ECONOMIC RESEARCH CENTER
DISCUSSION PAPER

E-Series

No.E14-9

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by

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November 2014

ECONOMIC RESEARCH CENTER
GRADUATE SCHOOL OF ECONOMICS
NAGOYA UNIVERSITY

Development of energy conservation technology in Japan, 1920–1970: specific examination of energy intensive industries and energy conservation policy*

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Abstract

This paper presents analysis of Japanese energy conservation technology development during the 1920s–1960s, particularly addressing energy-intensive industries, especially the iron and steel industry, and energy conservation policies extending to end-users.

After the end of the 1910s, the Japanese took an increasing interest in energy conservation. Mutual exchange of energy conservation technologies in iron and steel industries began. Osaka prefecture started to encourage energy conservation at small factories. These activities, which came to be called heat management, developed during WWII and bore fruit after the war. The iron and steel industry exchanged heat management scores of factories and compared good technological practices to facilitate technological exchange through competition among factories. The heat management policy was exercised and developed by the Ministry of Trade and Industry and its predecessor to promulgate advanced energy conservation technology of the iron and steel industry to others. These technologies and policies emphasized the improvement of worker awareness and skills of heat management rather than installing new and expensive equipment. The energy efficiencies of Japanese energy-intensive industries had already reached the highest level in the world in the early 1960s. The law that became the predecessor of the Energy Conservation Act of 1979 has been enforced since 1951.

* Research for this article was supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Young Scientists (B), 21330084, 2011–2014 and Grant-in-Aid for Scientific Research on Innovative Areas, 25101005, 2013-2017.

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1. Introduction

This paper presents a historical perspective and analysis of the development of Japanese energy conservation technologies. The energy intensity of Japan in terms of total primary energy supply (TPES) per unit of GDP is well known to have improved drastically from immediately after the oil crisis to around 1990, reaching the lowest level among IEA countries (IEA 2008; Sugihara 2009). Although some debate has arisen about whether Japan's energy intensity today is still the lowest or not, even critical observers would agree that such improvement to the lowest level occurred from the mid-1970s to the beginning of the 1990s (Morotomi and Asaoka 2010).

That decrease of energy intensity of Japan's economy mainly resulted from improvement of energy efficiency in manufacturing. This paper emphasizes a discussion of the following two characteristics related to this improvement. First, the improvement occurred from the development of energy conservation technology of energy-intensive industries, for example iron and steel, cement, and thermal power generation, as well as a change of industrial structure which means the growth of energy-saving and high value-added industries or relatively labor-intensive segments of capital-intensive industries, especially the machinery automobile and computer industry (Hashimoto 1991, cha.3; Sugihara 2013). The basic units for energy of these energy intensive industries represent the best practices in the world even today (Oda et al. 2012). Second, these improvements were achieved without strong regulation or taxation from the government. An important characteristic of Japan's energy conservation policy to end-users is known as voluntary or inductive regulation. Although the government obliges large energy users to have an energy manager who manages the improvement and supervision of methods for using energy through the Act on the Rational Use of Energy in 1979 (Energy Conservation Act), and although the Energy Conservation Center of Japan (ECCJ) has made technical guidance for energy use mainly to small and medium-sized enterprises, no legal penalty has been applied on amounts of energy consumption (IEA 2008; Kikkawa 2011).

These characteristics were nevertheless not generated suddenly after the oil crises. The energy efficiencies of the Japanese energy intensive industries had already been leading the world during the first half of the 1960s (Fig.1; Fig.2). The predecessor of the Energy Conservation Act, the Heat Management Act, had already been enacted in 1951, a quarter of a century before the OPEC oil crises (AIST 1971). Moreover, these two characteristics originated, as explained below, the technical improvements and policies that were undertaken in the 1920s.

Therefore, we should discuss the path from the 1920s to the 1970s when we analyze, from a historical perspective, why Japan has been able to improve national energy efficiency radically after the oil crises. Japan's recent history in this regard can be separated into four sections: the interwar era, the wartime period, the reconstruction period and the high-speed era. The discussion addresses changes of following two points, the energy intensive industry and the energy conservation policy to the end-user. We regard the iron and steel industry as the most typical case of energy-intensive industries.

2. Energy-saving activities in the interwar era

(1) Increasing interest in energy-conservation technology

After the end of the 1910s, Japan took an increasing interest in energy conservation technology for two reasons. First, industrialization and the increase of domestic coal production cost during WWI increased the price of coal. The relative price of coal in terms of the wholesale price index rose from 1.02 in 1913 to 1.35 in 1919. Second, the degree of coal self-sufficiency in Japan proper fell below 100%. Japan had been an exporter of coal from the Meiji era but the quantities of coal imports exceed exports in 1923, 1924, and continuously after 1927 (Kobori 2010, cha. 1; Kobori 2012).

Therefore, Japanese engineers and bureaucrats took a growing interest in the following two matters. The first was increasing fuel costs. The second was a limitation in domestic coal resources. For example, in 1920, Saishiro Sakikawa, the chief of Mining Bureau, Ministry of Agriculture and Commerce (MAC), was worried that Japan would not be able to continue mining domestic coal for many years and stated that Japan should "save the demands for coal" as well as making plans to "acquire foreign coal mines" (the Lower house of the Diet 1920). In fact, the Ministry of Agriculture and Commerce established the Fuel Research Institute in 1920 to undertake some studies of effective utilization of resources. Engineers and researchers interested in combustion engineering furthermore organized a group called the Fuel Society of Japan, not only to exchange their research results but also to enlighten ordinary people about the importance of energy conservation (Kobori 2010, cha.1).

(2) Technical guidance for fuel combustion by the Osaka prefecture

It was however not the government, but local authorities that conducted specific policies for developing energy conservation technology before WWII. The first and typical case was the Osaka prefecture, which was often designated as the "Manchester of the Orient" at that time. Osaka prefecture founded the Technical Guidance Division for Fuel Combustion belonging to the Osaka Prefectural Institute for Industrial Management (OPIIM) in 1929 and started to guide local factories to more efficient methods of combustion with a boiler.

The purpose of technical guidance for fuel combustion was not only the industrial rationalization of small factories clustered in Osaka prefecture but also decreasing the smoke issuing from them. Because air pollution by smoke in Osaka became severe after the Industrial Revolution, Osaka prefecture sometimes exercised campaigns against smoke during the 1900s–1910s. These movements failed, however, because the Osaka Chamber of Business was opposed to them because they sought to enforce economic loads on factories, for example by forcing the installation of smoke-prevention equipment (Oda 1983, cha. 6). However, in the campaign against smoke during the 1920s, Osaka prefecture cooperated with the engineers and researchers who joined the Fuel Society of Japan and planned the methods to prevent smoke without extra cost on factories. Therefore, Osaka prefecture succeeded in gaining entrepreneurs' consent. What was the method?

