofit basis, with relatively minor changes to the gas turbine and plant auxiliary equipment. Therefore, the decision to build a gas-fired power plant today does not necessarily lock in CO_2 emissions at the original level for the entire life of the power plant.

Future cost and technology breakthroughs may make hydrogen competitive as a zero-carbon dispatchable fuel source to complement renewables. Policies and incentives are being implemented in several countries to foster development of hydrogen infrastructure and drive down costs. These have the potential to significantly increase the availability and affordability of hydrogen, similar to what the wind and solar PV industries experienced through targeted policies and incentives.

Another pathway to net-zero carbon emissions for a gas turbine is through the use of either liquid or gaseous biofuels. Gas turbines are capable today of burning a wide variety of these carbon-neutral fuels.

Carbon capture or using hydrogen as a fuel are currently viable methods to decarbonize existing and future gas turbine power plants.

CCUS also has the potential to significantly reduce CO_2 emissions from all fossil fuel burning power generation and industrial processes. The Amine process is the most mature CCUS technology, with the capability to remove up to 90 percent of the CO_2 from an exhaust stream. Pilot projects are in operation today. Drawbacks include a near doubling of the upfront CAPEX of a power plant, additional space requirements, and a reduction in generation efficiency of almost 10 percentage points. Factoring in the additional cost and reduced efficiency results in an increase in LCOE of 30 percent to 50 percent.[32] Efforts are underway to optimize the power plant and CCUS thermal needs such that the impact on efficiency is reduced, and a price on carbon could make CCUS an economic option even with the increase in LCOE. Again, targeted CCUS policies and incentives, or a price on CO_2 emissions, could be the catalyst needed to foster technological innovation leading to reduced costs and widespread deployment of CCUS technologies.

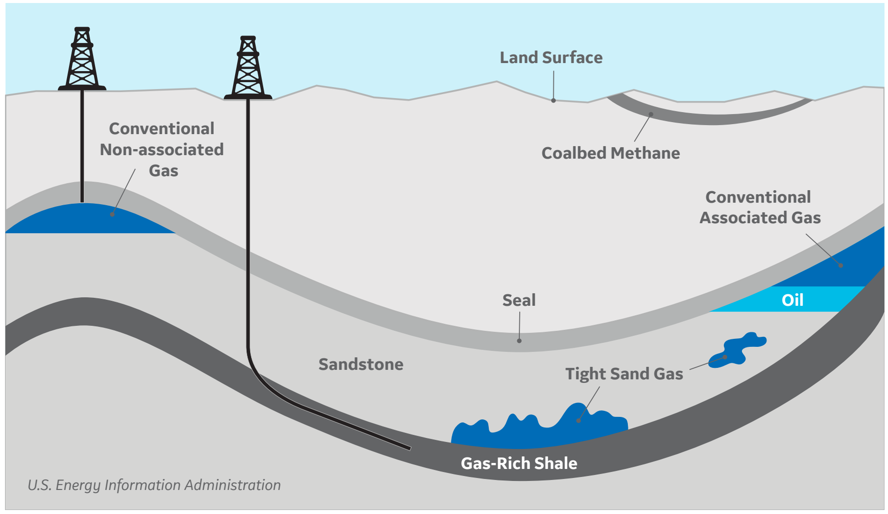


FIGURE 13: Geologic formations have stored gaseous natural gas, CO_2 and other hydrocarbons for hundreds of millions of years and may be feasible for safe and permanent CO_2 sequestration (image courtesy of the US Energy Information Administration).

Merely separating CO_2 is insufficient to reach deep decarbonization goals. It must be either used or stored safely and permanently. Public perception that captured CO_2 cannot be sequestered permanently is one of the biggest impediments to CCUS. Based on parallels to fossil fuel extraction technologies there is a strong technical basis that the **Earth has the capacity to store more CO_2 than humans can produce, and there is very strong evidence that we can safely store the CO_2 underground for hundreds of millions of years.** Every CO_2 molecule emitted began its journey underground, so the challenge is to put them back when we are done with them. Public perception and political sentiment are real, however, and need to be addressed before carbon sequestration is employed on a large scale. See Figure 13.

