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Abstract

In recent years, energy constraints are discussed from a historical point of view. This study aims at examining the copper industry's energy use in Japan from the Meiji period to the time of WWI and clarifying the process of, and reasons for, the energy source selection. This study considered not only energy use in the large-scale mines but also energy use in the small-scale mines and miners' homes. As a result, it was clarified that the mines changed into a space that is based on a diverse combination of energy depending on differences in location (access to energy), natural conditions, financial power, the required amount and price of energy, energy use technologies, ore quality, and end-product (usage).

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1. Introduction

This study aims at examining the copper industry's energy use in Japan from the Meiji period to the time of WWI and clarifying the process of, and reasons for, the energy source selection.

From the Meiji period onward, in Japan, rapid industrialization saw a considerable increase in the demand for energy sources. On a macro-level, between the 1890s and the early 1910s at the latest, the primary energy source shifted from firewood and charcoal to coal (Umenura et al. 1966, p.17; Nihon enerugī keizai kenkyūjo keiryō bunseki yunitto 2017, pp.314-317). However, as prior research has clarified, macro-level discussions have their limits[1]. At the micro-level, energy use varied depending on factors such as industry, location, and natural geographic conditions (Abe and Kikkawa 1988; Taniguchi 1998; Miyachi 2010; S. Sugiyama and Yamada 2015). In recent years, moreover, it is pointed out that the single-track shift from non-fossil energy to fossil energy[2] may not have been the only response to energy constraints. In other words, it is argued that there was another response: the economic development with energy diversity and the formation of an "energy diverse society" (Sugihara 2012; Kanda 2015 and 2017). The use of fossil energy was necessary for industrialization, but its diffusion process may have had more complex and diverse aspects.

Bearing this in mind, this study considers energy use focusing on the Japanese copper industry. In Meiji Japan, many industries imported from overseas, such as railway and electric power, used coal from the outset, whereas the copper industry, which was a continuation of the Tokugawa period, had been developed using traditional energy resources such as charcoal and firewood. When energy constraints occurred, the Japanese copper industry was able to overcome the crisis.

Prior research addressing energy use in the Japanese copper industry has been carried out by Imazu Kenji and Takeda Haruhito (Imazu 1979; Takeda 1987)[3]. Both researchers clarified the

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1 Regarding this, see S. Sugiyama (2016).

2 Regarding the shift from non-fossil energy (wood) to fossil energy (coal), see, for example, Allen (2009) and Wrigley (2010).

3 Takeda clarified not just energy use but labor management, technology, funding, and the copper market. In addition to this, representative studies concerning the Japanese copper industry are, for example, Kobata (1968

shift from firewood and charcoal to coal, coke, and hydroelectricity, focusing mainly on large-scale mining; Takeda notably analyzed the selection of energies and the development of technologies for their use at the corporate level. On the background of their results, this study aims at expanding the scope of inquiry to the small-scale mines and to show that the energies used in mining were more diverse.

Prior research concerning the Japanese copper industry has also investigated the forest management to guarantee resources, such as charcoal and firewood as well as pit props (Hatakeyama 1988, chapter8; Yasukuni 2002). It has been pointed out that when there was an energy shift from firewood and charcoal to coal, these forests (used for firewood and charcoal) were converted for pit props. This point makes us imagine that the mines had been freed at an early stage from the supply constraints of firewood and charcoal. However, in reality, the amount of firewood and charcoal consumption by the copper industry was, even in WWI period, about five times greater than the consumption of timber for pit props, utility poles, mine cars, and building materials for miners' houses. Firewood and charcoal, which are needed not only for copper production but also for miners' homes, may have been the main energy resource in the copper industry. This study also considers the energy used at miners' homes, and this is significant because home and industrial energy use should be discussed together. However, this is a point not considered in prior research[4].

Section 1 provides an overview of the distribution of the principal mines in Japan, the changes in copper output, and the number of miners, as well as the main energies used in the copper industry. Section 2 examines how the copper industry faced energy constraints. Section 3 considers its response to the energy constraints and, finally, the conclusions are offered.

2. Overview of the copper industry in Japan

The metal mines contain ores of gold, silver, copper, and iron, while the non-metal ones are mined to produce such as coal and petroleum. Figure 1 shows the distribution of the leading metal mines of Japan in the 1910s. Japanese copper ore deposits were classified into four groups: (a) Vein ore deposits, which extended from the Tohoku region to the Chugoku region facing the Sea of Japan,

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and 1986), Hatakeyama (1988), Nimura (1988), and Murakami (2006).

4 Regarding energy use in homes, see Makino (1996), chapter7.

comprise minerals such as quartz, iron pyrites, and galena; many of these ore deposits were relatively narrow. (b) Black ore deposits, which extended from the Hokkaido region to the center of the Tohoku region, comprise minerals such as iron pyrites and copper pyrites and contain gold, silver, sphalerite, and galena. (c) Sulfur deposits (or ore beds), which extended from the Kanto region to the Kyushu region of the Pacific side, comprise mainly iron pyrites, many of which were relatively wide and stratified. (d) Contact ore deposits, which were distributed in the Chugoku region of Western Honshu and one part of the Tohoku region, comprise cupriferous pyrites, such as copper pyrites and pyrrhotite, many of which were irregular in shape. Thus, because each mine's ore deposits were found in different conditions and each mine's ore components are different, mining and smelting technologies have improved to suit each mine's condition and have developed in their unique way (Tōkyō Kōzan Kantokusho 1911, pp.80-82; Iwasaki 1918, pp.165-399; Takeda 1987, pp.103, 144).

[Figure 1]

Figure 2 shows the metal output and number of miners from 1874 to 1920. The amount of copper production increased as much as iron (pig iron) did, growing tenfold from 2,110,000 tons in 1874 to 24,320,000 tons in 1900. Although the Meiji government had seized mines from the Tokugawa shogunate and various fiefdoms, the government preferred to acquire gold and silver mines rather than copper mines; after 1880, owing to fiscal constraints, the copper mines were privatized, and since then, the copper industry has developed as a privately managed businesses. Since the 1890s, the *zaibatsus* (a large, family-controlled business conglomerate) came to manage the copper business, the amount of copper production exceeded one million tons in 1916. The five main *zaibatsu*-run mines of Ashio (Furukawa-*zaibatsu*), Besshi (Sumitomo-*zaibatsu*), Osaruzawa (Mitsubishi-*zaibatsu*), Kosaka (Fujita-*zaibatsu*), and Hitachi (Kuhara-*zaibatsu*) produced over 50% of total output. However, the copper processing industry was still undeveloped in Japan, and therefore, the main markets for Japanese copper were overseas, in Europe, America, and Asia. Notably, Europe and America's increased demand for the use of copper in electrical machinery and electric wires led to Japanese copper industry developing as an export industry until the end of WWI in 1918. The proportion of export volume to production output was over 70% in the 1890s and 1900s, and although it fell a little in the 1910s, it was still over 50%. Japan had grown to become the world's second-largest copper-producing country in 1915 (with 7% of the global share, after the United States, with a global share of 60%) (Takeda 1987, pp.10, 51-55, 59-63).

[Figure 2]

The number of miners in metal mines increased proportionally to the copper production, growing from 60,000 in 1902 to 74,000 by 1912, rapidly increasing after 1913, and touching 165,000 in 1917. As described below, although mechanization of mines had been ongoing since the Meiji period, the copper production was heavily dependent on labor (human power).

