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# History of Power: The Evolution of the Electric Generation Industry

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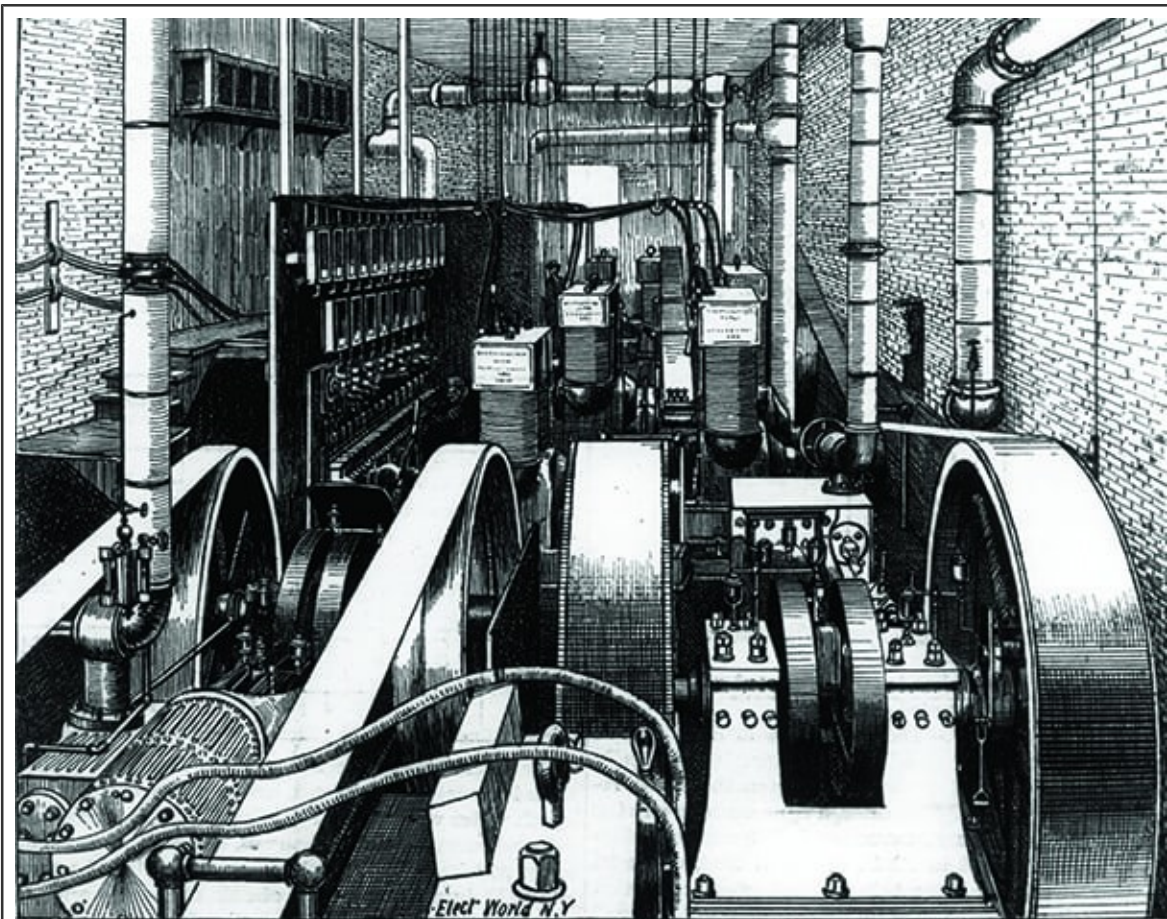
***POWER magazine was launched in 1882, just as the world was beginning to grasp the implications of a new, versatile form of energy: electricity. During its 135-year history, the magazine's pages have reflected the fast-changing evolution of the technologies and markets that characterize the world's power sector. These are some of the events that have shaped both the history of power and the history of POWER.***

