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ORIGIN AND DEVELOPMENT OF IRON AND STEEL TECHNOLOGY IN JAPAN

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CONTENTS

This paper is being circulated in a pre-publication form to elicit comments from readers and generate dialogue on the subject at this stage of the research.

I. INTRODUCTION

Wherever man lives a civilized life, whether in the East or in the West, whether in an advanced country or in a backward country, there are technology, iron and human wisdom at work. It is no exaggeration to say that mankind entered the gate of civilization when it began to use iron, and has since advanced its technology and developed its wisdom.

And as long as iron remains with people, or human life, undoubtedly the stream of ferro-technology and economic activities which go with it will enrich the soil of any country, eventually pouring into the ocean of world culture or flowing back in countertide into individual nations.

On this basis, I intend to trace the history of iron and steel technology in Japan within the perspective of the history of iron in the world.

Man, Technology and Iron

"They shall beat their swords into ploughshares, and their spears into pruninghooks." This is a divine message cited in Isaiah and Micah in the Old Testament, which is believed to have been compiled in about 400 B.C. It confirms the benefit of iron which can be readily processed into various forms useful to man, and further tells us that it is up to man to make what use he can of iron and that iron should be used in the cause of peace instead of war.

The Koran, the scripture of Islam, also has a chapter on iron (chapter

57), in which it is written that iron was bestowed on man by Allah because it has great power and can provide him with many conveniences. Iron is a symbol of strength and certainty from which derive such virtues as modesty, sincerity and charity.

In Japan, too, there have since remote times been many expressions describing the relevance of iron to the life of common people. For instance, an ancient poet sang:

> As I nailed it as fast as I would a door,
> My wife's heart will never oscillate.

In this short poem found in _Man'yōshū_ (an anthology of Japanese poems compiled in 795), the poet likened his affections and fidelity towards his wife to iron nails fastening together the wooden sections of a huge building.

One of the expressions which most aptly represent the role of iron in human life was written by Miura Baien* (1728-89), an eighteenth-century Japanese scientific thinker, in his work on economics, _Kagen_ [The principles of economic values] (1773):

> _Kane_** is the generic term for the five metals, which are gold, silver, copper, lead and iron. They are collectively referred to as _kane_. Among the five metals, iron is considered the supreme treasure, followed by copper and further by lead, because iron is inexpensive and yet useful for many purposes. People cannot live a day without it.

Baien thus very appropriately pointed out that iron was the most valuable treasure because it was extensively used by many people and daily life could not dispense with it, not even for one day.

By the time Fukuzawa Yukichi (1835-1901), a remote inheritor of Baien's ideological mantle, wrote in his _Minjō isshin_ [Refreshing people's

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* Japanese personal names herein are written in the traditional Japanese way, with the family name first.

** _Kane_ means either metal or money in Japanese, and the same character, when pronounced _kin_, means gold.

sentiment] (1879), "Iron is the soul of civilization and enlightenment," it seems that the foundation on which to transplant the European-originated system of mass production of iron had begun to be established in Japan.

Phases in the History of Iron and Steel Technology

The progress of iron and steel technology from antiquity to our days has followed basically the same pattern in Japan as in the West. In short, it was a sequence of developments from mining technology to manufacturing technology and further to scientific technology.

The development stages of iron and steel technology in the world and in Japan are schematically compared in tables 1 and 2.

With the Industrial Revolution, which took place in the eighteenth and nineteenth centuries in the West and around the beginning of the twentieth century in Japan, as the turning point, the fuel (reducing agent) for iron making switched from charcoal to coke (coal), and the power source also shifted from hydraulic energy (water wheels) to thermal energy (steam engines). These two changes primarily induced the subsequent major developments: (1) mass production of pig iron in coke-burning blast furnaces; (2) industrial-scale production of melted steel in converters, open hearths, and electric furnaces; and eventually (3) the establishment of an integrated system for production of steel from ore. Following these developments, iron metallurgy which had previously been an empirical technology evolved into a scientific technology, and the system for mass production of steel in many different qualities and shapes, as basic materials for present-day industry, was realized in up-to-date integrated steel mills, accompanied by a vast growth in scale, and greater continuity of processing and automation.

This is the progress, very roughly traced, of iron and steel technology through the modern age.

TABLE 1. Development of Iron and Steel Technology in World History

	Antiquity and Middle Ages (pre-industrial phase)	Modern Period (Industrial Revolution phase)	Contemporary time (technological innovation phase)
Iron-making material	Iron ore (iron sand)	Iron ore	Iron ore
Smelting device	Direct smelting furnace (*tatara* furnace) Vertical furnace Blast furance	Blast furnace	Large blast furnace
Steel-making material (forgeable iron)		Wrought iron	Pig iron and scrap iron
Refining device		Puddling furance	Converter Open hearth Electric furnace Oxygen top-blown furnace
Fuel	Firewood and charcoal	Coal and coke	Coke and petroleum
Power	Muscle power and water power	Steam power	Electric power
Prime mover	Waterwheel	Steam engine	Internal combustion engine; electric motor; nuclear-power engine
Means of transport	Oxcart, horsecart, and wooden ship	Railway with steam-powered train	Railway; automobile; large industrial carrier
Main determinant factor to siting	Availability of iron ore (iron sand) and charcoal	Availability of coal	Access to market
Type of technology	Mining technology	Manufacturing technology	Scientific technology

TABLE 2. Phases in Japanese History of Iron and Steel Technology

	1858		1901		1915		1945	Present day
Pre-industrial phase		Industrial Revolution phase				Technological innovation phase		
Until independence of iron and steel technology						After independence of iron and steel technology		
Period of raw materials-determined siting						From raw materials-determined siting (proliferation of electric energy)		Period of market-determined siting (proliferation of petroleum energy)
Iron, sand and charcoal		Iron ore		Coal				
Antiquity-1857		1858-1900		1901-1914		1915-1945		1946 up to date
Phase of tatara iron-making process		Phase of transition from tatara to Western way of iron making		Phase in which State-run Yawata Steel Works played central role		Phase of simultaneous development of integrated steel making and electric furnace steel making		Phase of integrated steel works in littoral sites
Mining technology		From mining technology to manufacturing technology				From manufacturing technology to scientific technology		
— Self-sufficient in iron sand and charcoal supply — Power derived from man-driven bellows	Construction of first Western-style blast furnace in Kamaishi	— Self-sufficient in iron ore, charcoal and coal supply — Power source shifts from waterwheel to steam engine	Inauguration of State-run Yawata Steel Works	— Iron ore and coking coal import begins — Power source shifts from steam engine to electric motor	Establishment of Iron and Steel Institute of Japan	— Import of American scrap iron and Indian pig iron activated (stopped by war) — Power mainly derived from electric motor	End of Pacific War	— Supply of iron ore, coking coal and heavy oil almost wholly depends on import as rationalization proceeds — Significant renovation in transport means, including introduction of large ore-carriers
I		II		III		IV		V

Iron and Steel Technology in Japan

As is well known, the iron and steel technology of modern Japan has basically evolved from the transplanted western technology. With reference to Table 2, apart from the tatara (foot-bellows) age of iron making (antiquity-1857), the importation of western technology constituted the greater part of the history of iron and steel technology in Japan from Phase II and thereafter.

In spite of this background, however, the technical capabilities and assets of the iron and steel industry of Japan, now the third biggest steel-making and the top steel-exporting country in the world, have been built up by the Japanese themselves. The capabilities of the Japanese in science and technology, as Dr. Saigusa Hiroto once pointed out, derive on the one hand from their creative intelligence and, on the other, from their organized productive force.

I would like to point out that Japan, by the time it started importing technology from the West in the 1850s, had already amassed admirable technological wisdom, with what might be called a rich soil of indigenous technology developed through centuries of manual experience without depending on a system of science.

Dr. C.S. Smith, a metallurgist in the United States, convincingly compares, in his History of Metallography (1960), the characteristics of the iron and steel technology of pre-modern Japan with those of Europe by reference to the techniques embodied in the Japanese sword:

> The finishing of a Japanese sword and its furniture is a metallographer's art par excellence. Yet, though it depends so intimately on an appreciation of the structure of the metal beautifully revealed to the naked eye, and has served to control practical forging and heat treating procedures, it has contributed nothing to the scientific understanding of the nature of metals or the manner of their solidification or transformation. In Europe, where both the microscope and the intellectual curiosity existed from the seventeenth century onward, the only metal surfaces available for study were either fractures or surfaces abraded or burnished so as to disguise the structure completely. Had either the Japanese

> been scientifically inclined or the Europeans better artists in metal, the history of metallography could hardly have failed to have been very different.

As Dr. Smith aptly pointed out, when the instrument for observation and measurement called a microscope was used for research on metals, the science of metals was developed in Europe ahead of Asia. In Japan, however, without the knowledge of such scientific theories or the laws of physics and chemistry, techniques for the heat treatment of metals had been established ahead of Europe. Here lies a unique characteristic of Japanese iron and steel technology up to the Edo period. It was, as it were, technology as down-to-earth wisdom.

This characteristic was transformed as it came into contact with European technology from the late Edo period on, and traditional Japanese technology has been developed, or sublimated, to the present-day level of iron and steel technology which is highly scientific and measurable over the century-long process of the establishment of western-style technology for industrial mass production.

So we can identify Phase I, the age of *tatara*-based iron making, as the period of technology as down-to-earth wisdom. Phase II, the transitional phase from *tatara*-based iron making to western-style iron making (1858-1900), began in December of the fourth year of Ansei (January 1858 by the solar calendar), when the operation of a western-style blast furnace was started at the Ohashi Iron Mine in Kamaishi in the Nambu fief (today's Iwate Prefecture). This marked the first step towards the replacement of the traditional *tatara*-based method of iron making, heavily dependent on manual work, by mass production-oriented modern iron-making technology. The most significant development in this phase was the establishment in Kamaishi of the coke-burning blast furnace method, the technique for mass production of pig iron, supplanting the iron of the Chūgoku region, the previous production centre in Japan.

Then the inauguration in 1901 of the state-run Yawata Steel Works (officially named the Imperial Japanese Government Steel Works under the competence of the Ministry of Agriculture and Commerce) started Phase III of the history of iron and steel technology in Japan.

> Up and up the hill ascends Yawata,
> Built are houses like steel pieces stacked up and up.

These are lines from a song the poet Kitahara Hakushu wrote in 1930, now engraved on a monument standing on a hill called Korodai Park in the Yawata Higashi Ward of Kitakyushu City. They well depict a typical location of the Japanese steel industry built up, through adroit use of the nation's limited territory with littoral mills as its core, along with the formation of a modern capitalistic society.

With the inauguration of Yawata, an integrated production system including pig iron making, steel making and rolling was established for the first time, which enabled a variety of steel to be manufactured by modern steel-making processes (with open hearths, converters and electric furnaces) and industrial steel demand to be satisfied. The technology of ferrometallurgy came into being not as the technology of metal mining but as that of metal manufacturing. Coke ovens of the byproduct-recovering type were introduced, and the complex-oriented tight combination of the techniques of iron and steel production and manufacturing chemistry established itself. All these were among the characteristic developments of Phase III.

When the Iron and Steel Institute of Japan (the first engineering society specializing in iron and steel) and the Research Institute for Iron and Steel (the present-day Research Institute for Iron, Steel, and other metals) of the Tohoku Imperial University were founded, in 1915 and 1919 respectively, Japanese iron and steel technology began to have bridgeheads at which it could come into contact with pertinent sciences. New iron and steel technology based on the fruits of research in iron and steel science or metal engineering was thus steadily created, and the shift from manufacturing technology to scientific technology started. These were the main features of Phase IV.

However, although such world-renowed alloyed steels as Dr. Honda Kōtarō's KS Magnet Steel and Dr. Masumoto Hakaru's Super Invar were invented, the dash into a wartime economy prevented the further development of science and technology, and the real bloom of iron and steel technology as such was delayed until after World War II, when Phase V began.

In this phase, all imported techniques were characteristically absorbed into the soil of technical knowledge built up in prewar days, and the production process, featuring pretreatment of materials, large blast furnaces, oxygen top-blown converters (LD converters), continuous casting, and continuous high-speed rolling, was developed in pursuit of economies of scale. At the same time, however, problems of environmental pollution and public hazards came to be recognized, with the consequence that chemical and equipment engineers were charged with the task of reducing NO_x and SO_x pollutants and saving the consumption of natural resources and energy, and ambitious attempts were made to create a new environment for human life. Deliberate efforts were also made to strengthen the iron and steel engineering sector and step up export of steel-making technology, resulting in increasing internationalization of the Japanese steel industry.

Now, in the context of the histories of iron and steel technology in the world and Japan outlined above, I would like to describe in the following chapters the process in which modern iron and steel technology took shape and developed in this country. The chapter "The Age of Technology as Down-to-Earth Wisdom" undertakes a revaluation of indigenous technology which underlay the development of modern iron and steel technology in Japan. "The Age of Transition from Traditional to Western Technology" discusses the relationship between indigenous and imported technologies in Japan's encounter with Europe's mass production system. And "The Age of Scientific Technology" considers the autonomous development of Japan's iron and steel technology and its contributions to the Third World.

II. THE AGE OF TECHNOLOGY AS DOWN-TO-EARTH WISDOM

— The Foundation on which Modern Iron and Steel Technology was Formed

Waza and Takumi — Links with Farm Labour

"No technology can exist without mining," wrote A. Neuburger, a German scholar on the history of technology, in his Die Technik des Altertums (1921). This would have become as valid a view of technology by the end of the Middle Ages as "No technology can exist without agriculture" had been in ancient Greece and Rome. Georgius Agricola (1494-1555), a sixteenth-century German physician and mining scientist, wrote a compendium of contemporary technologies entitled De re metallica [The science of metallurgy] (published in 1556), through which he presented to the whole of Europe his idea that no technology could indeed exist without mining.

What he meant to say was not just that all industrial techniques were put together at the scene of actual mining to constitute a mining enterprise, but that the development of mineral resources and the concomitant production of metal made up the very basis of the modernization of all industries.

De re metallica, to which Goethe gave his unstinted admiration, is known as a book on technology fully embodying a positive spirit, which marked a first step in the rapprochement between the world of technology and the laws of science. A particularly interesting aspect of the book to me is that it was, as I see it, the first technological classic which convincingly explained the relationship between mining (metals) and agriculture in the eyes of a technological historian.

In his foreword dated December 1550, Agricola wrote:

> Without doubt, none of the arts is older than agriculture, but that of the metals is not less ancient; in fact they are at least equal and coeval, for no mortal man ever tilled a field without implements. In truth, in all the works of agriculture, as in the other arts, implements are used which are made from metals, or which could not be made without the use of metals; for this reason the metals are of the greatest necessity to man. When an art is so poor that it lacks metals, it is not of much importance, for nothing is made without tools. [English translation by H.C. and L.H. Hoover.]

As is well known, farming culture in Japan began with the establishment and proliferation of the ironware civilization. How did iron back up agriculture? The answer must be obvious from Agricola's words quoted above. One need not be told by an archaeologist, if one only looks at them, that the abundance of wooden tools for agriculture and household use unearthed from the famous Toro remains in Shizuoka Prefecture, where an irrigated rice field is presumed to have existed in the third or fourth century, had all been wrought with sharp metal (iron) tools.

In recent years, I took part in comprehensive surveys of the relics of iron making which are extensively found in such areas of former Shimousa province (which included a part of present-day Ibaraki Prefecture) as Iwai, Yūki, and Mitsukaidō as well as in the Kashima area of Ibaragi Prefecture, well known for <u>Hitachi Fudoki</u>, an eighth-century description of its natural features. Relics, some of which were even exposed on the roadside, were exhaustively collected, and are now undergoing interdisciplinary scrutiny by experts in natural sciences, engineering, and the humanities. Interestingly, these relics of iron making were sometimes accompanied by a <u>kaizuka</u> [shell-heap] or <u>jōmon</u> [straw-rope patterned] earthenware, suggesting the existence of composite cultural activities in places which were both convenient to live in and suitable for productive work (smelting metal).

The findings of these surveys are evidence that iron had supported agricultural production throughout the plains of Kantō, particularly in the provinces of Hitachi and Shimousa (which constitute present-day Ibaraki Prefecture).

In considering the close relationship between agriculture and iron making, would it not be reasonable to suspect that, conversely, farm labour also made important contributions to the iron-making process? Iron-making technology, since its very beginning, had involved many factors susceptible to climatic and environmental conditions, such as raw material (iron sand or iron ore), fuel (charcoal), furnace material (clay) and motive power for the bellows to blow air, and in this sense was as much locality-bound as agriculture. This remains basically true with present-day steel-making technology, as endorsed, for instance, by the use of charcoal from waste rubber-wood by Malayawata Steel Co., Ltd., in Malaysia, and of natural gas by Qatar Steel Co., Ltd., in the Middle East, as reducing agent in the steel-making process.