With the increase in the amount of copper production, energy (motive power and heat energy) requirements also increased. Copper production involved three processes: mining, ore dressing, and smelting. Each of these processes required energy. The mining process required motive power for mining, transport, drainage, and ventilation. The ore dressing process required motive power for ore crushing and selection. Finally, the smelting process required heat energy for smelting as well as motive power for ventilation. Motive power included hydraulic power (waterwheels), steam power (steam engines using coal or firewood), combustion gas power (internal-combustion engines using coal, charcoal, oil, etc.), electricity (thermal power generation using coal, hydroelectric power generation using waterwheels), as well as human and horse power. Heat energy included firewood, charcoal, coal, coke, fuel oil, coal tar, and electricity. The selection of these energies was dependent on various factors, and was not based on a single uniform rule. The following sections address the issue of the selection of these energies.

3. Dependence on traditional energy sources and their constraints

Many of Japan's copper mines were distributed across sites between 200 and 1,000 meters in elevation, and it was difficult to transport coal and coke to these heights when the railways had not yet been developed. Although steam engines had been introduced in government-managed mines in the early Meiji period, very few were powered by coal, and the smelters used charcoal or firewood for fuel. In other words, in the Meiji period, except mines which could ensure enough coal to operate, all the rest had to depend almost entirely on firewood, charcoal, hydraulic power (waterwheels), and human or horse power (Imazu 1979, pp.96-97).

Among these sources, firewood and charcoal were largely supplied from *kōzanbirin* (forests that mines bought and reserved). The mines bought state forests, public forests, and private forests[5], and they established *kōzanbirin* within a range of about 40 kilometers from the mine unless the area was severely affected by smoke pollution (Nōshōmushō 1900; Suzuki 1924). In 1876, the Meiji government implemented a ranking classification of state forests to avoid reckless deforestation of them and began to sell level-3 state forests (used for firewood and charcoal) to copper mines that were key to the acquisition of foreign currency. Each mine applied for the purchase of state forest to the government, felled a contracted quantity of trees for firewood and charcoal, and smelted ores by using them in *fukidoko* (kilns made by digging a 1-2-meter pit, walling it off with stone or brick, filling the base with stone, and smearing the inside with a mixture of charcoal powder and clay). However, many of the state forests were in the backwoods, and although the mines transported wood from state forests using long-distance cableways or human and horse power, they also bought public and private forests that were easy to access. In the coal mining industry, though, the distance extended between forests that supplied the required wood (mainly pit props) and coal mines, which were supported by the expansion of the railways[6]. Since many copper mines were located in mountainous regions, the required wood (mainly firewood and charcoal) for the copper industry was mainly provided by *kōzanbirin* that were relatively close to the mine.

Therefore, since the forests that supplied firewood and charcoal to copper mines were often confined to *kōzanbirin*, these forests were prone to overcutting (Suzuki 1924, p.151). For example, the Ashio mine, which had proliferated to overtake Besshi as the largest copper mine in the 1880s, bought between 30 and 70 ha of state forest every year from 1878 to 1883. In 1884, when the amount of copper production rapidly increased, it bought 175 ha (43,750 trees), and 393 ha (76,500 trees) in the following year (Tochigiken-shi Hensan Iinkai 1984, pp.530-534). At the same time, the Ashio mine also made a contract with farmers to cut trees of the public forests (Ashio Kōgyōsho 1884-1899). From 1880 to1885, the amount of charcoal consumed by the Ashio mine rapidly increased from 225 tons to 11,873 tons, and the amount of firewood consumption increased from 334 m^3 to 3,700 m^3. The Ashio mine employed workers to produce more charcoal and firewood. The number of them was little over one-third of the total number of miners in the late 1880s. Moreover, the Ashio mine tried to reduce the specific consumption of charcoal and firewood used for smelting

5 In the Meiji period, forests were roughly classified into imperial forest, state forest, public forest and private forest. Public forests were owned by prefectures, counties, municipalities, and villages.

6 Regarding the procurement of timber in coal-mining industry, see yamaguchi (2015), chapter 3 and 4.

by paying a bonus for smelters who had a high-skill (Takeda 1987, pp.158, 163, 172; Nihon Keiei-shi Kenkyūjo 1991, p.117). However, the amount of charcoal and firewood consumption continued to increase, a striking shortage of charcoal and firewood occurred as an effect of the lack of tree and smoke pollution around the mine. By the 1890s, around 80% of the forests of Ashio became deforested. The public forests and private forests were also abandoned without replanting after deforestation, and owing to the poor arrangement of tree stumps, coppice regeneration did not produce enough growth (Wada 1897; Tochigiken 1893, pp.12-13, 20-21). Hence, the Ashio mine installed waterwheels to replace steam engines that used firewood (Nihon Keiei-shi Kenkyūjo 1991, p.152). However, the use of waterwheels was limited by natural conditions such as location and changes in the amount of water. At the Besshi mine too, from 1873 to 1879, along with the increase in the quantity of copper production, the amount of charcoal consumption increased rapidly from 4,734 tons to 7,313 tons, and the amount of firewood consumption increased from 2,383 tons to 3,085 tons. However, the shortage of firewood and charcoal intensified because of continuous felling since the Tokugawa period; given these difficulties in obtaining adequate supply from forests around the mine, problems arose in trying to reorganize the charcoal- producing system and reduce the use of charcoal (Yamashita 1884, pp.83-84; Sumitomo Ringyō Kabushiki-gaisya Sya-shi Hensan Iinkai 1999, pp.94-109; Sumitomo Kinzoku Kōzan Kabushiki-gaisya Sumitomo Besshi Kōzan-shi Hensan Iinkai 1991, p.401).

Thus, with the increasing copper production, it had become difficult to balance the supply and demand for energy in the region. The Japanese copper industry also had to enhance copper quality and reduce production costs by improving smelting technology and fuel saving to maintain its competitiveness in the overseas markets. So, each mine began to look for alternative energy sources to reduce the cost of smelting which affected business conditions significantly, also started to search for a selection and mix of energy sources with the introduction of Western-style furnaces and improvements of traditional furnaces (Takeda 1897, pp.68, 102-105).

4. Diversification of energy use

4.1 Macro changes in energy for copper industry

When these trends are considered on macro-level, the 1890s saw a significant change in energy use. During this period, the use of coal, coke, and electricity in large-scale mines increased. Figure 3 shows the price of charcoal and coal between 1886 and 1915 in Tokyo, Utsunomiya, and Matsue. Clearly, in each city, the value of charcoal suddenly increased in the late 1890s, and the price difference subsequently widened between charcoal and coal, whose output had increased due to the development of coal mining. Like the energy changes that occurred in the silk industry (S. Sugiyama and Yamada 1999), these changes in energy prices may have encouraged the development and spread of technologies that aimed at saving fuel by using coal and coke. The 1890s was a turning point also in the development of smelting technologies because this period saw not only the improvement in traditional smelting but also the introduction and improvement of Western-style smelting (Takeda 1987, p.99). Moreover, in the 1880s and 1890s, the energy source of the American copper industry also switched over from charcoal and firewood to coal (Charles 1998, pp.73-79, 89-94). Therefore, the intensification of competition in the copper market may have also been one of the factors encouraging changes in energy to lower the production costs.

[Figure 3]

Figure 4 shows the amount of charcoal, coal, and coke consumed by the two large mines of Ashio and Besshi from 1880 to 1920. At the Ashio mine, the amount of charcoal consumption rapidly decreased from 25,762 tons in 1890 to 6,694 tons in 1897, as a result of a suspension of state forest sales in 1893 caused by the repeated floods and destruction of the forests[7]. As discussed below, although the amount of coal consumption was relatively little, owing to the motive power of Ashio mine being mainly dependent on electric power through hydroelectric power generation, the amount of coal and coke consumption increased. The amount of coke consumption was 628 tons in 1887 and exceeded by 10,000 tons in 1896, after the Fukagawa coke factory (established in 1888) began to supply it[8]. At the Besshi mine, the amount of charcoal consumption fluctuated between 7,350 tons and 8,670 tons after 1880, dropped after 1890 and was reduced to 2,734 tons in 1897 due to repeated floods and destruction of the forests. However, after the suspension of firewood use for steam engines in 1893, the amount of coal consumption increased from 1,415 tons in 1890 to 6,094 in 1895 owing to the development of railways. The amount of coke consumption also increased from 1,288 tons in

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[7] The amount of firewood consumed by the Ashio mine also decreased from its peak in 1890 of 1,612 m^3 to 473 m^3 in 1897 (Tochigiken-shi Hensan Iinkai 1980, p.249; Nōshōmushō 1900, p.149).