The Osaka prefecture emphasized that smoke released by imperfect combustion with a boiler meant not only air pollution but also wastage of fuel because grains of smoke were unburned coal that had been released from chimneys. Osaka prefecture appealed that efficient mode of combustion contributed to the reduction of both production costs and of smoke.

What were the activities of the Technical Guidance Division of Fuel Combustion? Two main activities existed. First was practical guidance for fuel combustion at a factory. Second was the boiler men training course accompanied with a licensing system. Practical guidance at a factory was exercised for 192 factories during five years. Most trainees were small firms that had only simple and cheap boilers. The guidance was exercised after the application by the factory, free of charge from four to seven days at a factory. The guidance policy by Osaka prefecture was improving the efficiency of combustion without investment in extra equipment. Osaka prefecture emphasized that it was possible to decrease fuel costs by more than 10% merely by changing their working methods for combustion, for example, a kind of coal, the method and interval of throwing coal to the boiler and the way of regulating drafts. Osaka prefecture showed that even if new equipment were not installed, developing human resources who understood combustion would contribute considerably to decreasing fuel consumption.

The boiler men training course was the other method of developing human resources for combustion. To encourage reduction of both smoke releasing and fuel consumption, Osaka prefecture established a licensing system for boiler men in 1932. Factories using boilers located in Osaka City came to employ boiler men who had a license. At the same time, OPIIM started the boiler men training course. It took more than 100 hours to finish a course of lectures and practices, and more than 4000 students graduated in three years. The training course increased the human resources for combustion who were able to pass the boiler man license and made the boiler man license system more meaningful. Moreover, the training course and the license system should be evaluated as indirect and enforced practical guidance for fuel combustion at factories that did not apply it.

These practical guidance and training courses showed that even a small factory that could not install new or expensive equipment would be able to reduce energy consumption and smoke by improving boiler workers' skills.

Osaka prefecture's development of the guidance for fuel combustion was regarded as an excellent measure for industrial rationalization, and was therefore emulated during the 1930s by several local governments such as those of Tokyo, Kyoto, and Dalian. The Ministry of Home Affairs further established the boiler man license system over the nation in 1935 (Kobori 2010, cha.1).

(3) Development of energy conservation technology of the iron and steel industry

The iron and steel industry, representing a typical case of energy intensive industry, was also interested in energy conservation technologies. Actually, it was interested mainly in German energy conservation technologies. For example, Kuniichi Tawara, an outstanding engineer of the iron and steel industry, travelled to Europe and North America during June 1921 – July 1922 and reported, "[the US iron and steel industry] does not introduce many resource saving facilities because the US has sufficient resource. …[On the other hand Germany] has few resources, so the reason for the development of the German iron and steel industry was an attempt to develop its technology". He appreciated that Germany had developed energy-saving and resource-saving technologies aggressively under the constraints of a resource set that differed from those of the U.S. and U.K. He also said, "Japan is short of resources for iron and steel and its quality is bad, so we have to study hard like the German engineers" (Tawara 1922, pp.815-16). He thought that the Japanese iron and steel industries were compelled to follow the example not of US rationalization, which used large amounts of natural gas and heavy oil, but German rationalization, which tried with great difficulty to conserve coal. He further emphasized a policy of aggressive technology exchange with Germany, which promoted technological development.

Heat management, as a representative technology, was investigated and exchanged aggressively. Verein Deutscher Eisenhüttenleute (German Iron and

Steel Institute) established Hauptwärmestelle (Central Heat Management Office) in Dusseldorf to promote energy conservation. The tasks of Hauptwärmestelle were not only research of heat management but also of training engineers, exchanging technology among iron and steel mills, advertising of heat management, and so on. Each iron and steel facility also established a Wärmestelle (heat management center) and used Wärme Ingenieur (heat engineers) to improve heat management not by a skilled worker's intuition but by an engineer's instrumentation.

Some iron and steel works emulated German heat management technology, presenting two outstanding cases: the Yawata Iron and Steel Works in North of Kyushu district and Showa Steel Works (SSW) in Manchuria[3]. The Yawata Iron and Steel Works started to reuse surplus energy, especially blast furnace gas and coke oven gas, for other iron and steel making process. The per-steel-product-ton consumption of coal was reduced by half from the 1920s through the early 1930s (Fig. 3).

Yawata, however, established no department such as a heat management center, which investigates and guides the heat economy of all plants of a factory. A factory that had fully installed German heat management technology was SSW. It started the integrated iron and steel works in April 1935, and "was stimulated by German technology at that time and felt the importance of heat management strongly." SSW planned heat management "as the first trial in the East" (SSW 1940, p.235). SSW founded a heat management center in 1934 and the center undertook full activity in the second half of the 1930s, for example repair and control of instruments, R&D with some plants, and guidance to the job sites. More than 100 staff members worked at the heat management center, and the varieties and quantities of instruments increased. Recording of combustion was exercised automatically. In the second half of the 1930s, SSW installed and expanded

[3] Yawata was established in 1902, controlled by the government until 1934, semi-governmental until 1950, the ancestor of the present Nippon Steel & Sumitomo Metal Co. SSW was established in 1918 as a subsidiary of the South Manchurian Railway Co., named Anshan Iron Works until 1933 and abolished at the Japanese defeat of the war in 1945.

German heat management technology more rapidly than Yawata did (Kobori 2012).

Heat management at SSW was recognized gradually in the Japanese homeland. Its formal stage was presented by the Iron and Steel Institute of Japan (ISIJ), which consisted of company engineers as well as academic researchers. From 1926, ISIJ held research meetings once or twice a year "in order to promote the growth of the Japanese iron and steel industry and of the technology at the job site" (ISIJ 1945) and exercised presentations and discussions related to some themes such as iron, steel, and steel products. During the late 1930s, each division started to place energy conservation on the agenda and the Fuel Economy Division started in 1938. The first meeting programmed "real scenes filmed for heat management at blast furnaces, open hearth furnaces and a control room presented by Showa Steel Works" (ISIJ 1941). Masao Shidara, who was involved in heat management at Yawata during wartime and who served a Chief of the Heat Management Section after the war, recalled that the heat management of SSW had been superior to that at Yawata (Shidara 2007).

3. Energy conservation activities during WWII

(1) Energy conservation policy during WWII

The Ministry of Commerce and Industry (MCI, the successor of MAC) also started technical guidance for fuel combustion in 1938 as the Sino–Japanese war exacerbated the tight coal supply situation. The engineers who had guided fuel combustion measures in Osaka were used by MCI to spread the principles and practices of guidance.