The history of power generation is long and convoluted, marked by myriad technological milestones, conceptual and technical, from hundreds of contributors. Many accounts begin power's story at the demonstration of electric conduction by Englishman Stephen Gray, which led to the 1740 invention of glass friction generators in Leyden, Germany. That development is said to have inspired Benjamin Franklin's famous experiments, as well as the invention of the battery by Italy's Alessandro Volta in 1800, Humphry Davy's first effective "arc lamp" in 1808, and in 1820, Hans Christian Oersted's demonstration of the relationship between electricity and magnetism. In 1820, in arguably the most pivotal contribution to modern power systems, Michael Faraday and Joseph Henry

invented a primitive electric motor, and in 1831, documented that an electric current can be produced in a wire moving near a magnet—demonstrating the principle of the generator.

Invention of the first rudimentary dynamo is credited to Frenchman Hippolyte Pixii in 1832. Antonio Pacinotti improved it to provide continuous direct current power by 1860. In 1867, Werner von Siemens, Charles Wheatstone, and S.A. Varley nearly simultaneously devised the “self-exciting dynamo-electric generator.” Perhaps the most important improvement then arrived in 1870, when a Belgian inventor, Zenobe Gramme, devised a dynamo that produced a steady direct current well-suited to powering motors—a discovery that generated a burst of enthusiasm about electricity’s potential to light and power the world.

By 1877—as the streets of many cities across the world were being lit up by arc lighting (but not ordinary rooms because arc lights were still blindingly bright)—Ohio-based Charles F. Brush had developed and begun selling the most reliable dynamo design to that point, and a host of forward thinkers were actively exploring the promise of large-scale electricity distribution. Eventually, Thomas Edison invented a less powerful incandescent lamp in 1879, and in September 1882—only a month before the inaugural issue of *POWER* magazine was published—he established a central generating station at Pearl Street (Figure 1) in lower Manhattan.



**1. Pearl Street Station.** Thomas Edison in September 1882 achieved his vision of a full-scale central power station with a system of conductors to distribute electricity to end-users in the high-profile business district in New York City. *Source: U.S. Department of Energy*