[8] Furukawa Mining Co. began to run coal mines, aiming at self-sufficiency in coke (Nihon Keiei-shi Kenkyūjo 1991, pp.117-120).

1891 to 7,452 tons in 1895, and coke began to be produced at Niihama in 1897. In this way, in the late 1890s, charcoal was replaced by coal and coke at the two large-scale mines.

[Figure 4]

However, changes in energy use were not the same in all mines. It is necessary to examine energy use at the micro-level. Accordingly, the next section will consider heat energy and motive power to understand the energy selection at each mine.

4.2 Heat energy selection for smelting

4.2.1 *Yōkō* process

The smelting process comprises three parts: *yōkō*, *rendō*, and *seiren* (see Figure 5). *Yōkō* means refining crude ore into matte and increasing the grade of matte by 20–40%. A revolutionary technological innovation using new methods was introduced in this process to replace the traditional method (*tokobuki-hō*) that used charcoal and firewood. The new method was called *namakōbuki-hō,* and it was developed at the Kosaka mine in 1899. The Kosaka mine was developed in the Tokugawa period as a gold and silver mine, but it had to process copper sulfides containing materials such as lead and zinc, known as black ore because gold and silver ore was exhausted. Therefore, the Kosaka mine improved the furnace structure and established the *namakōbuki-hō*, and developed as a copper mine.

[Figure 5]

The *namakōbuki-hō* was a smelting technology developed to use coke to save fuel, and hence, coke was selected as the fuel. However, charcoal was probably almost eliminated as a choice of fuel for the *namakōbuki-hō* because hardness became one of the requirements of the fuel for the new method. In other words, if fuel broke down in the furnace, combustion was insufficient because of bad ventilation, and charcoal was not hard enough to withstand the increased weight of the ores in the larger furnaces. As a result, charcoal probably less used than coke, which probably was combusted with lesser waste[9]. From the early experiment, it was clear that introduction of the *namakōbuki-hō* led to a drastic reduction in the fuel utilization ratio from 22% to 6%; moreover, since the new method did not require the calcination that a process of before smelting, the demand for

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[9] I appreciate that Professor Takeda, Haruhito gave me advice about this. Powder ore was also smelted after sintering to avoid deterioration of the ventilation in the furnace (Kōzan konwa kai 1932, vol.1, pp.520-527, 534).

firewood used for that work also reduced. For example, at the Ashio mine, in the 1900s, coke was the main fuel for the *yōkō* process; the specific coke consumption dropped with the increase of crude ore throughput by the *namakōbuki-hō*, and fuel expenses fell (see Table 1). Since the 1900s, the *namakōbuki-hō* had been introduced at mines such as Hitachi, Yoshioka, Ikuno, Kanō, Mikkaichi, and Osaruzawa. In the early 1910s, this method spread to most of the principal mines, and after it was introduced to the Shisakajima smelter (the smelter attached to the Besshi) in 1916, the traditional *yōkō* methods were no longer used (Nihon Kōgaku Kai 1930, pp.469-499; Kōzan Konwa Kai 1932, vol.1, p.389).

[Table 1]

The *namakōbuki-hō* made it possible to refine many kinds of crude ore together and to expand the crude ore market that was supported by the decrease of rail fares from the late 1900s. Moreover, the system of buying and refining crude ores developed rapidly to avoid the restriction of new and additional smelting facilities or suspension of operations due to smoke pollution that had been occurring in all areas. Thereby, it became possible for large-scale mines to obtain crude ore enough for their large furnaces. On the other hand, small- and medium-size mines abandoned inefficient smelting and became able to specialize in mining. The ratio of mines selling ores increased from around 8% in 1905 to around 45% in 1913 and 78% in 1915 (Takeda 1987, pp.108-116). This was linked to energy savings in the entire Japanese copper industry.

4.2.2 *Rendō* process

Rendō means refining matte into crude copper and increasing the grade of crude copper to 90–97%. The *mabuki-hō* was a kind of Japan's traditional *rendō* method. In the large-scale mines of Ashio, Hitachi, and Kosaka, a conversion method was introduced to replace the *mabuki-hō*; this allowed for the switchover of fuel from charcoal to coke and increased the size of the converters. The Ashio mine introduced converters that produced 45 times the output of traditional methods in 1893, thereby increasing the grade of crude copper and reducing the cost of *rendō*. The Kosaka mine reduced the cost of *rendō* by 75% after introducing a converter, and the Hitachi mine, which began to use converters in 1909, also saw a reduction of more than 80% in *rendō* cost by 1911. However, the introduction of converters required a substantial investment, and only a small number of mines could produce crude copper enough to fill a very large converter[10]. Therefore, many other mines continued to use and refine the traditional method that was simpler and cheaper to build. The production output of crude copper through the *mabuki-hō* constituted 40–60% of all crude copper produced until the WWI period (Takeda 1987, pp.97-99; Nihon Kōgaku Kai 1930, p.511; Kōzan Konwa Kai 1932, vol.1, pp.437, 551-552, 558).

Table 2 shows the utilization of smelting fuel at each mine in the mid-1910s. While almost all mines used coke at the *yōkō* process, various energies such as charcoal, heavy oil, coal tar, coal, and coke were used at the *rendō* process. For example, the Kunitomi, Horobetsu, Abeshiro, Taishō, and Nagamatsu mines used charcoal, the Osaruzawa, Arakawa, Hanaoka, Hassei, Kusakura, and Sagaseki mines used heavy oil. Moreover, the Ogoya and Ikuno mines used charcoal as well as coal tar, whereas Kawaiyama and Naganobori mines used charcoal and coke. Except for large-scale mines such as Ashio and Hitachi, a majority of mines continued to use charcoal[11]. Thus, charcoal continued to be the main fuel used for *rendō*. Some mines may have chosen charcoal attaching importance to their original technologies because the fuel saving of the traditional *rendō* method was dependent on the technology of the smelter. Moreover, mines distributed in Niigata and Akita prefectures which have oilfields, and mines located in places relatively near, were more likely to use heavy oil, and mines located close to gas companies used coal tar which was a by-product of gas (Tanizaki 1914, part1, p.17).

[Table 2]

Thus, the energy selection for the *rendō* was dependent on the cost of energy, financial power, access to energy, and technologies. This may have resulted in diversified energy, and it is considered that there was no other country where *rendō* equipment was as diverse as in Japan (Ikeda 1933, p.917).

4.2.3 *Seiren* process

Seiren means refining crude copper into copper and increasing up the grade of refined copper to

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[10] It was not economical to introduce a converter if the amount of crude copper production did not exceed 120 tons per month (Ishikawa 1909, part 1, p.298).

[11] It includes mines that probably used charcoal such as Furikura, Mizusawa, Matuskawa and Sasagatani (See Table2).

exceed 99%. This process was necessary for removing gold and silver because the namakōbuki-hō processed various ores in the *yōkō* process and crude copper came to contain them. As shown in Table 2, crude copper was refined at the mines of Kosaka, Nikkō (the smelter attached to the Ashio mine), Hitachi, Sagaseki, Yūsenji, and Niihama (the smelter attached to the Besshi mine), and the Mitsubishi Ōsaka smelter. Crude copper produced at other mines was also transported to these mines and smelters and refined.