The East (China) was early to have an amazing technological classic work which pointed out that no human technology could establish itself without favourable climatic and environmental conditions. The following statement is found in Kaokouchi [Thinking on craftsmanship], believed to have been written in or around 30 B.C.:

> Heaven has its time, Earth has its temper, materials have their beauty, and craftsmen have their skills. Only when these four elements are well combined, can a good product be obtained.

"Heaven has its time" points out the importance of changes of the seasons, or climatic conditions, and "Earth has its temper" reflects the author's consideration of environmental elements, such as seas, mountains and rivers. The next clause, in which "materials" is self-explanatory, refers to the importance of selecting beautiful, good materials. Finally, the skills of craftsmen are pointed out, reaching a conclusion that technology can only be complete with the contributions of all such elements of nature, in the broad sense of the term, as climate, environment and materials. Underlying this statement is a view of production as a comprehensive system in which the four moments of Heaven, Earth, materials and skills are combined. It speaks of, as it were, the "wisdom of indigenous technology."

Here I would like to pause and think about two Japanese terms, waza and takumi, both referring to concepts which can be expressed in such English words as skill or technique. According to Professor Watanabe Shigeru, while gi in gijutsu (technique, skill, or technology) also reads waza,* waza is the voiced version of wasa, and accordingly waza and wasa are virtually synonymous; wasa in turn is an archaic form of wase (which commonly means early-ripening rice) according to dictionaries of archaic words, and wase more generally means early-ripening fruits of any plant, not just rice.

It can readily be inferred from this etymological background that wasa and wase denote forced plants, and waza and waze originally meant forcing techniques. Professor Watanabe further said:

> Waza, as industrial technology, constitutes the basis of production. Every human work involves its own waza, which, when highly developed, becomes the technology of an individual industry. In other words, from a good individual waza evolves a good industry, while an immature waza invites the decline of the industry which is based on it.

There is another word, takumi, which like waza seems to derive from an agricultural term. As an archaic word which was handed down by word of mouth in the daily life of early Japanese, it used to mean ta (rice field) o kumi-awaseru (matching). According to Professor Watanabe, while waza referred to forcing techniques, takumi meant a system for deciding what to plant in which combination of fields. Thus, "the techniques of early-ripening rice would naturally develop into a two-crop system of growing rice and wheat." They further implied a technological idea which "led to the knowhow of growing staple food plants and vegetables in their optimum combination." Combination or matching is so important here that takumi can as well be construed as meaning matching of "many" (which also is ta in Japanese).

* Each Chinese character used in writing Japanese usually can be read in at least two ways, one deriving from the Chinese way of reading the character, as it sounded to Japanese ears, and the other stemming from the indigenous Japanese word having the same meaning as that particular Chinese character. Here, the former applies to gi and the latter to waza.

Considering these points, we may well be justified in assuming that orientation to greater productivity and a systems approach were inherent in the empirical wisdom of indigenous agricultural techniques, and that Japanese farmers, even though lacking a capability to perceive the laws of nature logically, had built up in them resources to use climatic and environmental conditions tactically and organize productive forces in an integrated way. From the 1850s until the phase of rapid economic growth after World War II, a major part of Japan's industrial labour force, and consequently of the work force of its iron and steel industry, had transferred from the farm population. It was not just a quantitative change in demographic pattern, but a transfer to the iron-making sector of a work force having a qualitatively sophisticated way of technical thinking which had evolved over the 300-year Edo period.

Farming techniques primarily based on advanced rice culture in irrigated fields eventually served as a motive force behind the development of modern iron-making techniques in this country. However, because Japanese iron makers, except those in the Tōhoku (northeast) region, had long used iron sand as their principal raw material, they were unable, unlike their counterparts in Europe, to harness the water mills, which they had earlier developed to irrigate rice fields for iron making, to facilitate the use of larger furnaces and eventually to work out a mass production system. These points should be kept in mind as characteristic aspects of the history of iron and steel technology in Japan.

Origin and Development of Indigenous Iron-Making Technology

(1) Creative Activities by Individuals and Groups

As the traditional court nobles were completely deprived of their political power early in the second half of the Middle Ages and the Ashikaga warrior family unified Japan under its rule to restore short-lived peace in the country, trade with China was reopened and, from the fifteenth century on, demand gradually increased for swords and gold-, silver- and copperware as major export items from Japan. Merchants' and craftsmen's guilds, which had already originated in the Kamakura Period (thirteenth century), were organized in a significantly increasing number, and both commerce and industry rapidly developed.

Renovation was as conspicuous in the field of iron making as elsewhere. Professor Izuka Masayoshi, a scholar on the history of technological civilization who wrote *Sengoku no Hikari to Kage* [The Light and Shade of the Civil War] (1975), proposed a concept of "Muromachi Technological Revolution," referring to the proliferation of renovated production facilities in connection with the development of *kanna-nagashi* (iron sand isolation by the use of running water) in the process of iron sand extraction and concentration, *takadono tatara* (*tatara* furnaces used in a factory form), and *fukisashi fuigo* (reciprocating bellows) at the smelting (metallurgical) stage.

According to Professor Izuka, this revolution "developed, propelled by the mutually stimulative effects of technological innovations in agriculture and iron making, two major sectors turning out the basic needs of consumptive and productive lives." As such, the renovation in iron making was the fruit of "creative activities by individuals and groups" who had recovered their "technological sovereignty."

In fact, in every aspect of mining technology in Japan, the foundation for its modern development was quickly laid in the mid-sixteenth-century.

One of the oxidation-smelting techniques for copper developed in Japan in those days was *Yamashita-fuki*. Interestingly, this *Yamashita-fuki* was a sort of bessemerizing, as pointed out by Nakazawa Morito, author of *Hagane no Jidai* [The Steel Age] (1964). This technique, developed in Japan, which was known even to Europe as one of the world's biggest copper-producing countries throughout the Edo period, influenced the revolutionary ideas of Henry Bessemer (1813-99), the Englishman famed throughout the world for his converter-based steel-making process.

Ludwig Beck, who wrote a magnum opus on the history of iron, Die Geschichte des Eisens in Technischer und Kulturgeschichtlicher Beziehung (5 Bände, 1884-1903), took up in its first volume Japan's traditional metallurgy and stated, based on his knowledge of Japanese tinners' blowing technique through Voyage and Travels (1669) by J.A. Mendels:

> Japanese are as skilful as Chinese in the casting of tin pots. Tinners (Kessenflicker) use a notable method to keep molten iron in a fluid state, that is, vigorously blowing air from above with a bellows. Part of carbon is oxidized, as is iron also, so that sufficient heat is generated to keep the iron molten. This method is interesting in that it can well be regarded as a precursor to the Bessemer process, the most important renovation in modern iron making.

We thus find the wisdom of indigenous Japanese technology retained in oxygen top-blown converters, commonly known as LD converters, which play a vital part in the production of steel in present-day Japan.

(2) Tatara-fuki — Tradition of Iron Making from Iron Sand

Iron makers in sixteenth-century Japan created their own way of extracting and concentrating iron sand by using water, a natural resource (or gift of Heaven), as something like a tool. By this new technique known as kanna-nagashi, water was set to flow down a particularly steep mountain slope to degrade weathered granite rocks containing iron sand along the slope so that the washed-out sand iron was deposited by gravity in a pond at the foot. It was a method of concentration using the specific gravity of iron sand. Obviously the time and labour spent on concentrating iron sand were thereby tremendously saved.

Incidentally, in considering the modern development of this tatara process of making iron from iron sand, we have duly to appreciate the significance of developments at Tanegashima in the history of iron sand metallurgy.

What marked the beginning of Japan's acceptance of modern European technology evidently were the matchlock guns brought in the mid-sixteenth-century. In 1543, a Portuguese ship drifted to Tanegashima, one of the southernmost islands of Japan, giving the first opportunity for trade between Japan and western Europe. The Japanese thus began their contact with peoples and cultures they had never directly known before.

Japan's direct contact with Europe lasted for less than a century before her self-imposed isolation in 1639. However, Japan's iron-making and processing technologies, above all, were immensely stimulated and influenced by the proliferation of Tanegashima guns and imported steel. The process of making Tanegashima guns, in the meantime, was conveyed to gunsmiths in Sakai, Izumi Province (present-day Osaka Prefecture), in Kunitomo, Omi Province (Shiga Prefecture), and further to the rest of the country through swordsmiths in various provinces. A large number of guns thus came to be forged out of originally Japanese steel known as <u>tama-hagane</u>.

Tanegashima, especially its southern part, is known even today for the many ships which drift there by virtue of the current of the South China Sea and the geographical position of the island. We have here to renew our recognition that the inhabitants of Tanegashima were enabled by their contact with the cultures of the rest of the world, including continental China and Oceania, to become culturally sophisticated, or receptive of new techniques.

At least at Tanegashima, iron-making and processing technologies had developed by the early Kamákura Period (thirteenth century). The fact that abundant iron sand and many remains of iron making are found at Tanegashima and nearby Yakushima illustrates the historical truth that imported technology and its products cannot be autonomously digested and absorbed by the importing people unless they are sufficiently technically sophisticated to do so. The inhabitants of Tanegashima to whom a stray Portuguese ship brought European iron-making technology and its products in the sixteenth century were no exception. (How the guns came to the island and how the technique of making them proliferated are vividly described in Teppo-ki [Accounts on guns] written in 1607.)

In short, from only two guns which were brought to Tanegashima, Japanese smiths learned the technique of making them, which spread through swordsmiths in various provinces to the rest of the country, including Sakai and Kunitomo, the subsequent two major gun-production centres in Japan.

Iron-forging techniques were notably diversified, stimulated by the newly imported knowhow. A more significant consequence of this, however, was that the massive emergence of guns induced a revolutionary change in military tactics, which had solely depended on swords and lances, and eventually greatly helped the sixteenth-century warlords (Nobunaga, Hideyoshi and Ieyasu) to unify the country under their rule. Gunsmiths at Kunitomo, Omi Province, are known to have been generously protected by the rulers of the day, so that they later constituted, as it were, the arsenal of the Tokugawa Bakufu (Shogunate) in Edo (present-day Tokyo).

Now Japanese iron-making technology in early modern times, which featured the aforementioned kanna-nagashi in its ore extraction aspect, proceeded to the use of tatara-ro [bellows-blown furnaces, also called takadono-tatara by some researchers] in its smelting facet. These were iron-making furnaces installed in something like today's factories. The transition in the means of iron sand smelting from the old, very primitive type of furnace known as no-datara to tatara-ro is considered to have taken place in about the second half of the eighteenth century.

Also undergoing renovation along with these developments were fuigo [bellows] used for air blowing. The early tebiki [hand-driven] fuigo were replaced by fumi [foot-driven] fuigo, and then by a further improved type, tembin [balance] fuigo, with which tatara-ro, the main iron-making furnaces of the Edo period, achieved their perfection.

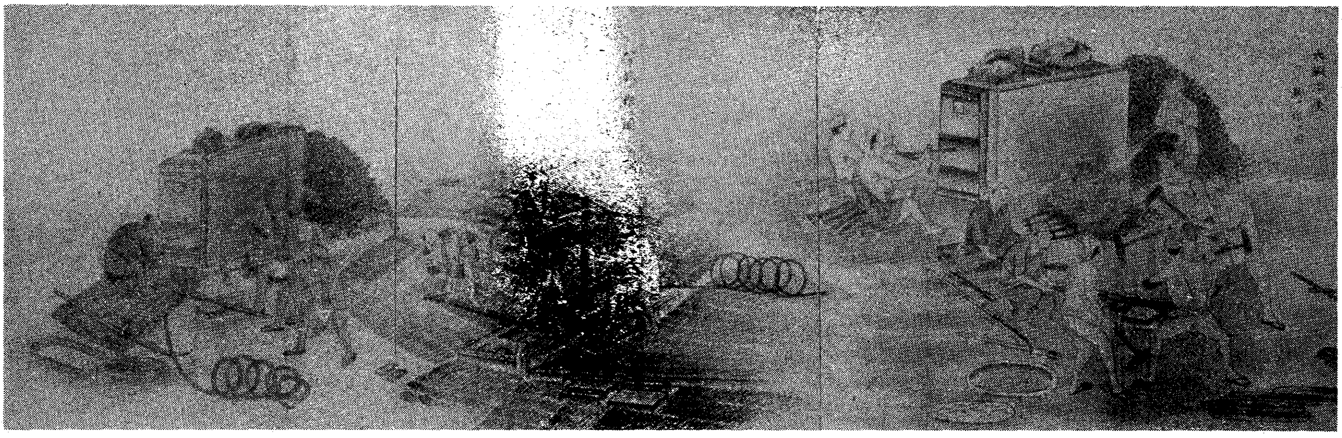


FIG. 1. Tebiki fuigo [hand-driven bellows]

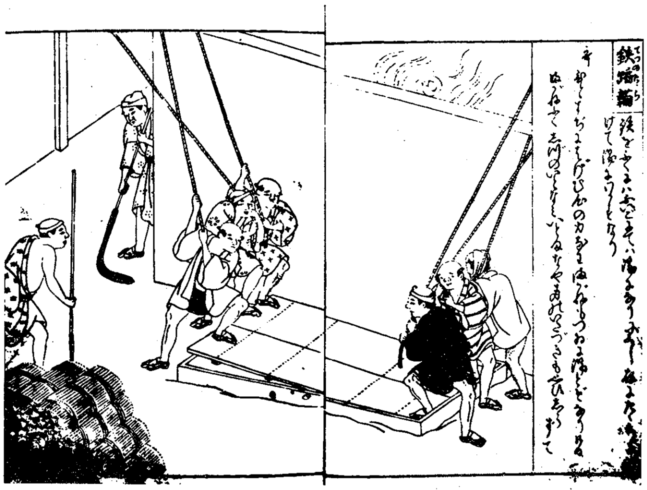


FIG. 2. Fumi fuigo [foot-driven bellows]

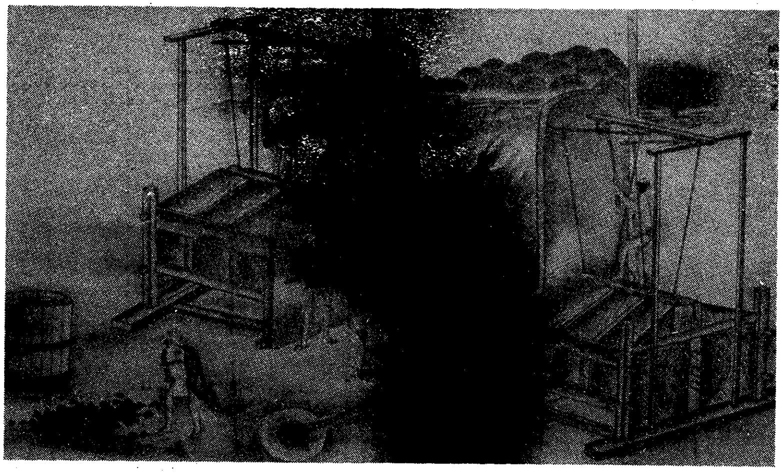


FIG. 3. Tembin fuigo [balance bellows]

A *tembin fuigo*, believed to have been invented in 1691, required only half the manpower needed for a *fumi fuigo*, which needed about ten *bango* [blowing workers], and yet permitted an expansion in furnace capacity, resulting in a remarkable improvement in operating efficiency. Moreover, the change from outdoor to indoor work enabled the steel mill to be operated 365 days or 60 *yo* [rounds] a year, each round taking three days and nights.

The purity of iron sand from Izumo Province (present-day Shimane Prefecture) reasonably satisfied the first requirement for making good steel. No better iron ore can be found in this volcanic country.

The second requirement was the purity of fuel for use in smelting. Coke, having a high sulphur content, can never give high quality steel. Good steel (*tama hagane*) was produced by smelting with charcoal.

The third requirement was a low smelting temperature. At a higher temperature, impurities would melt into steel from the furnace wall. The success in producing high-quality steel, in spite of that primitive process, was due to the satisfaction of all these requirements.

As it satisfied these three requirements, the *tatara-fuki* [bellows-blown] process was able to yield steel of even higher quality than that produced in Sweden, known world-wide for the excellent products of her steel industry. In a sense, Japan's *tatara-fuki* can be considered a forerunner of today's direct reduction processes, including Wiberg's. Moreover, *murage* or chief metallurgists responsible for supervision of the *tatara-fuki* process were old men in their sixties or even seventies who had no knowledge of modern science as such.

A round of *tama-hagane* making was carried out without interruption for 72 hours under the direction of the *murage* (or factory manager), during which time the workers stayed away from home and lived in the mill (*takadono* or *tatara*). They could sleep during breaks between tasks, but whenever required, even in the middle of the night, they would get up and add charcoal or charge iron sand. As women were strictly prohibited from entering the mill, the workers' wives or daughters had to hand them their meals at the entrance.