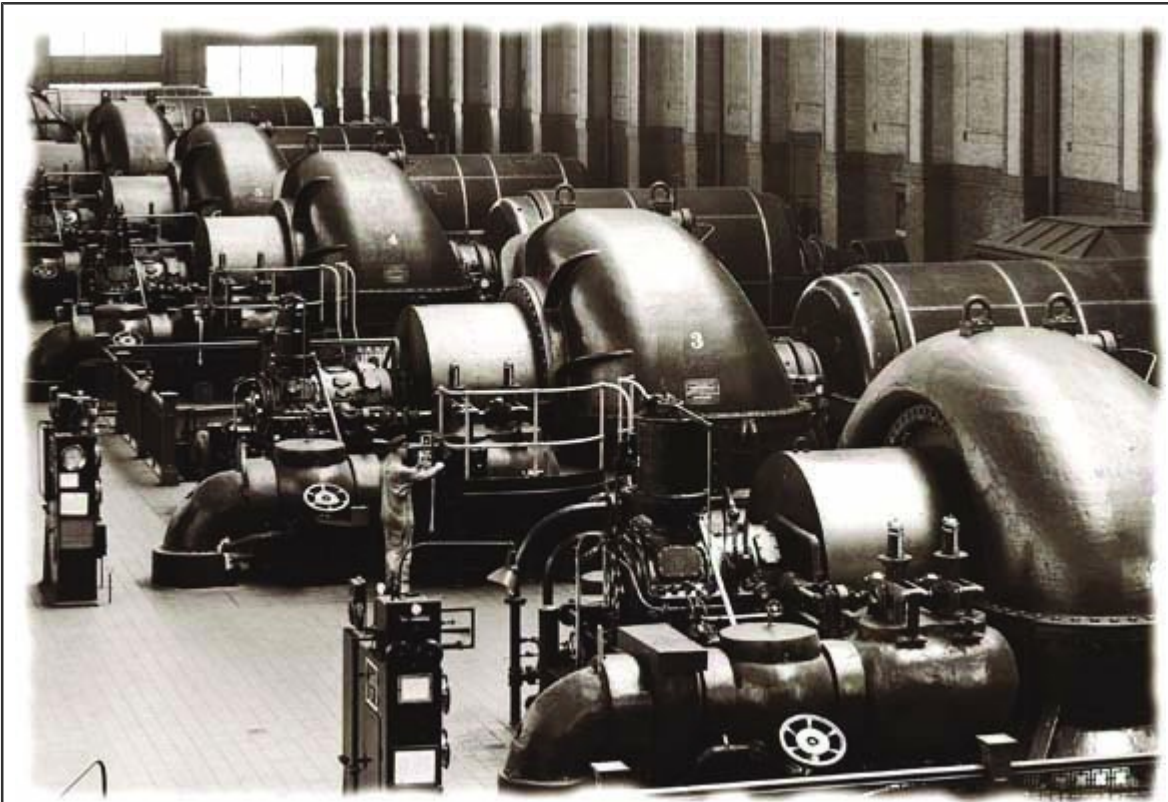
## A History Rooted in Coal

Advances in alternating current (AC) technology opened up new realms for power generation. Hydropower, for example, marked several milestones between 1890 and 1900 in Oregon, Colorado, Croatia (where the first complete multiphase AC system was demonstrated in 1895), at Niagara Falls, and in Japan.

By then, however, coal power generation's place in power's history had already been firmly established. The first coal-fired steam

generators provided low-pressure saturated or slightly superheated steam for steam engines driving direct current (DC) dynamos. Sir Charles Parsons, who built the first steam turbine generator (with a thermal efficiency of just 1.6%) in 1884, improved its efficiency two years later by introducing the first condensing turbine, which drove an AC generator. By the early 1900s, coal-fired power units featured outputs in the 1 MW to 10 MW range, outfitted with a steam generator, an economizer, evaporator, and a superheater section. By the 1910s, the coal-fired power plant cycle was improved even more by the introduction of turbines with steam extractions for feedwater heating and steam generators equipped with air preheaters—all which boosted net efficiency to about 15%.

The demonstration of pulverized coal steam generators at the Oneida Street Station in Wisconsin in 1919 vastly improved coal combustion, allowing for bigger boilers (Figure 2). In the 1920s, another technological boost came with the advent of once-through boiler applications and reheat steam power plants, along with the Benson steam generator, which was built in 1927. Reheat steam turbines became the norm in the 1930s, when unit ratings soared to a 300-MW output level. Main steam temperatures consistently increased through the 1940s, and the decade also ushered in the first attempts to clean flue gas with dust removal. The 1950s and 1960s were characterized by more technical achievements to improve efficiency—including construction of the first once-through steam generator with a supercritical main steam pressure.



**2. Purely pulverized.** The 40-MW Lakeside Power Plant in St. Francis, Wisconsin, began operations in 1921. This image shows the steam turbines and generators at Lakeside, which was the world's first plant to burn pulverized coal exclusively.

*Courtesy: WEC Energy Group*

Unit ratings of 1,300 MW were reached by the 1970s. In 1972, the world's first integrated coal gasification combined cycle power plant—a 183-MW power plant for the German generator STEAG—began operations. Mounting environmental concerns and the subsequent passage of the Clean Air Act by the Nixon administration in the 1970s, however, also spurred technical solutions such as scrubbers to mitigate sulfur dioxide emissions. The decade ended with completion of a pioneering commercial fluidized bed combustion plant built on the Georgetown University campus in Washington, D.C., in 1979.

