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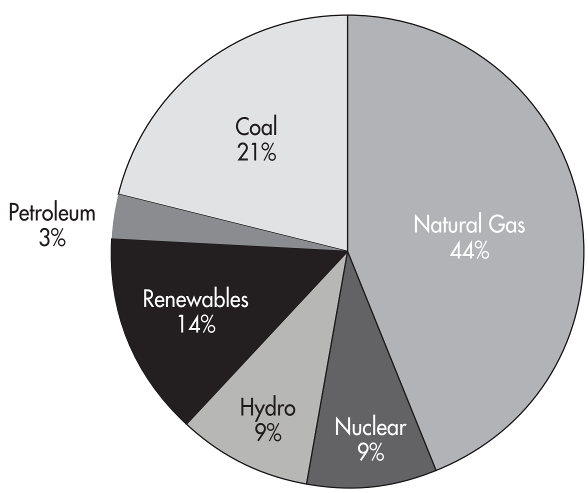
SECTION FOUR: GENERATION

Now that you have a general understanding of the needs of various electric customers, it's time to turn our attention to the physical system that is designed to deliver service to them. We will begin with a discussion of generation, which is the creation of flowing electrons. In later sections we will consider the other key components of the delivery system — transmission, distribution, and system operations.

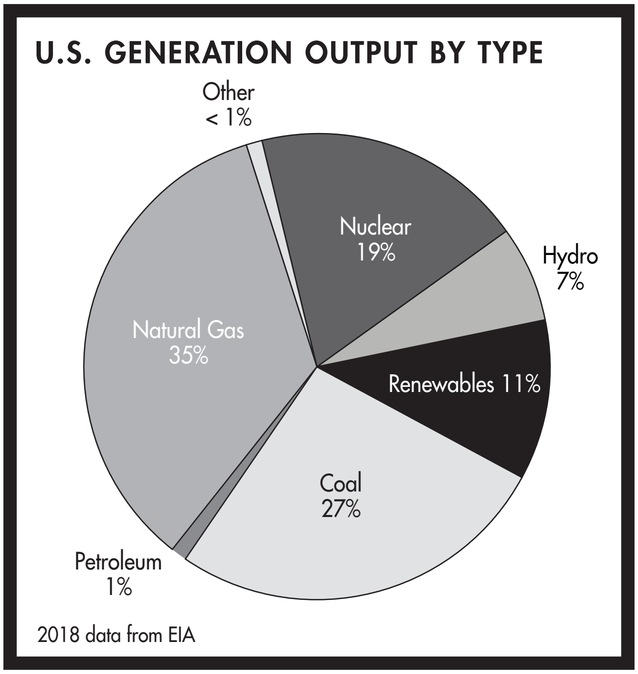
Generation fuel sources are quite diverse and include coal, nuclear, natural gas, petroleum, hydro, and various forms of renewable energy. Within any of these fuel sources, the technology employed to generate electricity can be diverse as well (for instance, gas technology includes steam turbines, combined-cycle turbines, reciprocating engines, and single-cycle combustion turbines). Each type of generation has unique operating and cost characteristics that make it more or less suitable to a specific supply need. This is why utilities or generating companies generally build generation portfolios comprising varied generation types. These can then be used to match the needs of their customers as well as the specific needs of their geographic location.

U.S. GENERATION CAPACITY BY TYPE



2018 data from EIA

U.S. summer generation capacity is approximately 1,150,000 MW. The United States' generation portfolio that provides this capacity comprises many types of power plants with natural gas plants having the largest total capacity. But because some units are run more frequently than other types of generation, the generation output percentages look significantly different as you can see in the chart on page 38. Note that natural gas and coal are the top sources for 2018, followed by nuclear, renewables, hydro, and petroleum. These percentages vary from year to year



based on factors such as the cost of natural gas and coal, the amount of hydro power available due to weather conditions, the growth of renewables, plant retirements, and the total amount of consumption.

U.S. generation capacity grew by an annual average of 1.2% for the 10 years from 2008 to 2018. The majority of this growth was due to construction of natural gas units and renewable projects, while a number of coal units were retired. As of 2019, the majority of planned new generation in the U.S. is natural gas, wind, and solar. Also expected to come online in the next five years are two new nuclear units. Coal capacity will continue to decline with over 75 units planned for retirement between 2018 and 2022.

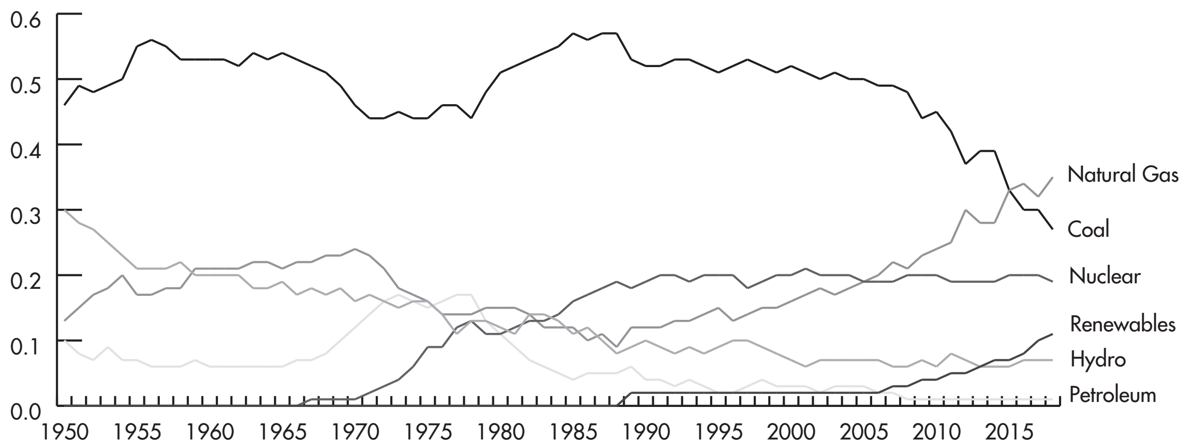
Changing Generation Output over Time

As market, technology, and regulatory conditions change over time, the types of generation used evolve as well. In the current decade, we are experiencing an unprecedented shift in generation output from coal to natural gas and renewables. Until recently, coal had been the largest source of electricity generation in the United States since the mid-1900s. But in 2016 natural gas supplanted coal as the largest source, and in the month of April 2019, renewables also generated more electricity than coal plants. It is likely that renewable output will eventually surpass natural gas output, though that is still a number of years into the future.

Types of Generation

Utilities or generating companies try to match generation types with the aggregate needs of their customers. To understand how this is done, it is important to first understand that each generation type has unique operating, financial, and environmental characteristics. Key characteristics include capital costs, variable costs, operational flexibility, environmental impacts, fuel availability, and restraints on locations

HISTORICAL U.S. GENERATION OUTPUT BY TYPE



where units can be constructed. Following is a discussion of each generation type and an assessment of the key characteristics outlined above. It is important that you clearly understand these fundamental characteristics as they will dictate which units run when and the generation type and technology used in the construction of new plants.