Technology is available and should be deployed to cost effectively reduce methane emissions

METHANE EMISSIONS... AN OPPORTUNITY FOR REDUCTION

A concern often raised about natural gas power generation is that it is responsible for a significant increase in global methane (natural gas or CH4) emissions. Methane is 25X more potent as a greenhouse gas than CO_2 on a pound-for-pound basis. 570 million metric tons per year of methane are emitted globally, of which 40 percent are naturally occurring and 60 percent are anthropogenic. Methane accounts for 16 percent of anthropogenic greenhouse gases on a CO_2-equivalent basis, while CO_2 accounts for 76 percent. Twenty percent of total methane emissions are attributed to fossil fuels, of which coal is 25 percent, oil is 34 percent, and gas is 41 percent. Total oil and gas (O&G) related methane emissions are nearly 80 million metric tons per year, and are attributed to a combination of intentional venting, incomplete combustion of flared gas, and leaks in the production, processing and distribution of O&G. Natural gas-related methane emissions alone are 47 million metric tons per year, but only about 40 percent of global gas consumption is used in the power sector. **Gas power sector methane emissions, at 19 million metric tons per year,[33] therefore account for just 3 percent of total global methane emissions.**

The IEA estimates that O&G sector methane emissions can be reduced by nearly 75 percent by deploying available abatement technologies and practices. And about half of that reduction is possible with no incremental net cost (i.e., the value of the methane recovered is greater than the cost of the abatement technology.)[34] GE is supportive of policy that would require the power and O&G sectors to implement available methane abatement technologies and practices.

DIGITAL TECHNOLOGIES CAN TIE IT ALL TOGETHER

A key element of decarbonization of the power sector will be to ensure the entire system, including generating assets, the grid, and loads are integrated efficiently in order to optimize electricity generation and thereby minimize carbon emissions. This is where digital technologies can play an important role.

System operators will need to integrate and optimize dispatch of all assets after factoring in wind and solar resources days or weeks ahead, while considering the actual cost of each generation source including maintenance costs. Gas power plant component life is largely dictated by thermal consumption of parts, whereas wind components are driven more by mechanical wear, solar plants by output degradation, and battery systems on the number of charge/discharge cycles. All these factors can be optimized digitally to ensure the lowest carbon/least cost generation solution is achieved in real- time.

Digital technologies can enable generation optimization to be coupled with grid optimization and a real-time understanding of demand to enable a system that works seamlessly across multiple generation sources, an intelligent grid, and varying demand, to maximize system efficiency, minimize CO_2 emissions, and ensure reliability.

POLICY: THE MISSING PIECE

GE supports the science and goals expressed in the Paris Agreement and the United Nations Framework Convention on Climate Change. The Paris Agreement was a landmark effort by 196 nations to agree to combat climate change and take actions and invest in a sustainable low carbon future. In alignment with the Paris Agreement, some states, municipalities, and utilities have also adopted zero-carbon or carbon-neutral pledges.

Cost reductions in renewables and advances in digital technologies are opening huge opportunities for energy transitions, while creating some new energy security dilemmas.

SOURCE: IEA WEO 2019

Meeting the targets of the Paris Agreement requires investment in new and upgraded technologies. Companies and innovators around the world are developing new technologies and solutions at an exciting pace. There is a range of decarbonization solutions that address the differences countries and regions experience in their energy needs. Governmental policies that define the objectives and foster innovation should help advance the goals of the Paris Agreement.