It is noteworthy that the targets of the guidance, which had been restricted to combustion with boilers of small firms, also expanded. As the coal supply situation became tighter and tighter, fuel conservation became necessary even at large factories that were not the targets of guidance during interwar era. Fuel engineers realized that many points aside from the mode of fuel combustion should be improved to reduce energy consumption further. They explained that it was necessary to improve combustion with a furnace, conserving fuel, controlling steam and keeping insulation as well as combustion with a boiler. They also emphasized that, to accomplish these improvements, it was necessary for any big or small factory to install instrumentation engineering for research or study using exact instruments and to employ full-time workers responsible for energy.

At the same time, the policy name changed from guidance for fuel combustion to heat management. The designation of heat management used by iron and steel engineers, especially by SSW, changed to have a general meaning of energy conservation at a factory or energy conservation policy. Heat management by SSW became famous not only among domestic iron and steel engineers through ISIJ, as described above, but also in the engineers who guided fuel combustion at Osaka prefecture or MCI. They sometimes visited and devoted attention to the heat management center of SSW and introduced it through speeches or articles to engineers who worked at other industries. The government exercised inspection and held heat management campaign during winter to enlighten and improve heat management (Kobori 2010, cha.2).

(2) Iron and steel industry

After the start of the Sino–Japanese War, several iron and steel factories in Japan also earnestly began to imitate heat management by SSW. Yawata, from May 1937, immediately before the start of the Sino–Japanese war, established the Fuel Division under the Iron Department to centralize the control of blast-furnace and coke-oven gas, which had been controlled separately until then. The Fuel Division was placed directly under the Head of Engineering in March 1942 and was changed to the Heat-Management Division in 1944. Tasks of the Heat-Management Division were added as “matters on heat management”, as well as control of gas and fuels. An Engineering Subsection, which dealt with “enlightening and advertising concepts of heat management engineering”, e.g. guidance of combustion at furnaces, measurements, and consulting about heat economy, in addition to analysis of gas. The status of the Heat-Management

Division was higher than that of Fuel Division in 1937, indicating a broader scope of the factory. Its tasks became to contain the guidance in improvement of the basic unit for fuel at each piece of equipment.

During wartime, the following three matters were tried: (1) a heat-control campaign to grow interest in heat management at a job site and to improve basic unit, (2) organization of a heat management committee to discuss heat management at each factory, and (3) improvement of instrumentation engineering (Kobori 2012).

(3) Achievements and issues of heat management during the war

Did these efforts by the government and iron and steel industry bear fruit at that time? To begin from the conclusion, basic data for fuels became much worse during the wartime era for four reasons.

The first reason was the worsening coal quality, which posed a general limitation on the Japanese wartime economy.

Second was a lack of instruments. After 1937, it became much more difficult to import instruments from abroad. The supply of industrial instruments for heat management stagnated because domestic production of instruments emphasized aircraft instruments and instruments for oil refining. Although the steel industry attempted to repair instruments through its own efforts, it was insufficient because of the lack of spare parts.

Third, the engineering level could not help being worse than during the interwar era because many skilled workers were drafted into the armed forces. Many unskilled workers were employed to increase output. The proportion of drafted workers to all employees at Yawata increased from 10.0% at the end of 1937 to 14.5% at the end of 1941. The length of a worker's continuous employment decreased from 11 years and 10 months in 1934 to 7 years and 3 months in 1940. After the start of the Asia–Pacific War, "special workers" such as students, Koreans, prisoners, and corps of women volunteer workers increased. They were required to perform tasks not only as assistants but also as regular workers. It is not difficult to imagine that these conditions lowered the engineering level at a job site that relied heavily on the experience and skill of long-term employees.

Fourth, even at factories where there remained numerous skilled workers, they often persisted in using conventional and intuitional practices. Some engineers reported that many skilled workers did not use the instruments for heat management even if they were installed. During the war period, it was too difficult for heat management officers or engineers to reeducate skilled workers patiently (Kobori 2010, cha.2; Kobori 2012).

Under these circumstances, the officers and engineers reported lack of "enthusiasm" of the heat management of the workers or managers (Nenryo oyobi Nenshosha Co., 1944). It was symbolic that the name of heat management campaign in 1945 was "Heat Management Suicide Attack Monthly". It is noteworthy that "lack of enthusiasm" was not only a spiritual instruction but also accompanied the indication of concrete problems, for example, leakage of steam or heat, lack of proper fuel keeping place, utilization of instruments. These points, which had not been recognized as problems during the 1930s, became recognized as problems during the wartime period by the Japanese themselves before US technology was installed after WWII. The war fostered interest in energy conservation technology. The officers and engineers who engaged in heat management after the war came to be recognized as problems for heat management during the war (Kobori 2010, cha. 2).

4. Heat management during Reconstruction

(1) Establishing the Heat Management Act

Japan lost its colonies. Many Korean miners disappeared from coal mines after Japan's defeat. Therefore, energy restrictions on Japan after the war became tighter than they had been during the war.

When the lack of coal became dire in December 1946, the Japanese government adopted the "Fundamental Policy for Strengthening Heat Management to Break the Coal Crisis" at a cabinet meeting. The government aimed to strengthen heat management as an "increase of coal output on the consumption side" in concert with a policy for increasing coal output. The Japanese energy policy at that time was the priority production system in the supply side and heat management on the demand side.

Japan however had the good circumstances that were not apparent during wartime; demobilization and disarmament of the Japanese armed force. Because of demobilization, skilled workers were not being drafted into the armed forces. This created the essential conditions under which post war Japan were able to develop engineering at the job site. Disarmament caused the loss of military demand, which compelled Japanese manufacturers to look for new civilian demand; one was tools for heat management, for example instruments and steam traps. In the context of these circumstances during reconstruction, the problems that had been acknowledged during wartime by officers and engineers began to be solved gradually.

The actors promoting heat management policies after the war were the Heat Management Division at the government and the heat management associations. The Heat Management Division was established at the National Coal Board in 1947 and moved to the Ministry of International Trade and Industry (MITI, the successor of MCI)-affiliated Agency of Industrial Science and Technology (AIST). The heat management associations were private institutions established by heat management engineers. They exercised research exchange and advertising heat management. There were also the eight local heat management associations and the Central Association for Heat Management (CAHM) which coordinated them.

Major policy initiatives exercised by these actors were industry-specific inspections of heat management, in addition to heat manager systems. The industry-classified inspection was exercised during 1948–1952. This inspection was exercised to 16 industries and 1204 factories, which were three fourths of the Designated Heat Management Factories (see the next paragraph). This inspection contained many detailed checkpoints which covered not only combustion but the whole field of heat management (Table 1). The results of the inspection were reported to each factory and good practices were commended at each inspection. Besides, some of them were opened on the bulletin or magazine issued by the heat management associations at any time. The opened information was not only about the general situation but also about the detailed introduction of good or bad case. Scores of all inspected factories were opened in some industries. Opening the characteristics or scores in each industry would contribute to develop and advertise heat management engineering. Even after the end of the industry-classified inspection, some heat management associations and public research organizations consulted for heat management.