Coal

The ready availability of low-cost coal historically made coal-fired generation a favorite of many U.S. utilities. Most coal-fired generation employs steam turbine technology where coal is burned to heat water in boiler tubes. The water becomes steam and is run through a steam turbine that drives a generator shaft to create electricity. Because of economies of scale, most coal units are fairly large — in the range of 250 to 1,500 MW. The capital costs associated with building coal units are generally high compared with gas units, but many existing units have been online for a number of years and thus have been significantly depreciated. Operations and maintenance (O&M) costs are relatively low depending on the age of the unit. Fuel costs historically tended to be among the lowest of generation sources in the U.S. Due to technological constraints, coal units have limited operational flexibility. If the unit is running at partial power it can often be ramped up or down in response to system needs. But if the boiler has gone cold, it will require several hours to get to full operation. Because burning coal is responsible for considerable emissions (including CO_2, NO_x, SO_2, mercury, and particulates) coal units have a higher environmental impact than other sources of generation. For this reason and because of high transportation costs, there are areas of the country that do not use much coal to generate electricity. Other areas have historically been highly dependent on coal generation.

Beginning in the mid-2000s a number of utilities and merchant generators planned for construction of new coal units. But rising construction costs, falling natural gas prices, and opposition due to concerns over emissions led to cancellation or postponement of many projects. By the 2010s, coal had fallen out of favor due to declining costs for natural gas and renewable generation and increasing concerns about environmental impacts. Numerous existing coal units were retired and virtually all planned new projects were cancelled. Some companies began to consider cleaner Integrated Gasification Combined Cycle (IGCC) units, and two new units were completed in the U.S. But high costs and operational barriers for these newer technologies have slowed further development. Meanwhile ongoing falling costs for renewable and natural gas generation led many in the industry to predict that in the next few decades we will see the end of all coal generation in the U.S.

GENERATION CHARACTERISTICS

Capital cost — The up-front costs associated with buying equipment and constructing the generation unit, expressed in $/MW capacity.

Variable cost — The costs associated with running a generation unit that are directly related to the unit output, including fuel, water, and maintenance. These costs are expressed in $/MWh.

Operational flexibility — How quickly can a unit be turned on or off, and how quickly can it ramp from low power to full power?

Time to permit and construct — How long it takes to permit and build a new unit.

Environmental impact — What environmental impacts result from construction and operation, and what is the cost of environmental mitigation?

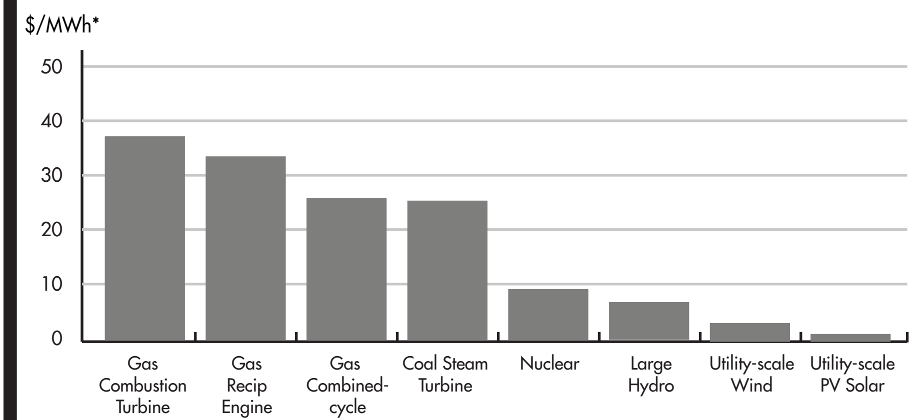
Fuel availability — How certain is future fuel supply?

Location — Can the unit be located near loads or is it located remote from loads thus requiring transmission investment?

Controllability — Can the output of a unit be dispatched by an operator to a specific output level or is output determined by factors such as wind, sunshine, or water flow? And if the unit is not dispatchable, how variable is the output of the unit?

Nuclear

A number of nuclear units were brought online in the United States in the 1970s and 1980s. These units are generally large and range in size from 600 to over 1,200 MW. Nuclear generation uses the heat of nuclear fission to create steam that is then run through a steam turbine. Capital costs associated with new nuclear units are very high, but as the units age and are depreciated their book values have declined. Variable costs including fuel are generally low, but fixed maintenance costs are high due to the extreme safety procedures required as well



VARIABLE OPERATING COSTS OF GENERATION

*Based on a gas price of $3.50/MMBtu and a coal price of $2.10/MMBtu

as the need to collect for future decommissioning costs. Because of the technology employed, nuclear units do not have good operational flexibility, and start-up times are usually measured in days. Because of this inflexibility, nuclear units are used for baseload needs. New development of nuclear generation in the U.S. has been hampered by key issues — the lack of a waste disposal site for spent fuel, public concerns over the risks of a major nuclear accident or terrorist attack, and high costs.

Public concerns about nuclear power risks were increased by the crisis in Fukushima, Japan, where the March 11, 2011, earthquake and tsunami caused severe damage to nuclear reactors owned by Tokyo Electric Power Company. The effects of the natural disaster damaged the power plants, disabling primary and backup power systems and resulting in core meltdowns, radiation releases, and the need to evacuate over 100,000 people from their homes. Although no deaths occurred directly related to the radiation release, long-term health effects are unknown. The units affected were permanently damaged and have been shut down. Some countries such as Germany responded by announcing plans to eliminate all nuclear power over time. Others such as the U.S. adjusted safety contingencies based on what was learned from Fukushima and continued moving forward with existing plans.

Despite the perceived safety issues, nuclear generation is favorable from the standpoint of emissions — no greenhouse gases or pollutants such as NO_x, SO_2, or mercury are emitted from nuclear generation. The first new nuclear unit in the U.S. since 1996 was brought into commercial operation in 2016, and as of 2019 two more new units are under construction and expected to be online later in the decade. A partially constructed two-unit project in South Carolina was cancelled in 2017 due to high costs and construction issues, and no further new units (beyond the two under construction) are currently forecast. Meanwhile, a number of older nuclear units are being retired, resulting in an expected overall decrease in U.S. nuclear capacity. But elsewhere, in countries such as China, India, Korea, Russia, and the United Arab Emirates construction of new nuclear units continues.

Natural Gas

Much of the new generation in recent years is natural gas-fueled. Gas-fired generation makes use of four primary technologies — combustion turbines that use natural gas directly to fire a turbine that drives the generator shaft; steam turbines that burn natural gas to create steam in a boiler that is then run through a steam turbine; combined-cycle units that utilize a combustion turbine (fired by natural gas) and then a steam turbine (wherein waste heat from the combustion turbine is used to produce steam that is then run through the steam turbine); and reciprocating internal combustion engines that use the motion of pistons to convert heat energy to mechanical energy that drives a generator. Utility-owned natural gas units vary significantly in size, ranging from as small as 1 MW to over 500 MW. Natural gas is also used to fuel on-site cogeneration units and backup generators for many buildings. Capital costs associated with natural gas units are considerably lower than other generation sources. O&M costs are also generally low. Fuel costs vary depending on the market value of natural gas. As you might imagine, a major concern among owners of natural gas generation are the historic fluctuations in natural gas prices. Depending on technology, natural gas units can be very flexible operationally. Combustion turbines and recipro-

WILL CHEAP GAS LAST IN THE U.S.?

