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*The Historical Evolution of Power Technologies**

Translation with revisions of "Dōryoku Gijutsu no Suii," in Tetsuro Nakaoka et al., eds., *Sangyō Gijutsushi* (*A History of Industrial Technologies*) (Tokyo: Yamakawa Shuppansha, 2001): 37–72.

Power technologies have formed the foundation of industrial technologies and modern society. In the West, watermills were widely used in medieval society, steam engines played a central role in the Industrial Revolution, and electric power station lighted cities and drove streetcars. These technologies were introduced into Japan from China and from the Western countries in different periods. They were brought to function in each historical context of medieval and modern Japan to drive mills, machines, ships, and trains. This chapter will survey the introduction, construction, and use of water, steam, and electricity power technologies in Japan. In addition, it will also see the use and development of wind power in prewar and postwar periods.

1. Water Power

Water Power in the Edo Period

Waterwheels were introduced from the Continent to Japan in the seventh century, and were used mainly to pump water for irrigation

* This chapter is a translation of a slightly shortened version of the chapter on the history of power technology in Tetsuro Nakaoka et al., eds., *Sangyō Gijutsushi* (*A History of Industrial Technologies*) (Tokyo: Yamakawa Shuppansha, 2001). The book covers other industrial technologies: mining, steel, machinery, transportation, textile, chemistry, information, and so forth. Its shorter version was also reprinted in Nihon Sangyo Gijutsushi Gakkai, ed., *Nihon Sangyō Gijutsushi Jiten* (Encyclopedia of the History of Industrial Technologies in Japan) (Kyoto: Shibunkaku Shuppan, 2007), which comprehensively covers the history of industrial technologies, including power technologies.

purposes. In the middle Edo period, water power was also used for extracting oil and cleaning rice. The staple food of Japan is rice, and flour was historically used only for several kinds of food, such as noodles. As a result, the demand for water power for milling flour was limited in Japan, unlike in other countries such as northern China.

In Japan, the use of oil lamps dates back to ancient times. Rapeseed was widely planted, beginning in the seventeenth century, and the extracted rapeseed oil made an excellent fuel for lamps. Water power was used to grind the rapeseeds, and the powdered seeds were steamed and squeezed to produce rapeseed oil.

Starting at the end of the seventeenth century, white rice became preferred to brown rice, and water power was widely used for polishing and converting brown rice to white rice. Polished rice was also needed for making saké (rice wine), and as the demand for refined rice wine increased in Edo city, more waterwheels began to be used. In the Nada area, around present-day Kobe, many waterwheels were used, both for grinding rapeseed, and, especially in the latter half of the 18th century, for polishing rice. In Nada, rice was typically polished and whitened by waterwheels for three days, and saké of good quality was produced in large quantities.

Water wheels were used for other purposes as well during the Edo period. The historian Tsutomu Demizu lists the uses of waterwheels during the Edo and later periods as follows:

> Pumping for irrigating rice fields, polishing rice, milling, making noodles, crushing clay for ceramics, stroking clay, washing potatoes, cutting woods, preparing tea leaves, thrashing, spinning cotton, making tobacco, making *konnyaku* (paste made from arum roots), pressing sugarcane, twisting threads, making starch, grinding rapeseeds, making dried bean curd, making agar, elongating copper, sending wind to bellows for metallurgical use, crashing saltpeter.[1]

Bellows were used to melt mined ores and iron sand. The unique Jap-

1. Tsutomu Demizu, *Suisha no Gijutsushi* (*A History of Technology of Waterwheels*) (Kyoto: Shibunkaku Shuppan, 1987), pp. 30–32.

anese method of iron making called *tatara* used iron sand, and required water powered bellows to melt it.

Another important function of waterwheels was their use for irrigation. Waterwheels provided a powerful motive power, and sometime disrupted the impartial allocation of water resource among farmers. This sometimes caused conflict among interested parties. For this reason, waterwheels were not used in summer and fall.

Waterwheels in Shibuya

Today, Shibuya is a prosperous shopping district crowded with young people. In the late Edo to Meiji periods, this area contained numerous waterwheels, along the Shibuya and Meguro Rivers. The area stood between a populated downtown area and farmlands. The waterwheels were used to polish rice for Edo citizens. Geographically, the region was on the boundary between the plateau of Musashino and the lower Edo area, and it abounded with steep slopes, providing excellent conditions for setting up waterwheels. Since the Tamagawa waterworks provided water to Shibuya River, the river contained enough water to run a number of waterwheels.