The amount of heat needed for *seiren* was inferior to that for *yōkō* or *rendō* and, therefore, in addition to charcoal and coke, electricity also became an energy option for *seiren*. As discussed below, the utilization of electricity as motive power had increased at all the above mines. All these mines except Besshi (Niihama) chose electricity for *seiren* and mainly produced copper for electrical wires. At the Besshi, coke was used as the energy for *seiren,* and electrical refinement of copper began later. The reason was that the Besshi mine produced copper for Shindoh, which needed a certain degree of hardness, and the Besshi copper contained almost no gold or silver. Moreover, because the reputation of Besshi copper was relatively high in foreign markets, the Besshi mine emphasized the improvement of traditional technologies (Sumitomo Denki Kogyō Kabusiki-gaisya 1961, pp.103-104, 220; Takeda 1987, pp.109-110). Such cases, where the selection of refining technology and energy was influenced by the quality of the produced goods and the quality of ores, can also be seen in iron mining. In the iron mines, although coke had been used since the 1890s, iron smelted using charcoal was of a higher quality than iron smelted using coke, and charcoal continued to be used wherever its supply was possible[12] (see Table 2).

4.3 Selection of motive power for mining, dressing, and smelting

As described above, the smelting process developed with the introduction of new and additional furnaces, converters, and electrical refining equipment, and the expansion of them. Accordingly, the manageable amount of ore increased, and it was necessary to increase the output of ore. In the Meiji

[12] At the Kamaishi iron mine, although only charcoal was used at first, the amount of coke consumption increased due to insufficient charcoal. However, the iron produced by using charcoal needed for weapons and warships, and it was more expensive than the iron produced by using coke. So even during the WWI, charcoal was transported from remote locations and used. The amount of coke consumed by main ironworks was 890,000 tons, and the amount of charcoal consumed by them was 260,000 tons in 1920 (Suzuki 1924, p.87; Kōzan Konwa Kai 1932, vol.2, table 16).

period, the motive power for mining, transportation, dressing, and smelting mainly relied on human and horse power, but the increase of ore production caused the shortage of motive power. So the mechanization was needed to resolve that problem. Although each mine's measures were different due to the condition of ore deposits and financial power, the installation of rock drills, winding equipment, electric motors, drainage pumps, and ventilators had progressed, and transportation equipment such as railways and cableways within and out of the pit also had enhanced, mainly in the large-scale mines (Kōzan Konwa Kai 1932, vol.1, pp.172-173, 248-252, 259-271, 281-289; Takeda 1987, pp.198-212).

Table 3 shows the classification of the principal mines' motive power into steam engines, waterwheels, internal-combustion engines (such as oil engines, gas engines, and others), dynamos, and electric motors. The aggregates are categorized by the total motive power of each mine as follows; (1) over 3,000 horsepower, (2) more than 500 but less than 3,000 horsepower, and (3) more than 1 but less than 500 horsepower. Because it is unclear whether each steam engine, waterwheel, and internal-combustion engine was used for electric power generation or not, this is not considered. First, looking at the overall trends, although it is important to bear in mind that many steam engines were reserves prepared for winter freezes or dry seasons (Imazu 1979, p.105), in 1898 they accounted for 63% (4,356 horsepower) of the total horsepower of steam engines, waterwheels, and internal-combustion engines combined. However, in 1906, waterwheels accounted for the majority, and in 1913 they reached 72% (48,256 horsepower). Looking at the trend by mine scale, from 1906 to 1913, at mines with over 3,000 horsepower, the proportion of waterwheels increased from 62% (5,960 horsepower) to 77% (32,252 horsepower), and at mines with more than 500 but less than 3,000 horsepower, it increased from 44% (3,410 horsepower) to 69% (12,565 horsepower); this indicates that the larger the scale of mine was, the more mines tended to depend on water power.

[Table 3]

The amount of horsepower of electric motors also increased at the same time. From 1906 to 1913, the proportion of electric motors in the total horsepower of steam engines, waterwheels, internal-combustion engines, and electric motors combined increased from 36% (5,382 horsepower) to 40% (28,061 horsepower) at mines with over 3,000 horsepower, and from 27% (2,873 horsepower) to 46% (15,546 horsepower) at mines more than 500 but less than 3,000 horsepower. As prior research has pointed out, particularly in mines with over 3,000 horsepower, Western-style waterwheels were introduced with a large amount of horsepower per device, and these had been linked to hydroelectric power generation. The completion of a hydroelectric power station at the Ashio mine in 1890 turned large-scale mines toward hydroelectric power generation leading to widespread electrification. In 1917, the horsepower of electric motors increased rapidly, and electrification by hydroelectric power generation progressed further. However, in areas such as Hokkaidō, Chūgoku, and Shikoku regions, which were close to coal fields, greater use of steam engines was seen than in regions such as Tōhoku and Chūbu, and this was sometimes linked to thermal power generation.

However, in small-scale mines with more than 1 but less than 500 horsepower, which constituted about 80% of all mines, the proportion of waterwheels in the total horsepower of steam engines, waterwheels, internal-combustion engines, and electric motors combined dropped from 56% in 1906 (2,370 horsepower) to 50% in 1913 (3,439 horsepower), but traditional small-horsepower Japanese waterwheels had been used for a long time. The proportion of waterwheel power was lower than in large-scale mines, and the proportion of internal-combustion engines was correspondingly higher. It was 3% (1,051 horsepower) in mines with over 3,000 horsepower, 13% (2,341 horsepower) in mines with more than 500 but less than 3,000 horsepower, and 32% (2,196 horsepower) in mines with more than 1 but less than 500 horsepower. From 1912 onward, suction-type gas engines were developed, which could run on cheap bituminous coal, rice husks, wood chips, and charcoal. Not just at small factories in urban areas, but also at mines, there was an increased use of these gas engines, which were more affordable than steam engines (Suzuki 1996, pp.212-220). For example, in not only small-scale mines such as the Taishō but also in relatively large-scale mines such as Ogoya and Furōkura, charcoal was used as fuel for gas engines (Nabeshima 1911, p.13; Nōshōmushō 1918, p.43; Kōzan Konwa Kai 1932, vol.1, p.629; Suzuki 1924, p.39). Accordingly, a new use of charcoal was established. In 1917, in mines with more than 1 but less than 500 horsepower, the proportion of internal-combustion engines had exceeded the proportion of waterwheels, and gas engines were used in electric power generation. This also amplified electric power purchase in the context of lower electricity charges, and the proportion of electric motors in the total horsepower of steam engines, waterwheels, internal-combustion engines, and electric motors increased from 20% (2,594 horsepower) in 1913 to 45% (7,423 horsepower) in 1917, and electrification progressed even in these small-scale mines[13].

4.4 Increasing supply of energy for living

The mechanization of power made progress in this way. However, many mines were limited in the mechanization by their lack of financial power. By 1917, no more than ten mines had more than 3,000 horsepower, and almost all of them were managed by *zaibatsu* that had more financial power. The condition of ore deposits limited even the well-financed larger-scale mines, and they could not avoid relying on human power. Although large-scale mines with advanced smelting technologies had reduced the number of smelters, the number of miners working in mining, conveying, and timbering increased. The total number of miners employed in metal mines increased from 53,474 in 1893 to 73,751 in 1906, and then to 165,151 in 1917 (see Figure 2). Since many of the miners lived with their families, the population of the mining communities was around 3–4 times greater than the number of miners. The demand for charcoal and firewood increased as the source of energy for the daily life of the community (for heating, cooking, and the communal bathhouse).