After a 72-hour round was over, they would tear down the furnace, about 90 centimetres tall and 1.8 metres long, inside which they would find a kera (block of steel) about the size of a tatami mat (90 x 180 centimetres) and a little over 30 centimetres thick. Nowadays, steel is usually made in a two-stage process (known as the indirect method), in which pig iron is first made from ore and then turned into steel, but tama-hagane was directly made from iron sand in a single-stage process (the direct method). This process was to some extent responsible for the high purity of the steel produced. Underlying it was the wisdom of indigenous technology.

In autumn 1969, an experimental reconstruction of the tatara process was conducted at Sugaya, Yoshida Village, Ii-ishi County, Shimane Prefecture, at the initiative of the Iron and Steel Institute of Japan. The experiment was recorded in a film entitled Wako Fudoki [Topography of Japanese Steel Making, 1970, produced by Iwanami Eiga Seisakusho] as well as in a report by the ISIJ under the title of Tatara Seitetsu no Fukugen to Sono Kera ni tsuite [On the Restoration of the Tatara Iron-Making Process and the Steel Ingot Thereby Made, 1971]. The attempt was made for no other reason that that the tatara process "involves precious hints and ideas that could help further develop modern metallurgy."

However, the tatara iron-making process which used iron sand as its principal material could never become a mass production system in the European fashion. In Japan until the Edo period, unlike in modern Europe, production technology did not develop through the interactions of the fruits of natural sciences, such as physics and chemistry. With instrumentation not readily developing on the scene of production, the Japanese were not very adept at grasping the laws of science. Nevertheless, through centuries of technical experience, they had acquired an abundance of wisdom and hence many technological truths.

Shimohara Shigenaka's *Tetsuzan Hitsuyō Kiji* [Iron Makers' Vade Mecum, 1784], a classic Japanese metallurgical work comparable to *De re metallica*, is filled with such technological truths.

Choice of good iron sand was indispensable for making good steel. Shigenobu described a method of assessing a sample of iron sand according to the sound and colour it presented when put into a fire, which has something in common with today's spark method of metal analysis.

> Iron sand is fine granules of intrinsically very heavy matter. The seemingly large ones which are occasionally found consist of iron granules sticking to sand grains. What matters is not the difference between larger and smaller but that between heavier and lighter granules.

This refers to the property of iron sand screened out by *kanna-nagashi*. Iron sand was broadly classified into *masa* iron sand, which was used for making steel (*tama hagane*), and *akome* iron sand, which was more suitable for pig iron. For either kind, the criterion of screening was its relative weight, in consistent observance of the principle of gravity concentration. Heavier iron sand was considered superior.

Along with this another major advantage of the *tatara-fuki* process was that iron sand of uniform grain, like a charge having gone through grain regulation in the modern steel-making process, could be obtained with the help of the natural force of water current. Considering that even the blast furnaces of today's huge steel mills cannot fully exert their high efficiency unless their iron ore charges are uniformalized in grain, one can be readily convinced of the theoretical excellence of the *tatara* iron-making process.

What should not be overlooked in the structure of the tatara furnace is its elaborate hearth, embodying tremendous efforts to keep the heat in the furnace and prevent it from dispersing out. However, the walls which constituted the superstructure were demolished every time a 72-

hour round of tatara operation was finished, because the furnace walls also served as the source of slag. Here was another sign of the remarkable wisdom which underlay the production of excellent steel in Japan. In this iron-making process there was no artifice which ran counter to the laws of nature. The man-driven fumi-fuigo or tembin-fuigo was used for air blowing because it could be readily controlled according to the progress of smelting, but no western machine would have found any place in this iron-making process, where the waza of nature and the takumi of man were ingeniously integrated.

The excellence of traditional Japanese steel was solely due to the manual process by which it was made. It was by no means compatible with the mass production system of modern Europe, but this was the very reason it lent itself to the production of such world-famous masterpieces of metal art as Japanese swords. (To produce material for Japanese swords as objects of aesthetic value, a tatara furnace was revived in 1977 at Yokota Town, Shimane Prefecture, marking the birth of a new local culture.)

We have found rudiments of heat treatment and surface treatment during, for instance, a metallurgical study on iron nails used in the Kondō shrine of Hōryūji Temple (believed to be the oldest existing wooden building in the world) ever since its construction in 607. Empirically succeeding this tradition, Japanese swordsmiths in the Edo period, as Dr. Smith pointed out in the paragraph quoted above, had no inferior skills in heat and surface treatments to their European counterparts.

In the way they coped with the forces of nature, too, our ancestors had considerations which are noteworthy even by present-day standards. As pointed out by Professor Yoshida Mitsukuni, who said, "Traditional technology always takes advantage of, but does not resist or fight, nature," the wisdom of craftsmen in the Edo period contains much to be reappraised, explored and used in a modern way to the benefit of those who live in the polluted environment of the late twentieth century.

The absence of science in traditional, indigenous technology does not mean it was an unscientific or anti-scientific technology. We have to acknowledge that any scientific technology, as long as it has been able to develop under given environmental conditions, can never truly be integrated into the society in which it was born unless it is in harmony with the indigenous culture of that society.

(3) Indigenous Technology of Tohoku Region — Traditional Use of Iron Ore (*mochi-tetsu*)

Nobody today would deny that the iron sand smelting process (*tatara-fuki*) which developed mainly in the Chugoku region (consisting of the San-in and San-yo districts), and the high-quality steel thereby produced, played a major role in the history of the indigenous Japanese iron-making technology which was established and proliferated in the Edo period.

But were there no other iron-making methods in pre-Meiji Japan than the *tatara-fuki* process of iron sand smelting? Yes, there were.

Positive study on natural iron ore, which previously was only briefly referred to as "*mochi-tetsu*," i.e. iron rocks like pieces of *mochi* (rice cake) in literature, has made remarkable progress over the last decade, and it has been ascertained that there was a long continuous tradition of indigenous iron-making technology, based on the smelting of iron ore, in a fairly large part of the Tohoku region centring on the Kamaishi area of present-day Iwate Prefecture.

Mochi-tetsu was a magnetic iron ore of considerably high purity with an average iron content of more than 60 per cent. Resembling the world-famous Swedish ore in composition, it gave excellent reduced iron. Iron making from *mochi-tetsu* had significant advantages, both quantitative and qualitative, over the smelting in the Chugoku region of iron sand, which had an original iron content of less than one per cent and was concentrated by the *kanna-nagashi* method.

The practice of *mochi-tetsu* smelting extended from the Miyako area in the north to Daito in the south, or around the upper reaches of the Satetsu River, a branch of the Kitakami River flowing through the vicinities of Hiraizumi and Ichinoseki.

Many pieces of iron ore, ranging from fist size to powder-like grains, can be readily collected in the region even today because of their strong magnetism. According to Niinuma Tetsuo, a local historian who energetically gathered mochi-tetsu pieces in the hilly part of Kasshi, Kamaishi City,

> If you scoop some soil in a place where mochi-tetsu is found and wash it with water in a basin, a large amount of powder will remain at the bottom of the basin while mud and sand grains, which are lighter, will flow out together with water. Larger pieces of mochi-tetsu can be readily broken with an ordinary stone — you need no hammer to break them. Granular mochi-tetsu can be reduced at low temperature in a simple smelting experiment with charcoal. Pulverized mochi-tetsu could even be as easily reduced at low temperature as in the smelting of iron sand.

Mochi-tetsu was found either in its purely natural form or in pieces containing gangue, rounded by the current of water. The former, in particular, was confirmed to have little harmful content, such as sulphur and phosphorus, but a high iron content.

In Kamihei Country, Iwate Prefecture, there is a town called Ōtsuchi, ajoining Kamaishi City. The Kobayashi family living at Kotsuchi in the town owns an inherited picture scroll depicting the scenes of iron smelting and processing in old times. Judging from the tools pictured therein as they were used for making farming or fishing apparatus, there is no doubt that the scroll dates back to the Middle Ages, though it is impossible to assess its date with any greater accuracy.

With a furnace at the centre, a fuki-toryo [smelting master] stands in the left part of the picture with a big spoon-like scoop in his hands, and on the right is a man who looks like a foreman, throwing material into the furnace with a small scoop. Beside the furnace there are six bango [blowing workers], supplying air for it with a bellows made of leather and wooden boards.

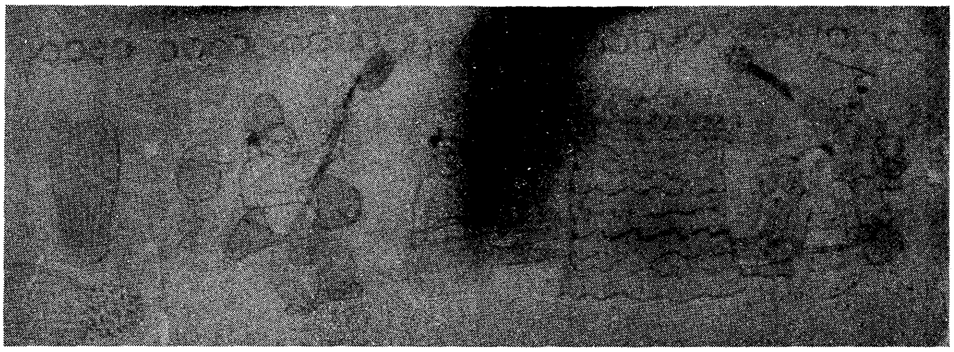


FIG. 4. The picture (scroll) depicting an iron making scene, found in Otsuchi Town, Iwate Prefecture

A problem here is deciding what the material being charged is. Niinuma, quoted above, analyzed the iron ore and slag found in the Kotsuchi remains of iron making located near the Kobayashi's home, and thereby confirmed that, although it was impossible to assess the era in which the depicted operation took place, the material used was a magnetic iron ore of high purity and the iron slag had resulted from the smelting of that ore. The material pictured in this scroll is thus presumed to be iron ore; that is granular mochi-tetsu.

Niinuma and his associates, Tada and Saito, actually tried low-temperature reduction of a sample of mochi-tetsu they had collected in a test furnace modelled after the ancient iron-smelting furnace, and presented their findings to the conference of the Japan Institute of Metals held in October 1975. Thus it was experimentally demonstrated that, in an even simpler process than the tatara-fuki smelting of iron sand, "oroshigane [steel] in the form of kera [ingot], in the terminology of iron sand smelting, can be obtained from mochi-tetsu."

A further survey of ancient or medieval iron making in the Tohoku region based on these findings has revealed that, along with the iron sand smelting typical of the Kuji area, smelting of mochi-tetsu was widespread in the central and southern parts of Iwate Prefecture and constituted an integral part of the regional culture.

We thus renew our recognition that the later iron makers in Tohoku, because of the progressiveness of their indigenous technology, were able to accept readily the blast furnace-based western process of iron making.

Thoughts on Iron

With the exception of iron ore (mochi-tetsu) smelting which was pioneered and proliferated to some extent in the Tohoku region, the main stream of iron-making technology in Tokugawa Japan consisted of the so-called tatara-fuki process of iron sand smelting. Geishū Kakei Sumiya Tetsuzan Emaki [a picture scroll depicting Sumiya's iron mine at Kakei, Geishū] which depicted a tatara-fuki scene in a part of Aki County, Hiroshima Prefecture, and Sakiozu Agawa-mura Yama-satetsu Araitori no Zu [scenes of wash-concentration of mountain iron sand in Agawa Village, Sakiozu] picturing scenes of iron sand collection, smelting and processing in an area extending along the Japan Sea coast in the northern part of Yamaguchi Prefecture, both now available in reproduction, reveal to us what point the iron sand smelting technology in this country had reached by the late Edo period, around the 1850s.

Modern iron-making technology in Japan, however, did not develop from iron sand and its tatara-fuki, but began with the introduction of western-style blast furnaces. It was established as a new indigenous Japanese technology through the combination of the traditional mochi-tetsu smelting techniques in the Tohoku region and the European-developed theory of modern iron metallurgy.

There certainly was discontinuity between the tatara method and the modern iron-making process as a mass production system. We should nevertheless not overlook the fact that the new technology was transplanted to, took root in, and proliferated and progressed from nothing else than the soil of Japanese thoughts on industrial technology concerning iron, which had been empirically cultivated by the traditional techniques of tatara iron making and mochi-tetsu smelting and the succession of iron-using techniques developed therefrom or, as it were, technology as down-to-earth wisdom.

I have already pointed out in the Introduction that Miura Baien, one of the foremost scientific thinkers in the Edo period, who was born and grew up on the Kokutō Peninsula in Oita Prefecture, said, "Iron is considered the supreme treasure" because it was extensively used by many people and daily life could not dispense with it, not even for one day.

Authors who, like Baien, duly appreciated the value of iron successively emerged in the Edo period. Shimohara Shigenaka (1738-1821), author of the above-quoted Tetsuzan Hitsuyō Kiji, wrote, "Iron contributes much to the welfare of the people of all estates," and "Since agriculture is the basis of political economy and iron is the foundation of agriculture, iron is nothing to be belittled." "Iron is the most beneficial to human life among the seven metals" is a well-known phrase in Keizai Yōroku [Principles of Economy, 1827] by Satō Nobuhiro (1769-1850), an economic thinker and mineralogist-metallurgist of the late Edo period.

Other notable expressions of technological ideas include one by Shimazu Nariakira (1809-58), lord of the Satsuma fief, who said that "the first point in promotion of agriculture" was the manufacture of farming tools. Shimazu, who successfully built a reverberatory furnace following a similar success in the Saga fief and built in Kagoshima the first western-style blast furnace in Japan, based his industrial technology policy on the belief that "Agriculture is the foundation of any nation, be her Japan, China or one in the West, and the foundation of agriculture is iron."

By the time this recognition of the vital importance of iron took root in the indigenous Japanese culture, the Japanese had come into contact with European books on science and technology imported via Nagasaki, and had begun actively to absorb Dutch technology. It was in those days that Taisei Shichikin Yakusetsu [A Study on the Seven Metals of the West], probably the first Japanese book on modern metallurgy, was published.

Whereas the significance of this book and how European (above all Dutch) technology was accepted will be explained in the next chapter, it may be sufficient here to point out that the soil of technological thought to which the Western iron-making method should be transplanted had been well prepared in Japan in the first half of the nineteenth century. For this very reason, Japan was able to "take off" towards modernity ahead of all other Asian nations.

III. FROM TRADITIONAL TO WESTERN TECHNOLOGY

— Encounter with European Mass Production System

Systematic Acceptance of Western Learning, Especially Dutch Technology

(1) First Japanese Book on Western Metallurgy — Taisei Shichikin Yakusetsu

Taisei Shichikin Yakusetsu, the first Japanese literature representing the local understanding of modern European metallurgy, was written by Baba Sadayoshi (1787-1822), a scholar of western learning in the late Edo period, who first served as a Dutch interpreter in Nagasaki and later made important contributions to translation (from Dutch, Russian, English and so on) at the Temmon-kata [astronomy office] of the Bakufu [Shogunate] as bansho wage goyōgakari [translator of western literature into Japanese]. The book was published in a limited issue of 200 copies in 1854, 33 years after Sadayoshi's death. Printed with wooden type, it is also regarded as an important landmark in the history of modern printing in Japan.

As its title indicates, the book consists of translated accounts of "seven metals," supplemented at the beginning with seven drawings illustrating western processes of smelting them. The whole work consists of five volumes, the first on gold, second on silver, copper and iron, third on tin and lead, and fourth and fifth on mercury, and states where, how and in what varieties each metal is yielded, how it is smelted, what properties it has and what purposes it is used for.

Perhaps because of Sadayoshi's own knowledge of and interest in medicine or because its compilation was supervised by Shibue Chōhaku, a well-known herbalist of the day and Bakufu-retained physician, the book dwells in particular detail on the pharmaceutical effects and uses of the metals. Thus it is less a book on metallurgy than one on chemistry and pharmacy. I would like to note the fact that, in this first comprehensive book in Japan to introduce western knowledge on metals, the significance of the seven metals was primarily grasped as they related to the basis of people's everyday life, and above all the role of iron was given a due position.

Sadayoshi is also known as the translator of a medical work entitled Tonka Hiketsu (completed in 1820, published in 1850), which was the first book to make known in Japan the "vaccination" method, announced by Edward Jenner of the U.K. in 1798 as an effective way to prevent infection from smallpox in his An Inquiry into the Causes and Effects of the Valiolae Vaccinia Known by the Name of the Cowpox.

Further, as Dr. Ogawa Teizo found out, this vaccination was successfully practised for the first time in Japan half a century after its invention by Jenner and exhibited a smallpox-preventive effect which was obvious to anybody, thereby demonstrating the superiority of western medicine which had been theoretically revealed by Kaitai Shinsho (a translated Dutch work on anatomy).