The use of natural gas for generation in the U.S. has been boosted by various factors. One is that natural gas combusts more cleanly than other fossil fuels meaning that emissions are significantly lower per MWh of output. A second is that advancements in combined-cycle generation technology have greatly increased the efficiency of gas generation. The last factor has been the drop in natural gas costs in the U.S. that began in 2008 due to development of new unconventional natural gas resources such as shale gas. A key concern over too much dependence on natural gas generation is that historically natural gas prices have been volatile. Natural gas generation looks very good when prices fall below $4/MMBtu, but when prices hit $12/MMBtu it seems very expensive! Henry Hub (which is the most common U.S. natural gas reference point) daily prices have fluctuated from a low of $1.77/MMBtu to a high of $11.98/MMBtu over the last 15 years. Despite this volatility, prices in recent years have been near or below $3/MMBtu.

Should supply planners assume that today's low prices will persist? Through new drilling techniques, gas producers have recently accessed huge new supplies that were previously unavailable, and many analysts believe that economic U.S. gas reserves have expanded many-fold. Current estimates suggest that we may have close to 100 years' worth of natural gas reserves. And as of 2019, the EIA forecasts Henry Hub prices below $5/MMBtu through 2050. History tells us that natural gas prices rise and fall periodically, and only the future will tell if this cycle is destined to repeat or low prices will continue.

cating engines, often called peakers, can be started and stopped within minutes. Combined-cycle turbines take a bit longer to start, but can reach full power within an hour. Combustion turbines, reciprocating engines, and combined-cycle turbines can be flexibly ramped once under operation. Steam turbines may require up to six hours to go from cold status to full power but have reasonable ramp flexibility. Gas units do have air quality impacts as emissions include CO_2 and NO_x. Emissions are less than from other fossil fuel power generation such as coal and petroleum, so in regions where new gas units replace these types of power, gas generation is often considered favorable from an environmental standpoint. But in regions where gas competes with renewable generation, it can be considered an environmental detriment.

HEAT RATE

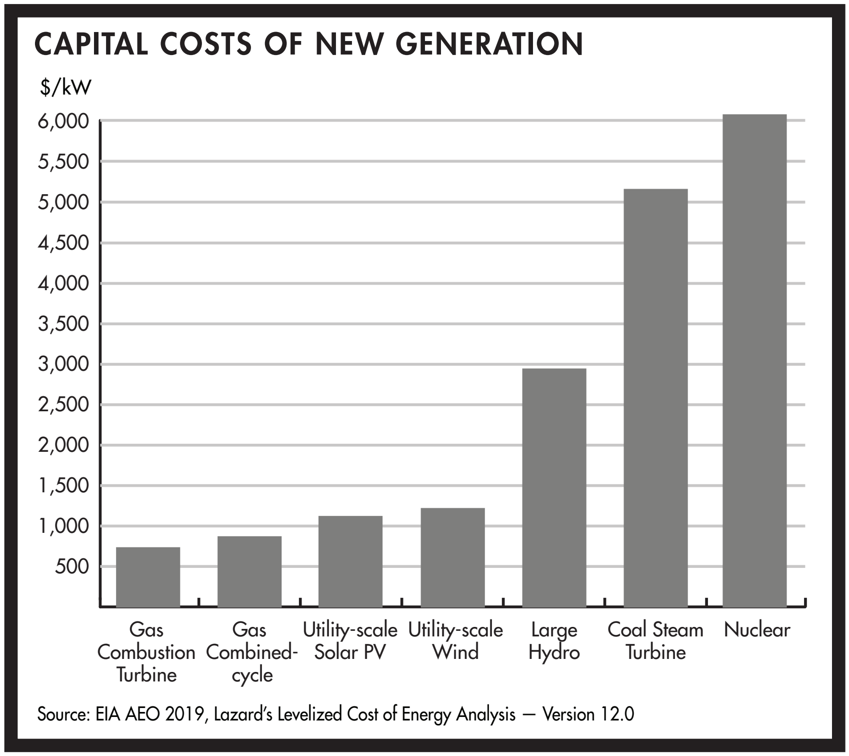
The heat rate of a generating unit is a means of measuring the efficiency of the unit by answering the question "How much fuel is required to generate a kWh of electricity?" Other factors being equal, a smaller heat rate is better, since this means less fuel is being consumed to create a unit of electricity. Typical heat rates for various generation types are as follows:

Unit Type	Typical Heat Rate (Btu/kWh)
Natural gas steam turbine	10,000 — 12,000
Natural gas combined-cycle	6,200 — 8,000
Natural gas combustion turbine	8,000 — 10,000
Natural gas reciprocating engine	7,500 — 8,500
Coal steam turbine	9,000 — 11,000
Natural gas turbine with cogeneration	5,000 — 6,500

The variable fuel cost of operating a unit can be determined by multiplying the cost of fuel by the heat rate (and usually making some unit conversions). For instance, a natural gas combined-cycle unit with a gas cost of $4/MMBtu and a heat rate of 7,000 Btu/kWh will have a fuel cost of $28/MWh.

Hydro

Hydro power is the backbone of many electric generation systems across the United States where significant hydro resources are available (notably the West and parts of the Southeast). Hydro power is created by running water from a reservoir or flowing river through a hydraulic turbine that spins and drives a generator shaft. For units with upstream water storage in a reservoir or holding pond, the power output can be controlled by simply adjusting the water flow, resulting in units with flexible output. Hydro units range from very small (100 kW) to very large (over 500 MW) with many units in the 100 MW range. Most hydro units were built a number of years ago (with some units dating back to the 1920s), so capital costs have generally been depreciated. O&M costs are generally low and, of course, there is no fuel cost once water rights are



acquired. Given their operational flexibility, many hydro units are useful for managing peak loads and for power regulation purposes (keeping supply and demand in balance minute by minute) as well as for restoring the grid after a blackout. Although a new hydro dam would now be considered to have large environmental impacts, existing units are generally considered environmentally favorable, with the exception of impacts on fish populations and downstream activities. A related technology is pumped hydro storage, which uses off-peak power to pump water uphill into a reservoir, thus making it available for generation during peak hours. This process is used by utilities as a form of electricity storage.

Petroleum

A limited number of utilities make use of petroleum generation as an alternative to natural gas. Petroleum generation is typically seen in regions where natural gas supply is limited or where utilities utilize fuel-switching units with onsite petroleum tanks to provide backup in the event gas supply is unavailable or prohibitively expensive. The technology used in petroleum generation is similar to natural gas with a few changes to account for physical characteristics of the different fuel. Thus operational characteristics of petroleum units are similar to natural gas units. The major drawbacks to petroleum units are that fuel is often significantly more expensive and environmental impacts are greater than their natural gas counterparts. In fact, some areas of the country do not permit petroleum generation due to air quality concerns.