The novelist Doppo Kunikida, residing near Shibuya, described its landscape in 1898 as follows:

> Water flow runs through the garden and goes through the gate to cross the street and enter a forest. Out of the forest, the land is suddenly lowered and the roof of a small cottage appears. Its waterwheel rotates. There are many waterwheels around there, and this is a smaller one.[2]

The History of Waterwheels in Shibuya, written by local historians, records the historical change in use of each of the waterwheels in Shibuya, from the Edo to the Meiji period.[3] Most waterwheels were used for polishing rice in the Edo period, but they were converted

2. Doppo Kunikida, "Wakare (Departure)," in idem, *Musashino* (Tokyo; Shinchosha, 1949), p. 51.
3. Shirane Kinen Kyōdo Bunkakan, ed., *Shibuya no Suishashi* (*The History of Watewheels in Shibuya*) (Tokyo: Shibuyaku Kyōiku Iinkai, 1986).

and used for various industrial purposes during the Meiji period. For instance, the old waterwheel of the Ishida family, made in the 1730s, had been originally used for polishing rice, but was used in the early 20th century for crushing graphite to prepare lead for pencils. During the Meiji period, other wheels were used for making cotton cloth and silk threads, elongating copper, and grinding lenses. The conversion of waterwheels was approved by the government in most cases, except for as a method of producing gunpowder. These changes reflected the industrial condition of a rapidly modernizing Japan.

Waterwheels in the Meiji Period

Many modern textile factories in the Meiji period relied on water power. National spinning factories in Hiroshima and Aichi were furnished with Western waterwheels, as well as Western spinning machines. They were made of iron and therefore had a larger size and increased power. Many of them were constructed by French engineers at the Yokosuka Dockyard. Until the late 1870s, the power at factories was mainly provided by water.

In his book *Suiryoku Kaihatsu-Riyō no Rekishi Chiri* (*A History and Geography of the Development and Use of Water Power*), technology historian Yoshiyuki Sueo explains, in detail, the usage of waterwheels in the Meiji period, based on several historical documents.[4] The examination of historical documents led him to the conclusion that water was an important source of power to various industrial sectors throughout the Meiji period.

Waterwheels were especially used for industrial purposes during the second decade of the Meiji period. "Nōshōmu Tōkei Hyō (Statistical Tables of Agriculture and Commerce)" was compiled on the basis of several statistical investigations during the second and third decades

4. Yoshiyuki Sueo, *Suiryoku Kaihatsu Riyō no Rekishi Chiri* (*A History and Geography of the Development and Use of Water Power*) (Tokyo: Daimeidō, 1980). Sueo relies on such statistical records: "Kyōbu Seihyō," national statistics compiled by the General Staff Office of the Army, "Yamatokoku Suisha Shirabe (Investigation of Waterwheels in Yamato)," an investigative report on the usage of waterwheels around Nara and its vicinity, "Nōshōmu Tōkei Hyō (Statistical Tables of Agriculture and Commerce)," and "Kōjō Tsūran (The Survey of Factories)," compiled by the government

of the Meiji period. According to the data in the report, the total number of factories in the nation in 1886 was 942, of which 405 were furnished with motive force. Of them, 193 used waterwheels, 101 used steam power, and 111 used both water and steam power. Later statistics, from 1888, excluded factories without power. According to that report, the total number of factories with motive power had increased to 657. Of them, 239 had water power, 253 had steam power, and 164 had both types. The number of factories using water power subsequently decreased to one quarter by the end of the third decade of the Meiji period. Waterwheels, however, continued to be used as a source of motive power, especially at small factories.

Water Power Policy

Bureaucrats in the Meiji government followed a policy of promoting water power for industrial use. In introducing modern Western production technologies, they did not attempt to rely on steam power, which was prevalent in the Western countries, but tried to use water power for as long as possible. A Japanese visitor to the World's Fair in Vienna, Austria, in 1872, where the Japanese government officially participated and displayed its industrial products, expressed his opinion in the report on their visit:

> Our country abounds with coals and is capable of using steam power. But wherever it is possible to install waterwheels, we should do so to replace or assist steam engines... There is no place without water in our country. We should make full use of water and should not waste [coals] by using steam engines.[5]

In 1879, Masayoshi Matsukata, who was responsible for restoring the financial condition of the Meiji government, also made a statement supporting the development of water power. At the time, he was head of the Bureau of Promoting Agriculture in the Ministry of Agriculture and Commerce and hoped to promote the domestic spin-