Sadayoshi was not a physician, but he "took great interest in the new method to prevent infection from smallpox by the inoculation of cowpox and, with a faith in its importance, wrote Tonka Hiketsu, which made major contributions to the development of medicine."

Japan at the dawn of her modernization could well take pride in the contributions of this and other scholars of western learning to the introduction of western knowledge on metals, above all iron, as basic necessities of human life.

In the 1810s when Sadayoshi wrote Taisei Shichikin Yakusetsu, his already extensive knowledge of western learning was further expanded by his contact with Russian literature and deepened by his encounter with Chomel's encyclopedia. His energetic activities now reached their peak. In 1854, his laborious work was finally published.

In his general consideration of gold in volume 1 of Taisei Shichikin Yakusetsu, Baba Sadayoshi wrote, "Among various metals, iron is the most useful to man, who cannot dispense with it even for a moment. Iron should be most highly valued," and declared, "As far as household use is concerned, iron should be considered the foremost of all metals." This idea can be regarded as following exactly the same line as the above-quoted statements of Baien, Shigenaka and Nobuhiro, which had grown from the soil of indigenous technological thoughts.

Further, in concluding his account of iron in volume 2, Sadayoshi again stated, "Iron cannot be dispensed with even for a moment in everyday human life," and pointed out its "main benefits," saying, "Used as tools or as medicine, iron has the most valuable benefits."

In short, Sadayoshi's own and his predecessors' statements indicate that, in terms of the very fundamentals of human life, both indigenous and advanced European thought could stand on exactly the same basis.

It is also worthy of note that not a sign of military orientation is found in the "thoughts on iron" of Japanese pioneers in the Edo period. I would like to point out that theirs were enlightening ideas which had naturally evolved from the indigenous technological thoughts referred to above, but which were completely different from those emphasizing military needs which developed after the establishment of the Meiji government.

(2) Intake of Dutch Knowledge on Ferro-Metallurgy
— Casting Process at the National Iron Cannon Foundry in Liège (Luik)

Next I would like to touch on the fact that Japanese pioneers in western learning and technology came into direct contact in the 1850s with a Dutch technological book from which they came positively to understand and learn the theory and practice of iron-making technology itself.

The book was entitled Het Gietwezen ins Rijks Iizer-Geschutgieterij, te Luik [The Casting Processes at the National Iron Cannon Foundry in Luik (present-day Liège), 1826]. It was a book on military technology and arms engineering, describing in detail the iron shell- and cannon-making processes used at the Dutch National Cannon Foundry then situated in present-day Liège. The author was Ulrich Huguenin (1755-1834), a major-general in the Dutch Army who then headed the foundry. The book was the first work on modern iron-making technology practised in the Netherlands of those days, and as such also served as a textbook on metallurgy, elaborately describing the properties of iron and its manufacturing process.

This book was able to satisfy fully the intellectual needs of the intelligentsia of Japan in the late Edo period, then under military pressure from foreign nations. It was translated in many provinces under different titles, and used in the 1850s as a manual in various parts of Japan (including Saga, Kagoshima, Hagi, Nirayama and Mito) for the construction of reverberatory furnaces which were used to cast cannons. The book further acted as one of the motive forces which brought about the construction of western-style blast furnaces in Kagoshima in the southwest, Kamaishi in the northeast and Hakodate in Hokkaido.

In the section on blast furnaces, K.J.B. Karsten (1782-1853), a German ferro-metallurgist, is frequently quoted, suggesting the author's historical understanding of iron making. Karsten was an engineer who put together the basic theory of iron-making technology and its practical applications in a guidebook entitled Archiv für Bergbau und Hüttenwesen [A Compendium on Mining and Metallurgy] and thereby was able to raise ferro-metallurgy into the position of a modern engineering science. Thus, a technological book which had been compiled with a view to helping the Kingdom of the Netherlands, lagging behind Britain and France in iron-making technology, to get rid of her backwardness, happened to find its place in the soil of western learning in Japan which had been cultivated with, as it were, fertilizers imported through Nagasaki. And it served as one of the sources of information which was used in the construction of blast furnaces and manufacture of pig iron in this country.

As will be described in the next section, Oshima Takatō (1826-1901), a scholar of western learning serving the Nambu fief (present-day Iwate Prefecture) who studied Dutch learning in Nagasaki, worked together with his classmate Tezuka Ritsuzō to translate Huguenin's book, and attempted to pave the way for the development of modern technology through the learning of European principles of iron making.

In the case of the construction of another reverberatory furnace at Nirayama in the Izu province at the initiative of Egawa Tan-an (1801-55), a sort of translated information centre was set up comprehensively and systematically to take in and absorb European science and technology, and suprafeudal joint research was promoted.

From Reverberatory to Blast Furnaces

By around 1850, as western powers had stepped up their demands for the opening of Japan to intercourse with them as well as their military pressures on the nation, fundamental reform of her iron-making process, or its modernization into a mass production system, had become a vital task for Japan. And the need for a massive supply of pig iron to be charged into reverberatory furnaces for the casting of cannons induced western blast furnace technology to be transplanted into this country under the leadership of Oshima Takatō and other pioneering engineers.

Takatō was born in Morioka, where his father was retained by the Nambu fief as official physician, and in 1846 went to Nagasaki where, together with Tezuka Ritsuzo, he studied Dutch learning. He learned "western military tactics, gunnery, mining and smelting techniques," and was given a certificate of full proficiency in gunnery by Takashima Asagorō, whose father Shūhan was renowned as the father of western gunnery in Japan. During his stay in Nagasaki, he also translated Huguenin's book on cannon foundry cited above.

Thus the industrial application of western-style blast furnaces, or mass production of pig iron, was started in Japan by Ōshima Takatō, scholar of Dutch learning born in the Tōhoku region (more specifically Iwate Prefecture), who had an opportunity to learn the modern European theory on iron making.

Scholar Takatō, who was also a samurai belonging to the Nambu fief, took part in a reverberatory furnace project undertaken by the Mito fief, and attempted exploitation of the Kamaishi iron mines back in Tōhoku to obtain pig iron to be charged into that furnace.

The first reverberatory furnaces in Japan were built in 1850 at Tsuiji and Tabuse in Saga.

As Saga-han Jūhō Enkakushi [History of Gunnery in the Saga Fief, 1934] and other historical records indicate, the first successful casting of a cannon with the reverberatory furnace of the Sage fief was achieved "through the combined working of the knowledge of scholars of Dutch learning, calculations by mathematicians and skills of casting workers and swordsmiths." The early operation of the Saga fief's reverberatory furnace is described in minute detail by Sugitani Yōsuke, its chief engineer, in his Hansharo no Yurai [A Memoir on the Reverberatory Furnace, 1852]. An eningeer from Hizen (today known as Saga) who later directed the construction of another reverberatory furnace at Nirayama in the Izu province, Yosuke had studied under Ito Gemboku, a practitioner of Dutch medicine, and worked with Gemboku to write Tekkō Zensho [A Complete Book on Iron Cannons, in 12 volumes supplemented with drawings], based on the above-cited work by Huguenin. He therefore had a far-reaching influence on other pioneer metallurgists of the late Edo period.

The development of the Sage fief's cannon-casting project amazed the rest of the nation, and many from the Bakufu and elsewhere asked the fief to impart its casting techniques or to cast cannons for them. Following Saga, the Satsuma fief achieved a brilliant success in its own reverberatory project. Not to be overlooked in regard to this success was the influence of the industrial technology policy and above all the scientific and technological views of Shimazu Nariakira, lord of the Satsuma fief, who constantly gave appropriate instructions to his engineers in the belief that "Westerners are human beings, Saga-ites are human beings, and so are Satsuma-ites." It may be relevant here to add that, both in Saga and in Satsuma, research in physics and chemistry was started by what was called Seiren-kata (the smelting laboratory) along with this process of the establishment of western-style military industry, stimulating for some time the development of chemical and shipbuilding industries. These activities had a close geographical bearing on the establishment by the Bakufu of its naval academy and iron foundry (which eventually evolved into the present-day Nagasaki shipyard of Mitsubishi Heavy Industries, Ltd.) in Nagasaki.

Preparations for the construction of the reverberatory furnace in Izu were begun in 1853 under the leadership of Egawa Tan-an, a scholar of western learning, with the technical assistance of the Saga fief. In that year, Hatta Hyōsuke, an "engineer specializing in cannon manufacture with a western-type furnace," went to the Sage fief to prepare for its construction at the instruction of Tan-an. He inspected the workings and studied the techniques of the reverberatory furnace in Saga, and brought his new knowledge back to Nirayama. Then in 1857, the Saga fief sent Sugitani Yōsuke and Tashiro Magosaburō, both capable engineers, together with a team of craftsmen, to Nirayama to reconstruct the reverberatory furnace there. Work on the furnace and further development of the cannon casting project were undertaken through technical exchange between the experts from Saga and local engineers. In this instance, scholars of western learning were mobilized to form a joint research body called Nirayama Ransho Honyaku-kata [Nirayama Dutch book translation office], whose mission it was to back up the first-line engineers engaged in the casting of cannons.

As reverberatory furnaces were thus built in quick succession, the Satsuma fief in 1854 pioneered the construction of a western-style blast furnace as a logical consequence of its canon-casting project.

However, handicapped by the limited supply of raw materials and demand for products, the fief was unable to continue full-scale industrial production, and had to be content with the honour of being a pioneer. In the meantime, another blast furnace was built at Kobui, Hokkaido, under the administration of the governor of Hakodate. The project was launched in 1855, at the initiative of Takeda Ayasaburō, a scholar of western learning who is also well known for his design of a Dutch-style fortress (Goryōkaku in Hakodate), but the furnace, intended to use iron sand as its principal material, was a failure.

In the same year, the Mito fief also constructed a reverberatory furnace under the leadership of Tokugawa Nariaki and Fujita Tōko, with Ōshima Takatō, Takeshita Seiemon and Kumata Kamon, respectively retainers of the Nambu, Satsuma and Miharu fiefs, serving as engineers. This reverberatory in Mito proceeded in 1856 to the casting of a mortier (mortar) from Unshū-sen (pig iron produced in present-day Shimane Prefecture). However, with a view to obtaining a large quantity of pig iron suitable for the casting of cannons, the work with this reverberatory led, at the initiative of Oshima Takatō, to the development of the Kamaishi iron mines in the Nambu fief through the introduction of a western-style blast furnace, which eventually constituted the origin of modern iron-making technology in Japan.

Then why was the industrial-scale production of pig iron with a blast furnace successful only in Kamaishi, but not in Kagoshima or Hakodate?

Considering the extent of the knowledge on the European iron-making process which Takatō had acquired through Dutch literature or the contents of Seiyō Tekkō Chūzō-hen [Casting of Western Iron Cannons], a technical guidebook he translated together with Tezuka Ritsuzo, it may not be unreasonable to say that the development from reverberatory to blast furnaces was just a matter of course. However, let us recall that, as pointed out in the foregoing section, many parts of the Tōhoku region including Kamaishi had been more advanced than elsewhere since ancient times in the mining and processing of metals such as iron, gold and copper. And we might well call Ōshima Takatō an incarnation of the folk spirit of Tōhoku.

Already, in July 1854, when he had not yet set about building the reverberatory furnace in Mito, Takatō was thinking about acquisition of "iron from Kamaishi, Nambu" and construction of a western-style blast furnace, and he confided his ambition to Sakuma Teisuke, an official of the Mito fief. Takato's intention was referred to in a personal letter by Sakuma which was incorporated into the latter's Hansha-ro Seizō Hiki [Confidential Notes on the Construction of the Reverberatory Furnace]:

> Oshima in fact thinks no ordinary tatara would be adequate for smelting the wanted pig iron, but a western-style furnace will have to be newly built. Therefore, he has hinted, he plans to go to Nambu (Kamaishi) as soon as the reverberatory furnace is completed, and built there the intended furnace, the pig iron from which should be procured. . . .

Indeed, engineer Takatō firmly believed that "The western process is the best of all. One has to be selective about the quality of iron. Even if a reverberatory furnace is built, it will serve no purpose without soft iron (pig iron made from iron ore). Only where there are soft iron and a furnace will there be (useful) iron, but neither is dispensable. I will never agree to make a cannon out of the other kind of iron." He further used an apt simile to explain the qualitative difference between "soft iron" and the other pig iron (pig iron from iron sand): "The other kind of iron is like ordinary rice, which cannot be kneaded smoothly however thoroughly it may be polished. Soft iron is like glutinous rice, which of whatever grade can be well kneaded into paste (from which rice cake is made)."

Takatō did not mean to deny the tatara furnace in principle. He knew that, if the Mito fief's reverberatory furnace was intended for melting pig iron for use in the casting of cannons, the kind of iron suited to the purpose, pig iron which was highly fluid when melted, uniform in quality and available in a large quantity, could never be obtained from the tatara furnace. He had a firm grasp of the indigenous iron ore-smelting technology in Tōhoku, and also was well versed in the European method of iron making. From the very beginning of his participation in the reverberatory project in the Mito fief, he had this scientific knowledge.

Thus in the Edo period, when no machinery or equipment could be imported from advanced countries, it was not possible anywhere other than in Kamaishi of the Nambu fief (Iwate Prefecture), which had Ōshima Takatō as its engineering leader, to accomplish the tremendous task of successfully building a western-style blast furnace with nothing to depend on but locally available knowhow, materials and labour, only guided by Dutch technical books and engineering dictionaries and financially assisted by industrial capitalists of the locality. As illustrated, the first western-style blast furnace in Kamaishi (also known as the charcoal-burning blast furnace because it used charcoal as fuel) was characterized by its use of water mill-generated motive power, another example of the practical exploitation of natural advantage.

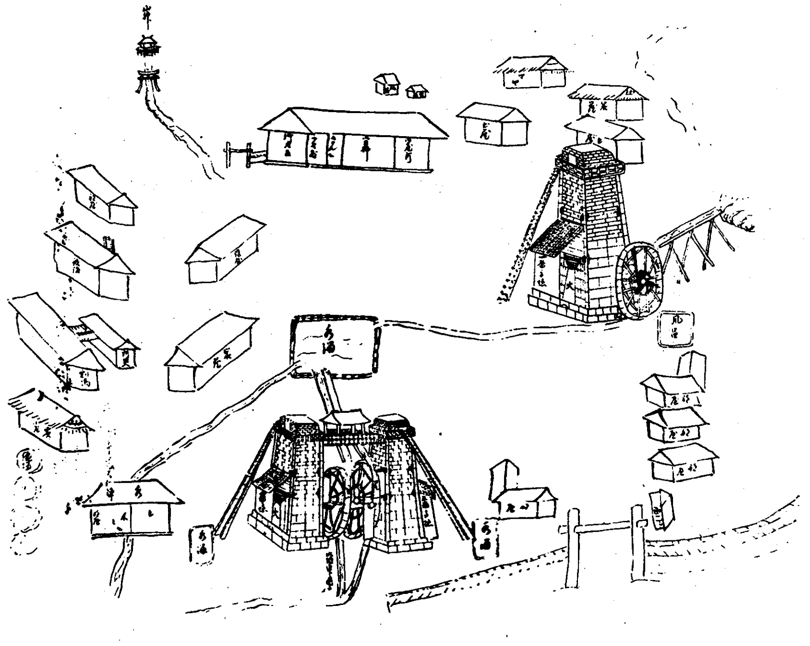


FIG. 5. An overall view of the Ōhashi blast furnace at the Kamaishi mines

The founding of a western-style blast furnace to achieve industrial smelting of iron ore, instead of iron sand, was an epochal event marking a first step away from the traditional small-scale, inefficient _tatara-fuki_ process and the dawn of modern iron-making technology in Japan. The start of pig iron making with a blast furnace not only gave the first opportunity to try to catch up woth European iron-making technology which was three to four centuries ahead, but also paved the way for the establishment of a modern iron and steel industry in Japan through the combination of the pig iron-making process with new steel-making knowhow.

Ōshima Takatō called his creation a "Japanese-style blast furnace," but never a "western-style blast furnace." Only the transplantation to Kamaishi of western-style blast furnace technology, instigated by the reverberatory project of the Mito fief, could become the starting point of the development of modern iron-making technology in Japan, not because the furnace was western-styled but because the principles of European iron making were scientifically materialized against the background of indigenous Japanese culture by the personal contribution of Takatō.

In contemporary China, the spirit of indigenous culture, the so-called _tu-fa_ [indigenous method], is expressed in the phrase "_chiu-ti chu-tsai_" [choose materials according to local circumstances], which means a new approach in technological creation starting from familiar ways of making things, or conventional, traditional means which people are used to, actively accepting western ways as long as they fit the natural environment and the availability of resources in the locality, and further improving the western ways themselves. The approach Takatō chose was on the same line as the basic way in which today's Chinese are trying to develop their industry.

