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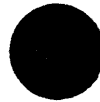


**TECHNOLOGY TRANSFER IN THE  
PETROCHEMICAL INDUSTRY**

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## **Technology Transfer in the Petrochemical Industry**

By Masami Tanaka<sup>1</sup>

### **1. Introduction**

The introduction of industrial technology from abroad is a very attractive method of industrialization. One reason for this is that, in today's economy, it is both time-consuming and costly for a company to establish technology through its own research and development. Furthermore, an earlier start of the industrialization process may, in many countries, help insure a more favorable position for further development.

Despite its ease, however, this method of industrialization does not always produce favorable results because:

1) The technology thus introduced competes with indigenous technology, often destroying it, and this can cause unemployment problems.

2) Technology improved by recipient enterprises and the profits of foreign-affiliated companies both flow out to foreign countries, and, at the same time, income gaps arise between workers in foreign-affiliated and local companies when the owners of the technology are mammoth monopolistic enterprises.

3) The technology introduced, in some cases, is not suitable for the overall economic situation of the recipient country; an example of this would be capital-intensive technology transferred to an economy with high unemployment.<sup>2</sup>

In Japan's case, however, these issues have proved less problematic; technology transfers from abroad have generally been well adapted, though with some twists and turns. Moreover, there have even been many Japanese industries that have re-exported technology that was initially introduced from abroad.<sup>3</sup>

There are many examples of technology transfer that can be smoothly accomplished. But what factors determine smooth transfer of technology?

Although many studies have attempted to answer this question, the variety of what is called "industrial technology" makes it difficult to obtain a definitive answer. The intertwining of various factors creates complexities in the causal relationships. Technology transfer is carried out interrelatedly with economic changes as its background. And, more importantly, the circumstances differ by field of industrial technology and by the status of the enterprises belonging to the industry receiving the technology. "Industrial technology" becomes useful only after the related scientific or technical knowledge becomes embodied into machines as well as human beings.

Of course, important technical knowledge is also contained in drawings, patent documents, and textbooks. This knowledge includes methods of design, process know-how, know-how related to the production operation setup, and methods of conducting feasibility studies. When technology is transferred from abroad, it comes to the recipient countries in the form of machines, manuals, and foreign engineers as advisors. It is vital that the engineers and scientists in the country receiving the technology "unravel" the technology properly. In doing this, it is important not only to understand the "know-why" (for example, why are pipes bent), but also the "know-how" (for example, how are they manufactured). It is also important to use the results of such learning with domestic machine manufacturers and scientists to develop improved machines suitable for the country so as to compete worldwide or to create new adaptive technology by combining the functions of such machines. Apparatus purchased on a turnkey basis may be said to be the spirit of technology, but the machines are installed without any information about how they are operated. Unless they are asked specific questions, foreign engineers, though familiar with a wide range of knowledge, might be only skilled people in how to operate and repair machines according to predetermined guidelines.

The ability to "unravel technology" from within a technology package or cluster and to master the essential elements among such subdivisions of technology is the most critical factor in making technology transfer succeed. Dissatisfaction with the transferred technology most often arises from an insufficient facility to unravel imported technology. Thus, it may be of the greatest importance to establish a framework to effectively accomplish this "unraveling of technology." In short, without deliberate and consistent efforts, technology transferred from abroad does not necessarily evolve easily in its new environment and become fused, through its own self-development, into the technology of its adopted country.

This paper deals with the development of the Japanese petrochemical industry from the 1950s through the 1960s solely from the standpoint of the process of technology transplanted. The Japanese petrochemical industry in this period is interesting as it relates to technology transfer to Japan because:

- 1) It was an industry at the core of the heavy and chemical industries, which were an important pillar of Japan's industrial policy.
- 2) It was a new technical field with no past history.
- 3) "Unraveling of technology" was successfully pursued, with the result that Japan became a petrochemical technology-exporting country in the 1960s.

Before embarking on the main subject, I will present an overview of the framework of the mechanism of technology transfer, in particular the "unraveling of technology."

## 2. The Mechanism of Technology Transfer and Factors Affecting It

There are two important elements related to technology transfer. The first is the choice of technology, i.e., what is to be purchased and under what conditions.<sup>4</sup> The second is the process whereby the transferred technology is elucidated and learned in the recipient country, followed by the manufacture of machines suitable for that country through improvement and adaptation of this technology. This process includes diffusion of technology into the local economy.<sup>5</sup> In this process, scientists and engineers, the organizations that regulate them in enterprises, as well as inter-industrial networks, become important in constituting local technical capacity at the given time.

### 2-1. Choice of technology

Technology that is accompanied by production activities is indispensable for transplanting a specific industry and developing it as the country's property. In modern society, the range of choice of technology is gradually becoming narrower because industrial technology in a specific sector becomes more elaborate through the process of competitive selection.<sup>6</sup> Extra costs are required to improve, for example, electronics process technology to produce new materials in developed countries so as to adapt to the level of developing countries without sacrificing efficiency. On the other hand, developing countries have firm intentions of purchasing technology available in developed countries as it is. If, however, equipment designed for the production scale of developed countries is transferred to developing countries without any modification, production costs may be too high because of the low rate of capacity utilization caused by the smaller market size. This will certainly be the case unless there is a considerable volume of export. The petrochemical technology introduced to Japan was a typical example of such a narrow range of choice.

On the other hand, industrial technology tends to elaborate its performance by improving and modifying its technical specification, and, therefore, each technology has its own development stage. To choose which stage of technological development usually depends on the amount of technological resources available within firms. For example, a firm with limited experience may prefer to introduce an established petrochemical process that is universally used in plants; in contrast, a firm with a high technological level may want to introduce one that is still in the development stage.

Through continuing consultations with sellers of technology, it may generally be possible to introduce technology by incorporating locally produced machines and equipment. In reality, however, it is difficult to sufficiently use local technology. Thus, the utilization of local technological capacity depends on the balance of the locally available technological resources and the inflexibility of choice due to the character of modern technology.

The terms and conditions are other important elements related to introducing technology.<sup>7</sup> The choice as to whether the introduction is solely "technology introduction" or associated with capital investment is the crucial matter to the developing economy. Direct

investment by the technology seller may have more influence on the buyer and the national economy as compared to the case of technology purchase only. Foreign companies tend to want more direct control of technological development within their organization, including foreign affiliates, compared to the case of solely introducing technology.