In the 1900s, the management system of miners switched from indirect management (*hanbaseido*) to direct management by a company. With this move, to resolve complaints of miners, each mine supplied miners with daily necessities, such as rice, miso, soy sauce, and charcoal, linked to a welfare program. Each mine provided miners that fulfilled certain conditions (such as employment rate and period of employment) with these daily necessities that were difficult to buy in mountainous regions at below-market rates (Takeda 1987, pp.174-177). Nonetheless, even at mines that had been free from ensuring charcoal and firewood for smelting, there were still serious problems of how to ensure charcoal and firewood for daily life.

For example, at the Ashio mine, 4-5 bags of charcoal were given every month to families of 4-6 people and 5-6 bags of charcoal were given every month to families of 7 people or above. According to documents concerning Ashio's charcoal in the late 1920s, it can be assumed that around 70% of the charcoal produced was for miners' homes, and the remaining 30% was for the copper

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[13] At mines with more than 1 but less than 500 horsepower, it can be estimated that 50–60% of mines bought electricity. Furthermore, the total amount of electric power generation and electricity purchased at all metal mines in 1917 was 70,459 horsepower, 18,561 horsepower, and in 1919 was 83,956 horsepower, 20,249 horsepower (Nōshōmushō 1917 and 1919).

industry (Ashio Kōgyōsho 1919 and 1931). Furthermore, the charcoal consumption for the Ashio and Besshi mines shown in Figure 3 only counts charcoal produced or purchased by the mines, so the amount may have been even more considerable including charcoal purchased by miners from merchants. Moreover, it can be assumed that many miners also tried to get charcoal or firewood by secretly felling trees from the *kōzanbirin*, because the most severe penalties were imposed on such miners (Nihon Keiei-shi Kenkyūjo 1991, p.386). In any case, even at large-scale mines, such as Ashio and Besshi, which had undergone a shift in the energy for smelting to coke and electricity, charcoal and firewood continued to be used. The Ashio mine, in particular, consumed a large amount of charcoal because it was a mine with vein ore deposits that were difficult to mechanize and highly dependent on human power.

In this way, the energy for miners' living was unavoidably dependent on charcoal and firewood, and therefore, the amount of charcoal consumption at all mines increased between 1912 and 1918 from 578,240 m^3 (66,500 tons) to 961,880 m^3 (116,790 tons), and the amount of firewood consumption increased from 69,500 m^3 to 283,560 m^3. Charcoal was used more than firewood in miners' houses given fire prevention (Sagō 1986, p.87). The amount of charcoal consumption in mines was estimated 6% of the nationwide charcoal consumption. The amount of timber consumption also increased from 133,440 m^3 to 186,260 m^3, with increasing demand for wood such as pit props, utility poles for electrification, sleepers for the expansion of railways, and construction materials for the growing number of miners; however, this was only one-fifth of the amount of charcoal and firewood consumption (Suzuki 1924, pp.21, 136-140).

Each mine could not help responding to an increased demand for wood, and continuously bought state, public, private forests, and felled trees. For example, as well as felling trees from 99 ha of state forest every year, the Ashio mine made up for a shortage by felling trees from 5,752 ha of private forest, and met the demand for charcoal amounting to 7,500 tons a year and other wood. The largest consumer of wood among all copper mines, Hitachi mine, met the demands of wood by buying trees in state and private forests; however, demand increased to supply charcoal and firewood to the miners under the enhanced labor movement in the period of WWI. The Hitachi mine had to buy trees from 645 ha of private forest that was far from the mine. Moreover, there were mines such as the Nagamatsu and Furōkura mines that had all the wood supplied from state forests, but almost all mines had to purchase wood from merchants, due to the shortage of forests close to the mine[14]. Each mine increased the purchase amount when it was cheaper to buy from merchants than to fell trees[15], and in such a situation, the forests (*kōzanbirin*) sometimes functioned to restrain merchants' activities of the driving price up. During WWI, there was a sudden increase in the price of wood, and many mines purchased forests (Suzuki 1924, pp.34-84; Dai-Nihon Sanrin Kai 1931, p.551).

5. Conclusion

As this study shows, on a macro-level, the main energies of Japanese copper industry shifted from firewood and charcoal to coal and coke in the 1890s in the context of changing energy prices; moreover, hydroelectric power also increased since the 20th century. However, on a micro-level, mining energy was diversified. Regarding heat energy for smelting, although the shift from charcoal and firewood to coke was seen owing to the development and introduction of *namakōbuki-hō* in the *yōkō* process, various energies such as charcoal, heavy oil, and coal tar were chosen in the *rendō* process, except in large-scale mines that introduced converters. Moreover, in the *seiren* process, electricity or coke were used depending on differences in the ore components and the end-product (usage). Regarding motive power, the mines depended on Japanese-style waterwheels, and human and horse power at first, but later, they began to use coal-powered steam engines, Western-style waterwheels, and charcoal- and coal-powered gas engines. The shift from waterwheels to hydroelectricity was seen more in larger-scale mines that had more financial power, and in smaller mines, use of gas engines increased as the use of Japanese-style waterwheels continued. However, there were limits to this kind of mechanization of power, and human power was still the essential source of power.

The mines changed into a space that is based on a diverse combination of energy depending on differences in location (access to energy), natural conditions, financial power, the

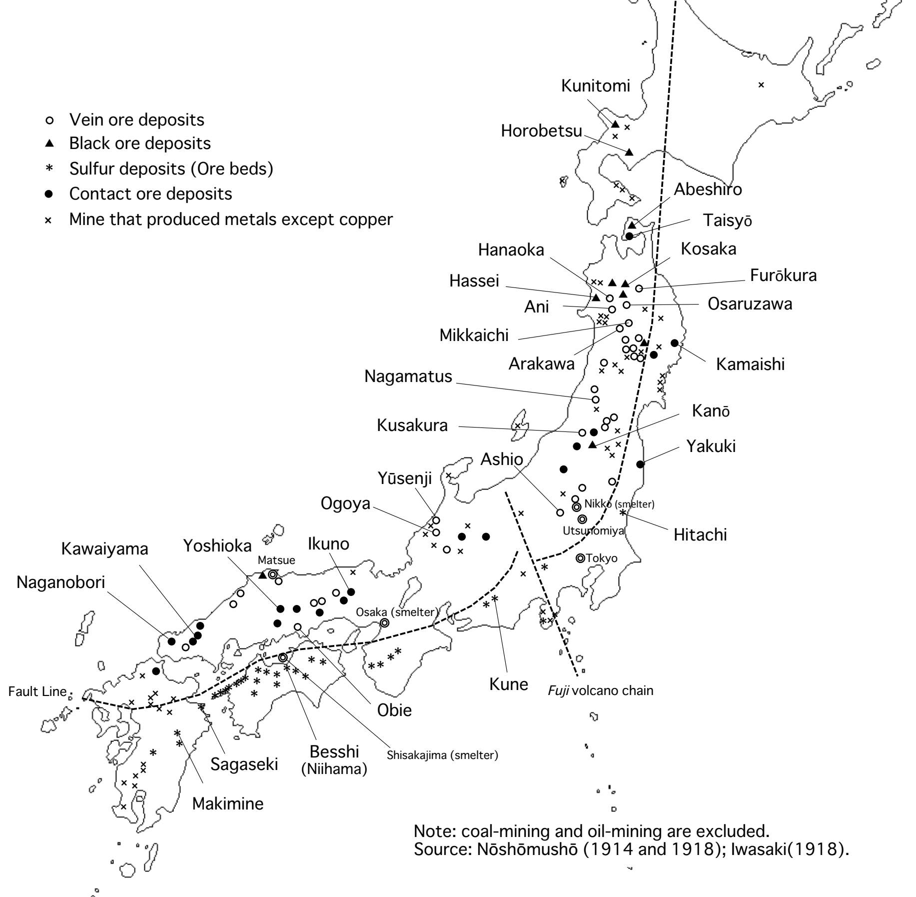
[14] For example, at the Besshi mine, although around 22,000 ha of forests (*kōzanbirin*) were managed, felling was not carried out because trees planted were not grown enough. So the way of wood procurement was shifted to purchasing from felling (Sumitomo Ringyō Kabushiki-gaisha Sha-shi Hensan Iinkai 1999, vol.1).