Establishment of Coke-Burning Blast Furnace Process

— Failure and success of Kamaishi Iron Mill

In 1858, the cannon-casting project of the Mito fief collapsed as a consequence of the sudden death of Fujita Tōko as well as intricate circumstances involving its lord Tokugawa Nariaki. However, iron making with western-style blast furnaces which began at the iron mines in Kamaishi rapidly proliferated in the Kamaishi area, with its product mainly used for the casting of coins and further for the production of farming tools and household appliances. It eventually developed into a new local industry on a scale comparable to that of manufactures on the eve of the industrial revolution in Europe. Following the first western-style blast furnace installed at Ohashi in the Kamaishi iron mining zone, blast furnace-based iron making was eventually actively undertaken in the Hashino area, where its remains are found today, and similar furnaces were also founded in other parts of the zone including Sahinai, Sunakowatari and Kuribayashi, all close to Tōno. About ten blast furnaces had been built in the district by the time of the Meiji Restoration (1868), totalling in an annual output of 700,000 to 800,000 kan (about 3,000 tons).

It was in this historical context that the Meiji government in 1874 decided to nationalize the Ōhashi iron mine in Kamaishi, and in the following year embarked on a programme to build a modern-scale iron works under the slogan of "Increase production and promote industry."

By that time, Ōshima Takatō was in his late forties. The Meiji government, though dominated by the Satsuma and Chōshū clans which had overthrown the Tokugawa Shogunate to which his Nambu fief had been loyal, could not help highly appreciating Takatō's rich technical knowledge and the experience he had acquired during his service with the fief, and the Ministry of Industry appointed him a technological administrator stationed in Kamaishi. Takatō was just back from America and Europe, which he had visited as a member of a fact-finding mission headed by Iwakura Tomomi, ambassador extraordinary and plenipotentiary.

In June 1874, Takatō set about planning the construction of a new iron works in cooperation with L. Bianchie, an engineer invited from

Germany. However, he disagreed with Bianchie over the question of where the iron ore extracted from mines in Kamaishi should be brought to, smelted and processed, i.e. the siting of the planned steel mill. Takatō's conviction was based on his knowledge of the local peculiarities of the Rikuchu area, where he had been born and bred, and on the details of his experience in technological development. Bianchie, on his part, was a proud specialist from the advanced European country.

Takatō chose a place called Otadagoe, north of one end of the Morioka highway, while Bianchie insisted on another place called Suzuko, about 900 metres southwest of the highway. There was no major difference between them as to the criteria of siting, such as the availability of water indispensable for iron making, access to a sea port and room for future expansion. Notably, however, Takatō attached greater importance to the environmental conditions of workers, as he said Ōtadagoe, his choice, "was enclosed by hills on three sides, west, north and east, and only open on the south side, so that the site would be affected by no rain storms in any season and be less chilly in winter, thus permitting continuous operations day and night."

However, viewed from the standpoint of those who had to think, in the overall context of the steel mill project, how the production technology could be established in that locality, there was an uncompromisable difference between the two proposed sites. Coming from Germany, which had already gone through the industrial revolution, Bianchie intended to build from the outset a big iron works comprising two relatively large, efficient blast furnaces, a modern railway to permit conveyance of iron ore by steam locomotive-drawn trains, and a rolling mill to roll wrought iron prepared from pig iron. In contrast Takatō, in view of his experience, selected what seemed to be the safest available site for night-and-day operations, and proposed a plan matching the Japanese technological standards of those days, according to which five relatively small blast furnaces would be built to be supplied with iron ore carried by economical horse-drawn rail carts. He thus intended slowly but steadily to develop the techniques on a safer path, in other words to choose a way "to bear a small baby and raise it big," as a Japanese proverb advises mothers. His choice of site was based on this principle.

For a developing nation nowadays to set up an integrated steel mill of her own, the best timing from the viewpoint of her economic growth is believed to be found in the phase where her per capita steel consumption has reached 20 to 30 kilograms a year. Japan's per capita annual consumption of steel when the state-owned Kamaishi Iron Works (under the competence of the Ministry of Industry) was planned is estimated at even less than one kilogram. Growth of a new technology in any country is dependent on whether or not its promoters are aware of the peculiarities of the indigenous culture, including the factors of demand, and have a technological method to establish productive forces therein, or in more general terms a technological thought with a broad perspective.

Unfortunately, paying respect to foreign eningeers invited from advanced nations, senior officers of the Ministry of Industry rejected Takatō's proposal and adopted Bianchie's. In the meantime, Takatō was transferred to the Kosaka mines in Akita Prefecture and had to leave Kamaishi. The state-owned Kamaishi Iron Works was now to import two large British-style blast furnaces (complete of course with refractories and all other necessary materials), railway components and other incidental equipment from the U.K. Under the guidance of a newly invited British engineer, the construction of the works was completed in September 1880, and pig iron making was then started.

Operation of the iron works resulted in one failure after another, and the Ministry of Industry in December 1882 had to decide on its closure. Kuwabara Masa, B.E., had already pointed out the most serious defect of the state-owned Kamaishi Iron Works in his article entitled "A Report on the Situation of the Kamaishi Mines," published in the August 1882 issue of the Kōgaku Sōshi [Engineering Records], and advised the competent authorities: "An old saying goes that where the trunk is affected the branches cannot be healthy. Ore extraction and conveyance constitutes the very trunk of metal industry. . . ."

Even when a vast investment is made in one sector of industry to install the latest large blast furnaces and machinery and a railway, if the peripheral areas are underdeveloped and operations are still at the stage of primitive techniques solely dependent on manual labour, accidents may occur one after another so that it is impossible for the whole system of technology to achieve steady development. Kuwabara referred to this point, which was exactly what Takatō was most concerned and worried about in the controversy over the iron works siting.

Fukuzawa Yukichi, a distinguished advocate of enlightenment in the period of westernization fever of early Meiji years, pointed out in his Oboegaki [Memorandum] of 1875, "Japanese government officials of today, though they once contributed to the reformation of the state, are poor in knowledge from the outset," and accordingly "they treasure hired foreign experts as their henchmen, whose help they count on in defending themselves." Fukuzawa sharply criticized Meiji bureaucrats for their lack of independent spirit, if not outright servility. Thus, the post-Restoration technical activities of Takatō, who had belonged to the Nambu fief which had opposed, during the civil strife, the Satsuma and Chōshū clans, i.e. the Meiji government, were in effect a fight against those bureaucrats lacking ideas of their own. If some of the competent high officials of the Industry Ministry had had their ideas rooted in the realities of the Japanese economy and technology, instead of being blind admirers of things western, and been courageous enough to accept the views of personalities like Takatō, who had a scientific spirit and were thoughtful on technological matters, the history of modern steel-making technology in Japan might have been quite different.

Although the fatal blow to the Kamaishi Iron Works was the blocking of the gate from which molten metal was to flow, owing to the "inadequate matching" of coke and iron ore, a more basic cause of the failure was a defect in such procedures as extraction and conveyance of ore which were fundamental to iron making.

Thus the progress of not just the Kamaishi iron works but Japan's iron and steel technology from the 1890s was sought through thorough investigation into and overcoming the technical failure of the state-owned Kamaishi Iron Works.

After the closure of the state-owned works, a revival of iron making in Kamaishi was attempted by merchant Tanaka Chōbee and his family. Chōbee, whose trade name was Tetsuya [iron shop], was an army- and navy-patronized merchant of foodstuffs who had previously supplied metalware to the Satsuma fief. At the recommendation of Matsukata Masayoshi, then Minister of Finance, he began buying the machine parts used at the Kamaishi iron works, and this gave him an opportunity to try an iron-making business. After experiencing many difficulties, he eventually established the Kamaishi Mines Tanaka Iron Works in July 1887.

It was beyond the technical knowledge and capability of the people of Tanaka Iron Works, virtually none of whom had had any contact with iron making, to operate the 25-ton British-style blast furnaces (the "25-ton" refers to the quantity of pig iron daily made). Working these huge furnaces was an enormously difficult task. Procurement of charcoal, to cite but one example, was restricted by the natural conditions of Kamaishi. So they adopted a new approach of first selecting a site "convenient for procurement of firewood and charcoal," building there a small blast furnace with a daily production capacity of five to six tons like the one Takatō had built and gradually expanding the scale of operations as they became increasingly skilled.

In the meantime, an attempt was begun to refine the pig iron produced by the Kamaishi Mines Tanaka Iron Works into steel and process it into weapons and military machinery at the army's Osaka Arsenal, which was playing a pioneering role in steel-making technology. In August 1890, tests were conducted to compare bullets made from Kamaishi pig iron on a trial basis with those from Italy's Gregorini pig iron, and the test results demonstrated that Japan's pig iron was not inferior, if not quite superior, to the world-famous Gregorini pig iron. This brilliant success enabled Tanaka Iron Works to find a major customer for its product in the Osaka Arsenal and eventually to build up enough capital realistically to contemplate the revival of the large blast furnaces inherited from the Ministry of Industry and the establishment of pig iron-making technology using coke as fuel. In 1893, inviting Noro Kageyoshi, D.E. (1854-1923), then a professor of the Engineering College of the Imperial University (the present-day Faculty of Engineering of Tokyo University) and an authority on ferro-metallurgy, as adviser and one of his pupils, Komura Koroku (then a probationary engineer with the Ministry of Agriculture and Commerce, later a doctor of engineering), as chief engineer, the iron works decided to move head on towards revival of "the big blast furnaces."

The start of the first successful operation of coke-burning blast furnaces in Japan was described by Noro as follows:

> At the Kamaishi iron works, where large blast furnaces built by the defunct Ministry of Industry were remodelled to make pig iron by the use of charcoal as fuel since January 1894, charcoal has been replaced since August 1895 with coke prepared solely from dust coal supplied from Yūbari, Hokkaido, and the result has been highly satisfactory in spite of the brittleness of the coke. This experience proves the suitability of Japanese-made coke for pig iron making.

According to his account, at first charcoal was burnt in the blast furnaces and then, from August 1895, coke made from coal supplied from Yūbari, Hokkaido, was used instead, resulting in successful coke-burning blast furnace operation. In reviving these blast furnaces, Noro Kageyoshi, on the basis of his technological knowledge and views, took all conceivable steps to improve them, including reshaping their interiors, redesigning the common chimneys for the hot blast stoves and boilers to provide low chimneys exclusively for the boilers and, because insufficient roasting of iron was still anticipated, installing new roasters. By the 1880s, Japan already had technical leaders capable of critically absorbing western knowhow and adapting it to the conditions of Japanese materials from a scientific point of view. Incidentally, Noro, after graduating from the Department of Mining and Metallurgy, Faculty of Science, Tokyo Imperial University in 1882, had studied mechanical engineering and electrical engineering at London University in England, and further learned the theory and practice of iron making from Adolf Ledebur, at that time the foremost authority on ferro-metallurgy, at Bergakademie zu Freiberg in Germany.

The pig iron output of the Kamaishi Mines Tanaka Iron Works, which stood at about 8,000 tons in 1893, reached some 13,000 tons in the following year, surpassing the combined output of all kinds of iron from tatara furnaces in the Chugoku region and accounting for 65 per cent of the total iron output of the nation. In this sense 1894 can be considered the year in which the basis of modern iron making was established for the first time in this country.

Establishment and Development of State-run Yawata Steel Works

The pig iron-making technology established at the Kamaishi Mines Tanaka Iron Works and the western steel-making technology developed mainly at the army's arsenals and the navy's dockyards, both by the 1890s, when combined with the scientific knowledge and views of pioneering engineers including Noro Kageyoshi, activities of enlightened political leaders, such as Enomoto Takeaki, who emphasized the importance of industrial development, and the active demand of the Japanese in the Meiji era for iron and steel, bore fruit in the start of iron and steel making at the state-run Yawata Steel Works (the Steel Works of the Ministry of Agriculture and Commerce) in 1901. Further supported by the growing demand for iron and steel and stimulated by the Russo-Japanese War (1904-05) and creative activities by scientific-minded engineers, an integrated pig iron steel-making system was technologically established at the state-run Yawata Steel Works for the first time in Japan.

(1) Initial Technical Failures

In the integrated pig iron steel-making process, as is well known, first the iron content (Fe) of iron ore (Fe_3O_4, Fe_2O_3) is turned into pig iron by reducing/melting in a blast furnace, then the molten pig iron taken out of the blast furnace is oxidized/refined into molten steel in a steel-making furnace, such as an open hearth, a converter or an electric furnace, and most of the steel ingots resulting from the solidification of the molten steel are rolled in a rolling mill into various shapes, depending on the purpose for which the ultimate product is intended. While rolling, the final stage, is a physical or mechanical procedure primarily accomplished with a machine (roll), the pig iron and steel-making stages which precede it consist of chemical or metallurgical procedures taking place in plants (furnaces), which obviously determine the quality of the steel that is eventually made.

Blast furnace no. 1 of the state-run Yawata Steel Works, blown in in February 1901, was designed by F.W. Lührmann, a well known German blast furnace engineer, and had a capacity of 495 cubic metres, giving a nominal daily output of 160 tons. The furnace, however, proved quite unsatisfactory in operation, and the pig iron it produced was not only unsuitable in quality for steel making but also very small in quantity, only 80 tons a day on average. Moreover, the coke rate (the amount of coke consumed for making one ton of pig iron) was as great as 1.7 tons. A succession of troubles finally obliged the furnace to be suspended from operation in July 1902. The way in which its technical failures occurred closely resembled the earlier case of the state-owned Kamaishi Iron Works.

The man who was asked to revive this blast furnace and played the central role in its technological consolidation in 1904 was, again, Noro Kageyoshi, who had retired from the professorship of the Imperial University and had been giving technical guidance to a private steel-making venture. Assuming the post of adviser at the request of Nakamura Yūjiro, director-general of the iron works (a lieutenant-general of the army and subsequently president of South Manchurian Railway Co., Ltd.), Noro made a thoroughgoing scientific investigation into the failure of the blast furnace and identified these problems: (1) structural defects of the furnace itself, (2) faulty blending of the charge, (3) coagulation of the charge in the furnace and (4) repeated blast stoppages. He concluded that the faulty operation was essentially due to "the commissioning of the project from aliens who had no experience with Japanese-produced raw materials, the excessive diameter of the tuyere and its excessive projection into the furnace, the use of coke of poor quality, and inappropriate blending of the charge, inviting an excessive basicity of slag." Immediately he modified the original design as far as was feasible, and at the same time made necessary preparations, including improvement of coke, for the resumption of furnace operation, which he successfully achieved.

The endeavours to revive the blast furnace were led in the field by one of Noro's pupils, Hattori Susumu (later a doctor of engineering), who was then manager of the works' pig iron department. In an article entitled "On the Blast Furnace Operation in the Steel Works" which he contributed to the magazine Tetsu to Hagane [Iron and Steel], Hattori wrote, "The prosperity today of what was initially a failure is not the result of a natural process like fine weather after a rainstorm but that of investigation into the cause of every aspect of failure, followed by efforts to correct all the faults so identified."

It is of course unreasonable to deny the contribution of foreign experts' guidance in iron-making technology during the initial phase of the Yawata Steel Works, but to draw the conclusion that the development of iron and steel technology in Japan was solely attributable to the guidance of foreign engineers and the import of overseas technology would be as wrong as overestimation of the technical knowledge and skills of the Japanese. (Incidentally, all the German engineers and foremen, totalling 20 or so, who had been employed at the time of the inauguration of the iron works were relieved of their duties between 1902 and the end of March 1904 except one converter foreman.)

In assessing the significance of the import of European technology in the history of modern iron and steel and mining technology in Japan, we should keep well in mind the following words of Noro Kageyoshi:

> Whether or not we should wholly commission the planning and operation of a whole works from aliens deserves careful

> consideration. Foreign technology proved unsuccessful in all our mining projects including those in Sado, Ikuno, Innai, Ani and Kosaka. In particular the instances of iron making in Kamaishi and Yawata, where the initial failures were reversed by subsequent endeavours by Japanese engineers, arouse deep emotion in me.

(2) Critical Acceptance of Overseas Technology

The technological success of the state-run Yawata Steel Works was only made possible by the attempt of Japanese engineers, including Noro Kageyoshi and his pupil Hattori Susumu, to reassess critically the formalistic design of the imported blast furnace, which disregarded the peculiarities of Japanese raw materials, and the careless way in which coke was used or treated, and to reorganize these elements of pig iron-making on the basis of their technological conviction.

From 1904 on, the blast furnace of the Yawata Steel Works significantly improved in productive efficiency thanks to its reshaping, the expansion of its capacity and the development of the skills needed to operate it. In contrast to the 25-ton blast furnaces at the Kamaishi Mines Tanka Iron Works whose capacity per ton of pig iron produced was four to five cubic metres when they were revived as coke-burning blast furnaces in 1894, the corresponding capacity at Yawata in the 1910s was two to three cubic metres, and that of a 500-ton furnace (blast furnace no. 1 at Yawata's Kukioka Plant), completed and put into service in 1930 as the first large blast furnace in Japan, finally reached 1.2 cubic metres, comparable to the German standard before World War I.