Even in cases of technology purchase only, the following issues are usually settled in various ways through negotiations between sellers and buyers:

- How shall royalties be calculated and paid?
- How long shall royalty payments be continued?
- How shall districts for export be restricted?
- How shall equipment be specified to be sold as tie-in articles for assuring the performance of the technology on the occasion of its purchase?
- What secret maintenance clauses shall be adopted to prevent the technology from leaking to third parties?

These issues are important to the seller of the technology. This is because the seller has developed the technology at considerable cost to itself. Often, these terms and conditions may function to hinder diffusion of technology in the area to which it is transferred. In many cases of technology transfer to Japan, there are some general characteristics:

- 1) As to the range of choice, the most advanced technology was adopted.
- 2) Introduction of technology was enthusiastically undertaken, but, in contrast, direct investment by foreign firms was carefully controlled.
- 3) The contracts included many restrictive clauses along general practices following worldwide standards for the introduction of technology.
- 4) In the case of purchase from monopolistic enterprises, however, large royalties were paid and direct investment was often involved.

## 2-2. Local technological capacity

Local technological capacity is an important factor at several stages of technology transfer. At the first stage, the capacity to "unravel knowledge" is required of technicians and workers at the production facilities. The initial operation of unfamiliar manufacturing equipment can be difficult, even with help from foreign engineers. In order to operate equipment safely as well as to improve the yield of products, local skills are required. If such skills do not develop, not only is future technological development from the equipment threatened, but industrial transfer itself becomes impossible. In fact, history tells us that some Japanese factories experienced such problems in the early Meiji period.<sup>8</sup>

In the second stage, the machinery industry in the recipient country should supply the necessary equipment. New manufacturing apparatus is, as a matter of course, composed of various devices embodying technical knowledge. Even if imported equipment is entirely unfamiliar to the machinery industry, its structure can be understood through consultations with engineers engaged in repair or operation of the equipment. In addition, the capacity of the local machinery industry is important to judge what parts should be replaced in order to make improvements suggested by local operators and to ascertain whether such improvements may infringe on patents of any other party.

Knowledge alone has no meaning until it has been embodied in machines. Thus, the capacity to "unravel knowledge" in the machinery industry has a vital role in the process of technology transfer. A more important matter is that the technology thus adapted contributes to the elevation of the technological level of industry as a whole through the diffusion of equipment to a wide range of industries in the recipient nation. In other words, the machinery industry, on which technology as knowledge converges, plays a role of being a core for information and work with other manufacturing industries that result in mutual progress.<sup>9</sup>

In the third stage, it is necessary to have the capability to change the process and product design as local needs change. Since such a capacity involves activities closely connected to R&D and, since the recipients can become competitors of the suppliers of technology in world markets, collection of the most advanced technical information is required. It is also necessary to grasp the needs of end users, not only in the domestic market, but worldwide as well.

As stated above, choice of technology and local technological capacity at various stages are factors that mutually determine successful technology transfer. The institutional factor may also play an important role, and it is impossible to disregard the status of the host economy, in particular, the economic condition of the industry associated with the technology transfer.

### 2-3. Institutional framework

The institutional framework established by the Government is an important factor in smooth technology transfer. It is obvious that enhancing the educational system in its role as provider of capable scientists and engineers is decisive for the assimilation and adaptation of technology. A typical example is to expand science and technology departments in universities.

Improvement of the patent system to promote smooth inflow of technology from abroad provides an incentive to domestic enterprises to develop or improve technology. At the same time, the patent system should be oriented toward smooth, adaptive technological development, rather than innovative progress. One example would be to aim at disapproving chemical product patents and awarding process patents for newly improved methods in

consideration of the technological level of the country within the framework of international patent rules.

The mechanism regulating introduction of technology or capital from abroad and the industrial policy that is adopted for nurturing a specific industrial sector are also important in the institutional framework. While the former is mainly a matter of choice of technology, as mentioned above, the latter has a decisive meaning in the progress of local technological capacity. The industrial policy may include many types of policy measures, such as subsidization of research activities, to promote nurturing of technology in a specific field by financial and tax measures.

In addition to governmental institutions, we cannot neglect the importance of organizational frameworks within private companies where technicians and laborers devote themselves to learning introduced technology, and how organizations are established to facilitate effective feedback from research departments to consumers when new products based on introduced technology are being developed. In addition, Government policy and the activities of private enterprises should be consistent, and there also should be a smooth information flow among all parties concerned so that decision-making is effective. In other words, these institutional networks by the Government and private sector play a vital role in technology transfer.

#### 2-4. Economic conditions of industries

Generally, the markets in developing countries are smaller than those in developed countries. Developing countries often take measures to protect infant industries that have the potential for future development. Such measures, however, can lead to the preservation of inefficient production facilities, and technological development aimed only at increased production, rather than the accumulation of technological capacity to reduce costs.<sup>10</sup> Competitive conditions in international markets are important in the process of technology transfer, and how such market conditions will change in the future is crucial in judging how to improve technology and how to expand facilities based on newly adapted technology.

When the future of the economy is unclear and interest rates are high, opportunities for investment will dwindle no matter how good the technology is. As a result, the chance of new technological development will be lost. In Japan, protective measures were taken until the mid-1950s, and this caused inefficiency in some industries. A very competitive policy, however, was adopted in key industries, such as the petrochemical and steel sectors. In fact, import, though somewhat protected by customs duties, was undertaken under very competitive conditions. This means that a policy was adopted for avoiding inefficiency in key industries, inefficiency that might have caused bad spillover effects in a wide range of industry. Thus, the firms were necessarily confined to an economic environment in which there was great incentive to improve equipment to reduce production costs in individual enterprises.



We can summarize this section as illustrated in Figure 1. The choice of technology and local technological capabilities are determined by the nation's institutional framework and the economic conditions of the industry involved.

Using this analytical framework, we will discuss technological changes in the Japanese petrochemical industry that took place during the period from the 1950s through the first half of the 1960s. The major issues of this topic are as follows:

1) How was the petrochemical technology that Japan planned to introduce and transplant changing globally? And what was the state of the local technological capacity in the Japanese chemical industry at the time?

2) How was the choice of technology made and how was the respective technological capacity developed? What was the nature and extent of technological changes?

3) What role did the Government play? How did the business organizations of private enterprises affect technological changes?

Chapter 3 covers the first question, and Chapter 4 gives answers to the second and third questions.

### **3. Summary of the Development of the Petrochemical Industry**

#### **3-1. Historical development of petrochemical technology**

The petrochemical industry is that part of the chemical industry that produces synthetic resin, synthetic rubber, material for synthetic fibers, solvents, and other chemical products by refining and chemically transforming petroleum and gas-based hydrocarbons.

