WORKING TOWARD A

Decarbonized Energy Future

The world is at a critical inflection point.

For over 200 years, economic and industrial developments—from the growth of access to electricity to the spread of the internal combustion engine—have driven a massive carbonization of the atmosphere as a result of the combustion of fossil fuels. The unprecedented material and human developmental gains that have resulted from carbonization have turbocharged progress and helped lift billions out of poverty.

The global scientific consensus, stated in reports by the Intergovernmental Panel on Climate Change (IPCC), is that ever-greater emissions of greenhouse gases (GHGs) like carbon dioxide (CO_2) will continue to lead to global climate change.[1] Rising GHG levels and associated climate changes threaten both the planet and the continued progress of humanity.

We cannot stay on the same path when it comes to energy production and consumption.

In fact, there is a limited "budget" of CO_2 emissions remaining for the world before it's too late and the 2° ceiling of average global temperature increase specified by international climate scientists and codified in the global Paris Agreement[2] is exceeded. That budget is 2,900 gigatons (Gt) of carbon emitted since 1870. From 1870 to 2017, the world emitted 2,150 Gt of carbon, meaning that 75 percent of the budget is already spent. There is 25 percent—or 750 Gt of carbon—remaining to be emitted before the 2° ceiling is exceeded. At the current rate, the remaining 750 Gt budget will be used in about 20 years.

The clock is ticking.

This is a formidable challenge. Under the International Energy Agency's (IEA's) Sustainable Development Scenario (SDS), which we believe is the clearest articulation of a future energy system that meets the goals of the Paris Agreement, global carbon emissions must peak around 2020 and then enter a steep and sustained decline.[3] To change course, the world must act quickly to decarbonize every aspect of modern life, from how we live, work, and play. This will require a massive, global effort that includes cooperation and coordination from every major institution, including governments and companies, to help face into the challenge. The Paris climate agreement, with its 195 nation-state signatories represents a welcome step forward. But this is just the beginning.

Limiting average temp rise to 2°C since 1870, requires total carbon limit of 2,900 Gt

At GE, we believe that the power sector can become a model of decarbonization for the rest of the economy. We also believe that zero-carbon technologies such as wind and solar, along with digital tools that make the power system more efficient, can dramatically slow CO_2 emissions growth.
But renewables are just part of the solution. In fact, there is no one-size-fits-all approach to decarbonization.
In response to the decarbonization challenge, different countries and regions have evolved different mixes of energy sources. For example, France is heavily invested in nuclear power, while China, despite diversifying in recent years, is still largely dependent on coal.

[1] There are two types of pollutants: criteria pollutants like NO_x and sulfur dioxide (SO_2), which cause local air pollution and have negative health impacts, and GHGs, which cause global warming and other types of climate change. Criteria pollutants can be controlled, though not entirely, when burning fossil fuels to generate electricity. GHGs are more difficult to control—some control measures include fuel switching, increasing efficiencies and implementing carbon capture and storage (CCS) technologies.

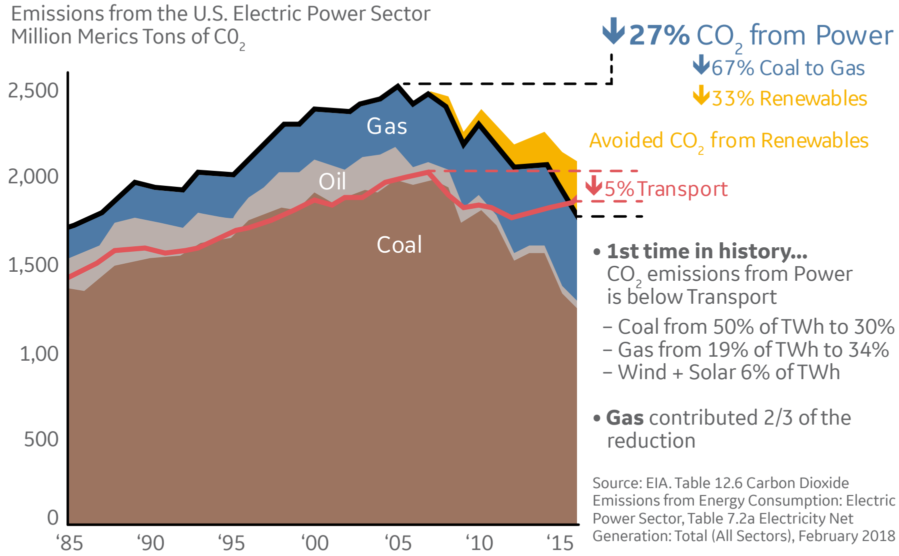
[2] According to the Paris Agreement, holding the increase in global average temperature below 2°C will significantly reduce the risks and impacts of climate change.