5. Takenobu Hirayama and Yoshio Tanaka, *Ōkoku Hakurankai Sandō Kiyō* (*Proceedings of the Participation of the World Exposition in Austria*) (Tokyo, 1897), vol. 2, p. 88.

ning and weaving industry, and prevent an increase in the importation of cotton products. He pointed out that, at the time, waterwheels were used only for polishing rice and extracting oils and stated:

> There are waterfalls in places accessible by transportation and therefore possible to install a large machine. But they have only served as scenic views to amuse poets and painters and not as motive power for practical purposes. It goes without saying that this is wasting a heavenly gift, and failing to take financial advantage.[6]

The historian of technology Tetsuro Nakaoka emphasized, based on several case histories, that Meiji Japan succeeded in introducing Western technologies by using intermediate or "hybrid" technology, which was adapted to the economic and technical conditions of Japan at the time.[7] Use of water power to drive imported machinery could be considered as another example of such an intermediate technology. As will be discussed later, water power was also used for generating electricity. After the invention of the turbine, water as a source of electric power became particularly important to the Japanese economy.

2. Steam Power

The Attempt to Make a Steam Engine at the End of the Tokugawa Era

Even before the arrival in Japan of United States Commodore Matthew Perry in 1853, an attempt had been made to build a steam-driven ship. In 1844, the Dutch government conveyed the invention of the steam ship to the Tokugawa government, explained that the invention reduced the distance between countries, and recommended

6. Ōkurashō Daijin Kanbō, ed., *Matsukata Haku Zaisei Ronsakushū* (*Financial Papers of Count Matsukata*), repr. in Hyōe Ōuchi and Takao Tsuchiya, eds., *Meiji Zenki Zaisei Shiryō Shūsei* (*Collection of Financial and Political Documents in the First Half of the Meiji Period*) (Tokyo: Hara Shobō, 1978), p. 529.
7. Takeshi Hayashi, *The Japanese Experience in Technology: From Transfer to Self-Reliance* (Tokyo: United Nations University Press, 1990), p. 213.

opening up the country. The Japanese government did not follow the recommendation. However, Nariakira Shimazu, the feudal lord of the Satsuma clan, was strongly attracted to the steam ship and became interested in constructing one. He acquired a Dutch manual for building a steam engine and ordered scholars fluent in Dutch to translate the book. It explained the physical nature and action of steam, as well as the structure and function of a boiler, a steam engine, and a steam ship with a paddle wheel. He then ordered a group of scholars and craftsmen to construct an actual steam engine, based on this single textbook. They visited a Dutch ship in Nagasaki, viewed the internal mechanism and structure, and finally succeeded in making a small workable steam engine in 1855. Installing it on a small boat, they made the first Japanese steam ship, named Unkō Maru. It was a wooden boat with paddle wheels of 16m in length, and it greatly surprised invited guests when the boat they were aboard started running on its own.

Around the same time, the Saga clan also attempted to construct small scale models of a steam ship and a steam locomotive. Clan lord Naomasa Nabeshima established a factory complex called *Seirengata* and invited scholars and inventors, like Hisashige Tanaka, to construct the models. The group completed their construction in 1854. They then made the Satsuki Maru, a ship which used a small steam engine, and sailed it from Hayatsue to Nagasaki.

It is a long and difficult process to move from understanding a textbook on the construction of a steam ship to realizing the actual construction of such a ship. Though they had been able to make a small-scale model of a steam ship, craftsmen found it far more difficult to construct a practical full-scale ship. Late Edo engineers experienced this difficulty. Traditionally, sword-smiths and other craftsmen were engaged in metallurgical processes, but the technique they were accustomed to was different from that necessary to make the parts of a steam engine. When they constructed a model of a steam ship in Satsuma, the craftsmen made all of the necessary parts through forging, even though they could have made them more easily by casting. One of the participants in the project, Shiro Ichiki, quickly realized the difficulty and recommended that it would be better to purchase a ship from the Dutch. As he later recalled:

> Without iron machines, I realized that traditional craftsmen alone could never construct practical military steam ships, and immediately after my return expressed my opinion that the clan had better purchase a steam ship from Dutchmen.[8]