Renewables

Renewable electricity generation is a broad category fueled by sources that can be naturally replenished. These include geothermal, solar, wind, biomass, municipal solid

RENEWABLE ENERGY

Renewable electricity generation is fueled by sources that can be naturally replenished. These include:

Biomass — Organic non-fossil fuel that is burned directly to create steam for a steam turbine, or biogas used in a gas turbine. Biogas is created by decomposition of organic material at landfill or agricultural sites and is often at least 50% methane.

Geothermal — Hot water or steam extracted from underground reservoirs in the earth's crust that is used to drive steam turbines.

Hydro — Small-scale hydro generation, often run-of-the-river (meaning no reservoir is created), and usually less than 30 MW in size.

Municipal Solid Waste (MSW) — Garbage incinerated in a furnace or fluidized bed combustor to create heat and then steam to drive a steam turbine.

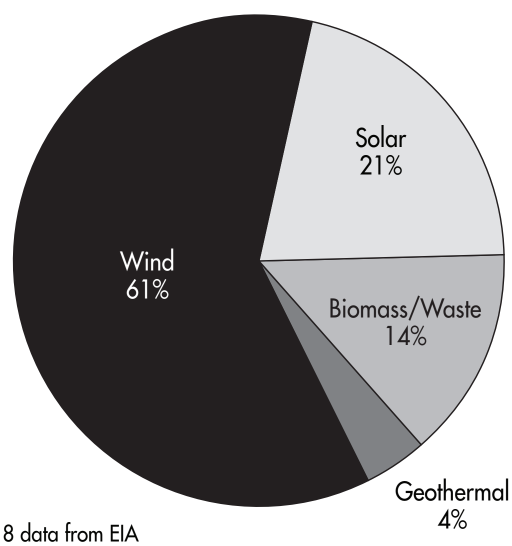
Solar — Sunlight applied to a photovoltaic cell (a substance that directly converts light energy to electricity) or sunlight used to heat liquids to create steam that is then used in a steam turbine.

Wave — Electric generator driven by the movement of ocean water.

Wind — Electric generator whose shaft is driven by the force of wind across a wind turbine.

waste, and smaller-scale hydro generation (usually less than 30 MW). Technologies used vary widely, and the size of renewable units tends to be small. Capital costs per unit vary greatly. Wind and utility-scale solar PV projects are often cost-competitive with other generation alternatives on a 10-year overall cost basis. O&M costs vary greatly by technology as well. The two big advantages of renewable power are that many technologies have no ongoing fuel cost (wind, solar) and environmental impacts are generally minimal. One drawback is that many renewable sources are variable and not always available. Thus system operators must plan for other flexible resources when including renewables in the generation mix.

RENEWABLE ELECTRIC OUTPUT IN THE U.S.



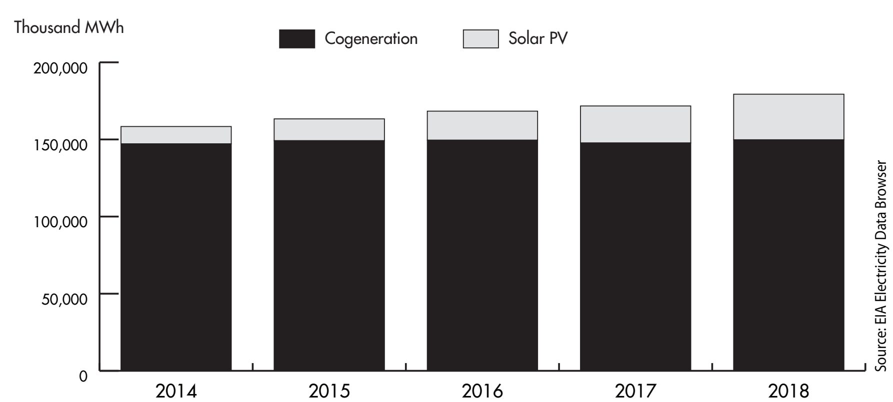
2018 data from EIA

Development of renewable generation — especially wind and solar power — has accelerated in recent years. Factors fostering this development include rapidly falling costs for wind and solar photovoltaic projects, concerns over future gas prices, concerns over environmental impacts of fossil fuel generation, renewable portfolio mandates in some states, green power programs offered by some utilities and retail marketers (which allow consumers the choice to be served by green power), and large corporate energy users choosing to invest in renewable power.

Distributed Generation

Distributed generation refers to generation that is located at an end-use consumer's site. Common technologies include generators driven by gas turbines or internal combustion engines and solar photovoltaic cells. Included in distributed generation are cogeneration units. Cogeneration units, also known as combined heat and power (CHP) generators, are units that utilize their energy input to create two forms of useful energy — electricity and heat. A common application would be to generate electricity using a combustion turbine or internal combustion engine, and then recapture the waste heat from the generator for use in direct heating or producing steam for internal processes. Alternatively, steam may be created in a boiler, used to drive a steam turbine, and then used for internal process needs. Because cogeneration makes dual use of the fuel, and because distributed generation does not result in transmission or distribution losses, cogeneration can be a highly efficient way to use fuel. Some CHP applications create efficiencies as high as 85% compared to the U.S. electrical average of about 35%. Location at the customer site can also reduce transmission and distribution costs and enhance local reliability. Future distributed generation may use new technologies such as fuel cells and micro CHP (small cogeneration units with a capacity of about 1 kW, which is a good baseload for a residence).

GROWTH IN U.S. DISTRIBUTED GENERATION OUTPUT



The late 2010s saw rapid growth in distributed generation in some regions driven primarily by growth in rooftop solar and community solar projects. In the five years from 2014 through 2018, output of distributed solar in the U.S. almost tripled.

Growth rates for distributed solar are expected to continue to increase due to lower costs, consumer desires, and governmental policy support.

ENVIRONMENTAL CONCERNS

Category	Specific Issue	Environmental Impact
Air Pollution	Particulates Sulfur dioxide (SO_2) Nitrogen oxides (NO_x) Carbon dioxide (CO_2) Mercury	Local heath issues Acid rain, local health issues Smog Global warming Local health issues
Water Resources	Use of water Thermal discharges River ecosystem disruption	Consumption of water resources Damage to fish and other species Damage to fish and other species
Nuclear Radiation	Release of radiation from fuel Major accident radiation release	Possible source of cancer Source of cancer and other diseases
Land Use	Disrupted environments — mining Disrupted environments — construction	Impacts on pristine areas Visual and economic impacts in urban areas, disruption to pristine land in rural areas

Environmental Considerations

The generation of electricity results in an environmental conundrum — use of electricity at the point of consumption is very clean (for instance, electric cars are nonpolluting) yet generation of electricity often has significant environmental impacts. These include air pollution, water pollution, greenhouse gas emissions, ecosystem and land-use disruption, and the potential for release of radioactive materials (see table above). Areas of greatest concern include electric generation's contribution to acid rain, smog, global warming, and local health issues, as well as the potential for radiation release.