The early 1980s, meanwhile, were marked by the further

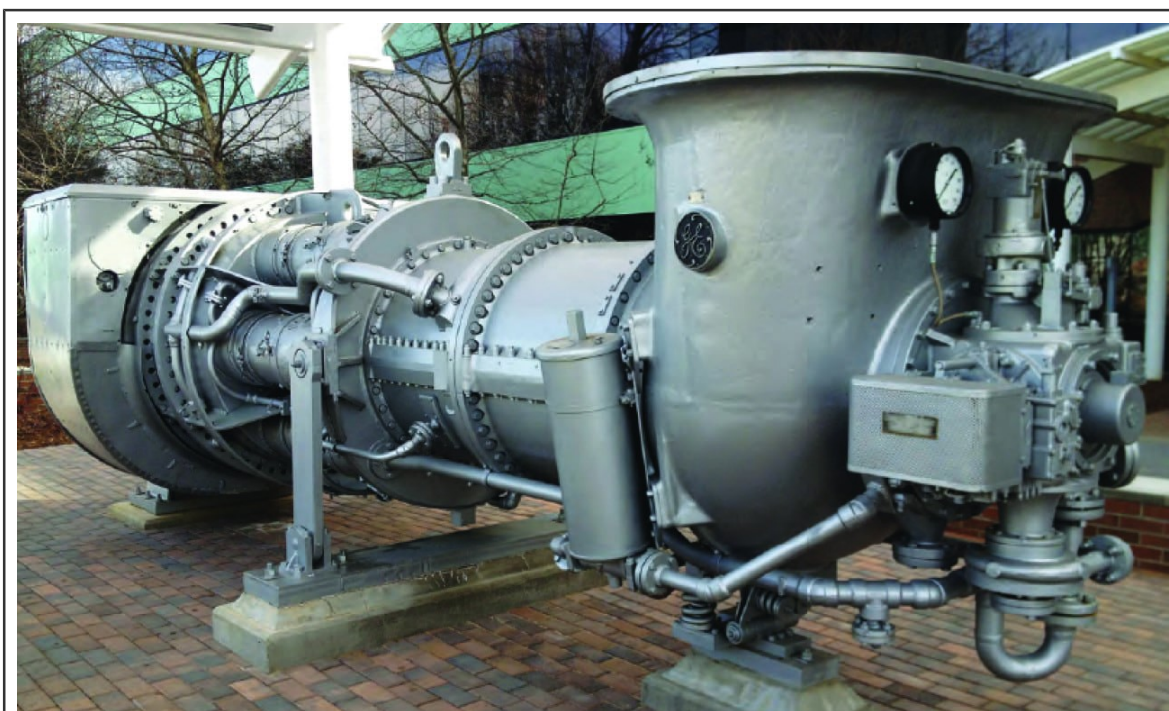
development of emissions control technologies, including the introduction of selective catalytic reduction systems as a secondary measure to mitigate nitrogen oxide emissions. Component performance also saw vast improvements during that period to the 21st century. Among the most recent major milestones in coal power's history is completion of the first large-scale coal-fired power unit outfitted with carbon capture and storage technology in 2014 at Boundary Dam in Saskatchewan.

## **Gas Power Takes Off**

Coal power technology's evolution was swift, owing to soaring power demand and a burgeoning mining sector. The natural gas power sector, which today takes the lion's share of both U.S. installed capacity and generation, was slower to take off. In 1896, about a decade after Charles Parsons developed his steam turbine generator, American inventor Charles Curtis offered an invention of a different turbine to the General Electric Co. (GE). By 1901, GE had successfully developed a 500-kW Curtis turbine generator, which employed high-pressure steam to drive rapid rotation of a shaft-mounted disk, and by 1903, it delivered the world's first 5-MW steam turbine to the Commonwealth Edison Co. of Chicago. Subsequent models, which received improvement boosts suggested by GE's Dr. Sanford Moss, were used mostly as mechanical drives or as peaking units.