[15] For example, at the Ashio mine, although the amount of charcoal purchased from merchants was about 45% of the amount of charcoal consumption around 1907–1908, this was about 10% during WWI (Ashio Kōgyōsho 1907-08 and 1920).

required amount and price of energy, energy use technologies, ore quality, and end-product (usage). These factors led mines to select new energy resources such as coal, coke, and electricity or traditional energy resources such as charcoal, firewood, and waterwheels. Charcoal and firewood were used not only for smelting but also for new gas engines and miners' daily life. As a result, the consumption of them increased. It was possible to use these traditional energy resources continuously due to the shift to coal, coke, and electricity as the main energy sources of large-scale mines. Therefore, it can be argued that, even if the mines were not aware of that, with the increasing efficiency of energy use in large-scale mines and the decreasing use of inefficient energies in small-scale mines, the mining industry succeeded in saving energy across the industry.

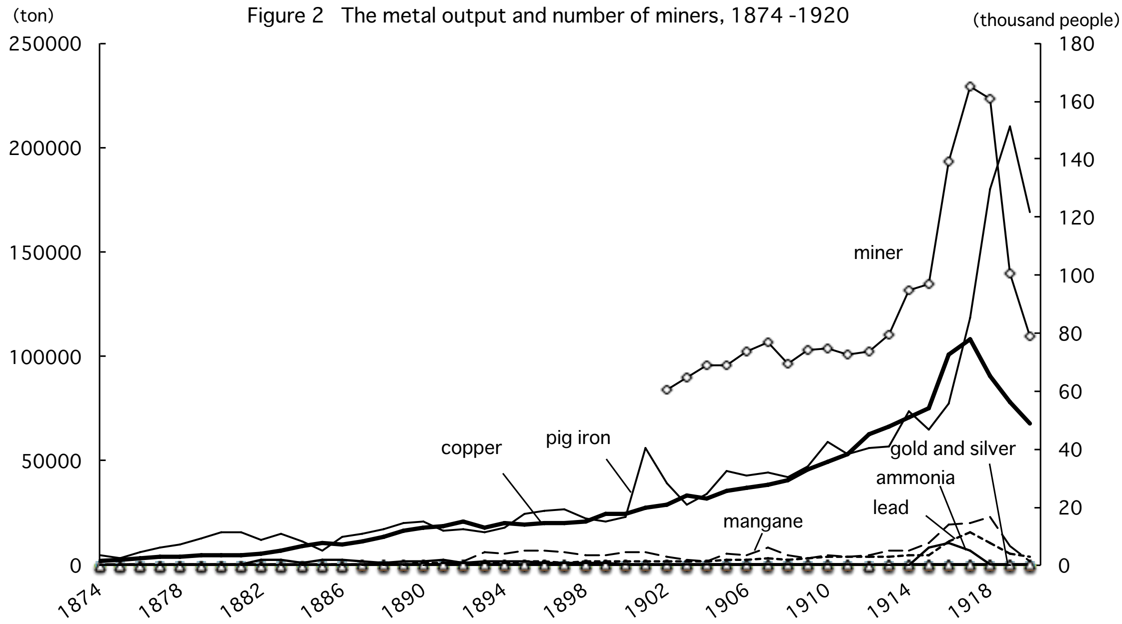
Although this study does not consider the 1920s and onward, when the trend toward coke and electricity strengthened, the copper industry's energy use from the Meiji period to the WWI indicates that energy shift was not a single-track, unified switchover but various selections of energy resource. Micro-level studies should be conducted in the future to go beyond the understanding of a single-track shift of energy and clarify the actual use of energy.

Figure1 The distribution of the main metal mines



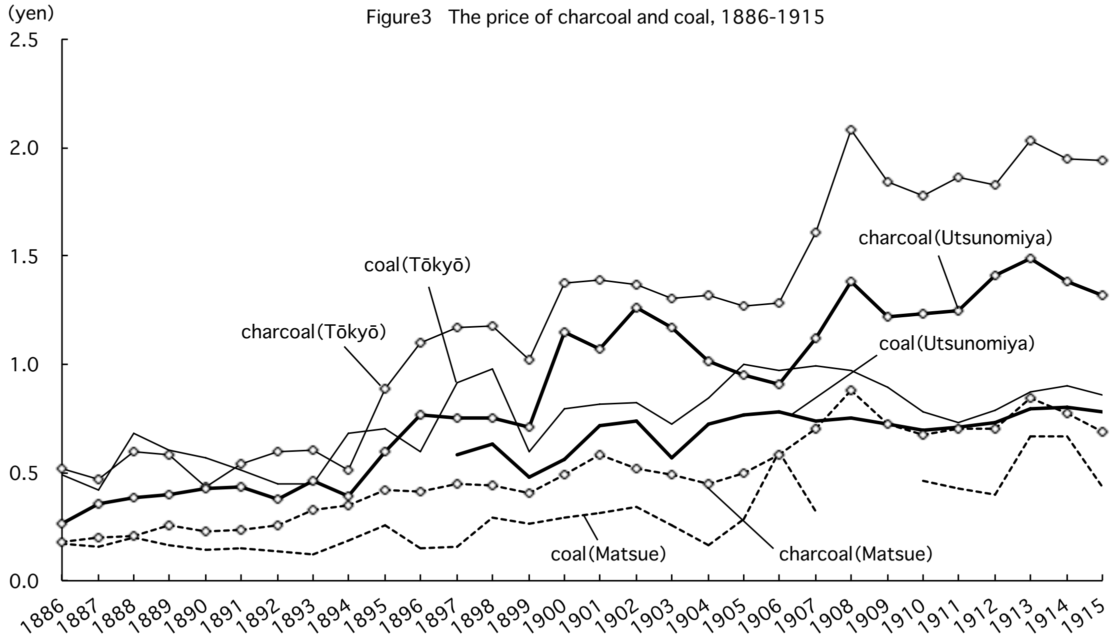
Note: coal-mining and oil-mining are excluded.
Source: Nōshōmushō (1914 and 1918); Iwasaki(1918).