The heat manager system was started by the Rule of Heat Management in 1947 and became firm by the Heat Management Act in 1951. The Heat Management Act was aimed at preserving fuel resources and rationalizing firms through more efficient use of heat energy. The Act designated factories using more fuel than 1,000 ton of coals (6,000 kcal/kg) annually as the Designated Heat Management Factories, which were obliged to select a Heat Manager, who was obligated to pass the national examination and become a Qualified Person for Heat Management. The manager of the Designated Heat Management Factories was obligated to respect the Heat Managers' opinion. Training and lessons for becoming a Qualified Person for Heat Management were often held. The Heat Management Act was unique because it tried to increase the skill and status of the heat management engineer to improve fuel efficiency; in fact the Japanese officer reported that such a law was not apparent in any other country, even in Germany.

Making and exercising these policies, the government officers requested the iron and steel engineers to make lectures or write papers on magazines for engineers of other industries. Tight public–private partnership contributed on the spillover of heat management engineering from advanced industries to others (Kobori 2010, cha.2).

(2) Iron and steel industry: developing to the best level in the world

The energy conservation of the postwar iron and steel industry was promoted by oxygen steelmaking as well as heat management. When we discuss these two technologies, it is impossible to ignore technology imports from the US. Technical guidance on heat management by American engineers exercised in 1949, and full scale use of oxygen to open hearth furnaces (OHF) started after WWII throughout the world, especially in the US, to decrease fuel consumption and to shorten working hours.

Nevertheless, the Japanese energy conservation technology developed after the war was not an exact copy of the U.S. technology. Japanese heat management technology after the war was much different from the U.S. efforts in its objectives and contents. Takami Ota, the chief of No. 1 Steelmaking Division of Yawata Iron and Steel Works and inspected an overseas in 1954, reported that the basic unit for fuels of the U.S. steel industry was inferior to that of Japan and analyzed the reasons (Ota 1954, p.770).

> "I intuited that Yawata and the other Japanese steel plants installed as high-level instruments and automatic managers as the U.S. highest class plants… a job sites of the U.S. OHF operators were not necessarily interested in research or improvements for burning at OHF or in checking burning scores of daily work…The reason why basic unit for fuels is not necessarily superior was that they attach the greatest importance to the efficiency of steelmaking (t/hr)…"

Ota recognized the most important objective of the formation of technology in the U.S. as the efficiency of steelmaking (t/h), and that the most important objective in Japan was the basic unit for fuels (cal/t). He also noted that the difference in the formation of technology influenced the difference in daily work between the U.S and Japan. We shall fail in grasping the characteristics of the post-war Japanese iron and steel industry if notice only the introduction of U.S. technology and ignore the history of energy conservation activities, which bore fruit after the war. Moreover, the introduction of oxygen steelmaking was regarded as negative by the American steel engineer who guided heat management during the reconstruction period. The process of introducing oxygen steelmaking was extremely independent and the amount and degree of oxygen use in Japan became much higher among all countries of the world during the 1950s. As a result of these feats of technical progress, the basic unit for fuel at OHF was already better than that of any other country by the early 1950s when old-type furnaces were still used to a considerable degree (Fig. 4).

What was the background of such rapid development of the Japanese energy conservation technology? We should specifically examine technology exchange and improvement at a job site.

The ISIJ played an important role in technology exchange. The Liaison Conference for Research of Iron and Steel Technology was held in July 1948 by ISIJ, the Japan Iron and Steel Association (called The Japan Iron and Steel Federation from November 1948, JISF), and the Steel Bureau of Ministry of Commerce and Industry. They sought to make the divisions of ISIJ active. Then ISIJ established eight divisions such as pig iron, steel-making, and steel products, and some divisions placed heat management as a research subjects. In the OHF division, each attending company announced and criticized technology (e.g. a burner blueprint) mutual to encourage standardization of technology. The OHF division also researched oil-burning, furnace structure, and oxygen steelmaking. This example illustrates that, by restoring research divisions in the 1920s–1930s, technology exchange was already started before technical guidance from U.S. engineers began.

These exchange relations enabled the contents of the U.S. engineers' guidance to be closely shared among the Japanese steel companies. For example, when the engineers visited Yawata, some heat management engineers belonging to other Japanese steel companies such as NKK and Sumitomo came along and watched their guidance at Yawata. Their guidance report was later published and sold. A division responsible for instrumentation and heat management technology, the Heat Economy Division, was established in ISIJ and some designs of furnaces and instrumentation which were best to progress heat management were standardized by the Division. In addition, the experimentation of oxygen steelmaking was exercised through cooperation with eight steel companies that belonged to JISF.

Moreover scores of the heat management were presented to ISIJ every month by each factory to be mutually exchanged. Some good practices were also exchanged and discussed. According to Shidara, factories did not hide work efficiency and knew each other's scores. During reconstruction, technology exchange through ISIJ, which started in the interwar period, was sufficiently displayed. Iron and steel factories mutually cooperated and competed for the development of heat management technology.

These exchanged figures and practices were reported to engineers and workers at job sites through heat management committee of each factory to stimulate the improvement of energy conservation technologies. Steel Plant No. 3, Yawata Iron and Steel Works, which was the first steel-making plant for which the basic unit for fuels became less than 1,000 kcal/t in Japan, was the typical case. The engineers of Steel Plant No. 3 tried various methods to interest workers in instrumentation and heat management and thereby improve basic units for fuel, such as adjustment of the arrangement of staff members to arouse competitive spirit related to heat management, making workers calculate the basic unit for fuels for themselves at every tapping and compare the scores with those of other factories or those in foreign countries, trying special programs to get the president prize of Heat Management Month, and instilling confidence of workers in their heat management. Such steady activities reformed minds of workers who had relied not on instruments but on their own appreciation.

Kiyoshi Sugita recalled the chief of Steel Plant No. 3 as the person who was very keen on heat management and said about the heat management in the 1950s as follows. "Unexpectedly, many men got promoted because they were deeply engaged in heat management. [The man who succeeded in heat management was] remarkable. It was a little different from general improvements on output" (Sugita 2008). Through the active exchange of technology and scores beyond the factory, the Japanese iron and steel industry had created a system under which an engineer or worker who was keen on energy conservation was rewarded (Kobori 2012).