[3] International Energy Agency, World Energy Outlook 2018

While decarbonization is an essential objective, many countries also must consider the need to provide affordable and reliable electricity as their economies and markets grow. In considering global decarbonization it is imperative to account for these many differences around the world and the varied levels of progress toward a no- or low-carbon future at which different countries find themselves. Indeed, a combination of continued, focused regulatory and policy action and technological innovation will be required to decarbonize the power sector.

GE's portfolio of products and services offers custom solutions to customers in their efforts to decarbonize. Our gas turbine solutions provide the lowest CO_2 emissions on a kWh basis of any fossil fuel-fired technology in the industry. Additionally, our solar solutions, utility-scale energy storage systems, HVDC equipment, and grid solutions all support effective integration of renewables onto the grid. And GE's broader portfolio of zero-carbon nuclear, wind and hydro power, all make decarbonization possible.

Gas is Contributing to CO_2 Reductions



The USA's CO_2 emissions from power plants peaked in 2005. From 2005 to 2017 CO_2 emissions from the power sector have come down by 27%, and they are now below CO_2 emissions from the transport sector. This reduction is driven by the fact that electricity generation from coal has gone from about 50% to about 30% of the total. Gas went from about 19% to about 34%, and renewables and wind have grown exponentially to the point that they now provide about 6% of the USA's electricity. Roughly 2/3rd of the reductions in CO_2 emissions since the peak in 2005 have come from coal-to-gas switching and 1/3rd from renewables deployment.

Regulatory and Policy Actions

National and provincial government regulations and policies are already helping to transform the global power system. Decision makers across the globe have taken steps to move their jurisdictions toward decarbonization. These actions have taken a variety of forms. Actions like net-metering programs and state-level renewable portfolio standards (RPS) in the U.S., feed-in tariffs in Europe, renewable energy auctions in Latin America, and a potpourri of other government subsidies and tax incentives for low-carbon generation sources in places like China and India have contributed to the decarbonization effort.

European policy makers have been the vanguard of decarbonization efforts since instituting the world's first feed-in tariffs and renewable energy targets in the 1990s. The U.S. followed suit, by incentivizing the production of renewable energy-based electricity with tax credits like the Production Tax Credit (PTC) and Investment Tax Credit (ITC). Congress first enacted the PTC in 1992 and has revised and expanded the credit numerous times since. Policies such as the PTC and state-level RPS programs are widely credited with both launching the wind power industry in the U.S. and driving down the cost of renewable energy.

Another policy approach to drive decarbonization has been imposing a price on CO_2 emissions. Despite having an excess of available allowances and therefore relatively low carbon pricing, carbon trading schemes such as the European Union's Emissions Trading Scheme (ETS), and U.S. programs such as the Regional Greenhouse Gas Initiative (RGGI), have served as prototypes for future CO_2 pricing mechanisms and have increased momentum toward a low-carbon future.

In light of the range of global policy experimentation, it is clear that decarbonization is not a one-size-fits all challenge and the methods employed by each country and region will vary. It is up to each individual sovereign nation to decide how they will best meet their decarbonization objectives within the overall framework of the Paris Agreement. Equally clear is that stable, long-term policies are an enabler to investment and can help drive the power industry toward meeting decarbonization goals.

Energy Innovation

Coinciding with the regulatory and policy "push" toward decarbonization is an innovation "pull" in the same direction, as technologies combine to lower the use of carbon in the global power system. This range of breakthroughs can be seen across the entire spectrum of electricity generation, from the most carbon-intensive, legacy coal-powered plants to new, cutting-edge hybrid systems combining natural gas, wind, solar, and energy storage systems.