After the arrival of Commodore Perry, the Tokugawa government established the Naval Training Center in Nagasaki, with help from the Dutch government, and began building a modern navy. A ship for training was donated by the Dutch King William III. The ship, originally named the Soembing, was renamed the Kankō Maru, and became the first steam operated naval vessel owned by the Japanese government. The Tokugawa government then ventured to construct a steam ship by themselves and successfully made a steamer named Chiyodagata in 1866. The body of this steam ship was constructed at the Ishikawajima dockyard, and its engine was made at the Nagasaki Ironworks. To build it, the government purchased machine tools from the Netherlands. It took four years to complete its construction. Later, the Yokosuka Dockyard was established, under the direction of French naval engineers, on the eve of the Meiji Restoration, and the new government proceeded to build military steam ships. The dockyard's first ship was the Yokohama Maru, one of many ships that it went on to produce.

Steam Locomotives

Commodore Perry brought gifts of various modern machines to the Tokugawa government. A steam locomotive was one of them, which greatly impressed the Japanese people. They called the steam locomotive *okajōki* (steam on land). The Seirengata factory of the Saga clan was engaged in making a model of a steam locomotive, and the Choshu clan purchased a locomotive made in France. The British merchant Thomas B. Glover imported a large-scale model of a British

8. Shidankai, ed., *Shidan Sokkiroku* (*Stenographic Records of Historical Recollections*), no. 40 (Tokyo: Shidankai, 1895), p. 54.

locomotive and, after having displayed it in motion in Nagasaki, donated it to the Shogun. A plan was made to build a railroad between Edo and Yokohama, travelled by the locomotive, but the plan was not realized, due to the upheaval of the Restoration.

The British government officially recommended the construction of railroads to the new, post-Restoration Japanese government. The first railroad, between Shinbashi and Yokohama, was opened in 1872. After that, most locomotives were imported from Britain or the United States. The first domestic locomotive was made in Kobe, at a factory owned by the government bureau in charge of railroads, and was constructed under the direction of Richard F. Trevithick. In 1896, *Kisha Seizō Gōshi Kaisha* (Joint-Stock Company for Making Locomotives) was established. The construction of the first locomotive by Japanese engineers, without the assistance of foreign engineers, was completed in 1901, though various imported parts, such as wheels and axles, were used.

Throughout the end of the Edo period, and during the Meiji period, the primary use of the steam engine was for transportation. However, steam engines were also used at some factories. Nariakira Shimazu attempted to use steam engines, as well as waterwheels, to drive spinning machines. He imported machines (consisting of 3,640 spindles) to spin cotton threads in 1866, built a spinning factory driven by steam the next year, and began its operation, under the supervision of British engineers. In 1872, a spinning factory in Tomioka opened which used steam-driven spinning machines. Steam engines were also used at dockyards as a source of power.

Steam engines were also used in the mining industry. At the beginning of the Meiji era, the Takashima mine in Nagasaki introduced the use of steam engines for transportation, for lifting, and for driving factory machinery. The Chikuhō Coal Mine attempted to introduce steam engines for pumping in 1875, but was unsuccessful. The Shakanoo (目尾) Coal Mine in Fukuoka prefecture successfully introduced the use of steam engines for pumping in 1881, and other mines followed.

Domestic Production of Steam Engines

Attempts to make steam engines started at the beginning of the Meiji era. Craftsmen were successful at making small engines, but unsuccessful at making large ones. The first domestically-made large steam engine was constructed at the Shibaura Engineering Works, which was established by Hisashige Tanaka and which would later become the Toshiba Corporation. This 1300 horsepower engine was used to drive 40,000 spindles, at the Hyogo factory of the Kanegafuchi Spinning Company (Kanebo). According to *An Illustrated History of the Development of Steam Industry in Japan*, the Shibaura Engineering Works was not furnished with machine tools, and the construction of such a large steam engine for factory use must have been a difficult task.[9] This feat was accomplished by the engineer Tomokichi Yoshida, who worked both for Shibaura and Kanebo, and his success amazed engineering experts. However, this engineering success was a managerial failure for Kanebo. The manager of the Kanebo's Hyogo Factory recalled that the decision to use a domestic engine was "a big mistake." Although a large number of imported spindles arrived at the factory from England on time, the delivery of the engine by Shibaura Company was so late that Kanebo missed the important business opportunity created by an economic boom after the Sino-Japanese War. For factory managers like him, to import a whole set of machines, including a steam engine, from abroad would have been more reasonable.[10]

Unfortunately, the Meiji government did not pay much attention to the introduction and development of machine tools, which were needed to make machines precisely. This neglect subsequently led to the weakness of the Japanese machine industry.

