Power Generation Technologies

Overview & Comparisons

Sargent & Lundy prepared this pamphlet on behalf of CPS Energy to provide an overview of commonly used and commercially available power generation and energy storage technologies in the power industry. The information contained within this pamphlet is at a high level and provided only as general information.

Notes

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Common Terms & Definitions

CO_2—*carbon dioxide*
A gas emitted in the burning of fossil or biomass fuels.

CT—*combustion turbine*
Uses energy from the combustion of an air-fuel mixture to drive a shaft.

Energy Storage Sizing—The size of a battery is determined by both power and energy:

- ***Power*** capacity = kW (similar to a water hose—how much water can be released in a given time)
- ***Energy*** capacity = kWh (similar to a water storage tank—the amount of water that can be stored)

Frequency Regulation—A tool used to maintain the frequency of the grid at 60 hertz, preventing it from substantial deviation from the 60 hertz setpoint.

Greenhouse Gas—The U.S. EPA defines greenhouse gases as “gases that trap heat in the atmosphere.” The most common greenhouse gases for electricity generation include CO_2 and NO_X.

kW—*kilowatt*
A kW is a unit of the amount of instantaneous power capacity available.

kWh—*kilowatt-hour*
A kWh is a unit of the amount of energy produced over an hour.

Load—The source that draws and needs energy.

Load Shifting—The concept of moving the load from one time of day to another, typically to reduce the peak load.

MW—*megawatt*
A MW is a unit that is equivalent to 1,000 kW.

MWh—*megawatt-hour*
A MWh is a unit that is equivalent to 1,000 kWh.

NO_X—*nitrogen oxides*
A group of gaseous air pollutants composed of nitrogen and oxygen formed when fossil fuels such as coal, oil, gas, or diesel are burned at high temperatures.

Peak Load—The maximum load demand at any given time.

Peak Shaving—The concept of reducing the total amount of generation needed to meet the peak load.

RICE—*reciprocating internal combustion engine*
A RICE is an engine that combusts an air-fuel mixture via spark or compression ignition, which drives a piston and turns a crankshaft. The crankshaft can be coupled to an electric generator for electric power generation.

Round Trip Efficiency—The ratio of energy recovered from the energy storage system to the energy put into an energy storage system.

Siting Considerations—With all power generating facilities, appropriately siting the facility is important. Key considerations include local, state, and federal regulations; visual and noise impacts; proximity to the grid interconnection; and emissions considerations. Fuel and water requirements and availability are also important to siting and the final design of the generating facility.

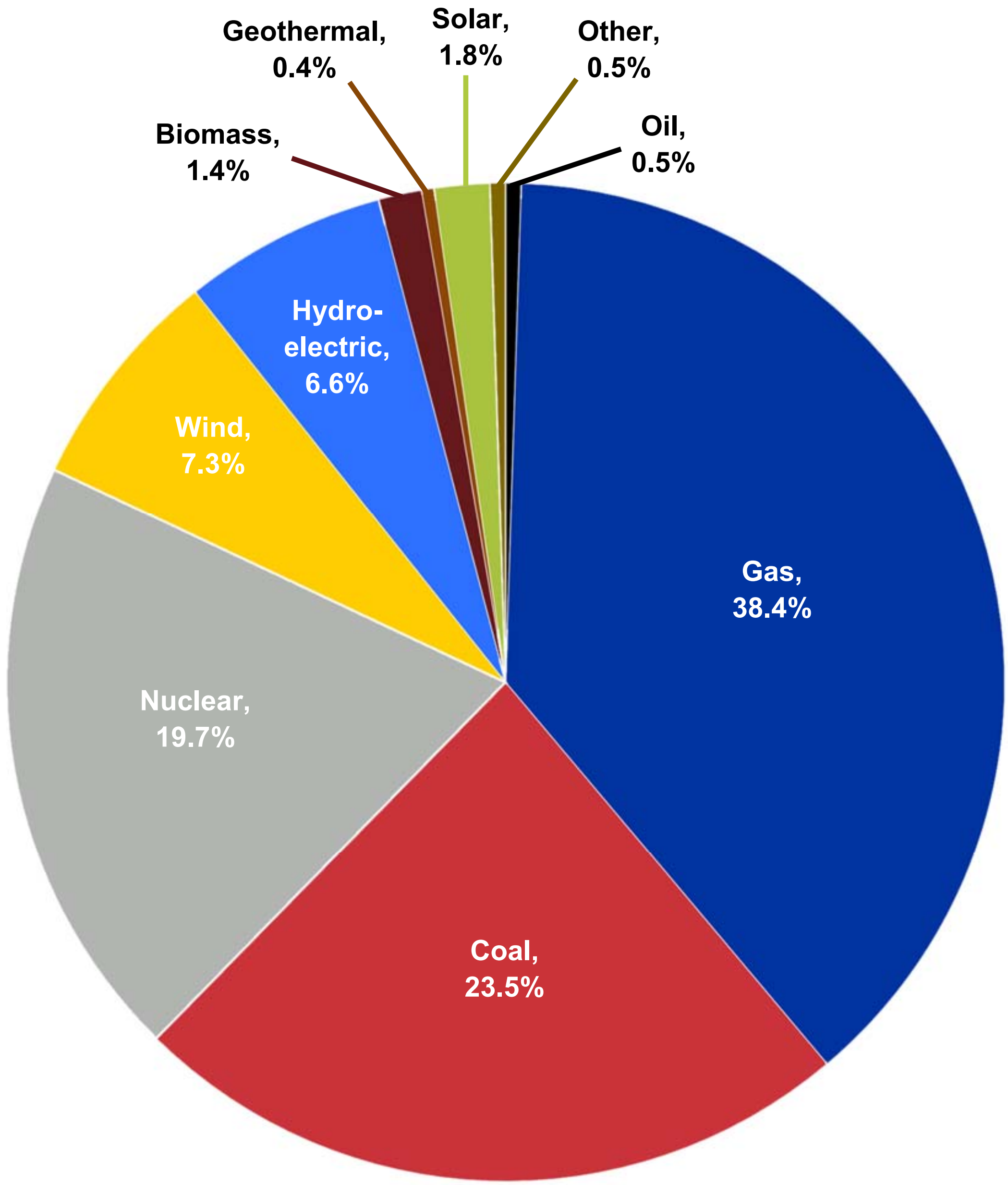
Steam Cycle—A thermodynamic cycle (known as the “Rankine Cycle”) where water is heated and pressurized and the high energy steam is used to drive a steam turbine for beneficial generation of electricity. Once the steam energy is used in the turbine, the steam is condensed back into water at a lower pressure, and the cycle is repeated.

Voltage Regulation—A tool used to maintain the system voltage at appropriate levels.

Overview

According to the U.S. Energy Information Administration, in 2019, about 4.12 trillion kWh of electricity were generated at utility-scale electric generation facilities in the United States. The energy was produced by different types of electric generation facilities and different fuel sources. In 2019, over 80% of electric generation was from natural gas, coal, or nuclear fuel.

2019 U.S. Electric Power Generation by Fuel Type



This document provides an overview of generating technologies used or considered by CPS Energy and other utilities. The generating facilities covered in this document include combustion turbines, boilers, combined cycle, coal, nuclear, reciprocating internal combustion engines, hydroelectric, wind, solar, geothermal, biomass, hydrogen, battery energy storage, and energy storage.

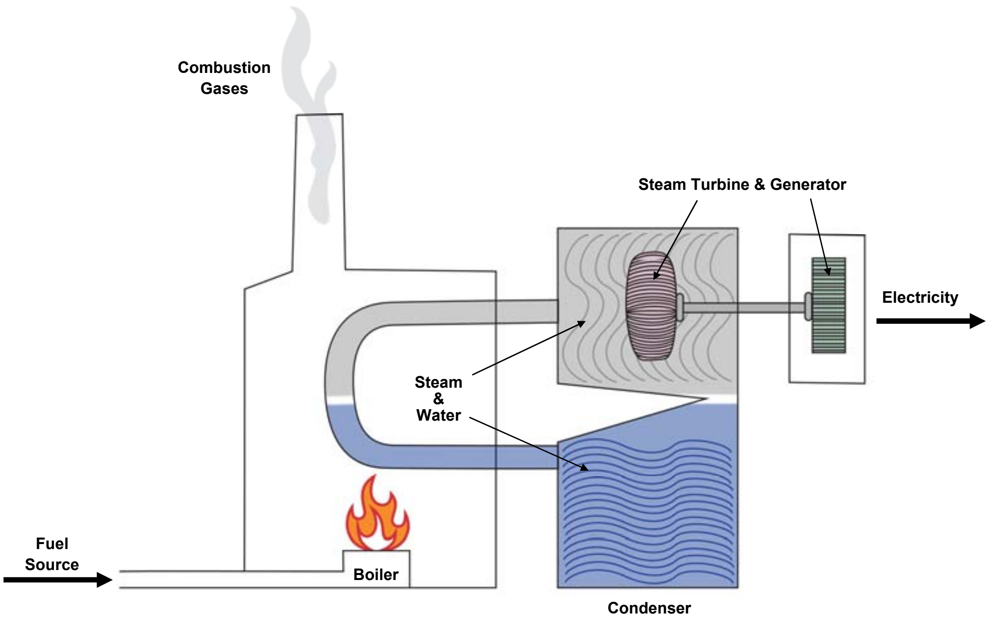
Conventional Steam Power

Steam power plants produce electricity by heating water in a steam generator (or "**boiler**") to produce steam, which is used to drive a **steam turbine**. The rotation of the turbine powers a **generator** that converts this mechanical energy into electricity. Steam is condensed back into liquid water and sent back to the steam generator for re-heating. This process is referred to as the "**steam cycle**," also known as the **Rankine Cycle**. Steam power plants can be configured for various fuel types. The steam cycle is used in coal, natural gas (except simple cycle), nuclear, and biomass power plants.