The last decade has seen tremendous improvement in the reliability, cost, and performance of renewable sources of energy, as they have matured from expensive outliers to practical alternatives to thermal sources, at scale. Over one terrawatt (TW) of solar and wind sources have now been installed globally. This acceleration is occurring for both centralized and distributed renewable sources like solar photovoltaics (PV) which are often located close to the point of use, thereby reducing the need for transmission & distribution (T&D) infrastructure. Continued innovation in flexible technologies within the electrical system will be needed to accommodate increasing levels of variable sources of energy like wind and solar.
Reductions in the cost of renewable energy technologies have also been impressive. The National Renewable Energy Laboratory (NREL) in the U.S. predicts that wind and solar energy will become even cheaper in coming years, while the levelized cost of electricity (LCOE) of conventional fuel-fired generation will remain relatively steady or even increase.[4] According to the World Economic Forum, benchmark prices for wind, solar PV, and battery projects in the U.S. have fallen by 65–90 percent in the past 10 years. Globally, solar and wind projects now have the lowest cost of energy of all electricity sources in select regions with strong wind and solar resources.[5]

Take onshore wind power costs in the U.S. for example. Wind power costs have declined 50 percent, from around US$135 per megawatt-hour (MWh) in 2009 to less than US$45/MWh in 2017.[6] Meanwhile, cumulative onshore wind installations rose from around 35 gigawatts (GW) to 84 GW over the same period. Decreases in installed cost have occurred in conjunction with ever-greater amounts of electricity being generated from a single wind turbine. Both improved output and lower costs have resulted from breakthroughs in rotor blade and wind tower design. Today, energy storage is being viewed by experts as an increasingly attractive option for integrating variable wind power into the transmission system, and also as an option to complement distributed PV systems.

Solar PV systems have also seen big cost decreases, with the installed cost of solar modules plummeting by around 84 percent since 2010[7] due to continued technology coupled with economies of scale gains as a result of the explosive growth of PV manufacturing capability.

[4] Annual Technology Baseline (ATB), NREL, 2018

[5] Renewable Infrastructure Investment Handbook, World Economic Forum (WEF), 2016

[6] ATB, NREL, 2018

[7] Bloomberg New Energy Finance, 2018

Focus on the DolWin3 Project

There's plenty of wind in the harsh North Sea, but harnessing that energy for use on land is no easy task. Even after constructing the giant wind turbines, there is the matter of converting the alternating current (AC) they generate into high-voltage direct current (HVDC) that can be transmitted efficiently to land. GE partnered with the Dutch-German electricity transmission operator TenneT to install the 18,000-ton DolWin3 converter platform out at sea in 2017, part of a multi-year project that will generate power equivalent to the electricity needs of 1 million German homes. This ambitious undertaking will help Germany reach its goal of generating 80 percent of its electricity from renewable sources by 2050. Read more here.

As is the case with all energy technologies, costs vary significantly for different types of solar modules in different parts of the world, but the overall direction since 2010 has been downward by 50 to 75 percent. These costs are expected to decline by a further 15 percent in 2018 as even more manufacturing capacity comes online. Distributed solar PV installations, meanwhile, have risen tenfold, from 17.3 GW in 2010 to 173 GW in 2017.[8]

The emergence of new battery and other storage technology have helped decarbonization, because energy storage technologies allow electrical output from wind and solar to be stored when it is generated and used later, when it may not be windy or sunny enough for wind farms and solar cells to generate power.

Improvements in technology have made this possible. The average global price of lithium-ion battery packs, for example, has fallen by 80 percent since 2010, from $1,000/kWh then to $209/kWh in 2017; as a result, a record 1.2 GW of battery storage capacity was installed in 2017, up from just 139 MW in 2010.[9]

Energy storage technologies like GE's new Reservoir Solution provide flexible and modular energy storage options for large and small applications. With this battery storage technology, power customers integrating solar energy into the grid, for example, can dispatch stored energy when demand peaks; avoid solar curtailment, preventing the loss of energy production; and provide fast regulation of grid frequency to balance supply and demand.