Innovations in aircraft technology, and engineering and manufacturing advancements during both World Wars propelled gas power technology to new heights, however. At GE, for example, engineers who participated in development of jet engines put their know-how into designing a gas turbine for industrial and

utility service. Following development of a gas turbine-electric locomotive in 1948, GE installed its first commercial gas turbine for power generation—a 3.5-MW heavy-duty unit—at the Belle Isle Station owned by Oklahoma Gas & Electric in July 1949 (Figure 3). Some experts point out that because that unit used exhaust heat for feedwater heating of a steam turbine unit, it was essentially also the world's first combined cycle power plant. That same year, Westinghouse put online a 1.3-MW unit at the River Fuel Corp. in Mississippi.



**3. Trailblazer.** In 1949, General Electric installed the first gas turbine built in the U.S. for the purpose of generating power at the Belle Isle Station, a 3.5-MW unit, owned by Oklahoma Gas & Electric. *Courtesy: GE*

Large heavy duty gas turbine technology rapidly improved thereafter. In the early 1950s, firing temperatures were 1,300F (705C); by the late 1950s, they had soared to 1,500F, and eventually reached 2,000F in 1975. By 1957, a general surge in

gas turbine unit sizes led to the installment of the first heat recovery steam generator (HRSG) for a gas turbine. By 1965, the first fully fired boiler combined cycle gas turbine (CCGT) power plant came online, and by 1968, the first CCGT was outfitted with a HRSG. The late 1960s, meanwhile, were characterized by gas turbine suppliers starting to develop pre-designed or standard CCGT plants. GE developed the STAG (steam and gas) system, for example, Westinghouse, the PACE (Power at combined efficiency) system, and Siemens, the GUD (gas and steam) system.

More recent gas turbine milestones came in 1990, with the introduction of the first advanced gas turbines, and installment of the first CCGT paired with a fuel cell in 2000.

## **Atomic Discoveries**

Although the concept of the atom was fairly well developed, scientists had not yet figured out how to harness the energy contained in atoms when the first issue of *POWER* magazine was published. But 13 years later, in 1895, the accidental discovery of X-rays by Wilhelm Röntgen started a wave of experimentation in the atomic field.

In the years that followed, radiation was discovered by Antoine Henri Becquerel, a French physicist; the Curies—Marie and Pierre—conducted additional radiation research and coined the term “radioactivity”; and Ernest Rutherford, a New Zealand-born British physicist, who many people consider the father of nuclear science, postulated the structure of the atom, proposed the laws of radioactive decay, and conducted groundbreaking research into the transmutation of elements.



Many other scientists were helping advance the world's understanding of atomic principles. Albert Einstein developed his theory of special relativity,  $E = mc^2$ , where  $E$  is energy,  $m$  is mass, and  $c$  is the speed of light, in 1905. Niels Bohr published his model of the atom in 1913, which was later perfected by James Chadwick when he discovered the neutron.

Enrico Fermi, an Italian physicist, in 1934 showed that neutrons could split atoms. Two German scientists—Otto Hahn and Fritz Strassman—expanded on that knowledge in 1938 when they discovered fission, and using Einstein's theory, the team showed that the lost mass turned to energy.

## Early Nuclear Reactors

Scientists then turned their attention to developing a self-sustaining chain reaction. To do so, a "critical mass" of uranium needed to be placed under the right conditions. Fermi, who emigrated to the U.S. in 1938 to escape fascist Italy's racial laws, led a group of scientists at the University of Chicago in constructing the world's first nuclear reactor.

The team's design consisted of uranium placed in a stack of graphite to make a cube-like frame of fissionable material. The pile, known as Chicago Pile-1, was erected on the floor of a squash court beneath the University of Chicago's athletic stadium (Figure 4). On December 2, 1942, the first self-sustaining nuclear reaction was demonstrated in Chicago Pile-1.