Siting Considerations

It is generally preferred to locate a steam-cycle power plant next to a large body of water (e.g., river, lake, or ocean). The available water can be used as a cooling fluid to remove heat from the steam used in the steam cycle. Colder water can help improve the system's efficiency.

Additional considerations for facility site selection usually include proximity to existing electrical infrastructure and fuel sources. The site should also be a suitable distance away from populated or environmentally protected areas.



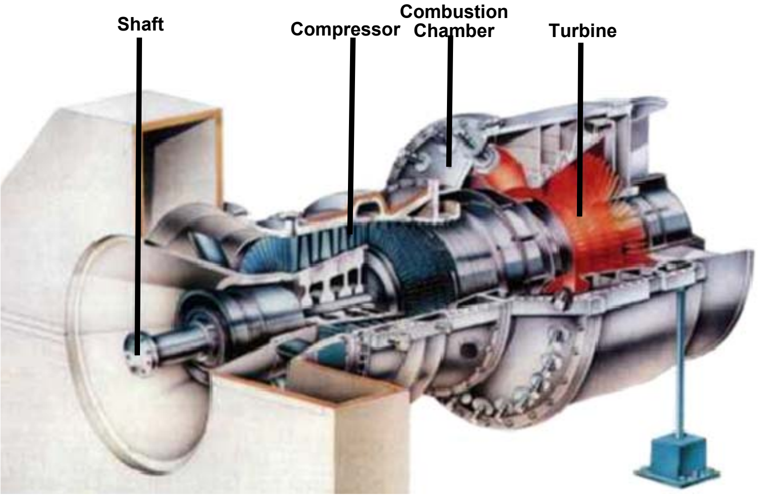
Advantages

- Steam generation is a well-established, commercially available technology that has been used since the late 1800s.
- Approximately 85% of the world's power generation is made up of some type of steam generation.

Challenges / Limitations

- The public may have a negative perception of power supplied by fossil fuels.
- Steam-cycle plants require more water per amount of energy produced when compared to combined-cycle plants.

Combustion Turbines



Combustion turbines (CTs), or **gas turbines**, use energy from the combustion of an air-fuel mixture to drive a **shaft**. The **compressor** draws air into the **turbine**, compresses it, and sends the compressed air into a **combustion chamber**. Fuel is introduced in the combustion chamber, and the hot exhaust gases drive the turbine section. The fuel's energy is transferred to rotational energy of the turbine shaft.

CTs generally fall into one of two categories. **Industrial / frame CTs** are robust machines designed exclusively for power generation applications. Smaller **aeroderivative CTs** are essentially stationary aircraft jet engines that have been modified for use in power generation applications.

CTs can be coupled to turn an electric generator or mechanical drive. They can be used independently (**simple-cycle** configuration) or with a heat recovery steam generator and steam turbine (**combined-cycle** configuration).

Siting Considerations

The quality and pressure of the natural gas supply are important for meeting minimum requirements to operate natural gas power plants. For increased performance, it is useful to consider cooler climates at lower altitudes.

Advantages

- Some CTs can be configured to operate on multiple fuel types, typically natural gas or liquid fuel. Should the primary fuel source become unavailable, the plant can operate on an alternate standby fuel.
- CTs have relatively low installed costs compared to other thermal generation technologies.
- CTs, when coupled with small on-site diesel or natural gas-fired generators, are capable of starting without grid interconnection (black start).

Challenges / Limitations

- Ambient conditions affect CT performance (e.g., hot conditions reduce efficiency and output).
- When compared to renewable generation like wind and solar, CTs have a longer permitting duration for new installations.
- Air emissions can become more difficult to control at low firing rates.
- The operating cost correlates with the cost of natural gas: higher gas prices = higher operating costs.

Simple-Cycle Combustion Turbines

An advantage of simple-cycle CTs (also known as the "**Brayton Cycle**") is that they have a moderate-to-good operational flexibility and therefore can more easily adapt to an area's load demands. They can be turned on or off relatively quickly, and units typically tend to have smaller output than combined-cycle plants. Therefore, they are often used in "peaking" operations. However, the efficiency of a simple-cycle CT is reduced at partial output levels—simple-cycle CTs have a moderate ability to run at part-load (turndown capability).

Combined-Cycle Power Plants

Combined-cycle power plants incorporate both the **Brayton Cycle** and **Rankine Cycle** concepts. In this configuration, multiple CTs can be used with a single steam turbine in a combined cycle. While this combination advantageously increases the power plant's efficiency, it also increases the amount of time it takes for the plant to reach full load. Natural gas, one fuel source option, is plentiful and relatively low cost in the United States; however, the plant should be located near a large gas pipeline and a transmission line to gain the full benefits.

Coal-Fired Power

For coal-fired power, coal is crushed and burned in a furnace (**boiler**) to boil water and generate **steam**; the steam spins a **turbine**, which turns an electric **generator**.

It typically includes multiple **heat recovery** sections to increase efficiency.

CPS Energy Coal Fired Plant – J.K. Spruce Power Plant 1 and 2

Siting Considerations

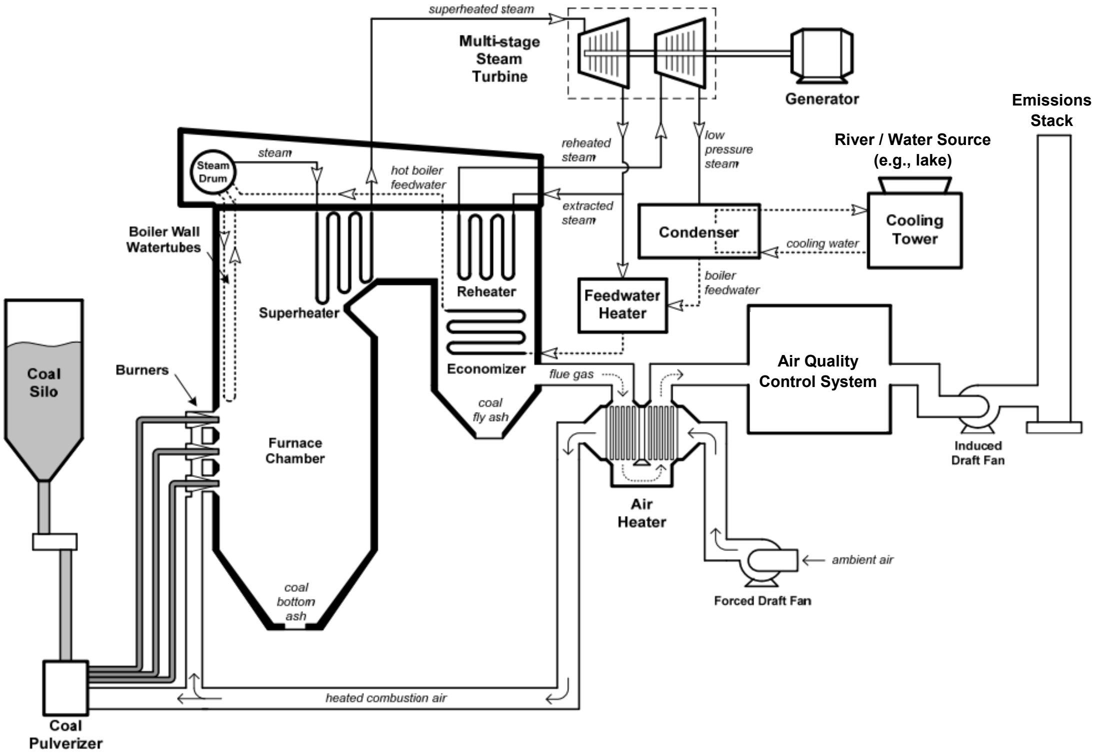
Coal-fired power plants typically require about 1,000 acres of space and are ideally located next to a coal mine, railroad line, river, or other waterway source for convenient coal delivery. Other considerations include a cooling water source, recycling opportunities for coal combustion byproducts, and disposal of coal combustion residuals

Advantages

- Coal is generally abundant and low in cost.
- Coal is easily stored on site.
- The facilities use well-established, reliable technology.

Challenges / Limitations

- Large coal quantities are needed (typically delivered by rail or with plants located near a mine).
- Coal plants have significant environmental regulations, pollution control requirements, and ash storage / disposal considerations.
- Plants have less operational flexibility than gas-fired combined-cycle plants and can take several hours to start.



Source: Office of Air and Radiation, U.S. Environmental Protection Agency. *Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from Coal-Fired Electric Generating Units.* October 2010.

Conventional Gas Power

Conventional gas power plants operate similarly to coal-fired power plants; however, they rely on natural gas for the fuel and require less supporting equipment and systems. Natural gas is **combusted** in a furnace (**boiler**) to boil water and generate **steam**; the steam spins a **turbine**, which turns an electric **generator**. It also typically includes multiple **heat recovery** sections to increase efficiency.

Siting Considerations

Like most other conventional steam power plants, large bodies of water (e.g., river, lake, or ocean) can be used as a source of cooling water for conventional gas power plants. The proximity and quality of the natural gas fuel source are also considered during site selection. A third consideration involves the availability and nearness of existing electrical infrastructure.

CPS Energy Conventional Gas Power Plant – Braunig 1, 2, and 3

Advantages

- Conventional gas power produces fewer emissions than coal-fired power.
- The facilities use well-established, reliable technology.