5. During high-speed growth

(1) Stagnation of energy efficiency improvement

Given the background of severe energy restriction, Japan tried to resolve it by improving energy efficiency. The basic-unit-for-fuel index of the Designated Heat Management Factories improved rapidly from 100.0 in 1948 to 89.0 in 1950, 69.7 in 1955, and 60.4 in 1960 (AIST 1971, p.9).

Anxiety about energy restriction, however, gradually calmed down in the second half of the 1950s because they estimated that crude oil production in Middle East would continue stably and that the increase of Japan's exports would enable the import of more energy. Furthermore, then, the energy revolution, the switching of energy resources from domestic coal and water to foreign petroleum progressed. The energy revolution in Japan was more rapid than in West Europe or the US (Table 2). Japan succeeded in importing oil at a lower price than those countries (Fig. 5). Japan created deeper ports and coastal industrial zones, especially along the Pacific coast, to accommodate the largest tankers in the world (Fig.6), which contributed to the cutting of crude oil transportation costs. Japan, which has a long coastline, was favorable for importing foreign energy and resources to Western countries, which had their industrial zones located inland. During high-speed growth, Japan did not avoid increasing the import of energy but tried to import energy as economically as possible. The rapid drop in the energy sufficiency rate was the consequence (Kobori 2010, part III).

Because of these changes, the progress of the heat management was weakened during the 1960s. The basic-unit-for-fuel index of the Designated Heat Management Factories (100 in 1948) was 60.4 in 1960, 55.8 in 1965 and 55.8 in 1969 (AIST 1971, p.9). The improving rate of basic-unit-for-fuel at an iron-and-steelmaking plant that belonged to Nippon Steel Corp. was 79.6% during 1953–58, 89.0% during 1958–63, 94.7% during 1963–68, and 95.7 1968–73 (Toyoda

1982, p.1677).

In fact, the Heat Management Division at the government was abolished in 1962. The heat management policy was exercised as one policy means for small firms because the government judged that the energy efficiency of energy intensive industries such as iron and steel, cement and electricity had reached the best level in the world (AIST 1964, pp.366-67). In addition, abolishment of the Heat Management Act was sometimes rumored in the mid-1960s (Yokoyama 1964, p.2; Komatsu 1966 p.47). The activity of the Heat Economy Division of ISIJ during the high-speed growth era was also seen as less dull than that during the reconstruction period (ISIJ 1982, p.25).

The following two points are also noteworthy. First, the energy efficiency of the Japanese energy intensive industries, for example iron and steel industry or thermal power generation, continued to be best in the world during the 1960s. How should we evaluate it? Secondly, the system of heat manager or technical exchange was not fully abolished. The Heat Management Act was not abolished and the Heat Economy Division and the heat management movement at each factory were also sustained. How did these institutions survive?

(2) Technological development during 1960s and heat management during the 1950s

Regarding the point of the aim of technology, the improvement of energy efficiency during the 1960 was secondary. The iron and steel industry during the 1960s regarded not heat management but mass-production or quality control as most important. Kiyoshi Sugita stated that the turning point occurred in about 1960. Creation of new plants or new processes came to be regarded as "positive" technology, but heat management came to be regarded as "rather conservative" (Sugita 2008). The role of energy conservation technology declined and heat management movements that had continued until WWII became obsolete. For example, the increasing size of a blast furnace contributed to improved energy efficiency but its first aim was mass production. Although the progress of LD converter, continuous casting or QC circle, which contributed greatly to energy conservation after the oil crisis started in the 1960s, the aim of these developments during the 1960s was not energy conservation either. The aim of the LD converter was mass production and reducing scrap iron consumption; that of continuous casting was the improvement of yield rate in special-steel making. In addition, the QC circle, which was exercised in close cooperation with engineers and workers at job sites, was of course intended for quality control (Sugita 2007 pp.113-14; Kajiki 2010 cha. 1).

Nevertheless, it is a mistake to think that such technology progress had no relation with the energy conservation technology at all during the reconstruction period. To realize the increasing size of a blast furnace, improving technology of instrumentation and furnace construction was necessary they were started to develop in the reconstruction period to improve heat management. The development of oxygen generators for oxygen steelmaking during the 1950s, which aimed the improvement of the basic unit for fuel at OHF, was one condition that enabled the development of LD converter during the 1960s. The activities for heat management at workshops by engineers and workers such as at Steel plant No. 3, Yawata, during the 1950s formed part of the foundation of QC circles (Kobori 2011).

As a result, although the aim of technology development in the high-speed growth era differed from that in the reconstruction period, the technologies which had developed through the heat management in the reconstruction period were inherited for the different purposes. Moreover, these inherited technologies contributed to sustain and improve the energy efficiency of Japanese energy-intensive industries at best level in the world as the secondary consequence in the high-speed growth era and the intended consequences after the oil crisis.

(3) Survival of heat management policy and engineers

Why did the heat management engineers survive? Worsening environmental pollution in Japan became increasingly severe during the 1960s. It came to be said that "Preventing smoke at a firm was often exercised by the person in charge of the heat management" (Saito 1965 p.10, see also Shidara et.al 1973 p.12). From the first half of the 1960s, some famous heat management engineers insisted, on the magazine published by the Central Association for Heat Management, *Heat Management*, that heat management engineers should devote attention to the prevention of air pollution (Kurokawa 1962 p.2; Yokoyama 1964 p.2). In fact, the prevention of smoke became one purpose of the heat management policy from 1963 (AIST 1962 p.56; AIST 1963, p.49). The subtitle *Energy and Pollution Control* was attached on *Heat Management* from 1968 and the theme of more articles on this magazine became the technology of air pollution (Tanishita 1969, p.8). Additionally, its title was changed to *Heat Management and Pollution Control* in 1971.

In the case of Nippon Steel Corp., the prevention of air pollution became one task on heat management (Maeda 1972 p.3). Masao Shidara, the chief of the Heat-Management Division at Yawata during the 1950s, became chairman of the committee on the prevention of smoke held by JISF in 1962. He thereafter became concerned with setting up of the national qualification, Pollution Control Manager, in 1971 and wrote a textbook for its examination (Shidara 1984).

After the oil crisis, these surviving institutions were used for energy conservation again. Most themes of articles on *Heat Management and Pollution Control* got back to energy conservation. The title was changed to *Energy Conservation* in 1978. The Heat Control Act and the system of Heat Manger developed to the Energy Conservation Act and the system of Energy Manager which contained the conservation of electricity as well as fuel. The Central Association for Heat Management was renamed ECCJ in 1978. It has continued to serve as technical guidance for energy conservation and the operation of national examination for the qualified energy manager to the present day.