The Problem of the Cost of Fuel

The use of steam engines at factories meant a need for fuel. For the

9. Watto Tanjō Nihyakunen Kinenkai, ed., *Zusetsu Nihon Jōki Kōgyō Hattatsushi* (*An Illustrated History of the Development of Steam Industry in Japan*) (Tokyo, 1939), p. 318.
10. See Jun Suzuki, *Meiji no Kikai Kōgyō* (*Machine Industry in Meiji Japan*) (Kyoto: Minerva Shobō, 1994).

daily operation of steam engines, factory managers had to purchase coal. As has been previously mentioned, during the Meiji era many factories employed water, instead of steam power, to drive their machines. This was mainly because the cost of coal was considered too high. At the time, silk was Japan's main export, and producing silk required the use of hot water, prepared by a boiler, to heat silkworm cocoons. Thus, at silk manufacturing factories, the implementation of steam engines should have been easy, due to the existence and daily use of boilers. Even so, few silk factories introduced steam engines.

The decision on whether or not to introduce steam engines depended on the availability of coal. Steam engines were relatively easier to use for transportation purposes, since locomotives and ships could move to ports and garages by themselves. To use steam engines at factories, however, meant transporting coal to factory sites. According to the estimate of Fuji Paper Making Company, the cost of installation of a waterwheel and a steam engine, in the later Meiji era, was almost equal, but the cost of operation and maintenance of the two was significantly different, about half of the cost of installation in the case of water power, but more than double the cost in the case of steam power. Most of the cost associated with steam power was due to the use of coal. For this reason, only a limited number of factories, like privileged national factories, and those near coal mines, introduced steam engines in the early Meiji era. However, as Japan's land and sea transportation network developed, and the price of coal decreased, the use of steam engines spread more widely among factories nationwide.

3. Electric Power

Building a Power Network in Meiji Japan

The construction and operation of an electrical power network requires a high level of knowledge of electrical engineering, and therefore such a project needs to include numerous electrical engineers and technicians who have studied at higher educational institutions. The

Imperial College of Engineering, established in 1872, played a role in producing such electrical engineers. It had the Department of Telegraphy, whose original purpose was to generate engineers to be in charge of the construction of an electric telegraphy system. The college's first professor of electrical engineering, William Ayrton, and his student assistants, constructed and powered arc lamps at the assembly hall of the college on March 25, 1878, the date now commemorated as the memorial day for electricity in Japan. With the development of an electrical network in the West, the department's focus turned increasingly to electric power technology, and it was renamed the Department of Electrical Engineering. During the 1880s, the senior theses of students of the department changed from those concerned with telegraphic inventions, like measuring devices, to those concerned with inventions related to power technology, such as incandescent lamps, dynamos, and power transmitters. Junsuke Miyake's thesis of 1888, for instance, was entitled "On Incandescent Lighting," and within it, he recorded his own experimental preparation and construction of a dynamo, a distribution facility, and of incandescent lamps.[11]

In 1883, Sakuro Yajima installed arc lamps on the street in Ginza and fascinated Tokyo citizens. He then established the Tokyo Electric Lamp Company in 1886, and started to distribute electricity in Tokyo city, through the establishment of power stations at four locations downtown: Kojimachi, Nihonbashi, Kanda, and Asakusa. The company invited an associate professor at Tokyo Imperial University, Ichisuke Fujioka, to join. A student of Ayrton, Fujioka had taken a position at the university, but accepted the company's invitation and resigned from the university to concentrate his work as engineering chief.

By 1891, Tokyo Electric Lamp Company was powering about 10,000 lamps, which included those in the Imperial Palace. After seeing the company's success in the power distribution business, entrepreneurs established companies in other regions of Tokyo, and in

11. Junsuke Miyake, "On Incandescent Lighting," unpublished diplomat essay, the College of Engineering, 1888, preserved at the library of Department of Electrical Engineering, the University of Tokyo.