Challenges / Limitations

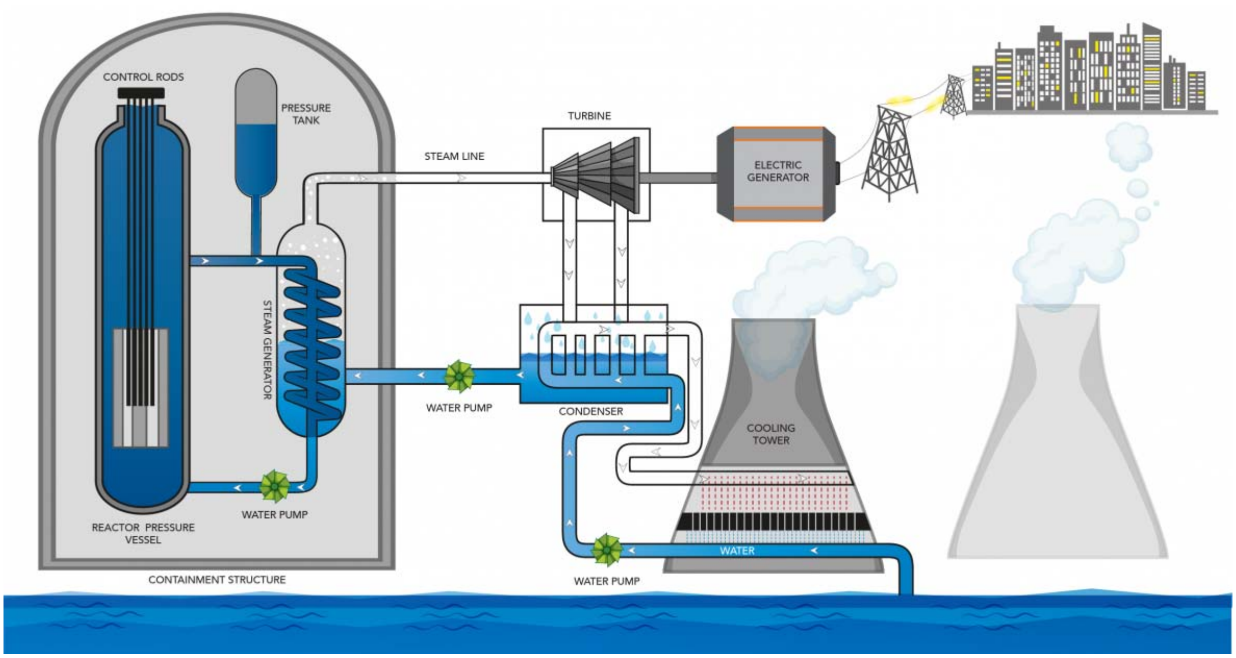
- Conventional gas power plants require more water per amount of energy produced when compared to a combined-cycle plant.
- Plants have less operational flexibility than gas-fired combined-cycle power plants, and they can take several hours to start.

Nuclear Power

Nuclear power plants generate **steam** by splitting **uranium 235** (U-235; the splitting process is called “nuclear fission”) in a **reactor** to heat water. The steam is used to spin a **turbine** that turns an electric **generator**. A small volume of fuel can create a large amount of energy without carbon emissions.

There are two main types of nuclear power reactors: **pressurized water reactors** and **boiling water reactors**. A newer type of nuclear reactor is the **small modular reactor**, and these units are significantly smaller than traditional pressurized water reactors and boiling water reactors.

Energy is produced continuously for 18–24 months, after which the plant is taken offline so the fuel can be replenished.



Pressurized Water Reactor | Graphic by Sarah Harman | U.S. Department of Energy

Siting Considerations

Safety and security are key aspects of nuclear power. The Nuclear Regulatory Commission regulates nuclear power in the United States to ensure the safety and security of the nuclear fleet. Similar to other traditional power plants, nuclear power plants are typically located near a river or other large body of water.

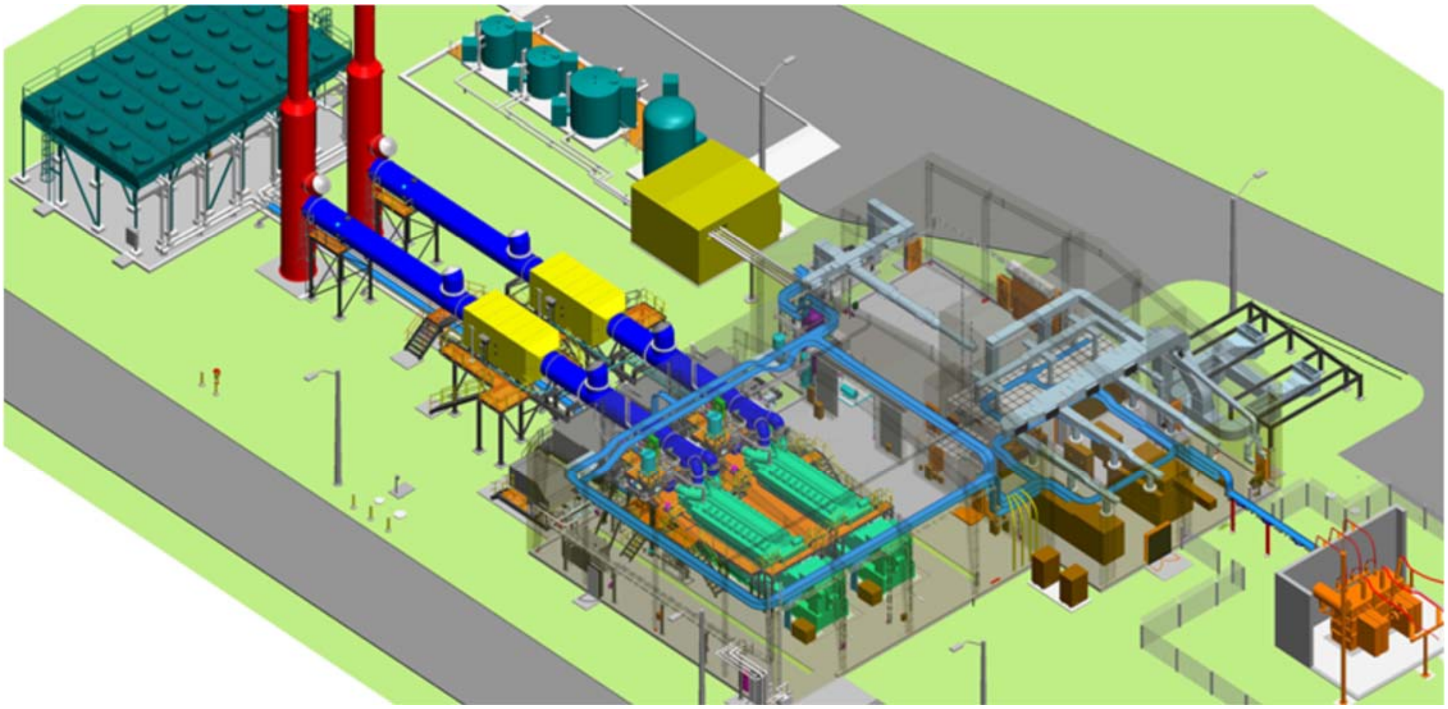
Advantages

- No greenhouse gas emissions.
- Reliable energy is produced continuously for 18–24 months, after which the plant is taken offline for fuel to be replenished.
- Long operating life; some licenses are extended for up to 80 years.

Challenges / Limitations

- Licensing new plants is a several years-long process to ensure all stakeholders can provide input and all environmental and social aspects are considered.
- Several high-profile accidents have created a perception that nuclear power poses a public safety concern.
- Stringent design criteria and quality requirements add complexity and scrutiny to a nuclear plant and add to the large capital investment.
- Spent (or “used”) fuel is stored on site. A long-term plan for storage has been in development for decades with no significant progress towards a politically acceptable solution.
- Plant operations and maintenance requires a large staff.

Reciprocating Internal Combustion Engines



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Reciprocating internal combustion engines (or "RICEs") are similar to engines used in fuel-powered vehicles. They combust an air-fuel mixture via **spark** or **compression ignition**, which drives a **piston** and turns a **crankshaft**. The crankshaft can be coupled to an electric **generator** for electric power generation.

RICEs have high efficiencies at both full- and part-load operations, which allows them to quickly respond to electrical load fluctuations, making this power generation technology a good complement to variable renewable energies.

Siting Considerations

RICE power plant sites are relatively compact when compared with coal and nuclear power plants. Multiple RICE units can be installed together to meet the generation requirements of the project. Due to the high noise level of RICEs, sound attenuation is a key aspect typically included in the design.

Advantages

- More efficient than simple-cycle CTs and have minimal efficiency reduction at partial output.
- Flexible operating capabilities and good load-following capabilities (e.g., fast ramp rates, short startup times, capable of multiple starts per day).
- Capable of high levels of turndown or part-load operations, especially when deployed with multiple generator sets.
- Can use a variety of liquid and gaseous fuels.
- Low sensitivity to ambient conditions.

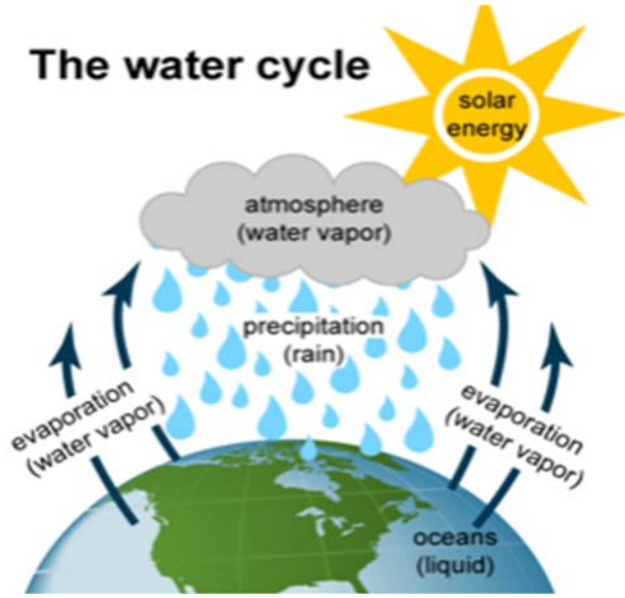
Challenges / Limitations

- Higher installed costs on a per-kW basis than simple-cycle CTs.
- The engines' high noise levels require consideration or mitigation. Depending on the location, additional mitigation may be required, which can increase costs.