This industry consumes large volumes of oil distillate and utilizes ethylene, propylene, butadiene, aromatic compounds, and other related compounds. As a bulk materials processing industry, costs can be cut sharply by enlarging the scale of operations. Different equipment is used, according to the feedstock and market size. Technology sustaining the petrochemical industry was developed along with the evolution of the oil refining industry in the United States starting around 1920. The growth of the automobile and aircraft industries required greater quantities of solvent used for paint in addition to expanded needs for gasoline refined from crude oil. This solvent created a new market for petrochemical products.

Starting around 1930, synthetic detergent and various kinds of synthetic resins were developed by I.G. Farben in Germany, and they enjoyed great market success. The rapid development of the oil refining industry, in particular, allowed cost reductions in petrochemical products as a result of the increasing scale of plants. This price reduction encouraged the growth of demand for petrochemical products.

In the 1940s, because of military demand, synthetic rubber and polyethylene resin for radar were developed in Europe and America. At the same time, there was the very famous invention of nylon by Dupont.<sup>11</sup>

After World War II, the mass production system continued to evolve, and there was accelerated diversification of products. In addition, new organic synthetic chemistry and polymer chemistry progressed, and technology to construct huge plants was also developed. These factors helped establish a new chemical industrial technology with several important features:

1) The technology was based on new process technology in which chemical reaction is continuously generated by the huge equipment used in the oil refining industry;

2) Engineering enterprises, which construct comprehensive and functional process plants with critical requirements for organic relationships among unit operations such as pumps, heat exchangers, compressors, and distillation towers, came to play an important role as a new industry in the United States; and

3) The connection with science became stronger, and collaboration was given more importance than individual efforts in R&D; organized research systems became essential in laboratories.<sup>12</sup>

In Japan, technical information about the striking developments in European and American technology was quickly absorbed, and petrochemical experiments were performed with small-scale test apparatus. The mainstream of the Japanese chemical industry, however, different from the petrochemical industry, was based on raw materials such as coal, lime, and other solid materials. An assessment of the Japanese chemical industry in 1949 indicated that: (1) the quality of raw materials was inferior; (2) the process was nonautomated and generally discontinuous; (3) the quality of the machinery was inferior; (4) scientific control with measuring instruments was not undertaken; and (5) technology and facilities were not advanced, and manufacturing was generally very time-consuming.<sup>13</sup> This shows that there was a very large technology gap between Japan and the Western world. Thus, technology transfer to the Japanese petrochemical industry, mainly technology introduction, began in the period from the 1950s through the 1960s, as shown in Fig. 2.

### 3-2. Establishment of the petrochemical industry

While government regulation of foreign currency allocation and a policy of protecting domestic industry had been in effect since the 1930s, petrochemical products could be imported with a 5-20% customs duty; thus, the petrochemical industry existed in a pretty free environment. Imports continued to increase in value until about 1961, but exports started to exceed imports in 1965 due to a gradual replacement of foreign products by domestic ones (Table 1). As a result, by the latter half of the 1960s, Japan's petrochemical industry was the second largest in the world, after that of the United States.

Although almost all of the technology had been introduced from abroad, improvements and product development for the Japanese market were made. Thanks to such changes, commercialization of new products using domestically developed technology began to be conspicuous around 1965; this was followed by active exports of technology starting around 1970.<sup>14</sup>

As a result of technology improvements under the competitive conditions of a free market, by the early 1970s, production costs of petrochemical products had been markedly reduced, and the performance of the Japanese petrochemical industry became excellent. One reason why such a firm position could be attained in only a decade or so was that there had been constant demand from the automobile and household electrical appliance industries. Therefore, new investment was always available, and, thus, the economic conditions surrounding the Japanese petrochemical industry itself were favorable. At the same time, particular government policies related to the petrochemical industry were adopted to strengthen international competitive power. These included measures to create scale production, to adopt efficient use of derivatives, and to foster the industry through improvement of the finance and tax systems.

Based on the above-mentioned outline, we will consider in the next chapter how the choice of technology was made, how local technological capacity was enhanced and what role the Government should play.

#### 4. Technology Transfer

##### 4-1. Choice of technology and the Government's role

The Foreign Investment Law is often mentioned as an important contribution to Japan's economic development. While cleverly regulating the introduction of technology and the inflow of capital, it was intended to foster Japanese enterprises by selectively accepting such technology and capital.<sup>15</sup>

In the case of the petrochemical industry, how was this selection or choice of technology made? What technology was chosen and why? How significant was Japan's technology gap with other industrial nations? How important was the issue of plant scale in of small market? And how were the terms and conditions of a contract and relationship with direct investment associated with the introduction of technology?

##### 1) Choice of scale

In the United States, waste gas from oil refineries or natural gas has been used as the main material for the petrochemical industry. In the mid-1950s, when the Japanese petrochemical industry was getting off the ground, the average scale of ethylene producing units was 50-60 kilotons per year. In consideration of the forecasted demand for petrochemical products, the minimum ethylene scale was 5.5 kilotons per year in Phase I

(1958-59) in Japan, and great importance was placed on the use of ethylene centered on polyethylene, though unused fractions occupied a considerable portion because an oil fraction (naphtha) was used as a material. When technology was introduced, the choice of technology was made with the above in mind.

While two competitive processing methods, the S&W method (Stone and Webster method) and the Lummus method, were available in the United States at that time, all of the Japanese petrochemical companies decided to introduce the S&W method, which was the most suitable process for utilizing naphtha as a feedstock. At the same time, the scale of the nation's ethylene plants was expanded to 10-20 kilotons per year to reflect an increase in forecasted demand. After this initial period, the minimum scale of ethylene plants, which was the guideline given by the Japanese Government, was as shown in Table 2, always in consideration of international competitive power. Choice of technology was also made with such considerations in mind.

Starting with Phase II (1960-64), many enterprises were confident that the petrochemical industry in Japan would expand, and their projects were developed to secure their promising future demand. Since unrestricted investment in such a situation could result in excessive investment, the various companies adjusted the timing of plant construction and collaborated to build large plants in order to avoid overcapacity and to enhance their collective international competitiveness. Thus, the industry always aimed at establishing a scale with international competitive power (Table 2).