The question is often asked: why doesn't the world simply deploy only renewable technologies going forward?

It comes down to two things, cost and technological capacity. According to IEA, investment in renewable generation in 2017 was nearly $300 billion, a decrease of about 7 percent relative to 2016.[10] To increase renewables generation to 700 TWh annually to meet the SDS goal would require immediate, sustained investment of more than $500 billion annually, which is more than is currently spent on renewable, fossil, and nuclear generation combined. As it stands now, the world cannot afford to invest in renewables at those levels, no matter how much popular and political will are behind the push.

$500 billion =
annual investment in renewables generation required to meet the IEA's Sustainable Development Scenario

And current battery storage technologies, even considering recent improvements, aren't yet able to seasonally shift solar and wind energy from when it is generated to the season when it is needed.

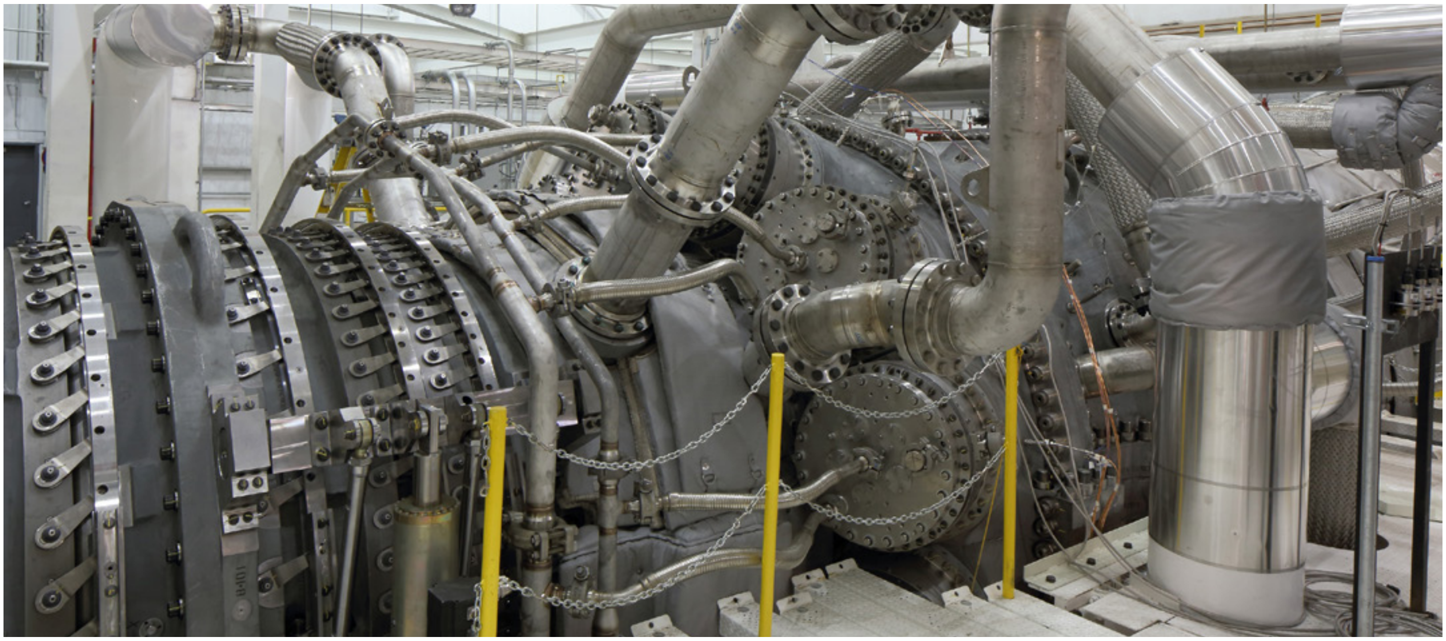
[8] *The Rise of Distributed Power*, GE, 2018

[9] Bloomberg New Energy Finance, 2018

[10] World Energy Investment, IEA, 2018

Focus on the Hybrid Electric Gas Turbine (HEGT)

In 2017, Southern California Edison (SCE)—which provides 15 million residents with energy in the greater Los Angeles area—launched the world's first hybrid battery-gas turbine power plant. The technology pairs GE's 10 MW/4.3 MWh battery system with its LM6000 "peaker" gas turbine, which can ramp up to 50 MW in under five minutes. This solution allows the battery to supply the grid with electricity for up to 30 minutes when solar and wind energy from the two sources ebbs. With the additional help of sophisticated software that matches demand and supply, the hybrid plant not only enables more use of renewables but also obviates the previous need to keep the gas turbine operating in spinning reserve mode, burning fuel and producing CO_2 and other emissions. Read more here.