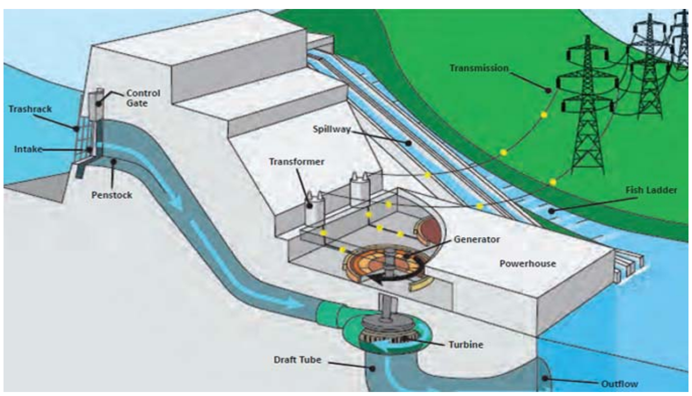
Hydroelectric Power

Hydroelectric power generation relies on water movement via the water cycle. Water from the surface of lakes, rivers, and oceans is evaporated by solar energy, which then condenses to form clouds and subsequently falls as precipitation. Conventional hydroelectric power involves building a dam in a river to create a reservoir that collects the precipitated water. Run-of-the-river hydroelectric power uses the natural river flow to generate electricity without a dam. In both cases, water flows via gravity from an elevated source through a water driven turbine, and it is released into a body of water at a lower elevation. The amount of precipitation and its variability in a given geographical area determines the amount of water available for hydroelectric generation.

According to a 2019 EIA publication, hydroelectric energy amounted for 6.6% of total U.S. utility-scale generation and 38% of total generation from renewables.



Source: U.S. Energy Information Administration. "Hydropower explained." n.d.



Source: Office of Energy Projects, Federal Energy Regulatory Commission. From *Hydropower Primer: A Handbook of Hydropower Basics.* February 2017.

Siting Considerations

The ideal location for a hydroelectric plant would be along the path of a river where it narrows and allows for collecting water for generation or diversion of the river. The flow of water from the water source must be high enough to overcome the loss of water through evaporation from the collection area to maintain energy production through the lifetime of the project. The land and man-made structures must be capable of holding back the weight and force of water and withstanding earthquakes. Materials used should be of high quality to meet long-term operational goals.

Advantages

- Quick startup and high ramp rates makes hydroelectric power able to respond to rapidly changing energy demands.
- Ability to store water at a low cost for dispatch later as a high-value clean energy.
- Can be created to serve specific industrial enterprises.
- Has the lowest lifecycle greenhouse gas emissions for power generation.
- Reservoirs can be used for irrigation support and to control floods downstream.
- Can provide startup power in case of a system-wide failure.

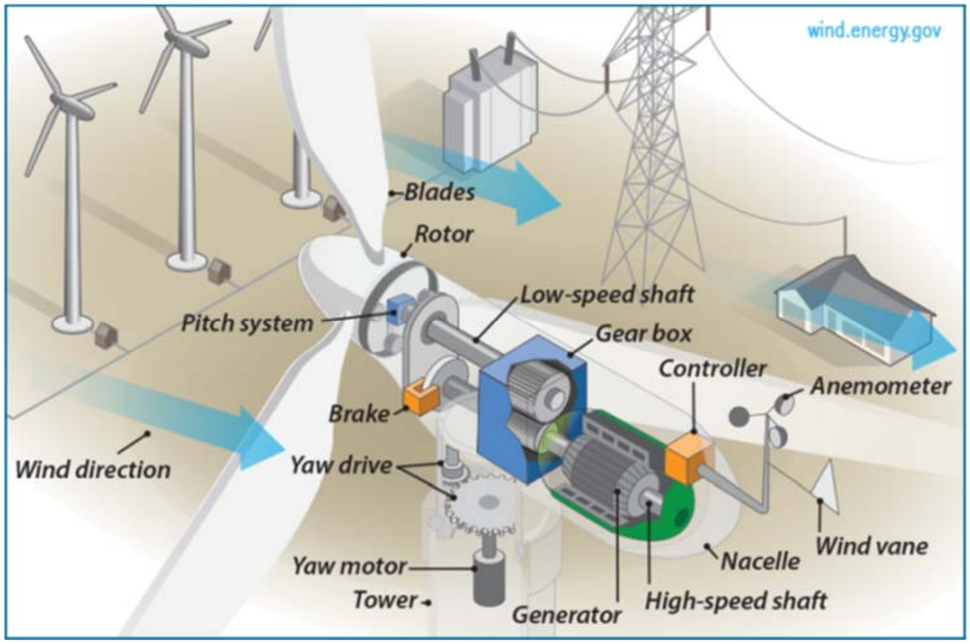
Challenges / Limitations

- Continual water losses due to evaporation reduce the available energy stored in the reservoir.
- Project siting can result in ecosystem damage, loss of land, and relocation of human population.
- Risks of dam failure exists even after decommissioning the power generation equipment.
- Subject to siltation and flow shortages.

Wind Power

Wind power projects use wind turbines to convert kinetic wind energy into electrical power. Lift is generated when wind flows around **blades**, which results in the blades rotating. The blades connect to a **central hub** and **drivetrain**, which turns a **generator** inside the **nacelle** (the housing unit atop the turbine tower). Longer blades increase the amount of energy created by the wind turbine; thus, many wind turbines are tall with long blades.

Numerous wind turbines are installed together in modern wind projects. The layout is engineered in such a way to maximize the output of each wind turbine.



Source: Office of Energy Efficiency & Renewable Energy, U.S. Department of Energy, *Animation: How a Wind Turbine Works.*

Siting Considerations

Wind power projects are typically located in rural areas, such as farms and ranches, with medium to high winds. Although wind turbines create a "*whoosh*" sound when operating, two people can typically carry a conversation when standing under a wind turbine on a windy day.

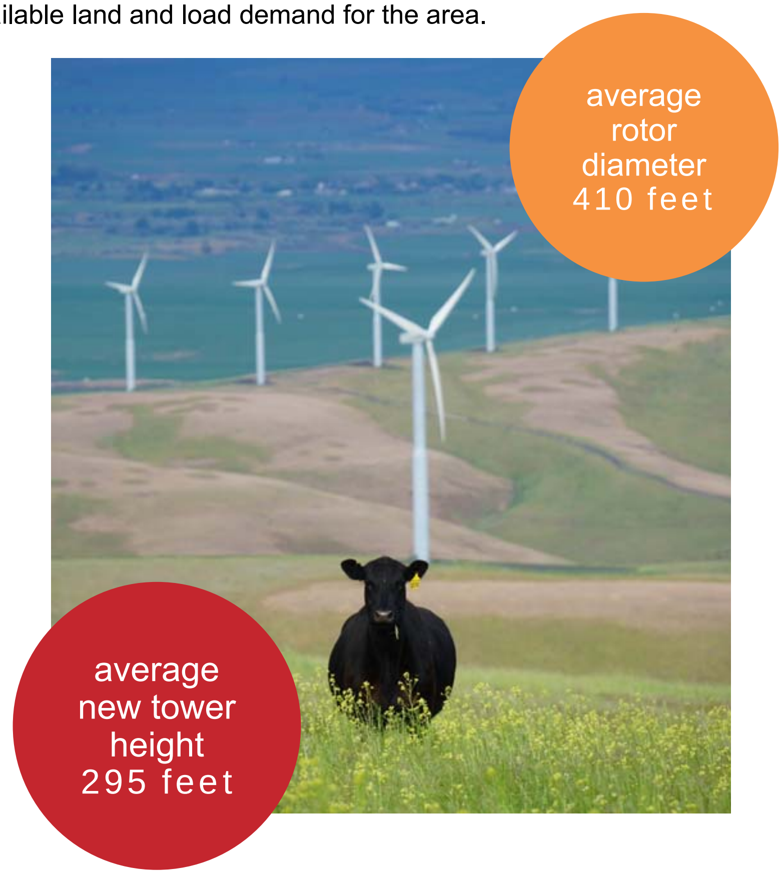
Environmental impacts to wildlife and visual impacts such as shadow flicker from the blades are also considered. The size of a project is dependent on the available land and load demand for the area.

Advantages

- Wind power is a zero-emission generation source.
- Land around the wind turbines can be used for other purposes (e.g., farming, ranching).
- Wind power projects use little to no water to operate.

Challenges / Limitations

- The fuel resource (wind) is non-dispatchable, variable, and intermittent.
- There is potential for audible, visual (e.g., aesthetic and shadow flicker), and environmental (e.g., avian) impacts; therefore, wind turbines are typically located away from urban / suburban areas.
- For efficient use, it is best to have wind projects in an area with a good, stable wind resource and near transmission lines capable of bringing the generation to the load / people using it.



Solar Power

Utility-scale solar power typically uses **photovoltaic** (PV) solar panel technology to generate electricity. The PV panels connect to **inverters**, and **transformers** bring the electricity to the grid. **Trackers** are sometimes used to increase the output of the solar plant. The trackers can be single-axis (e.g., move on a horizontal axis) or dual-axis (e.g., move on both a horizontal and vertical axis).

Solar power has increasingly been paired with battery energy storage so the energy can be stored and used when it is needed.