Regarding technical exchange among iron and steel factories, a head of Energy-Management Department of Sumitomo Metal Co. said, "The reason the iron and steel industry progressed energy conservation promptly after the oil crisis was that …the heat economy engineers attended the Heat Management Division of ISIJ to get information of each firm and discussed this information with their own colleagues" (ISIJ 1982, p.24). The institutions developed during the 1940s–1950s became less effective during the 1960s but became active during the 1970s.

6. Conclusion

The eras during which basic unit for energy in Japan improved were the reconstruction period and the oil crisis onward. The common background of both eras was their severe energy deprivation. We must make a sharp distinction, however, between the "possibilities" of the development of energy-saving technology in the context of limited energy supplies and their "realization." Why did the Japanese energy intensive industries not decline given the background of energy supply limitations during reconstruction? Why did some of them such as iron and steel, cement or thermal power station sustain the best practices of the basic unit for energy in the world, and maintain them even today? How and why did energy-intensive industries achieve the development of energy conservation technology to survive and grow?

This paper particularly described the iron and steel industries, which mutually exchanged energy conservation technologies, and described some policies which encouraged energy conservation. After WWI, Japanese engineers and bureaucrats took a growing interest in coal supply and started to take some measures. The iron and steel industry noticed German heat economy technologies, and emulated them. Some good practices they used, especially imported by SSW, were introduced to other factories through ISIJ. At the same time, Osaka prefecture started technical guidance for fuel combustion by small firms to reduce smoke and to rationalize their businesses; the guidance was imitated by some other local authorities.

These activities developed during WWII bore fruit during the reconstruction period. Heat management of SSW was imitated by other iron and steel factories, which established Heat-Management Divisions and hold heat management movement to try heat management by the instrumentation. In the reconstruction period, the scores of each factory as well as good practices were exchanged through

ISIJ; the technology exchange among factories was consistent with competition among them. Technical guidance of fuel combustion was exercised by Ministry of Commerce and Industry and changed to the guidance for heat management which meant the total fuel conservation technologies. This was influenced by the heat management of the iron and steel industry, especially SSW. The engineers who exercised the technical guidance contributed to the spread of advanced technologies of the iron and steel industry to other ordinary industries.

The heat management policy emphasized improvement of managers', engineers' and workers' awareness, information or skill of heat management through the guidance, license system by law or movement, rather than installing new and expensive equipment. Reforming workers' minds on the heat management was also an important method to improve the basic unit for fuel of the iron and steel industry. The policy and activity seems the skill-and-labor intensive development of energy conservation technology. Although this development became stagnant during the high-speed growth era, the innovation which secondly contributed energy conservation and rooted the improvement of the heat management during the 1950s started. The institutions related to heat management were not abolished because the heat management engineers emphasized the relation between the heat management and the reduction of air pollution. Results show that, after the oil crisis, these technologies developed still more to improve energy efficiency. The institutions which were not fully abolished in the 1960s contributed to their development and diffusion.

We note two research tasks. First is the relation between the development of the energy conservation technology and environmental technology. Although the development of fuel combustion or heat management contributes directly to the reduction of smoke, it did not contribute directly to the reduction of other air pollutants such as SOx (Tanaka 1972, p.27). Although the fact that perfect combustion was insufficient to reduce the discharge of SOx had already been known in the 1920s, the technical guidance for fuel combustion ignored this problem (Kobori 2010, cha. 1). A more severe case was the energy conservation through oxygen steelmaking. It actually worsened air pollution. The development of energy conservation by the Japanese iron and steel industry during the 1950s was encouraged by loose pollution regulations (Kobori 2012). Therefore, the relation the development of both energy conservation technology and environmental technology after the oil crisis should be discussed more carefully.

Second was the spread of Japanese energy conservation technology to other Asian countries. The export of the Japanese heat management technology was plotted in 1959 and the first observation team from overseas (India) was invited in 1966 (CAHM 1966, pp.48-56; Taga 1967, p.3). After the oil crisis, the Heat Management Act of South Korea ,which was established in 1973, was very similar to but more forcibly than that of Japan and the guidance for heat management by the Japanese engineers was exercised in 1975 (Shiozawa 1974 Hino 1975). Today ECCJ strives to export the Japanese institutions and technology for energy conservation to Asian countries (Taniguchi 2012). The flying geese pattern of the energy conservation in eastern and Southeast Asia presents an interesting theme for future research.

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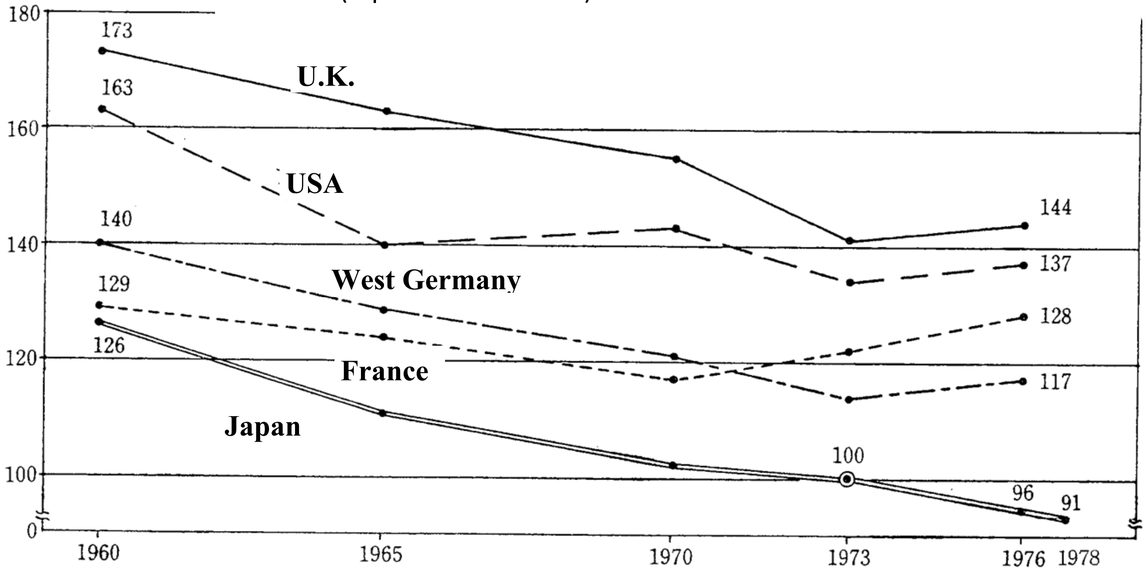
Fig.1 Energy consumption per a ton of steel material in five countries, 1960-78 (Japan in 1973 = 100).