## 2) Utilization of unused fractions

The utilization of unused fractions had been a major task for increasing efficiency of petrochemical plants using naphtha as the basic material; the ratio of the material use was less than half at the end of Phase I. Polypropylene technology effective for the utilization of unused fractions was developed by an Italian company in the late 1950s, and many Japanese companies planned to introduce it. The main aim of the Phase I project, however, was commercialization of polyethylene, the initial core of the petrochemical industry. There was concern that the production of polypropylene as a resin would badly affect this project by diversifying scarce capital and human resources beyond polyethylene. Another worry was that, while the Phase I project mainly involved already-completed technology, the technology for polypropylene was not completed and could not be fully digested at the technology level of Japanese chemical enterprises. Although the introduction of technology for the utilization of unused fractions was preferable for effective utilization of resources, the Government decided that this would be postponed in order to assure the success of the Phase I project and would be positively considered at Phase II and thereafter (Table 2).

### 3) Completed technology? Uncompleted technology? Domestically developed technology?

The Phase I project adopted as its principle of the choice of technology that Japan must "target only a few kinds of products that were relatively easy to produce from the technical viewpoint among essential and stable product demand."<sup>16</sup> Since many problems arose concerning initial operations related to introduced technology, a policy of disapproving the introduction of technology without any commercial life in the Western world was adopted in consideration of the technological capacity of Japanese enterprises in the Phase I and Phase II projects. This resulted in rejecting the introduction of technology for producing polypropylene and applications for the introduction of newly developed technology of the S.D. method (Scientific Design Corporation Method) for producing polyethylene filed by two companies.

In the Phase III and subsequent projects, however, an entirely opposite view was adopted: that the nation should "shift importance to introduction of uncompleted technology that would enable the transferees to establish know-how suitable for Japan with respect to lower production costs and other related matters and to commercialize new technology on the world level at the same time as Euro-American countries." It seems that, once the Japanese petrochemical industry had seen several years of smooth operation, the Government began to appreciate the capacity of Japanese industries to digest new technology.<sup>17</sup>

As to domestically developed technology, the Phase I project almost never addressed the issue, but, starting with Phase II, the importance of technology development efforts was widely recognized. This stemmed from concern about full-scale dependence on foreign countries and the desire to commercialize domestically developed technology if it was in competition with foreign technology.<sup>18</sup>

This means, although inefficient at first, a policy was adopted focused on establishing an accumulated technological base for development, by which ranges of choice might be broadened after Phase I.

Why did this choice of technology function well in an economic system based on a free market in which chemical companies would be able to pursue their own choice by neglecting the Government's policy? How did the Ministry of International Trade and Industry (MITI) coordinate the petrochemical companies? And was there any possibility of bureaucratic judgements that tended to miss market realities? The following three points are the main elements in answering the above questions.

The first is the mechanism of creating consensus. Before or after MITI drafted each plan, key personnel from industry, academia, and MITI would gather together and analyze the state of the art and related issues concerning the petrochemical industry in Japan as well as the technological trends in Europe and America (Table 3). They would then prepare a report, and MITI would put its policies in effect based on this report. This process evolved along

with the liberalization of trade and capital in the 1960s and the consequent reduction of bureaucratic power. Also, the method of developing plans became more and more cooperative between industry and government, rather than MITI alone being responsible for leadership. In 1964, the Petrochemical Cooperation Group was established, and the Phase III project was planned with consensus among representatives from the industry, financial institutions, government and neutral parties (Table 3).

The second point is concerned with the positive flow of information. The Petrochemical Association, an organization composed of petrochemical companies, was established in 1958, and information of interest to the industry was channeled through it. In addition, the Association sponsored various activities, such as discussion of proposals to the Government, policy appraisal by industry personnel of various levels, and technological trends related to new machines and materials beyond the petrochemical industry. Information that the participating companies could utilize jointly was widely circulated among those companies. Furthermore, overseas investigative teams comprising officers of member companies, financial institutions and government agencies were dispatched, and a shared understanding of Japan's situation evolved among related parties in the petrochemical industry. This kind of positive information flow was important not only in promoting consensus formation within deliberative bodies, but was also useful for many people to understand decisions made by MITI and other related organizations.<sup>19</sup>

The third is concerned with MITI's policy (guidepost policy), which clearly expresses the direction of the industry, and this is closely related to the first and second points. Clear announcements of what field of technology should be chosen and how the future demand trend should move were very helpful for enterprises to determine the range of their choice of technology based on the above-mentioned consensus formation and information flow. Measures taken against the choice of technology outside this framework (for example, the introduction of polypropylene technology or of polyethylene technology according to the S.D. method as an uncompleted technology in the Phase I project and adjustment of the period of construction) may have appeared undesirable to chemical companies. They thought it was more advantageous to follow MITI's guidance over the longer term, rather than pursue short-term benefits. Thus, MITI wielded considerable power as the coordinator to create consensus among the concerned parties.<sup>20</sup>

MITI's actions were flexibly taken on issues of technology introduction, including royalties, restriction clauses and direct investment, under the auspices of the Foreign Investment Law. Sometimes, MITI approved a case whose royalties were extremely high. For example, when Mitsui Petrochemical introduced high density polyethylene (HDPE) technology, which was not completed at the time, it paid 430 million yen, equivalent to 1.7 times its total capitalization. Generally, many restriction clauses were imposed on the area of the product exports and purchase of catalysts and machines, and clauses were also included that forced the vendor of the technology to utilize machines developed in Japan. On the other hand, it was a real fact that there was a marked technology gap between Japan on the one hand and Europe and America on the other. There was, above all, the fear that technology

could not be introduced smoothly from abroad if too many restrictions were to be imposed. At the same time, the vendors were threatened with losing their advantageous bargaining positions because of the nature of petrochemical technology. Since petrochemistry was a field with rapid technology innovation, a technology vendor could not easily maintain its monopolistic position for long, except in some special fields. How the Government maintained the balance of benefits between Japanese firms and vendors was the central point of government intervention. Namely, the Government played only a complementary role for flexibly dealing with an enterprise upon judging the vendor's situation (monopolistic or competitive).