Siting Considerations

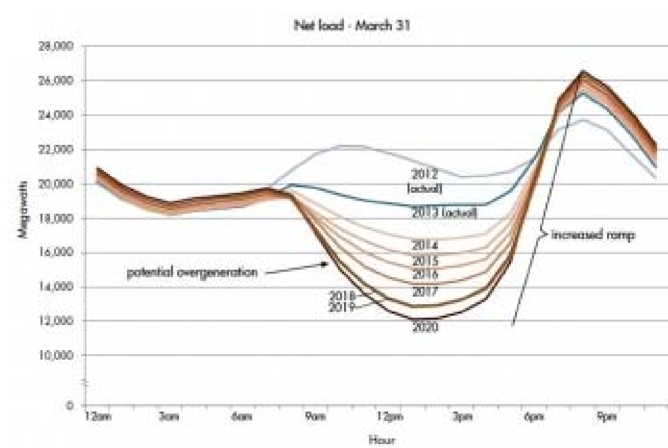
Solar power projects typically do best in areas with many sunny days located away from shadow sources. A flat, square, or rectangular surface away from tall buildings and trees is ideal; however, solar power projects can be installed in various locations. Avoiding proximity to airports is also important to consider since the glare from the PV panels can be problematic for pilots.

Advantages

- Solar PV is a zero-emission generation source.
- Solar power projects use little to no water to operate.
- Solar power projects can be scaled to almost any size.
- The technology is well defined and relatively simple.

Challenges / Limitations

- The fuel resource (i.e., sun) is non-dispatchable, variable, and intermittent and not as reliable as thermal generation sources like CTs since it is only available during the day and not available when there is cloud cover (or other obstruction like a tree / building shadow).
- Large amounts of solar power (without storage capabilities) can lead to a “duck-curve.” While the sun is shining, solar power can meet a significant amount of the demand. As the sun sets and early evening air-conditioning load increases, there is a sharp increase in the amount of other generation sources needed to meet the load.
- There is a large land requirement for utility-scale plants (approximately 4–8 acres of land is required to produce 1 MW of capacity); however, as the efficiency of panels increases, the land required is reduced.



Courtesy of California Independent System Operator

Geothermal Power

Geothermal energy harnesses heat (thermal energy) that is stored in the earth. **Steam** produced miles beneath the earth's surface—found in reservoirs of hot water—rotates **turbines** that convert this energy into electricity via a **generator**.

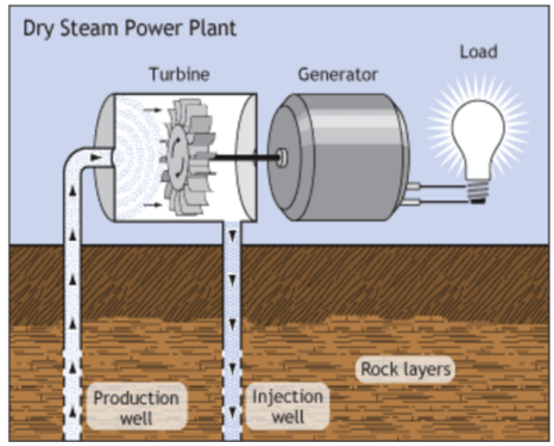
There are three main geothermal plant types: dry steam, flash steam, and binary cycle. These systems use naturally occurring aquifers that already contain hot liquid water or steam and are known as hydrothermal geothermal systems.

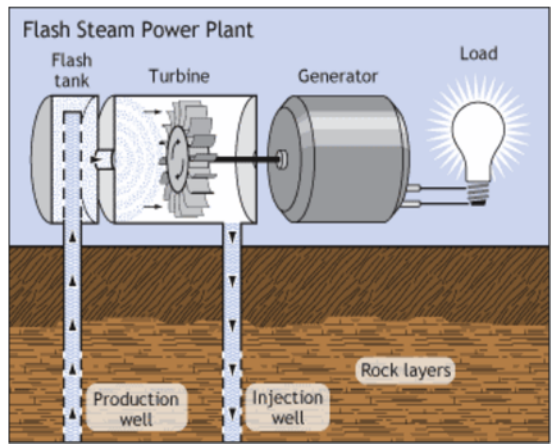
Dry steam power plants pump steam directly from underground wells to the power plant where the steam is then directed to the generator turbine. Dry steam is the most common type of existing geothermal power plant.

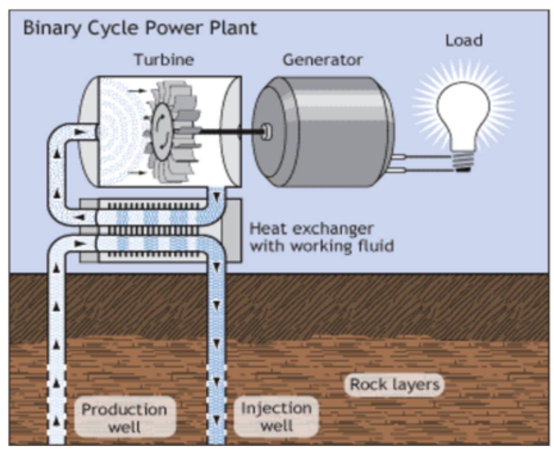
In **flash steam** power plants, hot water (typically greater than 360°F) flows up to the earth's surface, through wells, under its own pressure. As the water rises, pressure releases and some of the water "flashes" or boils into steam, which can then be separated and used to turn the generator turbine.

In **binary cycle** power plants, the geothermal water is passed through one side of a heat exchanger, where heat is transferred to a second (binary) liquid, called a working fluid. Typically, a binary cycle power plant utilizes a working fluid that boils at a lower temperature and can operate at temperatures of 225–360°F. The working fluid boils to vapor, which, like steam, powers the turbine generator. The working fluid is then condensed back to a liquid to be used again. Many new geothermal power plants are proposing binary cycle.

The U.S. Department of Energy actively supports research and development of enhanced geothermal technology, which is the injection of hot water or steam into porous rock structures to create electricity. As various types of this technology become commercially viable, new, more efficient methods of tapping the earth's heat for useful energy are likely to emerge.







Source: U.S. Department of Energy

Siting Considerations

Site location is important for geothermal energy generation because this technology relies on naturally occurring heat sources. While there is potential for development in eastern Texas, the western United States is a naturally more favorable location for geothermal energy generation.

Advantages

- Minimal land use for facilities, much of which can be reclaimed after drilling and construction are complete.
- Low or no emissions.
- Low operations costs due to lack of fuel costs.

Challenges / Limitations

- High site exploration costs, as extensive field research must be completed to ensure that the site is a viable location.
- Have low thermal efficiencies compared to conventional thermal power plants (e.g., coal or gas).

Biomass Power

Biomass power generation is a type of renewable energy that relies on organic material (**biomass fuel**) for the generation of electricity. Common examples of biomass fuel include wood, corn, and sugarcane. Other fuels like human waste and landfill gas can also be used.

The most common type of biomass power generation burns biomass fuel to heat water, creating **steam** that can turn **turbines** to generate electricity, similar to other steam-cycle generation alternatives. Biomass fuels can also produce power through a bacterial decomposition process or be converted to a gas or liquid to generate electricity.

CPS Energy Landfill Gas Plant – Covel Gardens

Siting Considerations

Due to the wide nature of fuels that biomass generation facilities can use, biomass power projects can be sited near any reliable fuel source where access to transmission lines and cooling water are available. Immediate access to any biomass fuel is helpful, but not required, for biomass generation; however, fuel delivery to the site is essential.

Advantages

- An abundance of biomass fuels can provide inexpensive fuel.
- The wide variety of fuel resources provides multiple options for development opportunities.
- Using waste products can reduce the amount that ends up in landfills.
- Biomass energy projects are generally accepted as carbon-neutral. Fuels are typically renewable organic waste.

Challenges / Limitations

- Burning biomass fuel can create NO_X and particulate emissions.
- Producing crops like corn, soy, or sugarcane for fuel requires large amounts of land.
- Has a low power density when compared to traditional fossil fuels.

Hydrogen Power

Hydrogen is considered a zero-emission fuel, which can be used to generate electricity, typically via a hydrogen fuel cell or as a fuel for a combustion turbine. Hydrogen has been used in fuel cell powered buses and in spacecraft propulsion systems for many years. When burned on its own, hydrogen's only combustion product is water vapor. Hydrogen, in varying concentrations, can also be burned with natural gas in combustion turbines to produce electricity.

Hydrogen for fuel use is typically produced through partial oxidation of natural gas or through electrolysis of water. Partial oxidation of natural gas is a high-temperature process in which steam reacts with methane to produce hydrogen. About 95% of hydrogen produced today is through this process, however Carbon Dioxide and Carbon Monoxide gases are released in the process, which contribute to global warming. Electrolysis is an electro-chemical process where electricity is used to split water molecules into constituent gases, hydrogen and oxygen. Electrolysis has no direct emissions resulting from the production of hydrogen.

To reduce fleet carbon emissions, several leading utilities and power generators have begun planning for generation of hydrogen from renewable energy resources. This hydrogen could be stored for later consumption in existing, or new, combustion turbines. Energy sources for this green production of hydrogen generally originate from wind, solar, or hydroelectric generation, which ultimately power electrolysis systems to produce hydrogen without direct, or indirect, release of greenhouse gases. Green hydrogen production is typically scheduled for periods of high renewable penetration, to take advantage of low grid supplied power prices.