other large cities, such as Kobe, Osaka, Kyoto, Nagoya, and Yokohama. The Edison Company of the United States provided direct-current generators to all of these new companies, except for one company, Osaka Electric Lamp Company. That company instead purchased an alternating-current generator from Thomson Houston Company. This decision was made by its chief engineer, Kunihiko Iwadare, who had studied electrical engineering in the United States, and had learned of the superiority of transmitting high voltage through an alternating current. After graduating from the College of Engineering, Iwadare had worked at the Bureau of Telegraphy, and went on to work at an Edison Company factory. Although he had worked at the Edison Company, he recommended that the Osaka Electric Lamp Company employ the alternating-current electricity offered by its rival. Whereas Edison Company distributed power through three electrical lines of 110 and 220 volts, Thomson Houston Company transmitted power through lines of 1000 volts. As Edison Company criticized the danger of high-voltage transmission, Tokyo Electric Lamp Company too criticized the dangerous use of high-voltage alternating current by Osaka Electric Company. Truthfully, high-voltage electrical transmission had caused some deaths. Following an increase in fatal accidents by electrification, the Ministry of Post and Telecommunication warned corporate suppliers and private users to deal with electricity more carefully and safely.[12]

Once power stations had been built in several places in Tokyo, a plan to build a larger power station was hatched. The new power station, equipped to generate 2000-volt alternating current, was built in Asakusa. Its dynamo was designed by Tokyo Imperial University Professor Hatsune Nakano and was manufactured by Ishikawajima Shipbuilding and Engineering Company. The dynamo generated three-phase 50Hz alternating current, which was distributed to various places in Tokyo. Subsequently, 50Hz became the de facto standard frequency for distributing alternating current to the Tokyo region.

12. Shigenori Katōgi, *Nihon Denkijigyō Hattatsushi* (*A History of Electric Industry in Japan*) vol. 1 (Tokyo: Denyūsha, 1916), pp. 657–669.

In the third decade of the Meiji era, a water power station was built in Kyoto city. It used water from the canal connecting the city to Biwa Lake, and installed an Edison dynamo to generate low-voltage direct current. In 1892, it imported an alternating current generator from Thomson-Houston Company and started to distribute alternating current to Kyoto city. In this decade, water power stations using river water were built in Hakone Yumoto, Nikko, Toyohashi, Maebashi, Kiryu, Sendai, and Fukushima.

Using Electric Motors

The use of electricity as a motive force only came into play after its use for illumination had been established. The *Ryōunkaku*, a twelve-story tower built in Asakusa in 1890, was furnished with an elevator driven by an electric motor, and at the third National Industrial Exhibition in 1890, an electric train ran within the site. However, the cost of running these machines was high. Motors and generators were investigated at the Imperial College of Engineering. The first domestically manufactured generator was made at the Miyoshi Denki Company in 1884. Ishikawajima Shipbuilding Company and Shibaura Engineering Works followed Miyoshi Denki in manufacturing generators and motors. At the Ashio Mine, electric motors were used for operating trains, lifting machines, and pumping, and the company started to manufacture motors in the 1910s.

The construction of street car lines in a city was important for the early development of a power network. Sakuro Yajima and Ichisuke Fujioka of Tokyo Electric Company planned and proposed to the government the establishment of a new street car company, Tokyo Electric Motor Company, but it was not approved, apparently because no experts in the Bureau of Railroads were able to judge the engineering adequacy of the proposal. Proposals made in other cities were also all turned down. The government experts worried not only about the safety of an electric railway, but also about the influence of aerial electric currents on telephone lines, and of the rails' currents on water pipes. The director of the Electric Testing Station, Ōsuke Asano, and other electrical engineers, such as Saitarō Ōi and Gitarō Yamakawa, were sent abroad to investigate the safety and plausibility of a street car system.

A street car was first officially approved and built in Kyoto in 1895. When the fourth National Industrial Exposition was held in Kyoto in 1893, a businessman named Bunpei Takagi proposed a plan for the construction and operation of an electric railway, and his proposal was approved for the first time by the Ministry of the Interior and the Ministry of Post and Telecommunication. In sanctioning the proposal, the government was most concerned with the safety of the streetcar itself. They set its speed limit at 25 km/h, and ordered the company to let a boy run before the streetcar so that he could warn walkers on the street. In Tokyo, streetcars were first built in 1903, between Shinabashi and Yokohama, and between Yurakucho and Kanda.

The Development of Water Power Generation and the Spread of Electricity

The History of Meiji Industry describes three periods in the development of electrical transmission, in its volume on electricity.[13] Until 1899, electricity was distributed only within the boundaries of a city. From 1899 on, electricity was transmitted beyond city boundaries. Finally, starting in 1907, electricity was transmitted between distant areas. Long-distance transmission lines were constructed when a large water power station was built in a mountain area, so as to transmit electricity to cities. The construction of these water power stations was needed because of the rise in price of coal, and consequently, of electricity. Yokohama Kyodo Electric Lamp Company, for instance, spent a quarter of its income on the purchase of coal in 1893, but had increased its spending to one half of its profits by 1897, which led to its decision to raise the price of electricity.