In contrast to introducing foreign technology, MITI has pursued a strict policy toward direct investment. Before the liberalization of capital transactions in the latter half of the 1960s, it was imagined that their free entry into the Japanese market would badly affect the sound growth of Japanese enterprises, which were in a weak capital position, while most of the technology originated with European or American chemical enterprises, which were quite superior to their Japanese counterparts. MITI adopted the policy that entry by means other than joint ventures would not be allowed. Low density polyethylene (LDPE) technology was owned exclusively by major companies (ICI, BASF, Dupont and the Union Carbide Corporation), and agreements were made in 1960 to establish a company with 50% capitalization each from Dupont and Union Carbide, since these firms would not sell technology except by direct investment.<sup>21</sup> While huge foreign companies have entered Japan under various joint management arrangements since then, the share of foreign-affiliated enterprises in the petrochemical industry was generally restricted due to the Government policy. A more important factor, however, in explaining the limited share is the nature of the Japanese market, which one of highly excessive competition that does not easily accommodate the investment system of Euro-American enterprises, which attach importance to profit ratios.

#### 4-2. Local technological capacity

Since the petrochemical industry produces many kinds of derivatives, it is difficult to comprehensively study various types of technological capacities in the case of technology transplantation mentioned in Chapter 2. This chapter discusses, mainly as regards the production apparatus of ethylene and polyethylene as the core petrochemical products, how important already acquired technological capacity is, how various kinds of technological capacity have been accumulated, and further, how government policies relate to industry.

##### 1) Technological capacity at the production plants

When petrochemical plants were introduced to Japan at the end of the 1950s, Japanese enterprises had little experience with integrated plants that continuously process large volumes of continuous fluids. Although there had been plants to continuously produce soda ash and ammonium for fertilizer and they had accumulated technological capabilities, this was the first time for Japan to have technology to continuously treat many kinds of inflammable

fractions.<sup>22</sup> One company, for example, bought an ethylene plant from S&W Corporation, but this company did not have enough experience with decomposing naphtha.<sup>23</sup> In spite of help from several foreign advisors, the company faced many difficulties, such as vibrating compressors, choking of pipes caused by improper operations, and dangers due to leaking of inflammable gas, for several months. Many problems also arose in polyethylene plants; these included adhesion of polymers on the walls of reactors, choking in pumps, and clogging in the drying process. While at first it was often necessary to halt operations due to minor mechanical problems, improvements were gradually made to the apparatus itself in consultation with the manufacturers. This trial-and-error approach provided a technical education on plant operations and gave the related parties, including the machine manufacturers themselves, insights on how to improve the apparatus. An accumulation of such experiences soon led to large-scale technical improvements.<sup>24</sup>

The evolution of technological capacity at the plant has two great merits. The first is that, when the next apparatus is introduced from abroad, a more focused choice of technology becomes possible. Furthermore, it becomes possible to have leverage to make requests about design due to a deeper understanding of the embodied technology. The second is that a large-scale increase of capacity with the input of only a small amount of capital, achieved by learning of technology, was a great capital-saving improvement in an era of scarce capital.<sup>25</sup>

This accumulation of technological capacity in production sites is not always successful. In ethylene plants, for example, there are cases in which methods other than the S&W method were adopted in the Phase II project. These include the SBA method introduced by Sumitomo Chemical Co., which, though technologically not established, coproduced ethylene and acetylene through utilization of derivatives in the company, and the Lurgi process introduced by Maruzen Petrochemical Co., which produced ethylene by an entirely new system of floating beds. These methods were improved in many aspects, but their lives were terminated after quite a short time, in 1966 and 1969, respectively.<sup>26</sup> It is natural that, if the potential to evolve on-going technology is lower than that of other competing processes, this sort of phenomenon will occur. From another standpoint, these examples illustrate how important the choice of technology is.

## 2) Technological capacity to manufacture machines and devices

The technology to manufacture chemical machines was backward in Japan when the petrochemical projects began. This is because there was no demand for new machines and devices at that time. At the same time, import of machines was not free before 1961 due to quotas on foreign currency and protective customs duties.

In 1956, the "Law Concerning Temporary Measures for Machines Industry Promotion" went into effect, and policies to strengthen the basic and parts sector of the machine industry were adopted.



The chemical machine industry was designated as an industrial category with priority to cope with the liberalization of imports in 1961. According to this law, deliberate nurturing of the industry was undertaken through taxation and financial policy. Import of machines from abroad meant that domestic machine manufacturers would lose their customers as well as opportunities for technological development. The import of necessary chemical machines was, however, positively promoted through exemptions from customs duties in the Phase I period because it was more worthwhile to implant an efficient petrochemical industry than to depend upon inefficient domestic machinery.

In the case of ethylene plants, cracking furnaces, heat exchangers, hydrocarbon compressors, and measuring instruments have been designated as duty-free items since 1959. It is noteworthy that the customs duties for machines and devices indispensable to the development of the petrochemical industry were eliminated when they could not be manufactured domestically. Securing stable plant operations is vital in the petrochemical industry, where there is severe competition among enterprises. Of course, domestic machine manufacturers adopt strict quality control, but this is not sufficient to produce machines and devices with high reliability. In order to secure reliability, technological knowledge of long-term operation and machine performance must include maintenance records and accident-related data in addition to machines that manufacture well. In other words, "buying" reliability is important.<sup>27</sup>

Among petrochemical machines, which had a short history in Japan, pumps, towers and tubs, heat exchangers, and centrifugal compressors were domestically procured by about 1958. As measuring instruments are the most important for "buying" reliability among various types of equipment, the adoption of domestically manufactured ones was the most delayed. They were not largely adopted on a wide scale until Mitsubishi Petrochemical Co.'s polyethylene plants did so in the Phase II project. More important is the fact that it became possible for Maruzen Petrochemical Co.'s 300 kiloton ethylene plant to be operated exclusively with domestically manufactured machines and devices in 1961.<sup>28</sup> What are the factors involved in replacing imported machines and devices with those manufactured domestically?

The first factor is that the machine industry intended to increase domestic manufacturing by introducing the necessary technology, as had been done in the petrochemical industry.<sup>29</sup> Many of the machines involved in technology introduction by domestic enterprises were replaced by domestically manufactured ones shortly after introducing the technology. Obviously, domestic machines with a level of performance corresponding to imported machines do not have to be transported at great cost, even though royalties have to be paid to foreign companies. Additionally, they are superior from the standpoint of after-sale service. The ratio of chemical industrial machines produced with imported technology to the total output of such machines remained at about 10% from 1955 to 1960.<sup>30</sup> Great efforts were made by the chemical machine industry itself to improve technology and thus sharply reduce the unit cost of machines with the same performance as imported machines.