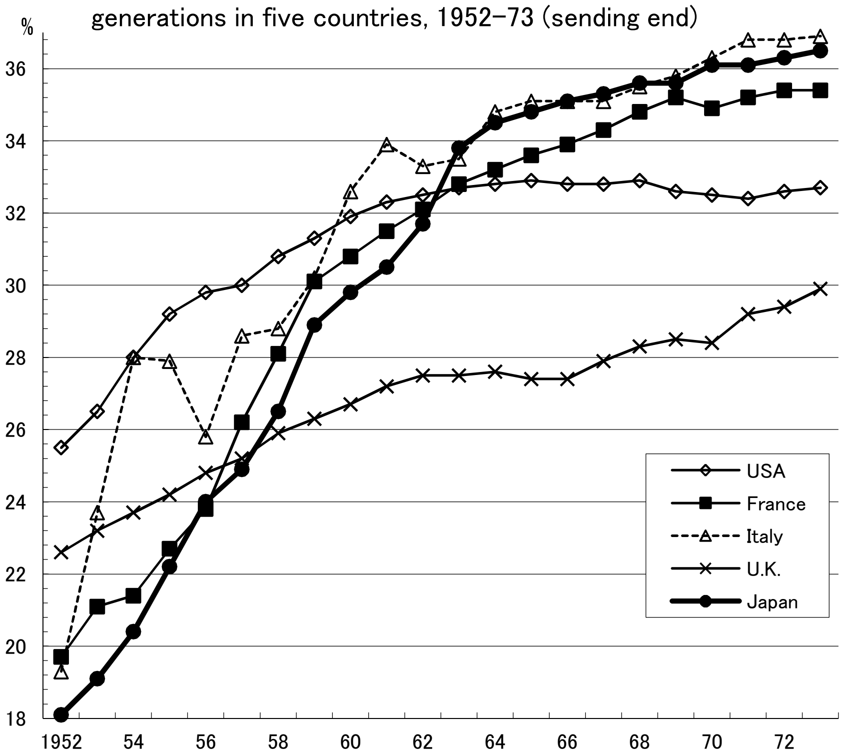
Source: Shinoda (1979), p.27.

Notes: 1. Using IISI's figures which are modified by the ratio of iron production to steel production of Japan in 1973.

2. Cokes : the amount of bought

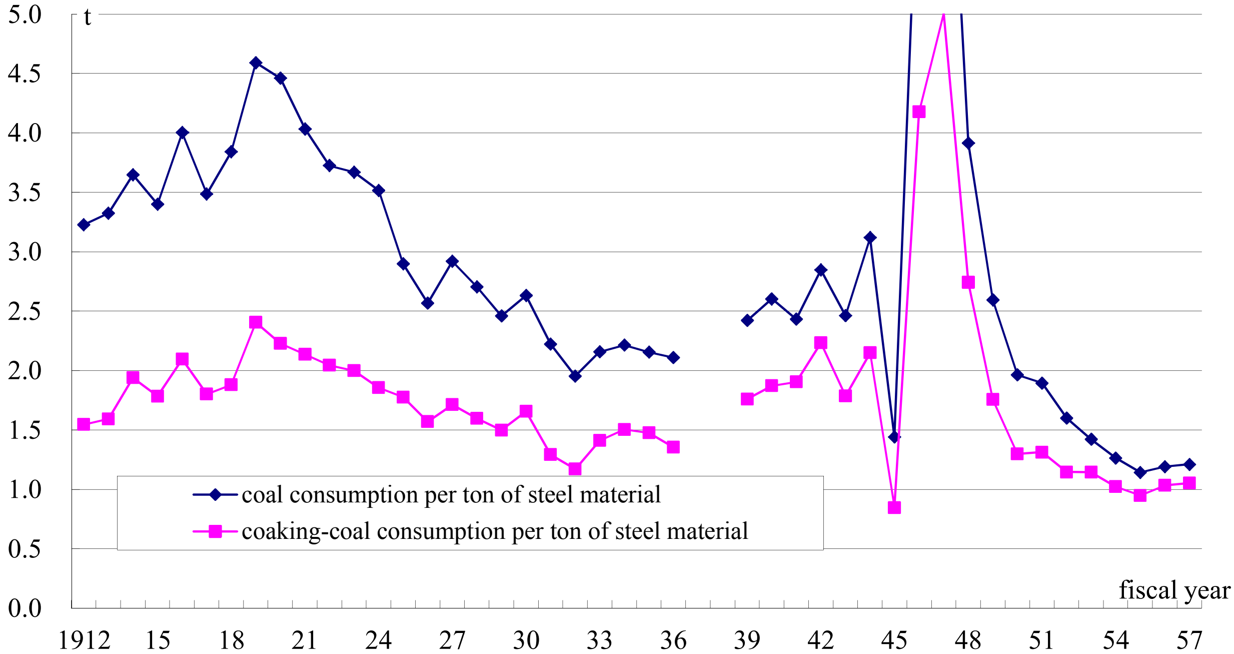
3. Ferroalloy: exclouded

Fig.2 Average thermal efficiency at thermal power generations in five countries, 1952–73 (sending end)



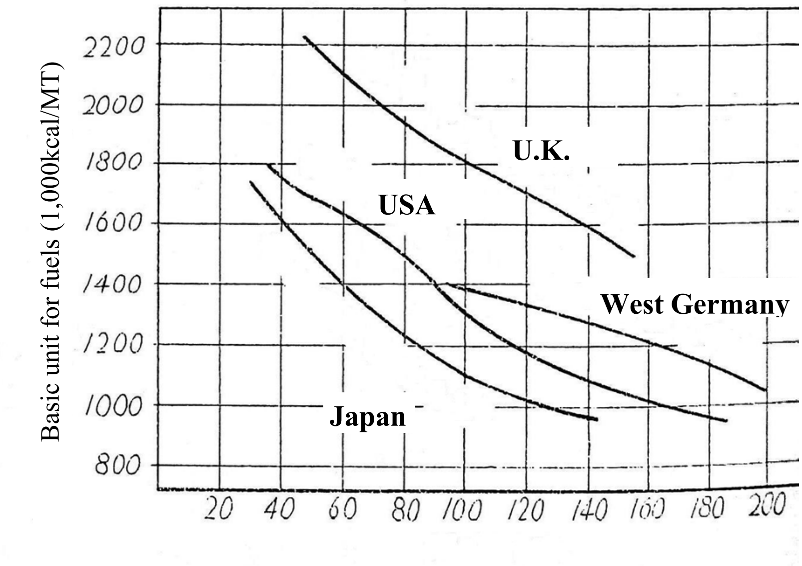
Source) Kobori (2010) p.21.

Fig. 3. Amount of coal consumption per a ton of steel material at Yawata, 1912-57.



Source: Kobori (2010), p. 107.

Fig. 4 Basic unit for fuels of OHF in four countries in 1953.