The Role of Natural Gas

Natural gas will be a necessary part of the energy mix going forward. In fact, the IEA's Sustainable Development Scenario (SDS) leans strongly on natural gas as a source of decarbonization relative to coal- and oil-fired generation.

As oil and coal fall back and renewables ramp up significantly in the SDS scenario, natural gas becomes the largest single fuel source for electricity generation in the global mix by 2030, but then it is surpassed by renewable sources such as solar PV, wind, and hydropower during the decaded from 2030 to 2040.[11] In developing countries with energy systems that depend heavily on coal (especially big players China and India), and where renewable alternatives are less available—gas again plays a key role in helping achieve the scenario's objectives.[12] In the race to decarbonize the electric power system, the rise in natural gas may at first seem counterintuitive. However, while natural gas emits CO_2, it does so at half the rate of coal, and because of its ready availability, it is a useful alternative to fossil fuels with a higher carbon content such as coal and oil in the short to medium term. In the long-term, natural gas-fired power plants leave open the possibility of future retrofits of existing natural gas plants with carbon capture and storage (CCS) technologies, which are already technically proven but have not yet been deployed at scale.

Focus on the Chubu Electric Power Nishi-Nagoya Plant in Japan

GE's 9HA gas turbine broke an efficiency record in Japan, where it enabled Chubu Electric Power's Nishi-Nagoya plant Block 1 to convert 63.08% of its fuel energy into electricity, a new record for a combined-cycle power plant. Powered by liquefied natural gas (LNG), the turbines at the plant provide electricity to 2.7 million Japanese homes. The 9HA, with its ability to ramp up quickly, also helps integrate Japan's growing share of renewable energy onto the grid. Read more here.

The advantage of natural gas is that it works either as a stand-alone option, as a flexible complement to variable renewables, or as an important part of hybrid systems with other low-carbon technologies.

Natural gas makes even more sense as a fuel of the future when you consider how turbine technology continues to improve and become more efficient, especially in combined-cycle applications that capture otherwise wasted heat exhaust to generate additional electricity. For example, in 2016 GE's 9HA gas turbine powered the world's most efficient combined-cycle power plant by achieving a record 62.2 percent efficiency.[13]

Additionally, gas turbines can power up and down rapidly, meaning they can work flexibly with variable and inconsistent generating resources like wind and solar. This emphasis on gas in its various applications—as a coal replacement and as an efficient working partner of renewables—is necessary to keep the world on its carbon budget.

[11-12] World Energy Outlook, IEA, 2018

[13] https://www.ge.com/power/about/insights/articles/2016/04/power-plant-efficiency-record

Urgent Action Required

One thing is clear: at this critical energy inflection point for the world, urgent action is required to keep the global temperature increases below 2 degrees Celsius. Ideally, technological gains made in the renewable sector could solve the problem, but they are not enough on their own.

Additional investments must be made in the power grid and in energy storage and gas generation technologies. This will make the power system flexibile enough to handle increases and decreases in variable resources like solar and wind.

To stay within our carbon budget and calm the overheated world amid humanity's continued progress, imagination, and collaboration—from Oslo to Guangzhou and everywhere in between—will continue to be essential. With leadership, imagination, and collaboration, we believe the power industry can continue to be a global exemplar for decarbonization while at the same time driving better outcomes for people everywhere.

Contact us to discuss your energy challenges and together explore how GE's low and zero-carbon generation, storage, grid, and digital technologies and services can help you meet your efficiency and cost goals, ultimately moving the planet towards a lower-carbon future. Join the decarbonization discussion with GE by following us on Twitter and LinkedIn.