In the initial phase of the state-run Yawata Steel Works, similar troubles to those in the blast furnace were also experienced and had to be overcome in the steel-making stage, especially in the open hearth sector. Imaizumi Kaichiro, another trusted pupil of Noro Kageyoshi (a classmate of Hattori) and the first steel-making manager of the works, wrote:

> The open hearth which belonged to the steel-making department, basically designed by Mr. R.M. Daelen, also had several defects.

> Moreover, its design was a mere desk plan tested nowhere else before, as I personally confirmed with Mr. Daelen in Germany in 1903. Of the most serious defects, the arrangement of the nozzle could be improved after experiment, but the elongation of the too short nozzle and installation of a slag chamber were prevented by the lack of space.

In short, "These defective designs of the vital parts of both the pig iron and steel-making sectors made work by the inexperienced personnel of those days even more difficult, so difficult that the plant could not be adequately operated for years," and the trouble was further aggravated by the poor quality of coke. Imaizumi continued:

> Few other iron works used coke of such poor quality as was initially used at the (Yawata) Steel Works. As reported by Dr. Noro, it not only gave rise to frequent troubles in the operation of the blast furnace, but also invited production of inferior pig iron with too great a content of silicon or sulphur, as well as an insufficient yield. This shortcoming, coupled with the defects in the blast furnace design, seriously obstructed pig iron and steel-making operations. This indeed was one of the major causes of the enormous pig iron and steel-making costs during the initial phase of the Steel Works.

In 1910 the state-run Yawata Steel Works earned its first profit, which owed as much to the establishment of coke technology resulting from the introduction of the Solvay-type coke oven as to the overcoming of the defects in the pig iron and steel-making equipment. Thus, as viewed from the standpoint of fuel for iron making, the development of the integrated pig iron and steel-making process was achieved in the form of increasingly effective use of gas from the coke oven and blast furnace in the steel-making and rolling stages, maximum practicable reduction of coal consumption in the gas generator, and supply of all the thermal energy needed for the whole process solely with coal charged into the coke oven.

The integration of iron- and steel-making and the rationalization of fuel economy led to the concentrated use of coal in the form of coke, and this trend, together with the shift in power source from steam to electricity which rapidly progressed in the 1910s, resulted in a sharp decrease in coal consumption per ton of steel produced at the Yawata Steel Works from four tons in or around 1920 to 1.58 tons in 1933.

Development of Private Steel Enterprises — Pursuit of Economic Rationality

Until World War I, from 80 to 90 per cent of Japan's steel output was produced by the state-run Yawata Steel Works. However, stimulated by the war, the nation's heavy and chemical industries achieved rapid growth, and in that connection private steel enterprises successively emerged in Japan and became able to meet the steel requirements of the growing industries. The Law for Promotion of Iron Manufacturing, brought into effect in 1917, facilitated the development of private steel-making ventures.

However, the production system preferred by these private steel enterprises was not the integrated pig iron and steel-making process using blast furnaces, but the open hearth steel-making process dependent on the import of cheap pig iron from India and scrap iron from America, or the scrap iron-based steel-making process. For private enterprises giving priority to a process of development in which technology and economy are well balanced, it was a logical choice. As indicated in Table 3, Indian pig iron (especially that from Tata) was not only less expensive than any Japanese pig iron but the least expensive in the world, and private Japanese steel makers found therein a way to avoid dependence on the state-run Yawata Steel Works or the blast furnace operator in Kamaishi. Nippon Kokan K.K., established in 1912 in the Tokyo-Yokohama industrial zone, was one of the typical private enterprises which pioneered the solution of the pig iron supply problem.

Massive, steady import of cheap American scrap iron and Indian pig iron satisfied the pursuit of economic rationality by the private steel makers. To compare the steel ingot production cost for integrated steel mills (those in Yawata and Kamaishi) with that for independent open hearth operators in 1931, the former's was ¥48.04 (with a 25 per

TABLE 3. International Comparison of Pig Iron Production Costs

Country	Steel works	Cost per ton (¥)
Japan	State-run Yawata Works	23.09
	Kamaishi Iron Works	27.30
	Toyo Seitetsu (in Tobata)	25.45
United Kingdom	Cleveland	23.92
	British India (Tata)	20.00
Germany	Westphalia	24.26
United States	Pittsburgh	25.31
	Chicago	29.43
China	Hang-yang	22.00

cent scrap iron mixture) in contrast to the latter's ¥40.32 (with a pig iron/scrap iron ration of 0.35 to 0.65), both per ton. The difference was primarily due to the per ton cost gap between ¥32.72 for the former's hot pig iron and ¥27.60 for the latter's cold pig iron.

Table 4, in which the financial positions of major Japanese steel companies in the first half of fiscal 1933 (April 1933-March 1934) are compared, reveals that open hearth steel makers including Nippon Kokan were far better off than the integrated steelmakers belonging to the zaibatsu groups of Mitsubishi and Mitsui. It deserves particular note that private enterprises had come to account for a greater share in Japan's total crude steel output than state-run mills by the early 1930s.

TABLE 4. Financial Data of Major Iron and Steel Companies in the First Half of Fiscal Year 1933

	Company	Total capital used			Revenue (¥)	Expenditure (¥)	Net profit (¥)	Total capital/ profit ratio (%)
		Owned capital (¥)	Borrowed capital (¥)	Total (¥)				
A	Mitsubishi Iron Co.	27,487	13,511	40,998	5,014	4,153	861	2.1
	Kamaishi Mine Co.	19,371	17,867	37,238	6,847	5,751	1,096	2.9
	Wanishi Iron Works	18,431	7,824	26,255	3,832	3,709	123	0.5
B	Nippon Kokan K.K.	15,542	17,158	32,700	16,463	13,321	3,142	9.6
	Asano Kokura Steel Co.	3,602	3,765	7,367	8,096	7,830	266	3.6

Note: Group A, integrated steel manufacturers; Group B, independent open hearth operators.

However, this was the time when dark clouds of autarky were thickening over the world horizon. The predominant dependence on open hearth steel making, first of all, would lose its very basis once the economic advantage of cheap Indian pig iron and American scrap iron ceased to exist. Secondly, apart from the US where machine civilization centring on the automotive industry was highly developed with a resultant large output of scrap iron, mass production of ordinary steel with open hearths, which were originally intended for production of superior steel, without having any converter which could dispense with scrap iron, was by no means an orthodox practice in the environment in which European steel makers found themselves.

Dissolution of these contradictions had to be carried over until after World War II.

IV. THE AGE OF SCIENTIFIC TECHNOLOGY

— Independence of Japanese Iron and Steel Technology

Along with the technological developments in the state-run Yawata Steel Works and private steel-making ventures, and the parallel progress of integrated steel-making and open hearth-electric furnace technologies, the Japanese iron and steel industry completely shifted from a mining to a manufacturing pattern. And on the basis of its achievements, there emerged opportunities for interactions of theory and practice of iron and steel making, leading to the start of basic research on iron and steel, and further on metal in general. In this context, the history of iron and steel in Japan can be regarded as having entered the age of scientific technology in the 1910s.

Establishment of the Iron and Steel Institute and Subsequent Developments — Progress of Research and Development

In February 1915, the Iron and Steel Institute of Japan was founded as an academic body specializing in research on iron and steel at the initiative of Noro Kageyoshi, Imaizumi Kaichirō, Tawara Kuniichi and others with a view to "studying and investigating scientific, economic and all other problems concerning iron and steel and thereby contributing to the improvement and development of iron and steel undertakings in Japan," and in the meantime Noro was named its first president. This institute of ferro-metallurgists was modelled after Verein deutscher Eisenhüttenleute of Germany, where its organizers had studied, and advocated "combination of theory and practice." The establishment of the Iron and Steel Institute of Japan, as I see it, marked an epoch in which Japanese iron and steel technology and industry emerged from their decades of imitation and transplantation and were able to establish a truly rational and scientific spirit in the Japanese soil. This mutual approach of theory and practice in iron and steel technology was made even more irreversible by the advent of Dr. Honda Kōtarō (1870-1954).

Moving ahead from such basic research attempts as physical study on highly magnetic objects and physico-metallurgical study on alloys, Honda invented a highly magnetic steel (known as KS steel) in 1917, created a unique system of iron and steel science with the help of metallographic research pioneered by Tawara Kuniichi, D.E. (1872-1958), and inaugurated the Research Institute for Iron and Steel (renamed in 1922 the Research Institute for Iron, Steel and Other Metals) at Tōhoku Imperial University in 1919. In an article entitled "The Progress of Iron and Steel Science in Japan," which he contributed to the Tetsu to Hagane [Iron and Steel] magazine in 1935, Honda wrote, "The recent progress of iron and steel science in this country is so remarkable that research papers published here are not inferior either in number or in quality, and even superior in some respects, to those presented in the advanced countries of the West," and recollected the past process of development in the following words:

> To look back, I think it was some time between the late Meiji era and the early Taishō years (the 1900s-1910s) that studies in iron and steel science were finally started in Japan. Although iron-making ventures had been undertaken and ferro-metallurgy studied at a number of universities before that, the studies were mainly concerned with what had a direct bearing on iron and steel making, and those on the material aspect of iron and steel, i.e., metallographical studies, were very few. By that time, iron and steel science had already firmly established itself in the advanced nations of the West, and significant research achievements had steadily been made in this field. Research in iron and steel science in Japan, which rather belatedly started at that time, was at first barely able to follow the achievements of advanced countries, but it began fast development around the period of the World War, and thereafter has made steady progress, finally reaching the level at which it stands today. This progress has taken place in a brief 20-odd years, and this amazing development is a matter for the sincere congratulation of our nation. Bodies engaged in these research efforts include the metallurgical departments of national and other public universities, the Research Institute for Iron, Steel and Other Metals, the Institute of Physical and Chemical Research, and research departments of the

> army's arsenals and the navy's dockyards, Yawata Steel Works and private steel companies. Many research papers are published every year in Tetsu to Hagane, Kinzoku no Kenkyū [Research on Metals], Suiyōkai-shi [Journal of the Wednesday Party] and technical reports of private companies.

Of these research organs, the one which played a truly pioneering role as a central body of iron and steel study endeavours was the Tōhoku University's Research Institute for Iron and Steel led by Honda, which in 1922 was reorganized and expanded into the Research Institute for Iron, Steel and Other Metals as it is known today.

Honda Kōtaro made extensively known the fruits of research by this institute through his Tetsu oyobi Hagane no Kenkyū [Studies on Iron and Steel, in four volumes, 1919-26], and further actively published them in technical journals overseas with a view to the international exchange of scientific findings. His inquiries into the true nature of iron and steel by the full use of (1) chemical analyses, (2) magnetic analyses, (3) microscopic observations and (4) X-ray analyses, and his successive inventions of new alloys, in which Japan can rightly take pride, mainly at the Research Institute for Iron, Steel and Other Metals, deserve the utmost appreciation in the history of science and technology in Japan. Among these inventions, particularly well known are Honda and Takagi Hiroshi's KS magnet steel (1929), Katō Yogorō and Takei Takeshi's oxidized metal magnet or OP magnet (1930), Honda, Masumoto and Shirakawa Yūki's new KS magnet steel (1932).

Among them, new KS steel was a precipitation-hardened magnet (an alloy of iron, cobalt, nickel, aluminum and titanium) created by Honda and his associates at Tōhoku University in prompt response to the invention by Mishima Tokushichi, D.E. (1893-1975), of MK magnet, an alloy of iron, nickel and aluminium, in Tokyo in 1931, and was twice as strong as the original KS steel in magnetism.

Accumulation of Technical Knowledge and Experience between Two World Wars

It would be no exaggeration to say that iron and steel technology in

Japan was enabled to proceed from the stage of manufacturing technology to that of scientific technology by the scientific achievements of Honda and the Research Institute for Iron, Steel and Other Metals which he led.

Japan had to wait until after World War II for that scientific technology really to bear industrial fruit. And along with the achievements of Honda and his associates, the many different attempts to develop original techniques also contributed to solidifying the basis for the development of iron and steel technology in postwar Japan. There are various examples of these attempts.

First, there was the invention of the low-grade ore magnetic roasting process under the leadership of Umene Tsunesaburō (1884-1956). The work started in 1920 at the Anshan Iron Works of South Manchurian Railway Co., Ltd., and was completed and patented in 1922. The invention paved the way for iron ore pretreatment techniques, which, together with the thoroughgoing heat control and conveyance control procedures of the Anshan Iron Works (later renamed the Showa Steel Works), were used after World War II in the Chiba Works of Kawasaki Steel Corporation, planned and built as the first postwar integrated pig iron steel mill.

A second example is the invention by Kuroda Taizō (1883-1961) of the Kuroda coke oven (a unique byproduct-recovering-type coke oven having a regenerative combustion device), which was recognized as the creation of a basic formula for the production and transfer of heat, overcoming all the complex problems of thermal engineering with a view to "producing the maximum quantity of steel with the minimum quantity of coal." After its invention in 1918, it served as the prototype for many subsequent byproduct-recovering-type coke ovens used in not only the Yawata Steel Works but all other integrated steel mills and gas/coke plants.

Thirdly, blast furnaces of much greater capacity were built, the first of which had a daily production capacity of 500 tons, planned and constructed in 1930 on the initiative of Yamaoka Takeshi, an engineer at the Yawata Steel Works, at its Kukioka Plant. It not only had a major significance in the history of the domestic production of iron-making equipment, but also set a precedent for the 1,000 ton (1,000 cubic metre) blast furnaces emerging from 1937 on, which in those days were among the biggest in the world.

The fourth is the Japanese version of the Thomas steel-making method which began to be used in 1938 at the Kawasaki Works of Nippon Kokan K.K. It may be reasonable to consider that, with the introduction and successful use of this production process, devised by Imaizumi Kaichirō, the basis of today's blast furnace-converter-rolling mill sequence of integrated steel production was laid before World War II.

Fifth, effective use of domestic resources was developed. Worthy of particular note among the attempts in this area was the development at the Wanishi (Muroran) Iron Works of the so-called coalite process to produce coke for blast furnace use from domestically available coal alone, resulting in a blast furnace operation solely using sintered ore originating in Hokkaido. It can be regarded as heralding the postwar achievements in pretreatment of raw materials and resources-saving techniques.

The sixth is the construction of a littoral plant for integrated pig iron-steel production, the Hirohata Works of Japan Iron and Steel Co., Ltd., whose no. 1 blast furnace was blown in in 1939. Only two and a half years were needed to start operating this 1,000 cubic metre blast furnace from the time the plan was formulated for the works, whose target for annual steel output was set at 400,000 tons. It is well known that, in the days of the Allied occupation after World War II, only this Hirohata Works among many steel mills in Japan was evaluated as "excellent" by experts from the US, then leading the world in iron and steel technology.

Seventh and finally, Japan's first strip mills were introduced. First in 1940, a cold strip mill began operation at the Tobata Plant of the

Yawata Steel Works, followed by a hot strip mill in 1941 at the same plant and a continuous plate mill in 1942 at the Hirohata Works. All these of course were imports from the US, but what deserves appreciation is the pioneering spirit of these steelmakers daring to try the new techniques.

Apart from these successful attempts at technological development, the Japan Society for Promotion of Science set up, as joint research bodies, steel-making and pig iron-making research committees in 1934 and 1943, respectively, starting activities with Dr. Tawara Kuniichi (then professor emeritus of Tokyo University) as chairman. These committees are worthy of particular note in that they provided metallurgical engineers and experts in basic physics or chemistry with opportunities for joint research through exchange of knowledge and views, which were rather hard to find elsewhere in the academic climate of Japan in those days. Today's orientation of integrated research by engineers and scientists, above all on the application of scientific instrumentation techniques to the iron- and steel-making process to achieve automatic control of pig iron and steel-making equipment, finds its origin in the activities of the JSPC's joint research committees.

Development of Integrated Steel Mills in Littoral Sites

The development of iron and steel technology in Japan after World War II, as is well known, derived its motive force from the importation of foreign techniques following the three-phased policy to rationalize production facilities adopted in 1951. As a result, the Japanese iron and steel industry has come to be ranked third in annual crude steel output (reaching its peak of some 120 million tons in 1973) and first in steel export in the world.

However, to find the reason that the Japanese iron and steel industry, in spite of its nearly fatal destruction during the Pacific War, has been able to achieve its present position in the world, at least these points should be understood: First, the Japanese had already had more than a century of experience and achievements in modern iron-making since the late Edo period, and had been capable of working together to find their own way ahead on the basis of these achievements; second, they have sensibly responded to the postwar changes in international economic environment, positively sought both domestic and international technological exchanges and made correct choices in importing techniques from abroad; third, the disappearance of military demand resulting from the defeat in the war enabled the iron and steel industry of postwar Japan to return to its intrinsic role of supplying basic materials to peace industries contributing to raising people's standards of living; and fourth, in the process of the industrial restructuring of Japan to give dominant roles to heavy and chemical industries, industrial machinery manufacturing which had failed to attain independence before the war succeeded in establishing its foundation. The overall technology of steel-related sectors achieved remarkable progress, leading to the formation of an industrial/technological environment in which "iron necessitates another supply of iron" and "one innovation leads to another."