Hydrogen produced during periods of high renewable penetration can be stored on-site, and can be later consumed in the plant's combustion turbines during periods of low renewable penetration. Co-firing a blend of hydrogen and natural gas can be accommodated in many existing turbines, up to certain hydrogen percentages. This co-firing results in reduced carbon emissions due to the reduction in natural gas combusted in the turbines. Most major turbine manufacturers have the ability to co-fire in the existing fleet, with minor modifications to the existing turbines. These manufacturers are also actively involved in research and development to implement 100% firing of hydrogen in the next generation of combustion turbines.

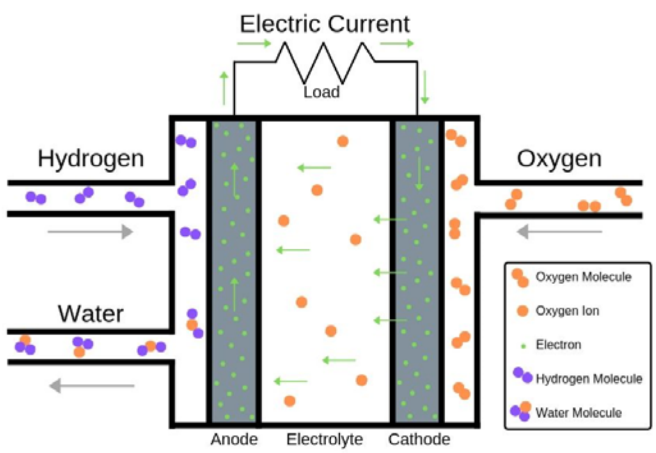
Siting Considerations

Hydrogen produced through various processes is liquified under high pressure, and stored and transported in cylinders for industrial use. Current infrastructure does not exist to produce hydrogen on a commercial scale, to store, transport, or distribute hydrogen in large quantities. Considerable infrastructure costs will have to be incurred before hydrogen can become a reliable fuel source for transportation. Safety is a major consideration when trying to build large hydrogen storage stations. Hydrogen is a flammable gas and any system handling must be designed to address the specific hazards it poses.

Advantages

- Hydrogen is an attractive transportation and energy fuel alternative to reduce dependence on fossil fuels and to lower pollution and greenhouse gas emissions.
- If produced from renewable resources, hydrogen fuel would have near-zero air pollutant emissions. Cleaner air would lead to health and environmental benefits.

Hydrogen Fuel Cell



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Challenges / Limitations

- Hydrogen's ease of ignition and its liquid storage at high pressures (10,000–15,000 psi) represent significant fire and explosion risks. Hydrogen’s ability to attack and damage storage containers, piping, and valves through hydrogen embrittlement must also be considered when considering large-scale storage and use.
- Cost of fuel cells will have to come down substantially without compromising safety and performance to make hydrogen a viable fuel alternative.
- Will require federal and state governments to implement and sustain a long-term energy policy to incentivize hydrogen as a viable fuel source.

Energy Storage

Energy storage systems are technologies connected to the electric grid that capture energy and store it to use later. There are many types of energy storage technologies, but all use a common three-step process:

1. **Charge** the energy storage technology with power from the electrical grid.
2. **Store** the energy for use later.
3. **Discharge** the stored energy when it is needed most.

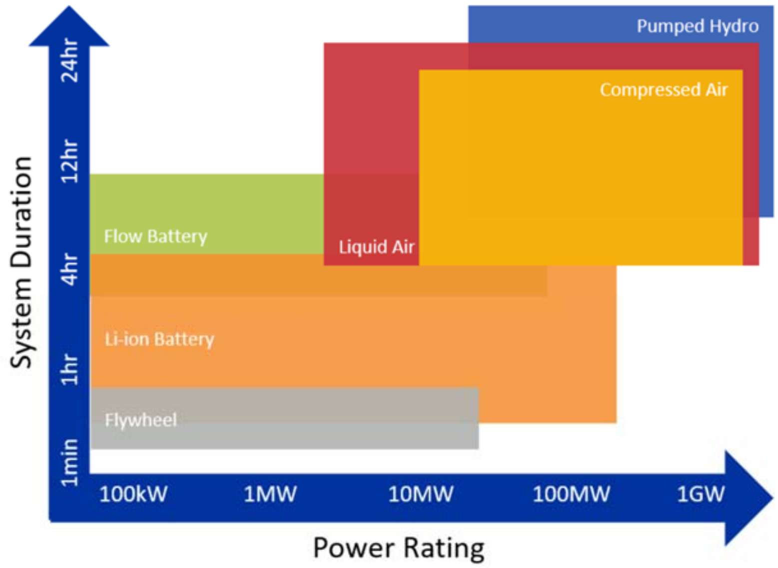
The energy is created by another source; energy storage systems are only the means to store and discharge electricity as needed. These systems are beneficial since they can use power at low cost periods to charge the storage system, and recover the energy when power costs are high, such as by *load shifting* or *peak shaving*. They can also be used to balance electricity needs with intermittent renewable energy (such as wind and solar). Additionally, energy storage can help stabilize the grid by providing *frequency regulation*, *voltage regulation,* and other power quality services.

Several types of energy storage systems are discussed on the next few pages.

Types of Energy Storage Systems

	Technology Overview	Technology Maturity / Installed Projects	Siting Considerations
Lithium-Ion (Li-ion) Battery Energy Storage	A chemical is used as the medium in a reversible electrochemical process to store and discharge electricity. There are nearly unlimited size configurations; battery cells are linked together to create desired voltage, capacity, and energy.	Thousands of projects installed worldwide.	Can be placed in almost any location; it is quiet and easily disguisable. Opportunity to place near intermittent power projects to provide reliability and resiliency to the grid.
Compressed Air Energy Storage (CAES)	Mechanical process to compress air that is stored in a reservoir, then released to spin a modified gas turbine generator to create electricity. Storage of the compressed air can either be constant pressure or constant volume.	< 5 commercial projects installed worldwide with the oldest installed in 1978. There is large potential as additional reservoir options are developed.	Plants typically require approximately 20–60 acres of land. For constant volume CAES systems, it is convenient to repurpose existing structures such (e.g., abandoned mines) for energy generation. Constant pressure CAES systems have typically required the storage vessels be built on the floor of a water source, usually the ocean.
Liquid Air Energy Storage (LAES)	A thermal mechanical process to cool down air to liquid form, which is stored in an insulated tank. Liquid air is then gasified to drive a turbine generator and create electricity.	Pilot and demonstration projects are still in development. The first commercial plant is planned to be operational in 2020 with additional projects planned to follow.	Does not require large amounts of land; a 50 MW, 300–500-MWh system requires approximate 2–3 acres. Locating it near existing thermal processes can allow for increased efficiency with use of waste heat from process.
Pumped Storage Hydroelectric	Water is stored in two reservoirs at different elevations—an upper and lower reservoir. Water flows from the upper reservoir to the lower reservoir via gravity through a turbine to create electricity. The storage system is charged by pumping water from the lower reservoir to the upper reservoir.	In use since 1920s. Most common energy storage installed worldwide (approximately 97% of energy storage capacity)	Requires a water source with a change in elevation.
Flywheels	Mechanical process that stores kinetic energy in a spinning or rotating mass. Flywheels are charged by a motor-generator to increase the speed of the mass. When the energy is needed, the rotational force drives a turbine-like device to produce electricity, slowing down the mass.	Well established; many projects installed worldwide.	Can be placed in almost any location; quiet and easily disguisable. Appropriate containment of the rotor is important for safety.
Flow Battery	Electrochemical storage device in which two liquid chemicals are separated by a membrane to store energy. When the chemicals pass each other, electrolytes pass from one chemical to the other, charging or discharging the battery, depending on which way the electrolytes are flowing.	Initially developed in the 1970s. Many projects have been installed and the technology is gaining prominence.	Can be placed in almost any location; it is quiet and easily disguisable. There is an opportunity to place it near intermittent power projects to provide reliability and resiliency to the grid. Environmental and safety containment features for potential electrolyte spills should be considered.

In this table, the Technology Maturity is an indicator of how established the technology is and number of projects installed. **Green** shading indicates that the technology is relatively mature. **Yellow** shading indicates that the technology is in the early stages of widespread commercial deployment.



Sizing

The size of an energy storage system is determined by both power and energy:

- **Power** capacity = kW (similar to a water hose—how much water can be released in a given time).
- **Energy** capacity = kWh (similar to a water storage tank—the amount of water that can be stored).

In selecting an energy storage system, it is important to consider both the power and energy requirements, which will determine the duration (e.g., a 4-MW / 20-MWh battery will provide five hours of energy). Different technologies are better suited for either short- or long-duration storage.

Uses	Advantages	Challenges / Limitations
Best suited for short-duration needs (up to 4-hour discharge); fast response time.	• High round trip efficiency (85%–95%). • No emissions. • Environmental permits (e.g., water or air) are typically not required. Permitting of projects is instead driven by local requirements, which can be less cumbersome to obtain.	• Short lifetime (< 10 to 15 years, or 10,000 to 20,000 cycles). • Fire concern with Li-ion batteries; fire prevention systems and HVAC system. • Degrades over time and requires recycling of spent batteries; can be accelerated by increased use.
Best suited for extended duration needs (up to 8–12-hour discharge or more).	• Uses proven equipment. • Uses less fossil fuels (diabatic CAES) than conventional technologies (with a heat rate of approximately 4,000–6,000 Btu/kWh) or no fossil fuels (adiabatic or A-CAES). • Can be combined with exhaust heat supplied to or from nearby industrial zones to increase round trip efficiency.	• Requires large storage area (can repurpose existing structures such as mines). • Efficiency can vary greatly depending on type of compressed air storage.
Best suited for extended duration needs (up to 8–12-hour discharge).	• Uses proven equipment. • No emissions. • Each process (charge, store, discharge) can be sized independently. • Can be combined with exhaust heat supplied to or from nearby industrial zones to increase round trip efficiency.	• Longer time to charge the system than discharge (about 2 times as long to charge as to discharge).
Best suited for extended duration needs (up to 8–24-hour discharge).	• Well established technology. • No emissions.	• Long licensing timeframe compared to batteries. • Perception of negative environmental impacts. • Requires large areas of land; • Efficiency and financial adequacy are strongly tied to elevation changes and geography.
Best suited for very short-duration storage (seconds to minutes) or other high power (MW) / low energy (MWh) applications	• High round trip efficiency (up to 95%); operating in a vacuum can increase the efficiency. • Can be cycled frequently with limited degradation. • Low O&M costs.	• Historically high-cost systems with complex designs. • Self-discharge at a higher rate when compared to other storage technologies.
Best suited for long-duration storage (> 6 hours).	• No emissions. • Limited degradation over the life of the battery. • Can operate over a wide temperature range (when compared to Li-ion batteries).	• Have a low energy density, requiring large storage tanks to increase the capacity of a system. • While not typically a concern for normal operations, some flow battery materials can become environmental contaminants.