The second factor is concerned with joint development between the chemical and machinery industries. In fact, there were cases in which replacement of foreign machines was realized through joint development at the petrochemical plants themselves. Typically, this involved improvement of machines and devices based on repairs and minor improvements and joint study between the machine manufacturers and chemical companies. One such example is the development of a quenching heat exchanger through joint study between Mitsubishi Heavy Industry Co. and Mitsubishi Petrochemical Co. The advent of quenching heat exchangers and centrifugal compressors resulted in extremely larger petrochemical plants starting in 1964, and the ethylene plant constructed in 1968 by Mitsubishi Petrochemical Co. adopted jointly developed heat exchangers.<sup>31</sup> Such close collaboration between the petrochemical and machine industries not only unraveled knowledge that had been embodied, but also became a major factor in generating improved machines and devices by adding newly found scientific information. As the example illustrated, a machine industry with a solid technological base was a large element in enhancing technological capacity in petrochemical companies. The most important element for functioning with the kind of dynamism seen in the petrochemical industry is frequent investment chances in very large-scale plants, chances that provide plenty of opportunity to adopt domestically manufactured machines and devices (Table 1).

### 3) Technological capacity to design

Accumulation of technological capacity at the plants allows recipients of technology to create new designs that make effective use of new technology generated by R&D divisions within the petrochemical industry and to improve not only the machine parts or operation manuals of the plants, but also the efficiency of the plants as a whole and their ability to generate their own technology.

Of course, the vendor of the technology specifies restriction clauses in the introduction contract to prevent the technology from being copied. It is often possible, however, to develop a substitute process without infringing on patents by choosing among many substitute processes or by using a different catalyst for achieving a purpose. Since the vendor of the technology is fully aware of this and undertakes defensive research and improvements, latecomers must overcome the advantages of those who are on the scene earlier. Although some firms<sup>32</sup> were exceptional in having such an ability and specializing in its own technology, it was about 1965 that improved technology newly designed from introduced technology began to emerge. In other words, the technological fermentation process progressed slowly and generated the ability to newly design technology about 10 years after many Japanese chemical engineers began to come in contact with petrochemical technology.

As for technology to newly create major systems different from existing technology based on entirely new concepts such as polyethylene and polystyrene, however, development by Japanese has been nearly nonexistent. In other words, is Japan's contribution to the development of petrochemical technology worldwide no more than improvement of plant efficiency by refining and strengthening various kinds of technological capacities?

The answer is that the Japanese petrochemical industry contributed a considerable amount not only to process improvement as mentioned above, but also to product development.

The case of the development of HDPE by Mitsui Petrochemical Co. is a typical example. In 1954, the company purchased, at a high price, the technology of HDPE, which had just been developed and was still imperfect, from Dr. K. Ziegler of West Germany. The company purchased the technology solely with the expectation of future need for polyethylene almost without recognizing the difference between already commercialized LDPE and HPDE. HPDE, which is processed with the Ziegler catalyst and is stereospecific with a highly crystallized character, is different in its performance from LPDE, which was then imported.

Before completion of production plants in 1958, the company performed a study on plant performance and improvement of catalysts, and it also undertook construction of pilot plants, but it only had experience with thermoplastic phenol resin. As to the plants and the Ziegler catalyst, almost everything belonged to an entirely new technological field. Conventional equipment was acquired from Mitsui Shipbuilding and other domestic enterprises, and, on the other hand, chemical catalysts, equipment to make pellets from polymers, and measuring instruments were purchased from abroad. Thus, plant construction progressed on the basis of the company's own study.

As already mentioned, mechanical problems often arose during the initial operations of the plants. These problems were solved within a month or two through the accumulation of experience gained by cooperation with engineers from Mitsui Shipbuilding and other companies. Since HPDE has properties that differ from those of LDPE and is difficult to process, demand for it was not easily established, and plants that manufactured it continued to operate at low ratios until 1962.

Next, I would like to discuss the process of technological development from the viewpoints of process and product development associated with HDPE.<sup>33</sup>

#### i) Process development

The major problems related to process are a) that, if the catalyst is exposed to the air, its performance deteriorates, and b) how such catalyst can be regenerated. Therefore, the catalyst performance was important, and systematic study of the catalyst was undertaken in the light of basic chemistry. The first breakthrough for high catalyst performance was achieved by Solvay Co. in Belgium in the mid-1960s. This catalyst allows the necessary chemical reaction in such a small quantity as to have no bad effect on the resin if the catalyst itself remains even in the resin. Adoption of this catalyst increases the production capacity of reactors, thus making the apparatus smaller and making the regeneration process for catalyst unnecessary. As a result, the utility fees and costs of facilities could be considerably reduced.

As a matter of course, Mitsui Petrochemical Co. also developed such a catalyst based on accumulated chemical knowledge and eventually commercialized its own process in the Phase III petrochemical project. Of course, improvement of technology during this period was not restricted to catalyst, but also extended to remarkable improvement in the mechanical performance of plants that had close connections with machine manufacturers. A great improvement in technological performance can be noted in the fact that the new plant producing HDPE at a capacity of 12 kilotons/year in 1958 cost 2.1 billion yen and the construction of another new plant with the capacity of 60 kilotons/year in 1968 cost 1.8 billion yen. Namely, a plant five times larger cost 0.3 billion yen less after 10 years of inflation. This technology finally began to be exported to many countries in 1970, and the company thus became a worldwide vendor of technology for HDPE.

#### ii) Product development

When it was commercialized around 1958, HDPE had many problems, such as inferior size stability and resin flow. Technology for LDPE films for daily sundries, on the other hand, had been established in Europe and America and was manufactured, without any problem, depending on importing machines. However, the HDPE technology was then underdeveloped, and many attempts had been made throughout the world to improve processing and product technology. The major targets were: (a) improvement of metal molds and blending with LDPE, and (b) improvement of quality itself, such as changing the flow by copolymer technology or change of molecular weight. Such attempts related to processing were performed in close liaison with the users. Mitsui Petrochemical Co. established study groups in charge of polymerization, structural analysis of polymers, material character, and manufacturing, and endeavored to grasp users' needs. Thus, the company gradually cultivated new demand for HDPE while repeating its own trial-and-error studies.

In 1959, the company succeeded, through a joint study with Honda Giken Co., in developing a product usable for motorcycle parts. As a result of such efforts, new products, such as monofilaments and extension tapes were developed. This case shows that the company took the world initiative in pioneering new needs. Demand steadily extended from daily sundries that competed with polyethylene to industrial materials for automobiles and home electrical appliances.<sup>34</sup> In parallel with the improvement of production plants, as mentioned above, HDPE polyethylene became one of the major synthetic resins in the mid-1960s.