**4. World's first nuclear reactor.** Chicago Pile-1 was an exponential pile. At least 29 exponential piles were constructed in 1942 under the West Stands of the University of Chicago's Stagg Field. *Source: U.S. Department of Energy*

But the U.S. was a year into World War II at the time, and most of the atomic research being done then was focused on developing weapons technology. It was not until after the war that the U.S. government began encouraging the development of nuclear energy for peaceful civilian purposes.

The first reactor to produce electricity from nuclear energy was Experimental Breeder Reactor I, on December 20, 1951, in Idaho. The Soviet Union had a burgeoning nuclear power program at the time too. Its scientists modified an existing graphite-moderated channel-type plutonium production reactor for heat and electricity

generation. In June 1954, that unit, located in Obninsk, began generating electricity. A few years later, on December 18, 1957, the first commercial U.S. nuclear power plant—Shippingport Atomic Power Station, a light-water reactor with a 60-MW capacity—was synchronized to the power grid in Pennsylvania.

The U.S. and Soviet Union weren't the only countries building nuclear plants, however. The UK, Germany, Japan, France, and several others were jumping on the bandwagon too. The industry grew rapidly during the 1960s and 1970s. Nuclear construction projects were on drawing boards across the U.S., with 41 new units ordered in 1973 alone. But slower electricity demand growth, construction delays, cost overruns, and complicated regulatory requirements, put an end to the heyday in the mid-1970s. Nearly half of all planned U.S. projects ended up being canceled. Nonetheless, by 1991 the U.S. had twice as many operating commercial reactors—112 units—as any other country in the world.

Nuclear power's history is tainted by three major accidents. The first was the partial meltdown of Three Mile Island Unit 2 on March 28, 1979. A combination of equipment malfunctions, design-related problems, and worker errors led to the meltdown. The second major accident occurred on April 26, 1986. That event was triggered by a sudden surge of power during a reactor systems test on Unit 4 at the Chernobyl nuclear power station in Ukraine, in the former Soviet Union. The accident and a subsequent fire released massive amounts of radioactive material into the environment. The most-recent major accident occurred following a 9.0-magnitude earthquake off the coast of Japan on March 11, 2011. The quake caused the Fukushima Daiichi station to lose all off-site power. Backup systems worked, but 40 minutes after the quake, a 14-

meter-high tsunami struck the area, knocking some of them out. Three reactors eventually overheated—melting their cores to some degree—then hydrogen explosions spread radioactive contamination throughout the area.

The consequences of accidents have played a role in decisions to phase out or cut back reliance on nuclear power in some countries. Nonetheless, China, Russia, India, the United Arab Emirates, the U.S., and others continue to build new units. Advanced reactor technology and small modular reactors also offer hope for revitalizing the industry.

## **Renewables: The World's Oldest and Newest Energy Sources**

While humans have been harnessing energy from the sun, wind, and water for thousands of years, technology has changed significantly over the course of history, and these ancient energy types have developed into state-of-the-art innovative power generation sources.