The Tokyo Electric Lamp Company recognized the need for water power, and investigated geographically suitable places for building stations. It also sent its chief engineer, Iwasaburō Nakahara, to visit and study American and European water power stations. Based on the results of these investigations, it constructed a power station in

13. Nihon Kōgakukai, ed., *Meiji Kōgyōshi, Denki Hen* (Tokyo: Nihon Kōgakukai, 1929), pp. 311–318.

Komahashi in 1907, which transmitted 110,000-voltage electricity to its substation in Waseda. The Komahashi station was furnished with six Swiss-made water turbines and six Siemens three-phase alternating current generators.

The late 1900s, despite an economic depression, saw an increase in the construction of water power stations. To search for sources of water power, the Special Bureau for the Investigation of Water Power for the Generation of Electricity was set up at the Ministry of Post and Telecommunication and executed a five year plan of surveying and investigating potential water resources throughout the country. Starting roughly in 1907, traditional steam engines were replaced by newly invented and more efficient steam turbines at power stations. Because of the expansion and improvement of the power generation facilities, the price of electricity dropped significantly, which, in turn, led to the rapid growth of the electric power industry.

In 1914, a large water power station was built by the Inawashiro Lake, and electricity it generated was transmitted through a long-distance line to Tokyo. After the establishment of this power station and long-distance line, the power distribution network was further expanded throughout the country. Water power generation companies started to target industrial customers. During the Taisho era, factories in various industrial sectors increasingly replaced steam engines with electric motors. The rate of diffusion of electrification in the spinning and weaving industry was 55% in 1919 and had jumped to 91% by 1923. By that time, that rate had become almost 100% within the machine industry.[14] Electricity was also used to refine copper and carbide through electric heating and electro-chemical reaction. The newly emerging electrochemical industry was becoming a large new customer of the electric power companies.

Unification of Power Networks and the National Management of Electricity

World War I brought an economic boom to Japan. With the rise

14. Teijirō Kanbayashi, "Nihon Kōgyō Denka Hattatsushi (The Development of Industrial Electrification in Japan," in Hirotake Koyama, Teijirō Kanbayashi, and Michitsura Kitahara, eds., *Nihon Sangyō Kikō Kenkyū* (*Researches on Japanese Industrial Structure*) (Tokyo: Itō Shoten, 1943): 149–308, on pp. 284–285.

in the demand for electricity, many water and steam power stations were constructed. After the establishment of the Komahashi power stations, other companies built power stations in the Kanto area and supplied electricity to the Keihin industrial region, along the coast of Tokyo Bay. However, following an economic recovery in Europe, Japan's exports decreased and its economy went into decline. The demand for electricity decreased, causing an overabundance. Market competition led to the consolidation of the power supply companies.

Until then, the power industry had been decentralized. Five hundred and ten companies generated and supplied electricity to Japan in 1915. Among them were five big companies: Tokyo Electric Lamp, Tōhō Electric Power, Ujigawa Electricity, Daidō Electric Power, and Nippon Electric Power. A plan was proposed to manage the whole electric power industry under the aegis of the government, and to create and operate a more rational and efficient system for the generation, transmission, and distribution of electricity. After World War I, the governments of the United States and Britain planned and constructed such a national system of electricity, connecting hitherto isolated networks. In Britain, a central electricity board was established to manage the nationwide network system, called the "National Grid." In order to manage the nation's electricity centrally, voltage and frequency, which widely varied from region to region, had to be standardized. In the United States, the New Deal policy was executed under President Franklin Roosevelt, and a large power generation facility was built at the Tennessee River Valley under the Tennessee Valley Authority.

In Japan, too, a national management plan was developed, modeled on the British Grid System. Government bureaucrats took the initiative in planning and realizing the national system. In 1937, a special investigative committee for electric power was set up to explore the possibility of a national system. As a result, the Electricity Management Act was enacted in 1938, and the Japan Electric Generation and Transmission Company (JEGT) was established, to manage the national electric power industry. Under this company, Japan was divided into nine blocks, for each of which a single power distribution company was responsible for distributing electricity.