Initially, demand for HDPE as well as that for polypropylene and synthetic rubber was not very developed. It is fair to say that Japanese enterprises played an important role in creating new demand areas for these products. Typically, this would result from requests for high-quality parts from the automobile and home electronic appliance industries and corresponding efforts within chemical companies to meet these requests.

Product development, based on market needs, created a method of R&D never seen before in Japan, whereby the R&D, manufacturing, and sales divisions within a company jointly own the necessary information and jointly provide new products responding to changing market needs. While there are similarities in catalyst but differences in performance of resins between HDPE and polypropylene, a request from a particular user may include mutually usable information and the possibility for mutual use of technical knowledge among different divisions. The framework for reflecting such a request from the market in product development within an enterprise and the organizational framework to diffuse new technical information where it can be used are a new method of R&D widely rooted in Japanese enterprises and are considered to be a "Japan-like" information flow in an enterprise. The process of accumulation and development of "local technological capacity" is deeply related to the institutional framework of management in an individual enterprise. The lifetime employment system and seniority promotion system strengthen the sense, on the part of the technicians and laborers, of belonging to the company. This system is characterized by continuous promotions and job rotations and by the ability, through various kinds of education, to utilize the technological abilities of individual employees as group property.<sup>35</sup>

Severe competition among enterprises, constant technological innovation in the petrochemical industry and the communication of national policies to local workers through a smooth flow of information all helped the workers recognize that this was their own petrochemical industry. They were eager to unravel technical information from introduced machines, devices, and plans as well as from foreign engineers and eventually to adapt it to domestic needs. The fact that the technological capacity necessary for technology transfer was formed in Japan was made possible by the contribution of these technicians and laborers.

## 5. Conclusion and Recommendations

The period from the mid-1950s through the first half of the 1970s was one of high growth for the Japanese economy. The petrochemical industry was a typical example of enjoying the prosperity in this period, but it was not without its problems. The policy of pursuing economies of scale by gathering different enterprises to one petrochemical center showed that, if demand fails to expand adequately, the common interests of the center firms deteriorate and they pursue only their own interest. This, in turn, showed the inflexibility of the petrochemical center during a depressed economy. The rise of raw material prices during the oil crisis, in particular, exacerbated such problems.

Entering the 1980s, the petrochemical industry was designated as being in structural recession, and, consequently, inefficient equipment was abandoned. Moreover, as the industry relied excessively on imported technology, it came to lack enthusiasm for promoting creative basic research.

The institutional framework of government and industry, which effectively promoted technology transplantation to Japan, functioned well during Japan's high growth period. If the same effort were made today, the results would be quite different. By learning the history of the technological development of the Japanese petrochemical industry--especially the dynamism of technology introduction, domestic production and export of technology during the 1950s and 1960s--however, the following lessons that transcend the differences in the economic and social conditions can be highlighted.

1) In the case of the Japanese petrochemical industry, technology transfer--unraveling foreign technology, adapting it to domestic needs, and stretching toward acquiring the own capability of reproducing new technology--was undertaken through a process of trial and error. This process was completed within a relatively short period of time, i.e., one decade.

2) The competitive nature of the Japanese market forced private companies to continuously make efforts to reduce costs and to respond to and cultivate new market needs. In other words, economic conditions made Japanese petrochemical companies constantly improve their performance.

3) The Government, always in close cooperation with the petrochemical companies, showed firm confidence in the present and future of the industry as well as underscoring the importance of cooperation among related parties. To achieve this, the Government made future forecasts of petrochemical technology and helped form consensus among the concerned parties.

The Government created an atmosphere whereby they could pursue a proper choice of technology, rather than the Government itself being directly involved in the process. The Government did not neglect the importance of fostering the machinery industry from the viewpoint of local technological capability, but the Government, with fine tunings, encouraged the adoption of efficient foreign-made machinery by the petrochemical industry--at the sacrifice of domestic machinery.

4) The capacity to digest introduced technology depends on the technological level based on past experience. Entirely new technology can take a long time to digest. Thus, there is a significant relationship between local technological capacity and choice of technology.

5) The machinery industry played an important role in stretching technological capability from acquiring operation skills, through adapting new equipment to existing plants, to designing new petrochemical plant processes.

## ENDNOTES

1. The author is a Professor at the Institute of Policy Science, University of Saitama. The research for this paper was undertaken as part of the project "The Conference for Industrial Cooperation Between China and Japan," which was held in Tokyo in 1988 under the auspices of the National Institute for Research Advancement.
2. This argument was made during the 1970s. See Cooper and Sercovitch, The Channel and Mechanisms for the Transfer of Technology from Developed to Developing Countries, Geneva, UNCTAD, April 1971.
3. Many articles explain these points. A comprehensive analysis relevant to this is C. Freeman, Technology Policy and Economic Performance--Lessons from Japan, Pinter Publishers, London and New York, 1987.
4. Details in Cooper and Sercovitch, 1971.
5. Regarding local technological capability, see Technological Capability in the Third World, (ed) M. Fransman and K. King, Macmillan Press, 1984.
6. Regarding flexibility in the choice of technology, see F. Stewart, Technology and Development, London, Macmillan, 1977.
7. Intercountry Income Distribution and Transnational Enterprise (C. Vaitos, Oxford Clarendon Press, 1974) gives a good explanation of the influence of terms and conditions of contracts on local technological development and balance of payments.
8. See P.C. Smith, Political Change and Industrial Development in Japan: Government Enterprise 1868-1880, Stanford University Press, 1955, and M. Tanaka, Industrialization on the Basis of Imported Technology: A Case Study of the Japanese Heavy Chemical Industry 1870-1930, Master of Philosophy Thesis, University of Sussex, 1978.
9. Regarding the role of capital industries for accumulation of technological ability in the U.S., see N. Rosenberg, Perspectives on Technology, (Cambridge University Press, 1976).
10. See J. Katz, Technological Innovation, Latin American Organization Industries in Technological Capability in the Third World, (ed) M. Fransman and K. King, 1984.
11. See B. Achilladelis, Process Innovation in the Chemical Industry, Doctor of Philosophy Thesis, University of Sussex, 1973, and D.A. Hounshell et al, Science and Corporate Strategy: DuPont R&D 1902-1980, Cambridge University Press, 1988.
12. The characteristics of technological changes in the oil refining and petrochemical industries are well explained by J.L. Enos, Petroleum Progress and Profits (1961) and C. Freeman, The Economics of Industrial Innovation (Penguin Books, 1974).