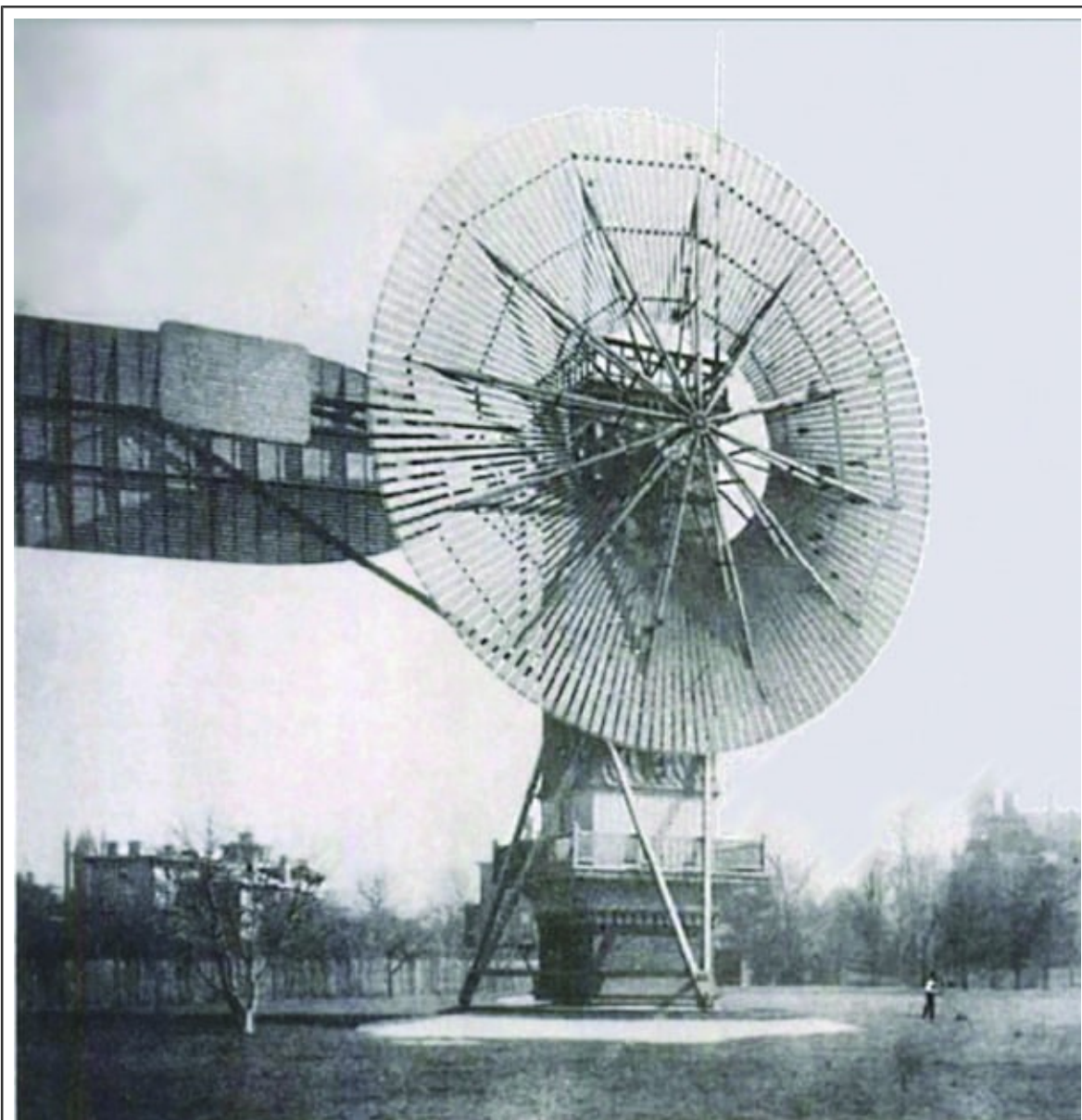
**Chasing Water.** What became modern renewable energy generation got its start in the late 1800s, around the time that *POWER* launched. Hydropower was first to transition to a commercial electricity generation source, and it advanced very quickly. In 1880, Michigan's Grand Rapids Electric Light and Power Co. generated DC electricity using hydropower at the Wolverine Chair Co. A belt-driven dynamo powered by a water turbine at the factory lit 16 arc street lamps.

Just two years later, the world's first central DC hydroelectric station powered a paper mill in Appleton, Wisconsin. By 1886, there were

40 to 50 hydroelectric plants operating in the U.S. and Canada alone, and by 1888, roughly 200 electric companies relied on hydropower for at least some of their electricity generation. In 1889, the nation's first AC hydroelectric plant came online, the Willamette Falls Station in Oregon City, Oregon.

Internationally, Switzerland was at the forefront of pumped storage, opening the world's first such plant in 1909. Pumped storage wasn't integrated into the U.S. energy mix until 1930 when Connecticut Electric Light and Power Co. erected a pumped storage plant in New Milford, Connecticut.