The role of JEGT in the nationally managed power industry was to purchase electricity supplied by power generation companies, allocate electricity to distributing companies through JEGT's transmission lines, and if necessary, generate power through its own steam power stations. In 1939 and 1940, a shortage of rain caused a shortage of electricity and of coal, and the government further tightened the control of electric power.

Frequency was standardized in this period. Before the emergence of JEGT and the national consolidation of electrical power suppliers, numerous corporations had supplied and distributed electricity, with frequencies which varied from region to region. The Investigative Committee for the Standardization of Frequency had been set up after World War I, but it had reached no practical agreement on the national unification of frequencies, due to the high cost of realizing standardization. It was, however, agreed by the committee that eastern and western Japan should have two different standardized frequencies—50Hz and 60Hz. Only after World War II was over was this standardization realized.

Postwar Reorganization of the Electric Power Industry

After the war, the General Headquarters (GHQ) of the allied powers democratized Japanese society and reorganized its industrial institutions. Under the Government Section of the GHQ, the JEGT was disbanded and the nine distribution companies were allowed to become independent suppliers and distributors. The plan to establish a new company to "interchange electricity" between user companies was rejected because of its basic policy of disbanding all regulative institutions organized during wartime. The rise in the demand for electricity and the increasing need for new electrical resources led to the establishment of the Electric Power Development Company (EPDC), under the 1952 Act of Electric Power Development.

After its establishment, the EPDC received a government order to build a dam and water power station in the Sakuma region, on the Tenryū River. This was an area where a strong section of the river ran through a narrow valley. It was appropriate for power generation but a difficult place to construct a dam. To realize this project, the EPDC introduced large American transportation machines and cooperated with American corporations on a technical level, which led to the completion of the dam and power station within a remarkably short period. This project was held up as an example of successful technical cooperation with foreign companies. Under the government's electric power policy of "water first, steam second," dams and power stations were constructed in Tagokura, Okutadami, and Miboro (御母衣). However, with the discovery of oil fields in the Middle East, and the improvement in the efficiency of turbines, more emphasis was placed on steam power plants. The emergence of nuclear power further reduced the significance of hydroelectricity.

4. Wind power

Wind power has had a long history of use in the West, but was basically not used until the 20th century in Japan. In pre-war Japan, wind power attracted the attention of an electrical engineer, Tamaki Motooka. As an engineer in Navy, Motooka observed the shortage of electricity on small islands in the Pacific. He investigated German literature on wind power generation, and realized its usefulness not only for islands but also for many other geographical areas. He resigned from Navy, and became a member of the Continental Science Institute in Manchuria, where he surveyed wind conditions in the area and developed windmills for power generation and irrigation. He planned the construction of a large wind power plant in Manchuria towards the end of the war, but the costly plan was not realized.

After the war, the "Yamada" style of windmill spread throughout farms in Hokkaido and other regions. Developed by the engineer Motohiro Yamada before the war, the windmills were made of silver fir. As such, their blades were light enough to be driven by weak winds but strong enough to withstand strong winds. Yamada established the Yamada Wind Power Electric Facility Company and produced small three-blade windmills which were able to generate 300W. The windmills were sold for 60,000 yen, but farmers were able to buy them at a government-subsidized price of 20,000 yen.

Because of the high performance and low price of the windmills, the company was able to sell 10,000 units in Hokkaido in the 1950s. The windmills were also exported to Africa and South America.

After the oil price shock of 1973, American and European countries developed further wind power technology as an alternative source of energy. In the United States, NASA developed large new windmill models, using synthetic materials for the propeller blades. In Japan, the Science and Technology Agency launched the Fūtopia (Wind Utopia) project, and the Ministry of Industry and International Trade (MITI) launched their Sunshine project, to develop technologies for alternative energy. In response to this government policy, the New Energy Development Organization (NEDO) was established in 1980. In the 1980s and 1990s, Tokyo and Tohoku Electric Power Companies constructed experimental wind power facilities, such as the "wind park" built on Tappi Cape in 1991.

We have seen above the development of various power technologies in Japan. The observation of their historical evolution shows the close relationship between their technological development and the economic, social, and geographical conditions of the period and the area they were used. Water power was continued to be used even after the steam power technology was introduced chiefly for economic and geographical reasons. The first construction of steam engines by Japanese engineers alone was a difficult engineering venture, whose technological success was regarded as a managerial failure. The development of electric power network was deeply influenced by the availability of water power stations and long-distance transmission lines. They evolved in the contemporary social milieu, shaped by it technical and economic conditions and in turn helping to construct a new Japanese society.