Capacity of an open hearth furnace (MT)

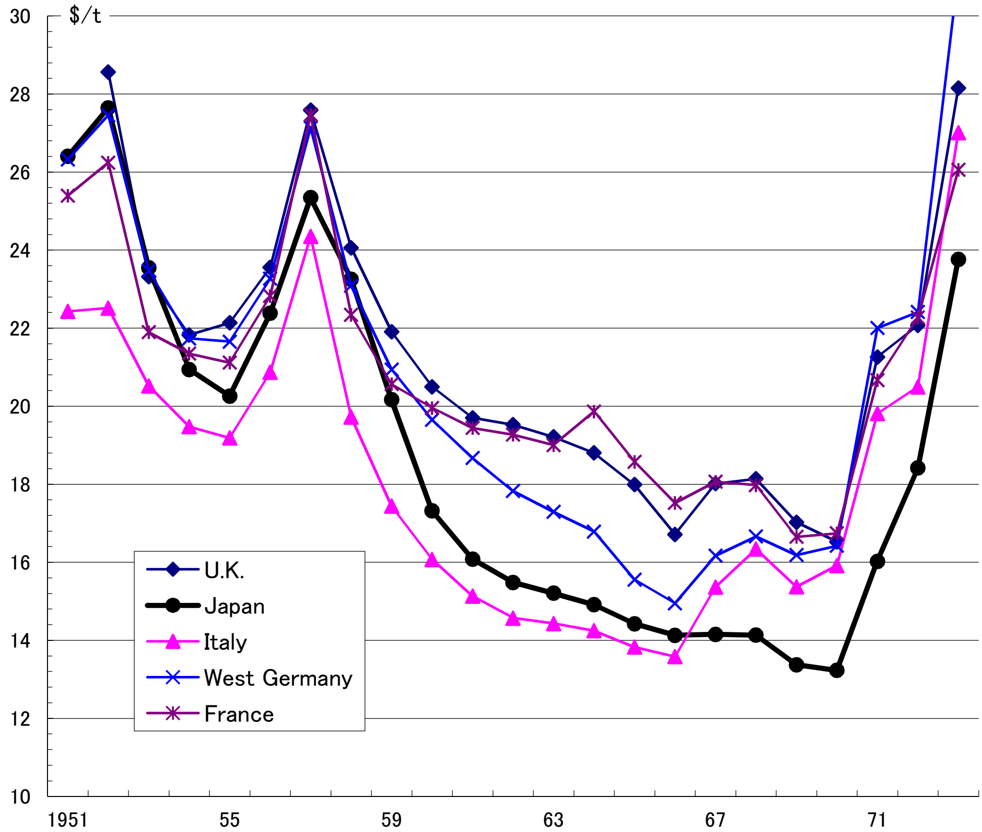
Source : Tabata (1956), p. 83.

Notes : 1. U.K. and Japan: all of the basic OHF

2. USA: all of OHF

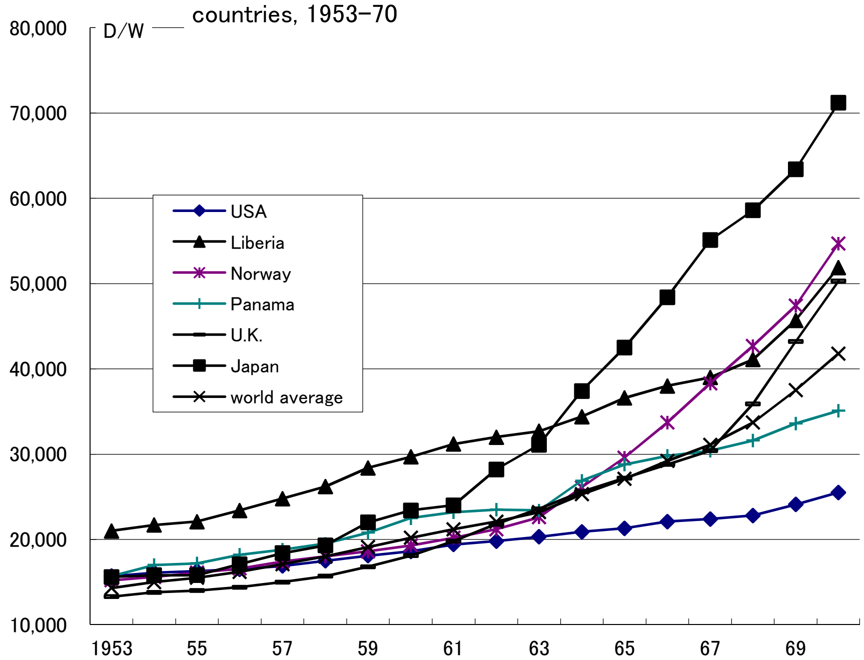
3. West Germany: all of the tilting OHF

Fig .5. Prices of imported crude oil in five countries, 1951–73



Sources）United Nations (various years).
Note）Including raw oil.

Fig.6. Average size of ocean-going tankaes in the world and six countries, 1953-70



Sources) Sun Oil Company (various years).

Notes) 1. As of December 31 every years.

2. Aggregate data of tankers of not less than 2,000 tons gross.

Table.1 Check points of the industry-specific inspections of heat management

	large classification	check points
1	institutions	activities of the heat management committee status of the Heat Manager documentation influence of the Heat Manager enthusiasm of a factory manager on heat management attitude of the factory toward the heat management
2	acceptance and management of fuel	routes metods of measuring and calibration of coal management the results of measuring and calibration
3	coal inventory management	roof and drainage equipment of coal yard methods of coal blending preventing from weathering and spontaneous combustion control of coal issuance coal type management
4	combustion management	training of boiler men and furnace operaters standardization of operation install and utilization of meters water supply and treatment cracks utilization of flue gas daily jobtime report contact method from and to a job site utilization of low grade coal
5	thermal and heat utilization management	piping insulation valve management steam leakage regulation of pressure and temperature steam traps
6	exhaust heat management	
7	basic unit for coal of each industry	

source) Tomimatsu (1949) pp.7-8.

Table 2 Self-sufficiency ratio in TPES of six countries, 1925–1973

year	Japan	France	West Germany	Italy	U.K.	U.S.A
1925	108.0	64.0	117.4	10.6	135.7	106.7
1938	83.8	62.1	111.3	17.4	117.6	108.4
1950	96.9	67.0	119.9	24.7	98.7	100.4
53	77.6	63.7	109.7	27.8	94.6	100.6
55	75.1	62.6	102.1	27.7	86.9	100.2
57	67.0	54.7	98.2	29.2	86.4	101.4
60	55.0	57.4	90.7	31.8	77.0	95.1
66	31.9	42.7	64.9	24.1	59.5	92.7
73	9.2	20.5	45.0	16.7	49.2	84.0

Sources) Darmstadter et.al (1971), IEA (1991).