Policy reform is needed to establish a framework for making long-term power sector investments

To achieve these goals, GE supports policies that:

- Measure and incentivize reductions in power sector carbon intensity (tons of CO_2 per MWh) with an emphasis on both near-term actions that drive the greatest reductions sooner, and a longer-term vision of ambitious carbon reductions leading to deep decarbonization in the coming decades.
- Are transparent and predictable, allowing lifecycle economics to drive investment decisions factoring in a cost of carbon in some form vs. generic mandates picking one technology over another.
- Establish market structures that value energy, flexibility and dependable capacity separately to encourage the optimum mix of technologies that are complementary in nature, provide energy security, and drive the greatest carbon reductions in an affordable and practical way.
- Reward R&D, innovation, and private risk taking.
- Encourage the free flow of goods and ideas consistent with the principles of the World Trade Organization.
- Reflect national and local circumstances.
- Set realistic timelines for reduction efforts with periodic reviews as knowledge of the science evolves and technology improves.

GE has set its own goal to become carbon neutral in its facilities and operations by 2030. GE's goal focuses on its over 1,000 facilities across the globe, including factories, test sites, warehouses, and offices.

CONCLUSION & RECOMMENDATIONS

Addressing climate change must be an urgent global priority, requiring global action, national commitments, and consistent policy and regulatory frameworks.

Solving the climate change challenge requires cooperation across national boundaries, across sectors of the economy, and across the political spectrum. As stated by Fatih Birol, Executive Director of the International Energy Agency, it calls for a "grand coalition encompassing governments, investors, companies and everyone else who is committed to tackling climate change."

According to IHS Markit, "gas plants are highly reliable—able to fill in long gaps in renewable production in ways that today's energy storage technologies cannot—and flexible enough to ramp up and down quickly depending on the needs of the system, with the potential to run on low-carbon gas in the future. As the value of these characteristics grows over time, new gas plants could be an increasingly attractive option as a complement to intermittent renewables."[35]

Renewables and gas power have the capability to quickly make meaningful and long-lasting reductions to CO_2 emissions from the power sector. Neither will be as effective alone at decarbonization at the pace and scale needed to avoid raising average global temperatures by less than 2°C as outlined in the COP 21 Paris Agreement.

The power industry has a responsibility, and the technical capability, to take significant steps to quickly reduce greenhouse gas emissions. The solution for the power sector is not an either/or, renewables or natural gas proposition. It requires a multi-pronged approach to decarbonization with renewables and natural gas power at its core.

Recommended steps for the power industry include:

- Invest in a combination of wind, solar, batteries and gas-fired power at scale and with urgency
- As coal-fired generation declines, replace this capacity with renewables supported by gas power
- Advocate for policies that align with the goals of the Paris Agreement to reduce CO_2 emissions, while ensuring a safe, affordable and reliable electricity sector. Such policies should: 1) incentivize reductions in power sector carbon intensity with an emphasis on both near-term actions that drive the greatest reductions sooner, and a long-term vision of ambitious carbon reductions, 2) are transparent and predictable, and allow lifecycle economics to drive investment decisions, and 3) promote market structures that value energy, flexibility and dependable capacity separately in order to encourage the optimum mix of technologies
- Increase funding in Research and Development and incentive mechanisms to: 1) continue the cost decline and performance improvements in renewables, 2) develop renewables hybrid and storage technology, and 3) accelerate cost effective CCUS, hydrogen, small modular reactors, and other potential low or zero-carbon technologies for dependable capacity to complement renewables
- Advocate for producers and users of methane to employ the best available methane capture technology
- Encourage cross-sectoral cooperation for CO_2 emissions reductions such as providing green hydrogen produced from zero-carbon energy for use in the transportation sector

Addressing climate change will require government and consumer action. GE as a company is uniquely positioned to play a key role through its scale, breadth, and technological depth. We have been a key player in the power industry since its inception and have a suite of complementary technology including gas-fired power, onshore and offshore wind, hydro, small modular reactors, battery storage, hybrids and grid solutions needed for the energy transformation.

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