Different types of generation have very different impacts, and environmental considerations can greatly influence how generation types are used as well as what types continue to be built. For example, environmental mitigation costs create an unattractive uncertainty for coal generation. Similarly, the potential for future political/environmental issues associated with nuclear generation have hampered nuclear unit construction in many locations. To foster cleaner generation sources, some states have moved to zero-carbon emissions standards or renewable portfolio standards

(RPS) that require utilities and/or retail marketers to acquire a certain percentage of their generation portfolio from renewable resources. Many utilities and generating companies favor new construction of renewable or gas-fired units in part due to the relative ease in obtaining environmental permits. At the same time many older coal units are being retired in part due to new more stringent environmental rules.

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ENVIRONMENTAL ISSUES BY GENERATION TYPE

Generation Type	Environmental Issues
Coal	• CO_2 • NO_x • SO_2 • Mercury • Other heavy metal particulates • Land use disruption for mining • Use of diesel locomotives to transport coal
Nuclear	• Low-level radiation release through mining and waste • Potential for high-level radiation release in an accident
Natural Gas	• NO_x • CO_2 • Land use disruption for drilling
Hydro	• Impact on downstream fish and other species
Renewables	• Land use disruption for wind, solar, and biomass

Electric Generation, Global Warming, and Greenhouse Gas Regulation

A majority of the world's scientific community and most of the world's political community now agree that man's activities in burning carbon-based fuels (coal, petroleum, and natural gas) are resulting in raised concentrations of greenhouse gases that increase the earth's average temperature and destabilize weather patterns. If the trend continues, results could be severe and include melting of ice packs, flooding of low-lying areas, interruption of food production, and increased incidents of severe weather.

Electric power production is responsible for about one-third of the greenhouse gases emitted due to human activity in the United States, which is in turn responsible for roughly 14% of the world's greenhouse gas emissions. Greenhouse gas emissions are measured in units of tonnes of CO_2 equivalent. Coal generation is responsible for more CO_2 than any other generation source. (Coal generation emits about twice as much CO_2 per unit of output than natural gas generation.) Control technologies for CO_2 emissions from traditional power plants are being researched but are not currently commercially available.

GENERATION CHARACTERISTICS COMPARISON							
	Coal	**Nuclear**	**Natural Gas**	**Hydro**	**Petroleum**	**Wind**	**Solar PV**
Capital Cost	Medium - High	High	Low	Medium - High	Low	Medium	Medium
Variable Cost	Medium	Low	Medium	Low	High	Low	Low
Operational Flexibility	Medium	Low	High	High	High	Low	Low
Time to Permit and Construct	Long	Long	Short	Long	Medium	Short	Short
Environmental Impact	High	Low	Low	Low - High	High	Low	Low
Fuel Availability	Plentiful	Plentiful	Plentiful	Limited	Plentiful	Depends on Location	Depends on Location
Location	Remote	Remote	Near Loads	Remote	Near Loads	Remote	Remote if Utility Scale
Controllability	High	High	High	High	High	Low	Low

In late 2016 an international accord called the Paris Agreement went into effect. The accord was signed by 194 countries, and its goals included holding down the increase in global average temperature due to greenhouse gases, increasing the world's ability to adapt to climate change, making financing available for pathways to reducing greenhouse gas emissions, and achieving global peaking of greenhouse gas emissions as soon as possible. A number of countries including China, the U.S., and the member states of the European Union made non-binding commitments to achieve specific targets associated with limiting greenhouse gas emissions. In 2017, the U.S. administration announced that it would cease all participation in the agreement and planned to withdraw from the agreement completely by 2020. Meanwhile other countries continued their support although as of 2019 many have yet to meet their initial targets. In the U.S. numerous states, cities, and corporations stated their support for the agreement, and many took positive actions to reduce their greenhouse gas emissions. Thus as of 2019, the power generation industry's movement toward meaningful reductions of greenhouse gas emissions remains uncertain.

Demand Response and Energy Efficiency as Alternatives to Generation

An alternative to some generation is to develop mechanisms that reduce or shift timing of end-use demand. Such programs are called demand side management, or DSM. DSM includes energy efficiency, which reduces overall energy intensity for a specific use, and demand response, which reduces demand during peak times. Demand response (DR) can be emergency demand response (where customers are required to reduce demand only during times when their failure to do so will create reliability issues) or economic demand response (where customers are given economic incentives to reduce demand during times when it is cheaper to reduce demand than to purchase or generate additional units of electric supply and/or shift usage to times when plentiful renewable supply is available).

In the 1980s utilities implemented DSM programs in an effort to reduce the need for costly new generation construction. These programs encourage customers to implement energy efficiency measures through rebates for more efficient appliances and offer incentives such as discounted curtailable rate schedules that allow the utility to curtail service during times when high demand threatens system reliability. There has been a trend lately toward DR programs. These programs can have a significant impact on reducing peak loads, shifting loads to times with plentiful supply, and/or muting price spikes in competitive markets. Thus, utilities and retail marketers have an interest in creating means by which customers can be compensated for reducing demand upon request. Traditional rates that do not pass real-time price signals to customers fail to incent this behavior. DR programs include:

- Real-time pricing — Customers pay hourly prices that reflect same-day or day-ahead market conditions.
- Voluntary load response — Customers are offered a payment for curtailing blocks of load, usually in the day ahead.
- Curtailable capacity call — Customers are paid a capacity payment to give the utility or marketer the right to curtail blocks of load under certain conditions; failure to curtail results in payment of market rates for that block of load.
- Automatic load response — Customers are paid a capacity payment to give the utility or marketer the right to remotely and automatically curtail blocks of load.

With the growth in renewables, system operators now require increasing amounts of flexible resources and often experience significant shifts in costs of generation across the day. DR is becoming an increasingly common option for meeting system need for flexibility. As of 2017, the EIA estimated that over 9 million customers in the U.S. participated in demand response programs that saved over 1,300,000 MWh and reduced actual peak demand by over 12,000 MW.