Energy Storage Technology Comparisons

	Li-ion Battery Energy Storage	Compressed Air Energy Storage	Liquid Air Energy Storage	Pumped Hydroelectric	Flywheels	Flow Battery
Typical Capacity Range (per Unit)	5 kW–400 MW 10 kWh–2.5 GWh	10–400 MW 40 MWh–2 GWh	5–200 MW 20 MWh–5 GWh	> 100 MW > 5 GWh	2 kW–20 MW 6 kWh–5 MWh	5 kW–30 MW 100 kWh–120 MWh
Typical Efficiency* (%)	85–90	50–70	50–70	70–85	60–95	65–85
Typical Startup Time	Almost Instantaneous	3–10 minutes	< 1 minute	5 seconds–10 minutes	Instantaneous	Almost Instantaneous
Construction Lead Time Before Operational (Months)	6–8	12–24	12–24	72+	6–18	6–12
Water Usage	Minimal	Low to Medium	Minimal	Significant	Minimal	Minimal
Operating Life (Years & Cycles)	10–15 years 500–10,000 cycles	25–50 years (expected life) 5,000–20,000+ cycles	30–40 years (expected life) 5,000–20,000+ cycles	50–60 years 5,000–20,000+ cycles	20 years 200,000+ cycles	15–30 years 10,000+ cycles
Installed Capital Cost ($/kWh)	$200–$600/kWh	$90–$200/kWh	$120–$200/kWh	$100–$200/kWh	$4,300–$11,500/kWh****	$400–$1,300/kWh
Fixed O&M Cost ($/kW-yr)*	10–30	15–20	5–30	15–30	5–8	8–20
Variable O&M Cost ($/MWh)	**	2–3	1–2	**	**	**
Levelized Cost of Storage* ($/MWh)**	165–325	100–200	100–250	150–400	200–800	200–700

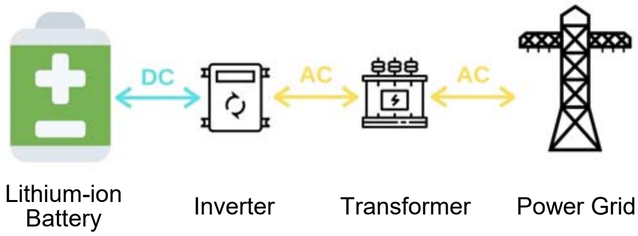
* The round trip efficiency excludes the efficiency of charging energy.

** All O&M costs are treated as fixed costs for the battery storage, pumped hydro, and flywheel technologies.

*** The levelized cost of storage (LCOS) is a measurement of costs over the lifetime of a storage project divided by the total electricity discharged. The costs include annual fixed charges on the capital investment, O&M costs, charging costs, and augmentation costs. Revenues received during electricity discharge and from ancillary services are not included in the LCOS.

**** Flywheels are typically only used for short-term energy storage (less than one minute).

Li-ion Battery Energy Storage



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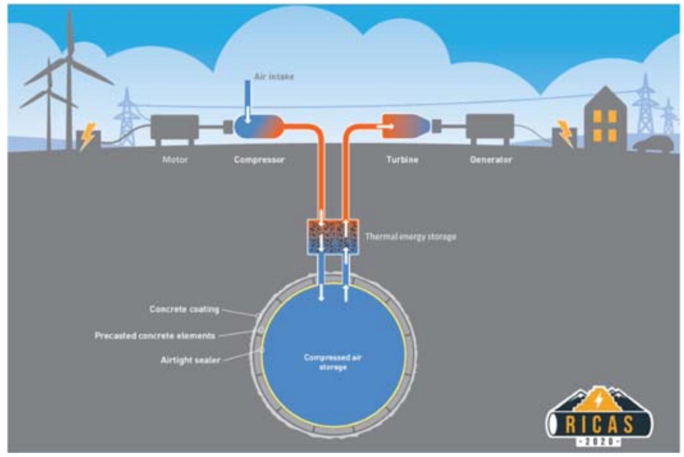
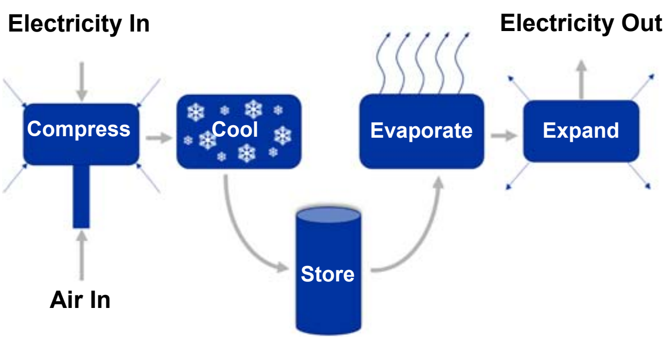
Compressed Air Energy Storage



A-CAES Example System
Courtesy of RICAS 2020 R&D project

Liquid Air Energy Storage



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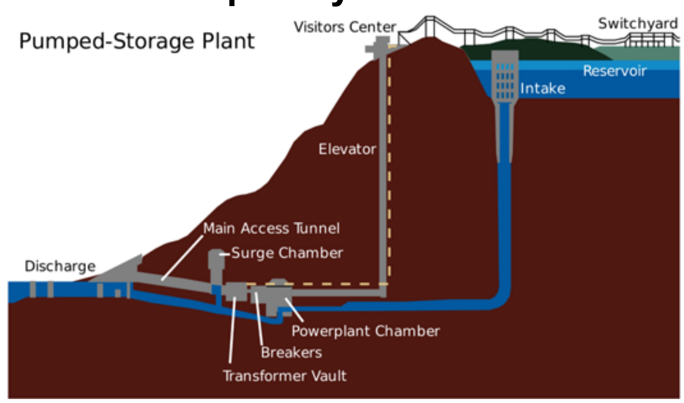
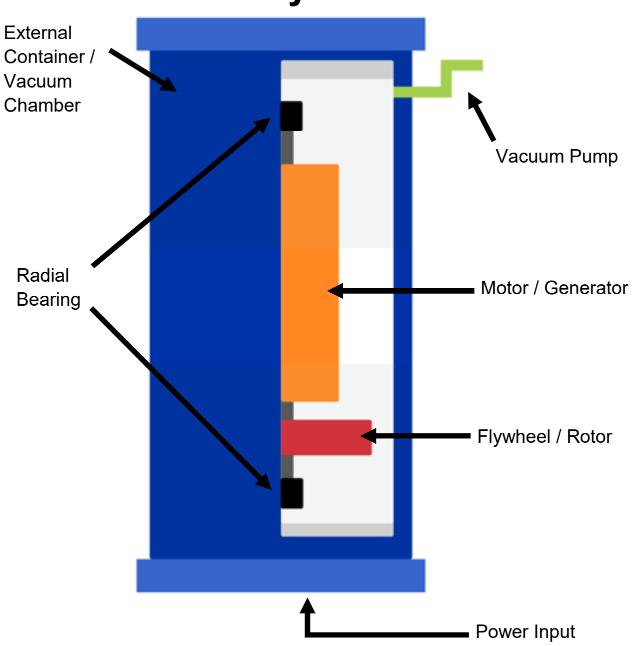
Pumped Hydroelectric



Public Domain | Raccoon Mountain Pumped-Storage Plant

Flywheel



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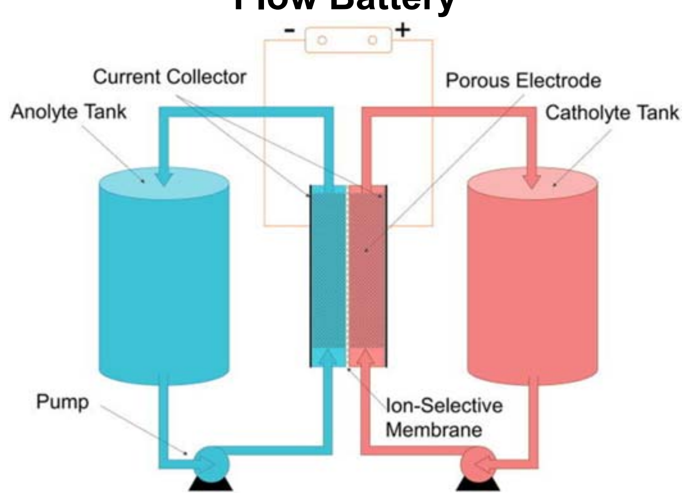
Flow Battery



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Power Generation Technology Comparisons