(1) Steelmaking Technology Committee — Progress of Autonomous Joint Research and Development Efforts and Technological Exchanges

What is considered today the most effective measure taken in the initial stage of the postwar reconstruction of Japan's iron and steel industry was the so-called priority production system implemented at the initiative of the Economic Stabilization Board from December 1946 on. Its rationale was to facilitate the industrial reconstruction of Japan by giving priority to promoting the production of steel and coal and thereby creating a snowballing effect on overall industrial recovery.

Apart from this, as far as iron and steel technology is concerned, I would rate highly the contribution of the interdisciplinary activities — in which experts from the government, private industry and academic circles all worked together — of a research body organized soon after the end of the war primarily by the Iron and Steel Institute of Japan (headed by Mishima Tokushichi, D.E. as president), with Yukawa Masao (later vice-president of Yawata Iron and Steel) as chairman, which resembled the prewar joint research committees of the Japan Society for Promotion of Science. Known as the Steelmaking Technology Committee, the body advocated as early as October 1946 what it considered the proper orientation of postwar iron and steel technology, saying, "The integrated pig iron-steel process is the most rational and effective system of steel production, permitting the most efficient use of natural resources."

Based on this fundamental principle, the committee also proposed (1) steps to improve iron- and steel-making techniques including thorough sizing of raw materials to be charged into blast furnaces, increased use of sintered ore, rational blending of coking coal and research on the production of high-grade coke from semi-caking coal, (2) scientific rationalization of operations, technological exchange and promotion of inventions, (3) effective use of high-grade steel to help reduce the consumption of steel, research on and improvement of steel quality and shaping, and greater use of welding and heat treatment, (4) mechanization of work, thorough operation and thermal control, and improved repair and maintenance of machinery, and (5) coordination and strengthening of steel-making research activities.

The proposals by the Steelmaking Technology Committee in the meantime led to the joint organization of the Iron- and Steel-making Technology Study Committee by the Ministry of International Trade and Industry, Iron and Steel Institute of Japan, Japan Institute of Metals and the iron and steel industry, paving the ground for technological development in the right direction, which featured above all joint experimentation and research on the oxygen steel-making process and joint purchase of patents on the oxygen top-blown converter, commonly known as the LD converter. These developments, together with international technological exchanges which began with the sending of a fact-finding mission by the ISIJ in 1950 to inspect the situation of iron and steel technology in the US, served to prepare the necessary conditions for the iron and steel technology of postwar Japan to bear fruit in the integrated steel mills sited in littoral areas.

(2) Technological Responses to Economic Environment

The technological innovation in the iron and steel industry of postwar Japan, in simple words, was characterized by the clever combination of the integrated steel production system — featuring the use of larger blast furnaces, extensive introduction of LD converters, active application of the continuous casting method and achievement of automatic, continuous and faster rolling — with scientific and rational systems of raw material transport and product distribution in the form of up-to-date littoral steel mills. The most significant factor in the innovation of iron and steel technology was the introduction of oxygen top-blown converters, commonly known as LD converters.

The LD converter was installed for the first time in Japan at the Kukioka Plant of Yawata Iron and Steel in September 1957, and the first large-capacity blast furnace, by postwar standards, was built in 1959 at the Tobata Area Works of the same company. In those days, scrap iron in Japan was in short supply as well as more expensive than in the rest of the world, and the prewar practice of open hearth steel making (scrap iron-based steel making) by the use of inexpensive American scrap iron and Indian pig iron imported in large quantities had almost completely lost its advantage. Accordingly it was economically indispensable to depend primarily on the blast furnace-based production system for the ample and steady supply of inexpensive pig iron.

Fortunately for the Japanese iron and steel industry, it so happened that LD converters, superior in productive efficiency, had begun to be used on an industrial scale by that time in Austria, where scrap iron was also relatively scarce. LD converters well matched the economy of larger-capacity blast furnaces.

Iron and steel production technology in postwar Japan, adapting itself to the international economic environment, was thus characteristically developed, in spite of the lack of domestically available natural resources, by pursuing economies of scale, reducing the cost per output unit and thereby strengthening the international competitiveness of her iron and steel industry.

In 1951, when the Japanese iron and steel industry launched a round of modernization programmes, the Korean War, which had broken out the year before, strongly stimulated the Japanese demand for steel for use in construction, shipbuilding and the manufacture of electrical products and automobiles. Based on the experience they had built up in independent development of new techniques, Japanese iron and steel manufacturers availed themselves of imported technology and were thereby enabled to engage in an all-out pursuit of economies of scale.

The industry's first rationalization programme (1951-55) mainly emphasized the modernization of rolling mills, and above all the installation of new hot and cold strip mills. In this period, Kawasaki Steel Corporation (separated from Kawasaki Dockyard Co., Ltd. and independently incorporated in 1950) which, led by Nishiyama Yatarō (1893-1966) with an engineering background, had planned integrated pig iron-steel production since prewar days, built in Chiba City an integrated steel works with strip mills, and this first postwar integrated steel works began operation in 1953.

Under the second rationalization programme (1956-60), overall modernization of production facilities was attempted, featuring the construction of larger-capacity blast furnaces and LD converters. It was in this period that the Tobata Area Works of Yawata Iron and Steel and the Wakayama Works of Sumitomo Metal Industries, Ltd. were inaugurated. Cooperation was made in the development of mines abroad, and rationalization of transport was actively promoted, taking advantage of Japan's natural features and achievements in civil engineering and naval architecture, for example by the use of large ore carriers and improved port facilities, so that raw materials could be efficiently carried from increasingly distant supply sources.

The completion in this period of the mass production system based on the sequence from pig iron making with a large blast furnace to steel making with a converter and further to massive rolling of a few kinds of steel products at the Tobata Area Works of Yawata Iron and Steel marked the end of the historic role of the same company's Yawata Area Works which, initially known as the state-run Yawata Works, had produced many different kinds of steel since 1901. The Tobata Area Works, dubbed "the steel mill built on the sea," set a typical pattern for many subsequent integrated steel works built in littoral sites.

The third programme (1961-65) featured the construction of integrated steel works in new sites along with the strengthening of existing ones. The Nagoya, Sakai, Kimitsu and Ōita Works of present-day Nippon Steel Corporation, Fukuyama Works of Nippon Kokan, Mizushima Works of Kawasaki Steel, Kashima Works of Sumitomo Metal and Kakogawa Works of Kobe Steel, Ltd. were either begun to be built or planned in this period. Every one of these new steel mills constituted the core of a littoral industrial zone and was accompanied by a regional development and industrial complex project.

It was in this period that Japan's industrial machinery industry established its technological foundation and became able to supply steelmakers with sophisticated rolling mills, including strip mills which were considered most difficult to manufacture, meeting the highest international standards. This achievement meant that the ground was now paved for subsequent technological cooperation in the field of iron and steel making, jointly undertaken by steel manufacturers and plant builders.

In the second half of the 1960s, Japanese steel companies continued to invest in expansion of their facilities, where operations were increased in terms of both dimension and continuity and further computer-controlled, and there emerged littoral steel mills with annual crude steel outputs of around ten million tons each. The opening of the world's first integrated steel works based on a wholly continuous casting system with no blooming mill (Nippon Steel's Ōita Works) was a major landmark in the history of technology from all points of view, including that of energy saving. One of the most notable aspects of the postwar development of iron and steel technology in Japan was that it resulted from the close link established for the first time between iron and steel technology and the process of the shift of emphasis in the nation's economic structure to heavy and chemical industries, which was characterized on the one hand by the development of industrial machinery, chemical and civil engineering-construction industries and, on the other, by the progress of theoretical studies in natural sciences and engineering.

From Import to Autonomous Development of Techniques — LD converters and OG system

It is pointed out in Tekkō Gijutsu-ron (1968), a posthumous collection of treatises on iron and steel technology by Sasabe Takao, D.E., who left many enlightened writings contributing to the autonomous development of iron and steel technology in Japan, that the remarkable technological innovations in use in present-day Japan were imported from overseas in a brief period following the first rationalization programme, and it is further warned that the dependence on imported technology often proved a major obstacle to autonomous technical developments. He wrote:

> The principal part of pig iron-making technology was imported from the US and West Germany, the oxygen top-blown converter knowhow from Austria, and the heavy oil-burning steel-making system from the US. The introduction of strip mills in the rolling stage was not just a matter of purchasing whole sets of rolling equipment from the US, but an all-embracing package of technology import covering guidance on the techniques of making steel to be rolled with the strip mill, supply of drawings and operating knowhow, supervision by foreign engineers and training of Japanese technicians as well. Major steel companies individually imported strip mills in succession under more or less similar arrangements.

The reality was exactly as Sasabe pointed out, and the reliance on imported technology was the most effective way for the Japanese iron and steel industry quickly to fill its wartime lag. However, he added:

> The development of the oxygen top-blown converter process to its present level, in a long-range perspective, is the cumulative result of invaluable creative activities by such distinguished individuals as the chemist who discovered oxygen, metallurgist Robert Durrer who invented the LD converter, physicist P.L. Kapitsa and so on. What should not be overlooked here is that none of these achievements could have been completed without the collaboration of many people, and that all were based on the scientific and technological knowledge and experience built up by many people from generation to generation. This aspect is important to autonomous technological development. Durrer started his study in 1932, but the industrial production of LD converters was not begun until 1953. Japan bought his achievement and is now actively making steel on that basis. Given the high technical standards of her engineers and workers, Japan can readily import new techniques from abroad if she can afford to. However brilliant it may appear, this kind of technological development, in its true nature, consists of buying things with money. It is more a commercially-oriented technological development and as such impedes the autonomous development of technology.

The fruit of one's own research and development endeavours is one thing, and that of another's bought with money is another. There is an essential difference between them in the underlying meaning even though they appear the same. A creative spirit can be fostered through autonomous cooperation, but can never be bought with money. This is exactly the point Sasabe wanted to stress.

Thus he very aptly maintained that "Although it is obviously necessary directly to encourage research in science and technology, such research cannot be appropriately oriented, considering the peculiar circumstances of Japan, unless even greater emphasis is placed on studies from the viewpoint of social sciences," and he proposed that the autonomous development of technology would require the establishment of a powerful setup for joint economic research by social scientists, natural scientists, engineers and workers. In fact, the lack of such a social and economic background and of efforts to create a favourable environment for interdisiplinary studies is one of Japan's major shortcomings carried over from prewar days.

However, it is no less true that, while fighting against impediments to the autonomous development of technology, leading personalities of the iron and steel technology of postwar Japan have responded in practical ways to changes in economic environment, have actively created new techniques of their own based on imported ones, and have thereby strengthened the competitiveness of their industry in the world market. I would like to elaborate a little more on this fact, referring to the specific example of "the development of the OG system from LD converters."

The technical leader in this development was named Yukawa Masao (1903-69). As if faithfully following the policy advocated in the report of the aforementioned Steelmaking Technology Committee at his own initiative as its chairman, Yukawa materialized the concept of "integrated steel mills built on the sea," first in the Tobata Area Works of Yawata Iron and Steel, with a mass production sequence of Pretreatment of iron ore → large blast furnace → LD converter → continuous casting → computer-controlled high-speed precision roll → heat treatment or surface treatment as required. At the same time he had the old Yawata Works specialize in production of higher-grade steel, completed Usinas Siderurgicas de Minas Gerais (commonly known as the USIMINAS steel works) in Brazil, which is generally considered the starting point of overseas technical cooperation by Japan, and at the end of his life as engineer and business manager made arrangements for the first International Conference on Iron and Steel Science and Technology held in Japan.

An old friend of Yukawa, Dr. Hermann Schenck, who is one of the foremost authorities on ferro-metallurgy in the contemporary world and previously was president of Verein deutscher Eisenhüttenleute, admired the Japanese steel industrialist as "a great man standing out in the history of modern iron-making technology" and said his achievements were known to steel industry experts in every country.

Yukawa was one of the positive advocates of technology import from the West after World War II. At the same time, however, he had a firm faith in the creativity of the Japanese to develop new techniques, organized and trained younger engineers, and thereby built the foundation on which Japan's iron and steel technology could contribute to many other nations of the world.

Let us briefly look back on the history of the Tobata Area Works, the starting point of integrated steel manufacturing in littoral sites in postwar Japan.

By August 1956, when the second rationalization programme for the iron and steel industry was mapped out, the Yawata Works was over half a century old. Its layout had been spoilt by the successive construction of additional shops, and its production lines complicated to affect the efficiency of its operation and the quality control of its products, making its management keenly realize the need for "better ventilation." In other words, the works needed a drastic surgery.

As chief engineer and administration manager of Yawata Iron and Steel, Yukawa formulated a master plan under which the role of the Yawata Works would be altered to the production of more profitable higher-grade steels by gradually removing the blast furnace sector and improving as well as strengthening its plate shop, silicon-sheet shop and rail shop. At the same time more efficient mass production of a few kinds of goods in an integrated system starting from blast furnaces would be concentrated in the Tobata Area Works, located in a more spacious site, with a view to "consolidation from the iron-supply source on." For the production of higher-grade items, improvement in product quality was attempted from the early 1950s through technology imports: Yawata entered into a long-term technical licence agreement with Armco Steel Corporation of the US concerning (1) galvanizing of hoops, (2) manufacturing of hot-rolled silicon steel sheets, (3) rolling of sheets with strip mills and (4) production of "Dur paint" (bonderized) steel; an arrangement with Heinzmann of Germany for (5) production of mining U-beams, and another with the American Can Company for (6) electric tinning of steel sheets.

The layout of the new works at the Tobata site, where the presence of strip mills since before the war had also to be taken into account, was determined in order to achieve the following three main targets with the overall objectives of increasing the output and materializing new technology:

1. Highly efficient operation should be sought to attain the greatest possible scale of production;
2. The flow of raw materials and products should be accelerated, and
3. The variety of products should be minimized.

In this general framework was launched the project to build a new steel works with an ultimate annual capacity to produce 2.5 million tons of crude steel, basically consisting of (1) two 1,500 ton blast furnaces, (2) three 60 ton oxygen converters, (3) a blooming and slabbing mill, (4) an 80 inch semi-continuous hot strip mill, (5) an 80 inch reversing mill for cold rolling of hoops and (6) equipment for galvanizing, tinning and bonderizing.

Noteworthy among them are the 1,500 ton blast furnaces, far greater than the biggest prewar furnaces, and the continuous cold rolling mill ((5) above), which was planned for self-sufficiency in the supply of wide cold-rolled sheets for passenger cars, previously imported from the US, in anticipation of increased automobile production in the future. More so is the use of 60 ton oxygen top-blown converters (LD converters) to match the huge blast furnaces.

The LD converters, which had attained their first industrial success in Austria after World War II, drew the interest of Nippon Kokan (NKK), having a technical tradition in the use of Thomas converters, before any other Japanese steel company. Stimulated by an article published in the West Germany magazine Stahl und Eisen late in 1950, NKK began its study on the new converter, sent a fact-finding mission to Europe and in 1952 started experiments in secret. A little later, younger engineers at Yawata also read a 1952 issue of The Journal of the Iron and Steel Institute of the UK specially featuring the new converter, and began enthusiastically to think of uses for it. The man who promptly responded to their enthusiasm was Yawata's chief engineer Yukawa Masao, who, as a lifetime member of the Iron and Steel Institute (of the UK), had been constantly sensitive to technical information from overseas since the days of his study in Europe around the 1930s. In the spring of 1953, at his instruction, the previous one-ton experimental furnace was replaced with a five-ton test converter permitting both horizontal and upward blowing. Well advanced in his study on the oxygen generator and other related equipment, Yawata forestalled NKK in the converter development project. Before starting the tests, chief engineer Yukawa did not forget to order development of dolomite bricks for converters, indispensable for further advancement of the bessemerizing process.

As soon as the test results and survey findings gave reasonable prospects for the future of the LD converter process, Yawata sent to Europe its steelmaking manager Takeda Kizō, who in May 1955 started negotiations with BOT, the special corporation controlling the rights to the LD converter process. However, as it soon turned out that NKK had begun to contact BOT at about the same time, Yawata proposed to name NKK as the sole representative of the Japanese iron and steel industry in these negotiations, and took the initiative in organizing the Japan BOT Group LD Committee. A gentlemen's agreement was made to relicense subsequent participants equally to practise the LD converter techniques, thereby providing opportunities for the exchange of information and views among the engineering staffs of major steel companies. This circumstance can be interpreted as meaning that the LD converter techniques, which would prove one of the major triggers to the postwar technological innovation in Japan, were "autonomously" imported after scrupulous preparations on the part of the importers.