Figure 2 The metal output and number of miners, 1874 -1920



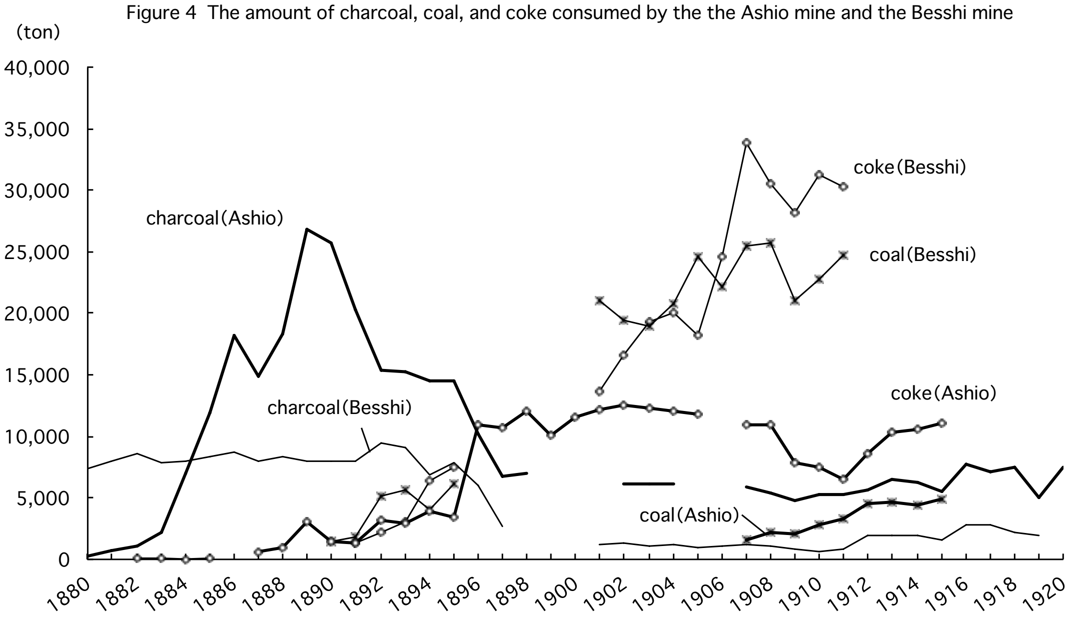
Note: The output of pig iron does not include the output by the state-owned Yahata Iron Factory.
Sources: Nōshōmushō (1911-1922), 28th to 39th; Nōshōmushō (1910-1921); Nihon Kōgaku Kai(1930); Tokyo Kōzan kantokusho(1911).

Figure3 The price of charcoal and coal, 1886-1915



Note: charcoal : the price per 10 *kan* (=37.5kg) coal : the price per 100kg
Sources: Nōshōmushō (1888-1917), 5th to 34th.

Figure 4 The amount of charcoal, coal, and coke consumed by the the Ashio mine and the Besshi mine



Note: The amount of coke consumed by the Ashio from1899 to 1905 is estimated figure.

Source: Nihon keieishi kenkyūjo(1991); Ashio Dōzan (1892); Ashio Dōzan (1889);Tochigikenshi hensan iinkai(1980), pp.249, 251; Nōshōmushō(1900); Hosoya(1905); Suzuki(1924); Sueoka(2000).

Figure 5 The process of smeltimg

crude ore grade5～10% → ① *yōkō* → matt grade20～40% → ② *rendō* → crude copper grade90～97% → ③ *seiren* → refined copper grade99～99.9%

Table1 The *rendō* at the Ashio mine

	The amuout of crude ore processed (thousand *kan*)	Grade of crude ore (%)	The ratio of crude ore throuhput by the *namakō buki-hō* (%)	The ratio of the amount of coke consumed to the amount of crude ore processed(%)	*Rendō* cost per 100*kin* of crude copper (*yen*)		
					Total	wage	fuel
1897	3,100	16.1	0.0		5.09		
1901	5,605	?	(12.7)	25.8	4.87	0.78	2.76
1903	6,003	15.6	52.6	21.0	5.01	0.94	(3.02)
1905	6,529	14.2	71.1	18.4	5.41	1.11	(3.23)
1907	6,345	13.0	98.7	18.5	6.04	1.11	2.66
1908	7,293	12.9	84.0	16.7	5.57	1.33	2.33
1909	7,640	12.8	98.0	10.8	5.38	1.21	1.67
1910	7,872	12.4	100.0	9.6	5.12	1.23	1.39
1911	8,398	12.3	100.0	9.6	4.86	0.93	1.17
1912	9,309	12.3	100.0	10.5	4.62	0.79	(1.21)
1913	11,589	11.8	100.0	10.2	4.34	0.83	(1.14)

Note: Figures in parentheses are estimeted. 1,000*kan* =37,500kg 100*kin* =6kg

Source:Takeda(1987), p.106.

Table1 The utilization of smelting fuel at main mines in the mid-1910s

	Mine name	place: Regin	place: Prefecture	Holder of mining right	*Yokō*	*Rendō*	*Seiren*	The amount of ore smelted in 1917 (ton): Total	Purchase
	Kunitomi	Hokkaidō	Hokkaidō	Tanaka Mining Co.	coke, coal	charcoal		47,785	18,751
	Horobetsu		Hokkaidō	Ryōji Oda	coke	charcoal		5,480	0
	Abeshiro		Aomori	Tanaka Mining Co.	coke	charcoal		150,896	77,754
	Taishō		Aomori	Taishō Mining & Co.	coke	charcoal		16,003	0
	Kosaka		Akita	Fujita Mining Co.	coke	coke, coal(converter)	electricity	153,510	211,125
	Osaruzawa		Akita	Mitsubishi Goshi Kaisha	coke	heavy oil	(→Mitsubishi Ōsaka smelter, electricity)	53,303	7,262
	Arakawa		Akita	Mitsubishi Goshi Kaisha		heavy oil	(→Mitsubishi Ōsaka smelter, electricity)	18,686	7,127
	Ani		Akita	Furukawa Mining Co.	coke	charcoal	(→Nikkō smelter, electricity)	16,412	0
	Furokura		Akita	Furukawa Mining Co.	coke	charcoal?		8,708**	142
	Daira		Akita	Furukawa Mining Co.	coke			742	0
	Hanaoka	Tōhoku	Akita	Seiichirō Kobayashi		heavy oil		110,744	0
	Hassei		Akita	Dainihon Mining Co.	coke	heavy oil		44,588	23,902
	Ōkura		Yamagata	Yokoyama Mining & Co.	coke			12,009	4,716
	Nagamatus		Yamagata	Furukawa Mining Co.	coke	charcoal	(→Nikkō smelter, electricity)	16,223	609
	Ōtori		Yamagata	Furukawa Mining Co.	coke		(→Nikkō smelter, electricity)	5,349	0
	Tsunatori		Iwate	Mitsubishi Goshi Kaisha	coke, coal	charcoal, heavy oil	(→Mitsubishi Ōsaka smelter, electricity)	10,230	4,814
	Ōarasawa		Iwate	Fujita Mining Co.			(→Kosaka Mine, electricity)	20,613	12,924
	Mizusawa		Iwate	Furukawa Mining Co.		charcoal?		5,219	20
	Washinosu		Iwate	Kyōritsu Mining Co.		charcoal?		3,523	1,388
	Matuskawa		Iwate	Yone Oguri	coke, charcoal	charcoal?		1,754	52
	Yakuki		Fukushima	Yakuki Mining Co.	coke	heavy oil		59,507	11,249
	Kanō		Fukushima	Kanō Mining Co.	coke			12,506	2,412
	Hitachi		Ibaraki	Kuhara Mining Co.	coke	coke, coal(converter)	electricity	609,229	237,632
	Ashio	Kantō	Tochigi	Furukawa Mining Co.	coke	coke, coal(converter)	(→Nikkō smelter, electricity)	(115,146)	(14,854)
	Kidogasawa		Tochigi	Kidogasawa Mining Co.	coke	heavy oil		61,386	50,361
	Kusakura		Niigata	Furukawa Mining Co.	coke	heavy oil		491**	0
Copper	Mochikura		Niigata	Koide Mining Co.		heavy oil		20,139	222
	Takane		Gifu	Mitsubishi Goshi Kaisha	charcoal?	charcoal		1,876	0
	Kurokawa	Cyūbu	Gifu	Kōeki Syokusan Co.	charcoal	(→Chigirishima smelter, coal tar)		636	0
	Ogoya		Ishikawa	Yokoyama Mining & Co.	coke	charcoal, coal tar		22,809	2,394
	Yūsenji		Ishikawa	Takeuchi Mining Co.	coke	coke, coal(converter)	electricity	20,832	13,062
	Omodani		Fukui	Mitsubishi Goshi Kaisha			(→Mitsubishi Ōsaka smelter, electricity)	10,427	222
	Ikuno	Kinki	Hyōko	Mitsubishi Goshi Kaisha		charcoal, coal tar	electricity	66,550	22,083
	Ōmori		Shimane	Furukawa Mining Co.	coke, coal		(→Kosaka Mine, electricity)	7,662	0
	Hōmanzan		Shimane	Tōjūrō Hori	coke			4,164	641
	Sasagatani		Shimane	Tōjūrō Hori	coke	charcoal?		14,939	6
	Yoshioka	CyūGoku	Okayama	Mitsubishi Goshi Kaisha	coke, coal	charcoal	(→Mitsubishi Ōsaka smelter, electricity)	30,876	1,907
	Obie		Okayama	Fujita Mining Co.	coke	coke	(→Mitsubishi Ōsaka smelter, electricity)	69,836	67,391
	Kawaiyama		Yamaguchi	Furukawa Mining Co.	coke	charcoal, coke		12,607	0
	Naganobori		Yamaguchi	Tōjūrō Hori	coke	charcoal, coke		2,464	162
	Yakuōji		Yamaguchi	Shintarō Kishimoto	coke			1,506	359
	Ofuku		Yamaguchi	Yone Oguri	coke			2,039	71
	Besshi		Ehime	Kichizaemon Sumitomo	coke	coke, coal	coke, coal(→Shisakajima smelter, coke)	318,750	0
	Nishinokawa		Ehime	Kichizaemon Sumitomo		charcoal	(→Shisakajima smelter, coke)	9,618	0
	Shirataki	Shikoku	Kōchi	Otsunomiya Sōjūrō	coke	coke		13,585	0
	Tomioka		Kōchi	Tanaka Ginnosuke		charcoal		3,843**	0
	Kamiseki		Kōchi	Utsunomiya Mining & Co.	coke, charcoal	charcoal?		1,913**	0
	Iya		Tokushima	Fujita Mining Co.		charcoal?		4,087**	0
	Sagaseki		Ōita	Kuhara Mining Co.	coke	heavy oil	electricity	13,077	9,815
	Itsuki	Kyūsyū	Kumamoto	Nishizawa Goshi Kaisha	coke			1,815**	0
	Hidaira		Miyazaki	Seikyo Naitō	coke			14,668	0
	Makimine		Miyazaki	Mitsubishi Goshi Kaisha	coke	coal		19,784	0
	Tanaka		Kagoshima	Seizō Tanaka	coke			2,170	0
	Kamaishi		Iwate	Tanaka Mining Co.	charcoal, coke			181,187*	43,769
Iron	Sennin	Tōhoku	Iwate	Sennin IronFoundry Co.	charcoal	(charcoal)		7,774*	7
	Kuriki		Iwate	Kuriki Tetuszan Co.	charcoal	-		5,443	0