Electric Storage

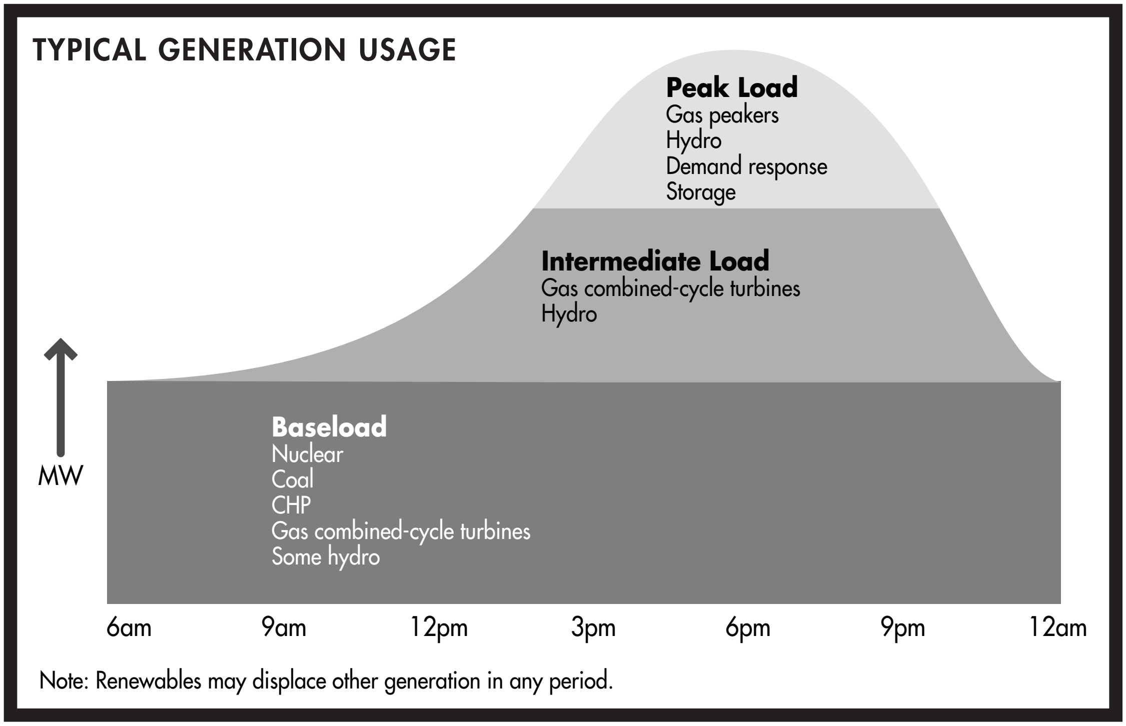
System operators must match supply to demand instantaneously across the hour. With fluctuating customer loads and increasingly variable supply from renewables, the ability to store and then withdraw energy from storage is a valuable tool in managing a grid. Historically, pumped hydro storage has provided the only economic means of storing electric supply. Pumped storage provides the capability of time-shifting energy between off-peak and peak hours and also can be used for short-term supply adjustments used for frequency regulation and spinning reserves. As of 2017, the U.S. had over 22,600 MW of pumped storage. But expansion of pumped storage is difficult given the need for specific resource capabilities, and it is not expected that pumped storage capacity will expand much in the near future.

Other methods of storing electric energy include batteries, thermal storage, flywheels, and compressed air energy storage (CAES). In the 2010s, battery costs declined rapidly making it feasible for batteries to be used as a grid storage resource. As of 2019, there is about 1,000 MW of utility-scale batteries installed in the U.S. The EIA forecasts that this will expand to over 2,500 MW by 2023. Batteries offer many grid benefits including frequency regulation, five-minute load following, spinning reserves, and local voltage support as well as time-shifting of energy over a few-hour time-frame. They can also be designed as part of a wind or solar project to provide more steady output. Many industry analysts expect that batteries will soon become an integral part of grid design and operations.

Use of Generation to Satisfy the Load Curve

The key to understanding electric supply markets is to understand which generating units are dispatched at what times to meet the load curve (the aggregate demand of all customers in a specific region). This has a major impact on wholesale electric markets since the cost of the last resource required in any given hour (the marginal cost) often determines the market price of electricity in competitive markets.

Generating units are typically scheduled hourly (one day in advance) based on least-cost supply subject to reliability, operating, locational, and regulatory constraints. Use



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of generation is often divided into three categories — baseload, which is generation run all 24 hours of the day; intermediate, which is run from mid-morning until the evening; and peaking, which is run during the peak hours (often from early afternoon until early evening). Units typically scheduled include:

Baseload

Baseload is typically satisfied by nuclear units, high-efficiency coal and natural gas units, wind, and hydro generation (all due to low variable costs), and Qualifying Facilities (due to regulatory requirements). In addition, system operators may schedule as baseload less efficient coal, gas, or petroleum generators that need to run to provide locational support to the grid (known as must-run generation). It is also sometimes necessary to run less efficient coal, gas, or petroleum steam turbine generators at minimum loads because their full capacity will be needed later in the day and their boilers must be kept warm so that the units can be ramped up for availability during the intermediate period.

Intermediate

Intermediate loads are often satisfied by coal units ramped up from minimum loads, combined-cycle gas turbines, and hydro power. These are used because their operational flexibility allows them to be ramped up and down as loads rise and fall during the day, and also because their variable costs are lower than other options. In some regions, wind or solar power also provides intermediate supply.

WHAT IS A QUALIFYING FACILITY (QF)?

In 1978, the U.S. Congress passed the Public Utilities Regulatory Policy Act (PURPA), which contained measures to encourage more efficient use of energy resources. Among these provisions was a requirement that utilities buy the output of qualified cogeneration resources at the host utility's avoided cost rate, which is the cost the utility would pay to generate replacement power if the QF did not exist.

Pursuant to PURPA, the Federal Energy Regulatory Commission (FERC) set forth criteria for determining which facilities could receive Qualifying Facility (QF) status. To be a QF, a generating facility must produce electricity and another form of useful thermal energy (such as heat or steam) used for industrial, commercial, heating, or cooling purposes and must be less than 50 MW in size and meet certain ownership, operating, and efficiency criteria. Since investor-owned utilities are regulated by the states, FERC left it to them to define the avoided cost rate. Some states such as California initially set attractive QF rates resulting in significant development of cogeneration facilities (as much as 16% of the California ISO's supply comes from cogenerators), while other states set much lower rates and did not see much in the way of cogeneration development. QFs are typically located at large industrial facilities in industries such as food processing, refineries, and wood processing.

The Energy Policy Act of 2005 resulted in changes in rules for new QFs so that in competitive markets they will no longer receive regulatory-set pricing.

Peaking

Peaking loads are usually satisfied by single-cycle gas turbines (also known as peaking turbines), gas reciprocating engines, hydro power, pumped hydro where available, other forms of storage, economic demand response, and in some regions solar power.

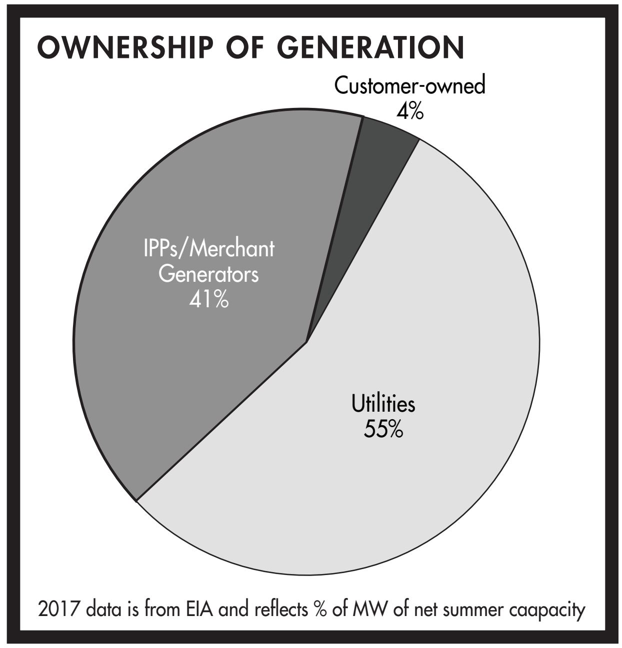
Reserves

As we will learn in a later section, system operators must also schedule generation reserves to ensure system reliability. Good sources for reserves include hydro power, gas combined-cycle, combustion turbines, reciprocating engines, and coal steam turbine units that are running at partial capacity.