**Blowing in the Wind.** At about the same time that hydropower was gaining popularity, inventors were also figuring out how to use the windmills of the past to generate electricity for the future. In 1888, Charles Brush, an inventor in Ohio, constructed a 60-foot wind turbine in his backyard (Figure 5). The windmill's wheel was 56 feet in diameter and had 144 blades. A shaft inside the tower turned pulleys and belts, which spun a 12-kW dynamo that was connected to batteries in Brush's basement.



**5. Birth of the wind turbine.** In 1888, Charles Brush, an inventor in Ohio, constructed a 60-foot wind turbine capable of generating electricity in his backyard. *Source: Wikimedia Commons*

Wind-powered turbines slowly and with little fanfare spread throughout the world. The American Midwest, where the turbines were used to power irrigation pumps, saw numerous installations. In 1941, the world saw the first 1.25-MW turbine connected to the grid on a hill in Castleton, Vermont, called Grandpa's Knob.

Interest in wind power was renewed by the oil crisis of the 1970s, which spurred research and development. Wind power in the U.S. got a policy boost when President Jimmy Carter signed the Public Utility Regulatory Policies Act of 1978, which required companies to buy a certain amount of electricity from renewable energy sources, including wind.

By the 1980s, the first utility-scale wind farms began popping up in California. Europe has been the leader in offshore wind, with the first offshore wind farm installed in 1991 in Denmark. According to Wind Europe, Europe currently has 12.6 GW of capacity from 3,589 grid-connected wind turbines in 10 countries. In late 2016, the first offshore wind farm in the U.S. began operation in the waters off Block Island, Rhode Island.

**Let the Sunshine In.** Compared to other commercially available renewable energy sources, solar power is in its infancy, though the path that led to its commercial use began almost 200 years ago.

In 1839, French scientist Edmond Becquerel discovered the photovoltaic (PV) effect by experimenting with an electrolytic cell made of two metal electrodes in a conducting solution. Becquerel found that electricity generation increased when it was exposed to light. More than three decades later, an English electrical engineer named Willoughby Smith discovered the photoconductivity of selenium. By 1882 the first solar cell was created by New York inventor Charles Fritts, who coated selenium with a layer of gold to develop a cell with an energy conversion rate of just 1–2%.

It wasn't until the 1950s, however, that silicon solar cells were produced commercially. Physicists at Bell Laboratories determined silicon to be more efficient than selenium. The cell created by Bell

Labs was “the first solar cell capable of converting enough of the sun’s energy into power to run everyday electrical equipment,” according to the U.S. Department of Energy (DOE).

By the 1970s, the efficiency of solar cells had increased, and they began to be used to power navigation warning lights and horns on many offshore gas and oil rigs, lighthouses, and railroad crossing signals. Domestic solar applications began to be viewed as sensible alternatives in remote locations where grid-connected options were not affordable.

The 1980s saw significant progress in the development of more-efficient, more-powerful solar projects. In 1982, the first PV megawatt-scale power station, developed by ARCO Solar, came online in Hesperia, California. Also in 1982, the DOE began operating Solar One, a 10-MW central-receiver demonstration project, the first project to prove the feasibility of power tower technology. Then, in 1992, researchers at the University of South Florida developed a 15.9%-efficient thin-film PV cell, the first to break the 15% efficiency barrier. By the mid-2000s, residential solar power systems were available for sale in home improvement stores.

In 2016, solar power accounted for just 0.9% of U.S. electricity generation at utility-scale facilities. However, it is gaining steam. According to the Solar Energy Industries Association, “[t]he U.S. solar market had its biggest year ever in 2016, nearly doubling its previous record and adding more electric generating capacity than any other source of energy for the first time ever.” (For more details on the history of all power generation types, see supplements associated with this issue at [powermag.com](https://www.powermag.com).) ■



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