Main components of the converter were ordered from Demag and other European manufacturers, and steelmaking engineers were successively sent to Europe for negotiations or training in the operation of the converter during the progress of its construction. Unfortunately, in October 1956, the Suez Crisis broke out, closely following the insurrection in Hungary, and the delivery of the converter ordered from Europe became certain to be delayed. Yukawa decided that Japanese technology should be relied on to prevent the delay, and immediately ordered a substitute converter from Ishikawajima Heavy Industries Co., Ltd. The imported converter from Demag was eventually used as the second unit.

Thus in January 1957 Japan's first oxygen top-blown converter went into operation exactly as planned. Notably, in contrast to the ordinary bearings used in the movable parts in the European design, roller bearings made of bearing steel were adopted in the Japanese-built converter to reduce the motive force requirement, as they had proved superior when used in Yawata's test converter.

Now, one renovation led to another, and this imported technology provided the basis for a subsequent technical development which became known across the world, a system to recover and treat waste gas generated from the oxygen converter in the process of steel refining, and thereby utilize the otherwise wasted energy and at the same time completely prevent air pollution. Known as the basic oxygen furnace waste gas cooling and clearing system (OG system), it was conceived by electrical eningeer Akita Takeo, who was in charge of the construction of the power system. However, a basic patent on this mechanism had already been acquired by a boiler manufacturer named Yokoyama Industries Co. (later abosrbed by Kawasaki Heavy Industries, Ltd.). Then Yukawa and his colleagues, in the summer of 1955, decided to collaborate with Yokoyama Industries. They organized a joint committee to develop the OG system, to which Aihara Masumi and other steelmaking engineers were assigned on a full-time basis. In a paper entitled "The Curriculum Vitae of a Technique — the OG System," the circumstances of the development of the system are described.

The committee, using a two-ton test furnace, made a thorough study on the conceptual design, safety and economy of the OG system. Carbon monoxide requires particular precaution against explosion and poisoning. These precautionary arrangements were estimated to cost about as much as the furnace itself. The overall construction cost would run up to well over ¥2,000 million, it was estimated. So when Yukawa and his colleagues gave a prompt OK, chairman Aihara himself wondered if he had been dreaming.

The work on final technical details needed for implementation of the plan was delegated to the subcommittee for OG system implementation headed by Maebara Shigeru, chief of the converter subsection. The subcommittee consisted of about 60 men at shop subsection chief and foreman levels, coming from Yawata, Yokoyama and Fuji Electric Co., Ltd. They busied themselves with various tests in the shop all day long, and continued their discussions until late at night, drinking glasses of sake in a nearby inn. Experts in different fields from different companies thus brought together their knowledge, experience and wisdom.

The subcommittee developed in quick succession an automatic gas analyzer, various instruments and safety devices, and moreover an automation system based on the same idea as the present-day mini-computer control. Further it compiled "The Test Run Handbook," consisting of three telephone book-sized volumes, which even today is valued as the bible of converter operation. An elaborate manual was needed because even a small error could prove fatal.

In view of the progress of the research, Yukawa in December 1960 proposed to the meeting of executive directors (and they agreed) to apply the OG system to the second converter shop (with a 130 ton converter) at Tobata, then the biggest in Japan, and so doing he amazed the engineers who still saw many difficulties ahead. The shop started operation of the new system in March 1962 and, keeping pace with the new no. 3 blast furnace (1,947 cubic metres) of the same works, was thereafter able to increase tremendously its output, thereby marking successful completion of the mass production system at the Tobata Area Works.

The OG system was one of the epochal inventions in the history of technology in postwar Japan, along with the Esaki diode (1957) and Sony magnet diode (1968). Because of its relatively low equipment cost and efficiency in waste gas recovery, contributing to the prevention of pollution, the OG system was successfully used, after its introduction at Tobata, by many other Japanese steel companies including Sumitomo Metal and Osaka Steel. It also attracted successive inquiries from foreign steel makers including Armco Steel and US Steel, both of the US, and the Steel Company of Wales of the UK, and eventually became a major technology export item. Today the OG system contributes much to the nation's balance of payments in steel technology trade.

For the Benefit of Future Technology

— Steel Technology matching natural features of the country, even though on a small scale

Two economists at Middle Tennessee State University in the United States, Hans Mueller and Kiyoshi Kawahito, wrote a laborious work on Steel Industry Economics (1978) at the request of the Japan Iron and Steel Exporters' Association. It is regarded as a virtual refutation of the white paper of the American Iron and Steel Institute which, published in May 1977, blamed Japanese steel makers for alleged dumping practices, and what attracts my particular interest in this work are the data comparing the steel production capacities of the US, Japan and the European Economic Community over the last two decades, quoted here as Table 5. The earlier date selected for comparison, 1956, was the year in which the Japanese iron and steel industry launched its second rationalization programme featuring the construction of integrated steel mills in littoral sites. Over the following 20 years, Japan's production capacity increased by 137 million net tons, but that of the US grew by only 40 million net tons in spite of far greater investments made during those decades than in Japan. The difference is attributable to the circumstance that, in contrast to the expansion of Japan's capacity which primarily took place in green fields, America's was achieved by remodelling or rebuilding existing steel works.

In the EEC (six countries), the steel production capacity was increased

TABLE 5. Investments in Steel Making Facilities and Their Production Facilities in US, Japan and the EEC

	Production capacity in 1956 (in thousand net tons)	Production capacity in 1976 (in thousand net tons)	Difference between 1956 and 1976 (in thousand net tons)	(%)	Investments in facilities between 1957 and 1976 (in millions of dollars)
US	119,000	159,000	40,000	34	34,800
Japan	14,000	151,000	137,000	979	26,900
EEC	59,000	167,000	108,000	180	29,700

Source: H. Mueller, K. Kawahito, Steel Industry Economics, 1978.

Note: EEC includes only its first six member-nations.

during the same decades by 108 million tons, a much smaller increase than in Japan in spite of the somewhat greater investments in facilities, to which outlays in green fields again accounted for a relatively small proportion. Thus the steel industry of Japan achieved far greater economies of scale than those of the US and the EEC.

In 1901, US Steel, the biggest steel trust in history, was inaugurated in the US with a capital stock of $1,400 million and an annual production capacity of 10,600,000 metric tons, and it was in the same year that the state-run Yawata Steel Works was born as the first integrated steel mill in the Orient with a very modest production target of 90,000 tons a year. The Yawata Works, together with its subsequent extension Tobata Works, has now developed into a huge mill yearly turning out some eight million tons of crude steel. However, it is far less efficient than the Kimitsu Works which is the new champion steel mill of the 1970s, and the former's per capita productivity is only a quarter to two-fifths of the latter's. These figures vividly indicate how unfavourable it is to rely on an older mill in pursuing mass production in greater dimensions.

In its all-out pursuit of economies of scale, Japan's steel industry in 1964 surpassed West Germany's in crude steel output, which in 1973 registered an all-time record of 119,320,000 tons. In the same year, the apparent per capita steel consumption in Japan reached an amazing level of 802 kilogrammes.

TABLE 6. Productivities of New and Old Steel Works

Works	Crude steel output in 1973 (thousand tons)	Number of employees	Per capita productivity (tons)
Kimitsu (new)	9,023	5,206 (those of Nippon Steel Corp. alone)	1,733.2
		13,343 (including those of related companies)	676.2
Yawata (old)	8,361	19,627 (those of Nippon Steel Corp. alone)	426.0
		30,557 (including those of related companies)	273.6

However, the oil crisis which was triggered in the autumn of 1973 by the Yom Kippur War gave an unprecedented opportunity to give a second thought to the philosophy underlying Japanese technology, which, taking advantage of rapid economic growth, had sought renovation after renovation and polluted the environment everywhere. I have summed up the lessons of the oil panic in this way:

1. We should make more sparing use of the finite natural resources of our irreplaceable planet. To make it possible, technology from now on should be more thoroughgoing in its pursuit of savings in materials, energy and labour and recycling of resources.
2. We should better understand the rationale of nationalistic policies in order to conserve natural resources, and think how genuine exchange can be achieved between developing nations which are rich in natural resources and advanced industrial nations which are not. Japanese technology in the future world should be so oriented as to be helpful to the solution of North-South problems in the spirit of "self-reliance."
3. In general, we should revive dialogues between things (nature) and man. It must be in the pursuit of a technological idea which can co-exist with nature that man is able to create genuine technology without risking his existence as a human being.

After the oil crisis, the world economy has undergone a sweeping change.

The Japanese steel industry, suffering from a recession largely owing to the appreciation of the yen, has a huge production capacity of about 150 million tons per annum, but is obliged by the drop in demand (particularly in the civil engineering, construction and shipbuilding sectors) to operate at less than 80 per cent of its capacity, like its counterparts in America and the EEC.

Nippon Steel Corporation, which surpassed US Steel to become the biggest steel manufacturer in the world, in October 1978 announced its corporate rationalization programme to survive "the period of slow growth." The gist of the programme is to suspend operation of the old facilities at Kamaishi and Yawata, and concentrate production activities in the up-to-date facilities at Kimitsu and Oita in order to improve the overall efficiency, strengthen the company's engineering division and thereby consolidate its position in the world. The point is to reinforce the corporate competitiveness by seeking greater economies of scale even in disregard of the impact of these shifts on the local economies. Japanese iron and steel technology seems to have arrived at a major turning point.

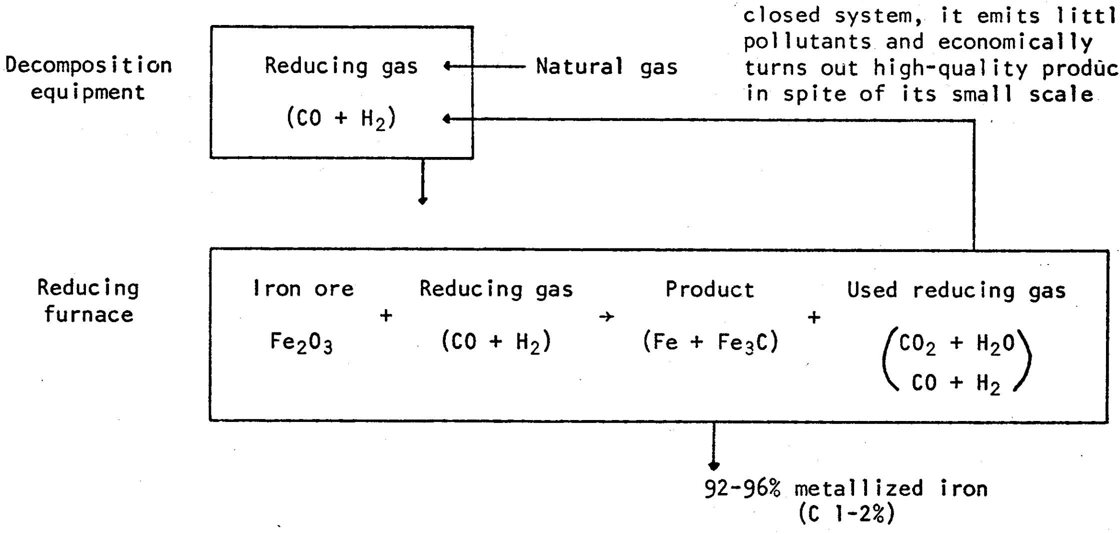
The blast furnace-oxygen converter process obviously constitutes the main stream of steel making today. From the economic point of view, the predominance of the integrated process starting with the blast furnace will remain unchallenged in the foreseeable future. However, as Yukawa was early to point out with his remarkable foresight, no optimism is justifiable about the future availability of coal, i.e. coking coal, as a reducing agent, although iron ore is likely to remain in ample supply for a much longer time because large deposits of high grade ore have been discovered in many parts of the world. It will therefore be a matter of course that "the system of producing iron and steel with a non-coal reducing agent, such as natural gas or heavy oil," which has been belittled as merely one of many conceivable alternatives, begins to prove economical enough, where local conditions are favourable, to be regarded as an industrially feasible system of iron-making by direct reduction.

L. von Bogdandy, a West German metallurgist, has pointed out that the blast furnace-LD converter process is more favourable for a steel mill with an annual output of five million tons or above, while the reduced iron/electric furnace method is preferable at an annual output level of 400,000 to 500,000 tons, and the combined use of electric furnaces and LD converters may be feasible for steel works in between. Although, obviously, the economy of either system would be much affected by the energy and material supply conditions in the locality, above all the relative costs of hot metal, scrap iron and reduced iron, and by the trend of pollution-preventive techniques, a steel mill scale of two million tons in annual crude steel output can generally be considered a turning point between the blast furnace-oxygen converter process and the direct reduction/electric furnace method. (Where the annual output is around one million tons, the equipment for the direct reduction/electric furnace process is 30 to 40 per cent less expensive.)

The latter, unlike the former, is free from the theoretical waste of going through the two steps of reduction and oxidization, and moreover the reduction in this process requires no heavy caking coal. For these reasons, economically efficient integrated steel mills have been built in recent years even where local conditions do not permit the construction of large blast furnaces, and the Japan Iron and Steel Federation reportedly "foresees yearly production by direct reduction iron-making processes will reach 60 million tons by 1985."

One of the most extensively proliferating among direct reduction processes is the Midrex method based on the shaft furnace. Presupposing the use of this method, Kobe Steel, Ltd. in October 1974 established Qatar Steel Co., a joint venture with the government of that Middle Eastern country, and built a works having an integrated production system from direct reduction to electric steel making, continuous casting and rolling and an annual capacity to produce 400,000 tons of crude steel (250,000 tons of bars and about 60,000 tons of billets), which started operation in March 1978 (see the diagram following).

Principle of the Midrex Method Used at Qatar Steel



Because natural gas is an inexpensive reducing agent and the mill permits the use of a closed system, it emits little pollutants and economically turns out high-quality products in spite of its small scale

Chemical Reactions in the Process

Reduction: $Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

Carbon admixture: $3Fe + CO + H_2 \rightarrow Fe_3C + H_2O$

Decomposition: $CH_4 + H_2O \rightarrow CO + 3H_2$

$CH_4 + CO_2 \rightarrow 2CO + 2H_2$

Source: Kobe Steel, Ltd.

In Qatar, a typical oil-producing country earning about 97 per cent of her revenue with oil, some 80 per cent of the natural gas discharge had not been used and CH_4, which constitutes a major part of the gas, has been effectively employed as the source of reducing agent (H_2 + CO). Not only can this steel works count on a virtually unlimited supply of fuel, but its process (being a closed system) emits few pollutants, if any. Accordingly the mill required only a relatively small investment, and permitted automation and labour saving beyond the standards of the blast furnace-LD converter system.

A decade before, Malayawata Steel Co., Ltd. in Malaysia, using disused rubber trees as the source of reducing agent (charcoal), started with

170-ton charcoal-burning blast furnaces producing altogether about 120,000 tons of steel a year (1967). This strategy has been proved efficient from the standpoint of modern theory on inter-industry relations [Torii Yasuhiko, "Malayawata Project no Keizai Kōka (Economic Effects of the Malayawata Project"), Tekkō-kai (Iron and Steel World), October 1978]. Both in Malaysia and in Qatar, new indigenous technologies tailored to local peculiarities under the principle of "chiu-ti chü-tsai" (choose materials according to local circumstances) were created in conformity with the laws of science and economic rationality with the assistance of iron- and steel-making experts from Japan.

Speaking about integrated steel works, in Sweden which once was the biggest steel-producing country in the world, the biggest blast furnaces are little over one million tons each in capacity, comparable to the smallest in Japan, which are used at the Kamaishi Works, and the nation's annual output of crude steel is about five million tons, only one twentieth of Japan's. Nevertheless the Scandinavian nation, early to combine her iron-ore resources with electric power potential, was a pioneer in the field of high-grade and alloy steels, has provided the world with such useful inventions as the direct reduction method (Wiberg method), electric shaft furnace and autogenous sintered ore, and enjoys an ideal steel-trade situation of having a surplus in value in spite of a deficit in quantity. Sweden's apparent per capita crude steel consumption is always among the world's biggest.

Both the North (Sweden) and the South (Qatar) seem to be telling us a way to new, beautiful, pollution-free technology matching the natural characteristics of each country, and suggesting one of the directions in which iron and steel technology should be oriented from now on.

POSTSCRIPT

For the statistics and other materials on which my accounts are based, readers are referred to another work of mine published in April 1979 by Tōyō Keizai Shimpo-sha under the title of Nihon Tekkō Gijutsu-shi [The History of Iron and Steel Technology in Japan]. A chronological table and a brief bibliography are also contained in History of Steel in Japan, an English-language booklet based on my writing, published in 1973 by Nippon Steel Corporation.