Flexible Generation

As penetrations of renewable energy grow, electric grids require increasing amounts of flexible resources that can compensate for the variability associated with wind and solar generation. Key sources of flexibility include gas combined-cycle, combustion turbines, reciprocating engines, hydro and pumped hydro units, batteries, and demand response.

Ownership of Generation



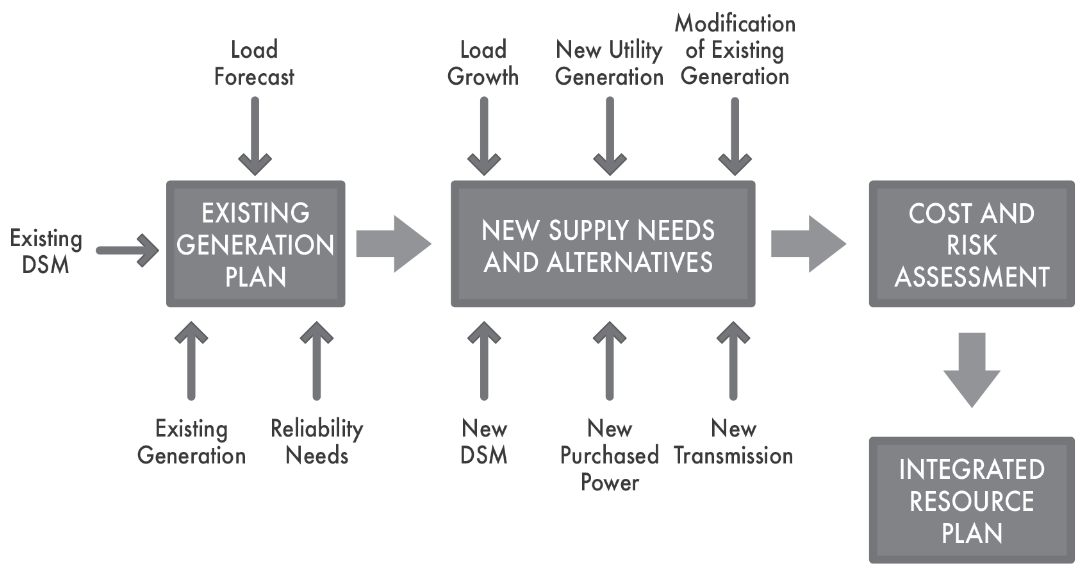
Prior to electric restructuring, virtually all the generation in the United States was owned by either investor-owned utilities, public utilities and rural co-ops, related generation and transmission agencies, or federal agencies. Since the advent of electric deregulation, a new category of generation owner has entered the market. These are non-utility generators, often called independent power producers (IPPs) or merchant generators. Non-utility generators are companies that own generation as a stand-alone business and not as part of a vertically integrated utility. These generators aim to own and operate their units for a profit by selling energy or capacity to utilities, marketing companies, and/or directly to end-use customers. In some states, utilities have divested of their generation assets by either selling them to non-utility generators or splitting the assets off from their utility function and creating their own non-utility generator subsidiary. In other states, non-utility generator ownership is limited to new units that have been built in recent years. Customer-owned generation is a final category and has been increasing in recent years.

Developing a Generation Portfolio

Companies that own generation must determine the best portfolio of generation units to satisfy the energy and capacity needs of their customers. In the past, this was a relatively simple task. Utilities responsible for providing supply start with their existing generation base, compare this against load forecasts, and then evaluate options to fulfill any additional supply requirements. Options might include modifications to existing utility generation, new utility generation, demand side management programs, purchased power (from neighboring utilities or non-utility generators), and new transmission lines to areas with excess generation. These options are then evaluated from the standpoint of cost and risk resulting in an integrated resource plan (see illustration on page 55). Integrated resource plans are typically filed with the state utility commission for approval before being implemented.

Non-utility generators must also evaluate generation portfolios, but their evaluation focuses on how to best create a return on shareholder investment. Thus a non-utility generator would carefully evaluate the market value of specific generating units as well as the strategic value of units relative to the company's other assets and business strategy (see box on page 56). Rather than an integrated resource planning process, non-utility generators use portfolio theory to attempt to maximize returns relative to perceived market risks.

INTEGRATED RESOURCE PLANNING



In either case, generation planners must evaluate future load growth and the capability of existing generation to satisfy that growth, and then look for points in the load curve where new generation is needed.

The Future of Generation

Given the lead times necessary to construct new generation, owners are continually planning for the future. In some cases this involves retiring older units and replacing them with new and more efficient ones. In others, it involves building new generation to meet growing loads or needs such as renewable portfolio standards. Considerations in deciding what types of resources to build include capital costs, ongoing O&M, expected fuel costs, risks associated with fuel cost volatility, costs for future environmental mitigation, and market needs for specific characteristics such as flexible generation or renewable output.

As of 2019, the majority of new units planned for the U.S. are natural gas, wind, and solar generation. A large amount of coal generation is expected to be retired with almost no new units coming online. Although two new nuclear units are expected to come online in 2022, their output will be offset by retiring older nuclear units. It should also be noted that the outlook for generation in the U.S. does not necessarily reflect the situation in other countries. Some regions of the world have plans to build significant amounts of nuclear and/or coal generation.