Note) *: includes copper. **: the amount of ore smelted in 1913. The smelters that did not have mines, such as Mizushima(in Okayama prefecture), Hibi(in Hiroshima prefecture),chigirisima(in Hiroshima prefecture), and Sashima(in Ehime purefecture), used coal tar for the *rendō* process(*mabuki-hō*).

Sourse)Nōshōmushō(1914 and 1918); Kōzan Konwa Kai(1932),vol.1;・Nihon Kōgaku Kai(1930);Takeda(1987), pp.109, 113.

Table2 The classification of the main mines' motive power

Year	The number of mines	steam engin (a)				water wheel (b)				internal-combustion engine (c)				subtotal (d=a+b+c)		dynamo (e)			electric motor (f)				total (g=d+g)	
		The number of engins	HP	(a)/(d)	HP per device	The number of water wheels	HP	(b)/(d)	HP per device	The number of engins	HP	(c)/(d)	HP per device	HP	HP per device	The number of dynamos	HP	HP per device	The number of lectric motors	HP	(f)/(g)	HP per device	HP	HP per device
Total																								
1898	80	213	7,564	63%	36	286	4,356	37%	15	-	-	-	-	11,920	149	-	-	-	-	-	-	-	-	-
1906	73	149	8,082	37%	54	852	11,740	54%	14	41	1,761	8%	43	21,583	243	9	1,275	142	280	9,477	31%	34	31,060	425
1913	118	144	13,294	20%	92	1,009	48,256	72%	48	112	5,588	8%	50	67,138	457	147	51,328	349	979	46,200	41%	47	113,338	960
1917	159	163	19,155	25%	118	597	45,487	60%	76	155	10,901	14%	70	75,543	358	273	68,169	250	2,047	106,385	58%	52	181,928	1,144
1925	83	37	8,119	9%	219	144	80,820	85%	561	51	5,621	6%	110	94,559	448	220	96,584	439	2,586	101,858	52%	39	196,416	2,366
Over 3,000 horsepower																								
1906	3	46	3,615	38%	79	12	5,960	62%	497	1	6	0%	6	9,581	3,194	5	839	168	148	5,382	36%	36	14,963	4,988
1913	6	59	8,595	21%	146	45	32,252	77%	717	27	1,051	3%	39	41,898	3,492	47	34,491	734	403	28,061	40%	70	69,959	11,660
1917	10	99	12,581	27%	127	47	29,925	64%	637	17	4,447	9%	262	46,952	2,762	121	44,463	367	1,049	61,783	57%	59	108,735	10,873
1925	15	31	7,082	9%	228	104	71,957	87%	692	8	3,310	4%	414	82,349	4,844	145	82,079	566	1,733	80,453	49%	46	162,802	10,853
More than 500 but less than 3,000 horsepower																								
1906	11	52	2,900	37%	56	33	3,410	44%	103	10	1,465	19%	0	7,775	707	1	306	306	81	2,873	27%	35	10,648	968
1913	25	35	3,394	19%	97	532	12,565	69%	24	16	2,341	13%	146	18,300	732	60	14,491	242	447	15,546	46%	35	33,846	1,354
1917	29	19	4,132	21%	217	386	12,974	67%	34	29	2,281	12%	79	19,387	669	72	19,119	266	617	18,949	49%	31	38,335	1,322
1925	19	1	680	7%	680	19	8,195	85%	431	6	766	8%	128	9,641	507	47	12,868	274	512	15,582	62%	30	25,222	1,327
More than 1 but less than 500 horsepower																								
1906	58	51	1,567	37%	31	807	2,370	56%	3	30	290	7%	10	4,227	73	3	130	43	51	1,221	22%	24	5,448	94
1913	87	50	1,305	19%	26	432	3,439	50%	8	69	2,196	32%	32	6,940	80	40	2,346	59	129	2,594	27%	20	9,534	110
1917	120	45	2,443	27%	54	164	2,589	28%	16	109	4,173	45%	38	9,205	77	80	4,586	57	381	7,423	45%	19	16,628	139
1925	49	5	357	14%	71	21	668	26%	32	37	1,545	60%	42	2,570	52	28	1,637	58	341	5,823	69%	17	8,392	171

Note: Table2 covers mines that produced more than 5 kan of gold, or more than 100 kan of silver, or more than one hundred thousand kin of copper, or more than other metal of three thousand yen for a year.

The number of mine that had no motive power except laber and horse power: 17 mines (1906), 29 mines (1913), 52 mines (1917).

1kw is converted to 1.359 horsepower.

The reduction of waterweel HP at mines with over 3,000 horsepower from 1913 to 1917 may result from the inaccuacy in the waterwheel HP of Ashio mine.

Source: Nōshōmushō(1900); Nōshōmushō(1907); Nōshōmushō(1914,1918 and 1926).

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