	Typical Capacity Range (Per Unit)	Typical Capacity Factor (%)	Typical Efficiency (%)	Typical Minimum Output Capability	Typical Heat Rate (Btu/kWh)	Fuel Type
Simple-Cycle Combustion Turbine	1–425 MW	1–20	20–40	25%–50% of Nominal	8,000–12,000	Natural Gas / Diesel / Fuel Oil
Combined-Cycle Plant	300–1,000 MW	30–90	40–60	25%–50% of Nominal	6,000–9,000	Natural Gas / Diesel / Fuel Oil
Coal-Fired Power	100–650 MW	50–80	35–45	25%–50% of Nominal	8,000–14,000	Coal
Nuclear Power	600–1,000 MW	90–98	30–40	30%–70% of Nominal	9,000–12,000	Nuclear
Small Modular Reactors	10–300 MW	85–98	30–50	20%–70% of Nominal	6,000–12,000	Nuclear
Reciprocating Internal Combustion Engine	10 kW–18 MW*	10–50	30–50	10% of Nominal	7,000–10,000	Natural Gas / Landfill Gas / Diesel / Fuel Oil
Hydroelectric Power (Conventional)	1–22,500 MW	20–95	85-–90	0%–100% of Nominal	Not Applicable	Water
Wind Power	1.5–5 MW* (typical onshore wind turbine size)	35–50	35–45	Not Applicable	Not Applicable	Wind
Solar Power	Not Applicable	10–35	15–30	Not Applicable	Not Applicable	Sun
Geothermal Power	1–300 MW	70–90	5–20	15%–20% of Nominal	Not Applicable	Natural Steam
Biomass Power	0–75 MW	50–95	30–40	40%–50% of Nominal	13,300	Organic Matter / Landfill Gas / Biofuel

* Typically configured in multi-unit installations to meet the generation requirements of the project.

Typical Startup Time	Construction Lead Time Before Operational (Months)	Water Usage	Operating Life (Years)	Installed Capital Cost ($/kW)	Fixed O&M Cost ($/kW-yr)**	Variable O&M Cost ($/MWh)	Levelized Cost of Energy**** ($/MWh)
5–30 minutes	18–20	Low to Medium	40	700–950	5–20	3–6	70–150
1–2 hours	30–36	Low to Medium	40	700–1,300	10–30	1–8	40–70
4–8 hours	60+	Significant	40	3,000–6,250	35–70	3–12	65–155
12–24 hours	72+	Significant	40–80	6,000–12,200	90–130	2–6	115–195
30 minutes –5 hours	60–72+	Significant	20–80	2,500–9,000	95–145 (can be higher for smaller SMRs)	2–4	50–120
< 5 minutes	30	Minimal	30	1,300–2,000	13–40	4–8	60–100
60–90 seconds	24–204	Significant	50–100	1,050–8,000	20–25	***	20–270
Not Applicable	10–16	Minimal	25–30	1,100–1,700	5–56	**	25–60
Not Applicable	9–12	Low	25–30 (expected life)	900–1,100	15	**	30–45
5 hours	60+	Low to Medium	40	2,500–5,000	125–130	1–5	35–40
3–5 hours	60	Low to Medium	40	3,500–5,000	120–130	4–5	50–180

** All O&M costs are treated as fixed costs for the solar, wind, and battery storage technologies.

*** Hydroelectric generation does not have wastes/consumables related to energy production. Variable O&M cost is considered Not Applicable by ISO.

**** The levelized cost of energy represents the average revenue per unit of energy production that would be required to recover all investment and operating costs over a specified project financial life. Levelized cost of energy comparisons across technologies may be misleading because of differences in economies of scale, capacity factors, and other system-specific factors.

About CPS Energy

Established in 1860, CPS Energy is the nation's largest public power, natural gas and electric company, providing safe, reliable, and competitively-priced service to 840,750 electric and 352,585 natural gas customers in San Antonio and portions of seven adjoining counties. Our customers' combined energy bills rank among the lowest of the nation's 10 largest cities—while generating $7 billion in revenue for the City of San Antonio for more than seven decades. As a trusted and strong community partner, we continuously focus on job creation, economic development and educational investment. True to our ***People First*** philosophy, we are powered by our skilled workforce, whose commitment to the community is demonstrated through our employees' volunteerism in giving back to our city and programs aimed at bringing value to our customers. CPS Energy is among the top public power wind energy buyers in the nation and number one in Texas for solar generation.

CPS Energy by the Numbers

Industry Leader
Among the lowest rates of Top 10 largest U.S. cities

3,100
employees

#7
in nation for annual installed solar power

#1
for solar generation in Texas

gas customers
352,585

#24
100 Best Fleets in the Americas
2018

Among largest municipal wind buyers in nation with
1,066 MW
wind capacity

electric customers
840,750

Recognized as
Environmental Champion
2017, 2018, 2019

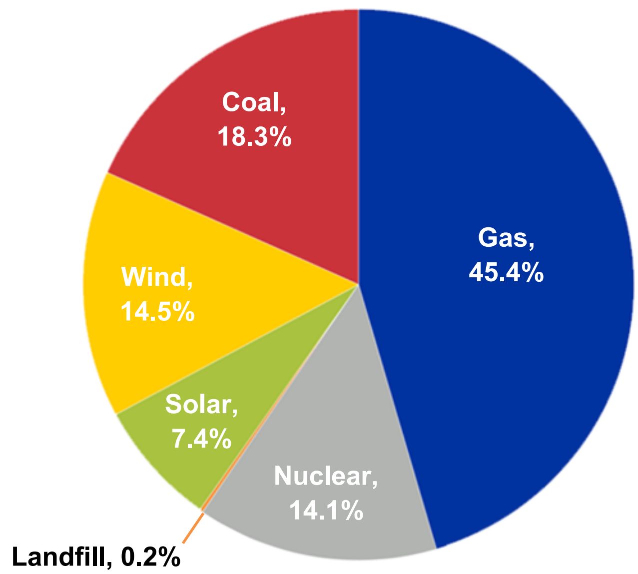
most
trusted brand
in U.S. southern region
2017, 2018

CPS Technology Overview

CPS Energy has a portfolio of different energy sources:

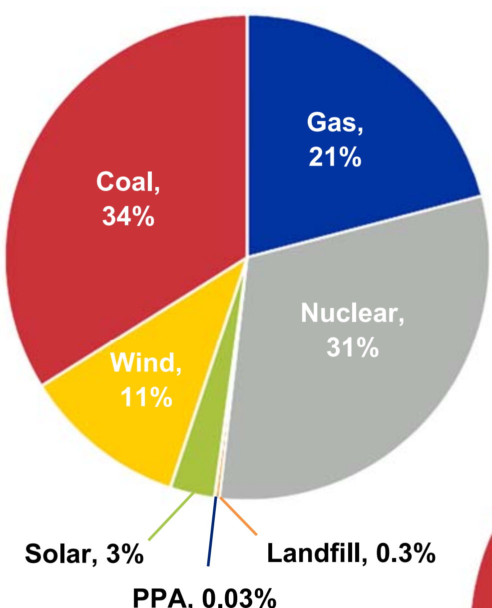
- 15 natural gas units at 6 plants providing approximately 3,380 MW.
- A 40% stake (approximately 1,041 MW) in South Texas Project Electric Generating Station, a nuclear power plant. Shares ownership with NRG Energy and City of Austin.
- Operates the two-unit J.K. Spruce Coal Plant (1,300 MW).
- Purchases 553 MW of solar power from 16 solar plants—the most in Texas.
- Purchases 1,066 MW wind power from several wind farms located in West Texas and along the Texas coast.
- The Covel Gardens (9.6 MW) and Nelson Gardens (4.2 MW) landfill gas plants that provide approximately 14 MW of renewable energy.

Fleet Capacity by Fuel Type

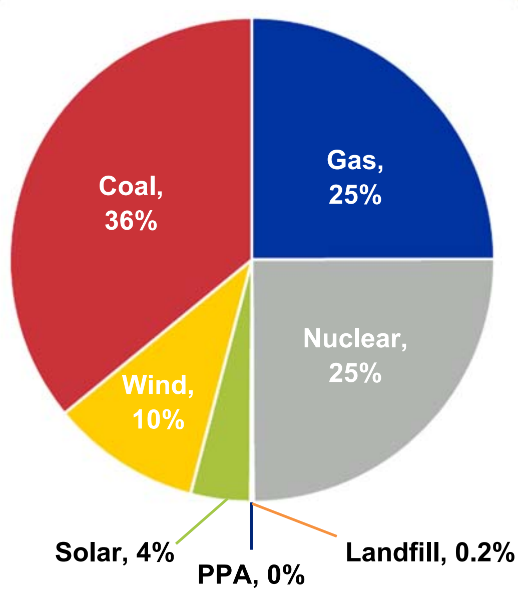


Annual Generation by Fuel Type

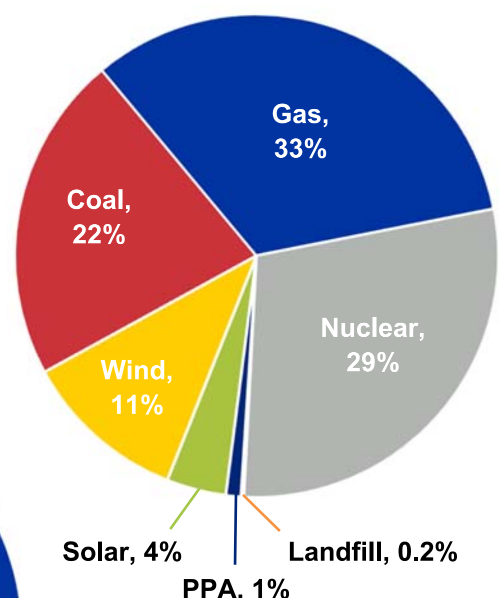
2017



2018



2019



Nuclear
South Texas Project

Gas
Arthur von Rosenburg Plant

Wind
Desert Sky Wind Farm

Coal
J.K. Spruce Coal Plant

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