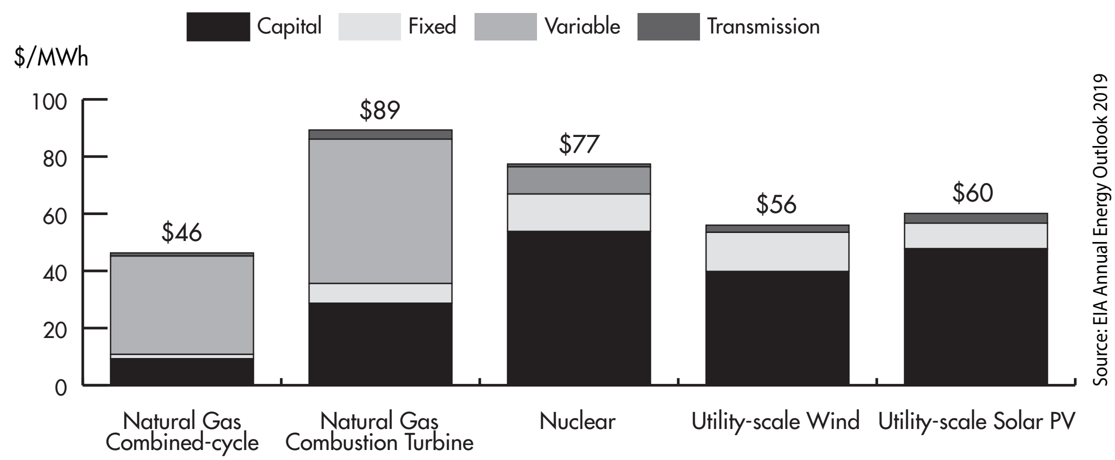
FACTORS AFFECTING THE VALUE OF GENERATION

- Physical flexibility of unit
- Expected O&M costs
- Fuel efficiency
- Future price expectations for fuel
- Future price expectations for energy
- Future price expectations for ancillary services
- Expected price volatility and price spikes in each market
- Environmental and operating permit risk/benefit
- Location relative to transmission capacity
- Opportunity for reliability must-run contracts
- Opportunity to expand at site
- Impact on a company's sales strategies
- Impact on a company's risk portfolio
- The applicable discount rate of capital

Technological innovation continues to drive changes in the generation mix. Development of the combined-cycle technology has made gas a favored fuel source in recent years. Substantial cost decreases in wind and solar driven by innovation in materials, design, and manufacturing have made these technologies a cost-effective alternative to fossil fuel generation. Construction of off-shore wind projects may provide more steady wind resources. New technologies that may impact the future include integrated gasification combined-cycle units (IGCC), small modular nuclear reactors (SMR), and fuel cells.

IGCC units use coal as a fuel but eliminate many of the environmental concerns by gasifying the coal prior to combustion. This improves the efficiency of the combustion process and results in emissions that are similar to natural gas units. It is also possible through additional processes to remove most of the carbon prior to combustion, making IGCC even more environmentally attractive (see box on page 58). The carbon can then be sequestered by storing it underground to prevent its release into the atmosphere. Some in the utility industry are optimistic about IGCC (a few test units

LEVELIZED COST OF NEW GENERATION FOR YEAR 2023



Note: Costs do not include any tax credit benefits.

are currently running) and believe this will become an important technology once cost barriers are overcome. Others believe the complexity of the technology will preclude its widespread use.

A significant barrier for future growth of nuclear generation is that current designs are for large units that usually exceed 1,000 MW. This typically requires investment of over $6 billion. Such an investment is difficult for companies unless they are a very large utility with regulatory guarantees of cost recovery or the investment is backed by government guarantees. And since the capacity of the unit is so large, it raises the significant possibility that the full amount of its output will not be needed until loads grow years into the future. In many parts of the world

U.S.SUMMER GENERATION CAPACITY CHANGES (PLANNED FOR 2018-2022)

Type	Additions (MW)	Retirements (MW)
Coal	1,142	22,817
Hydro	414	176
Natural Gas	60,738	11,007
Nuclear	2,200	9,475
Petroleum	40	586
Solar	14,204	2
Wind	25,981	20

Source: EIA Website 2019

CARBON CAPTURE AND SEQUESTRATION

Carbon sequestration refers to the capture and storage of carbon as an approach to reducing greenhouse gas emissions during the gas or coal generation process. In this process, carbon is removed, usually as carbon dioxide (CO_2), either prior to the combustion of the fossil fuel or after combustion in the exhaust stack. The CO_2 is then transported via pipeline or other means to a location where it can be stored. CO_2 might be stored in deep underground geological formations or in the ocean, or by transforming it into mineral carbonates. Most current research is focusing on geological formations. While carbon sequestration has been proven in concept, it is not yet developed for commercial-scale use. And the effects of long-term storage are still unknown. Costs of adding and operating technology for carbon capture and sequestration will certainly increase the cost of power generation. However, this concept may provide a useful tool in the battle to reduce greenhouse emissions from fossil fuel generation.

where competitive wholesale markets have evolved, including the U.S., these factors have been a huge barrier for nuclear power growth. One possibility that would make new nuclear power easier to finance and integrate into power systems would be construction of smaller units. Various nuclear companies are in the R&D phase of attempting to develop a cost-effective small modular nuclear reactor, or SMR. These units, typically in the 250 MW range, are conceived as modular units that would not need to be customized to specific sites and would better fit into financing capabilities and market needs. If development of a cost-effective SMR proceeds, growth in nuclear power may exceed current expectations.

Fuel cells may eventually change the way that we think about electric generation. A fuel cell is an electrochemical device that converts a fuel's chemical energy directly to electric energy. Fuel cells have no moving parts and are like a battery except that while batteries only store energy, fuel cells can actually produce electricity continuously given an ongoing supply of fuel. Fuel cells can run on various fuels including natural gas, gasoline, biogas, methanol, ethanol, and hydrogen. The big advantage to fuel cells is that with certain fuels their emissions consist of water and oxygen and thus are environmentally friendly at the point of generation. They are also well-suited to CHP applications. Some analysts believe that with technological advances, stationary fuel cells could become a valid option for widespread use in distributed electric production, thereby fundamentally changing our electric systems over the next 50 years.

While much of the discussion around new technologies still centers on centralized generation, some in the industry believe this is the wrong focus. It is possible that the industry will become increasing decentralized, with significant amounts of new resources being built on the distribution system. Many envision that a large number of

COULD THE FUTURE BELONG TO ZERO-CARBON GENERATION?

Can you imagine a world where fossil fuel generation is completely replaced with sources that emit no greenhouse gases? Many U.S. states and European countries can. As of 2019 California, Hawaii, and New Mexico have passed legislation setting 100% zero-carbon electricity mandates as have the countries of Denmark, Finland, France, Norway, Sweden, and the United Kingdom. A number of additional states and countries are considering similar requirements.

Falling costs for renewable generation and evolution of the grid have made plans for zero carbon feasible. Between 2009 and 2018, levelized costs for utility-scale wind power dropped by 69% while costs for utility-scale solar power dropped by 88%. A clean energy future that once looked very expensive has now become cost-competitive. Some regions are planning for 100% renewable generation portfolios while others will continue to make use of nuclear power in conjunction with renewable sources.

Key factors to make 100% zero-carbon possible include technological improvements and cost declines for battery storage, energy efficiency growth that reduces the amount of load that needs to be served, and flexibility in loads to allow electricity to be used when it is available from renewable resources (for instance, electric cars that can charge when power is available and stop charging when it is not). Also helpful is a robust transmission system that can move power across large geographic areas so that resources can be shared and balanced based on varying clean generation and customer demand in different regions. Will this occur? No one can say, but in recent years the concept has gone from fantasy to real possibility.

distributed energy resources including flexible demand response, distributed generation, and distributed storage will be orchestrated by distribution system operators to replace much of the supply currently provided by centralized power plants. The amount of distributed resources and their speed of growth will likely vary regionally with some regions moving toward distributed models in the next few years while others evolve more slowly.