13. Agency of Industrial Science and Technology White Paper on Industrial Technology, 1949.

14. The changing trend of technology exports in the petrochemical industry is as follows.

(Unit: cases)

1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
3	4	3	6	5	5	8	14	14	21	16
1975	1976	1977	1978	1979	1980					
13	10	25	25	11	5					

Source: Twenty Years History of the Petrochemical Industry, Petrochemical Industry Association, 1981.

15. See C. Johnson, MITI and the Japanese Miracle: The Growth of Industrial Policy 1925-1975, Charles E. Tuttle, 1982, Chapter 6.

16. Guideline for Cultivating the Petrochemical Industry, MITI, 1954.

17. Report of the Chemical Industry Group, Industry Survey Committee, 1963.

18. Ibid 15.

19. R. Boyd, Government-Industry Relations in Japan and in Comparative Government-Industry Relations, Ed. S. Wilks and M. Wright (Oxford Press, 1987), and S. Wilks and M. Wright, Policy Issues and Policy Networks in Ed. S. Wilks and M. Wright, The Promotion and Regulation of Industry in Japan, MacMillan, London, 1991.

20. These are typical MITI guidepost policies.

21. Petrochemical Industry Association, Ten-year History of the Petrochemical Industry (1971).

22. The heritage of past technological accumulated is discussed in several histories of industrial developments. See, for example, History of the Japanese Ammonium Sulphide Industry, Association of Ammonium Sulphide Industry, 1968.

23. Ibid 19. Chapter 4.

24. Ibid 19. Chapter 4.

25. Capital-saving technological changes were also popular in the Meiji Era. See G. Ranis, Industrial Sector Labour Absorption, Economic Development and Cultural Change, April 1973.

26. Twenty Years History of the Petrochemical Industry, Petrochemical Industry Association, 1981.



27. Nikki Fifty Years of History, Nikki, 1979, pp 98-104.
28. Ibid 26.
29. Japanese Association of Industrial Machinery, Industrial Machinery Industry--Its Development Process, (1965), pp 361-385.
30. Ibid 29 p. 382.
31. Ibid 26, p. 340.
32. For example, Nihon Shokubai Kagaku Co. (Japan Catalyst and Chemical Co.) developed its own processes, such as ethylenoxide.
33. The description that follows is based on Twenty Years' History of Mitsui Petrochemical Corporation, M.P.C., 1976.
34. The joint research of the Japanese automobile industry is well described in J.P. Womack et al, The Machine That Changed the World, Rawson Associates, New York, 1990.
35. See M. Tsuda, Logic of Japanese Management, Chuo Keizai Sha, 1977.

Figure 1 MECHANISM OF TECHNOLOGY TRANSFER

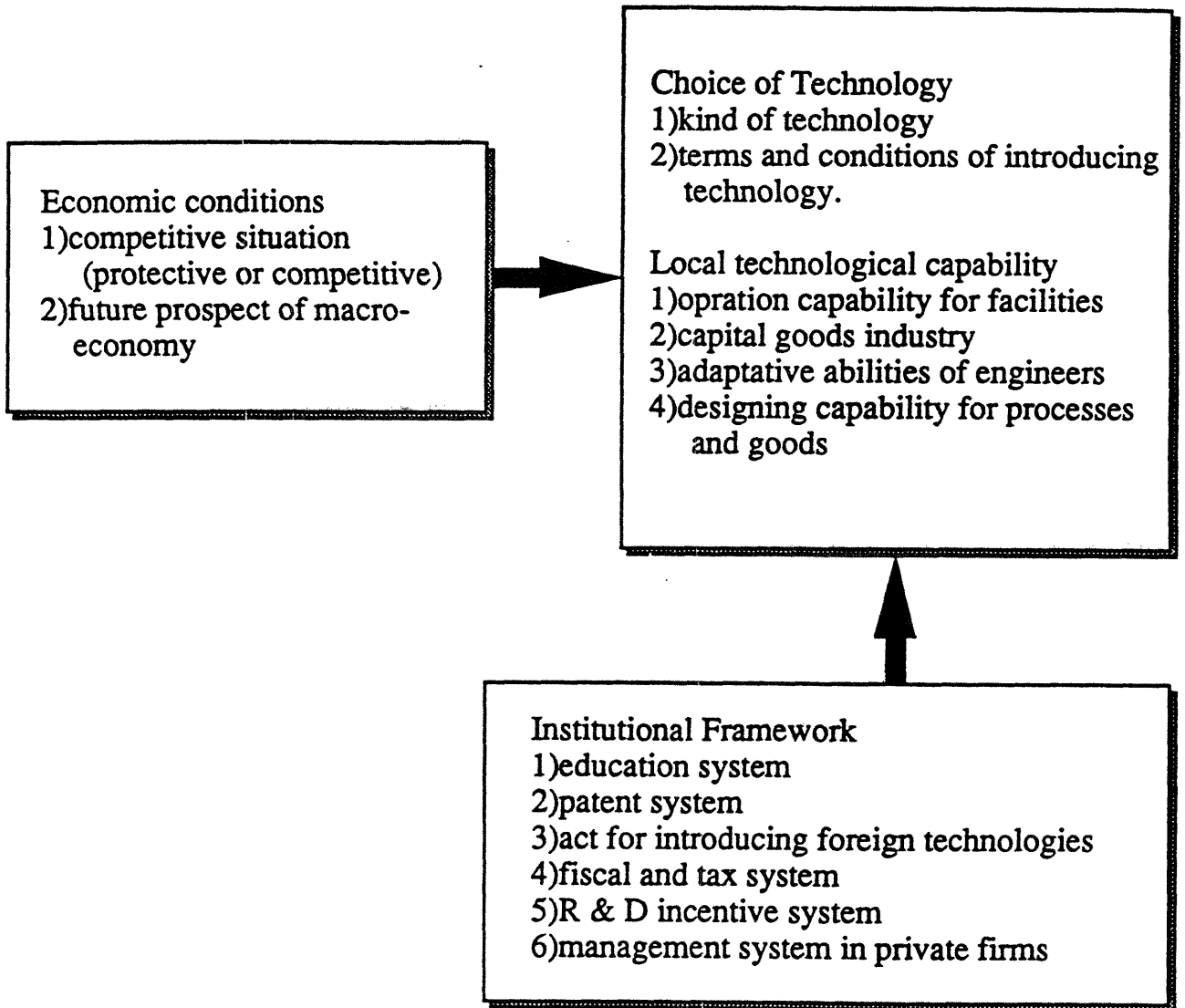
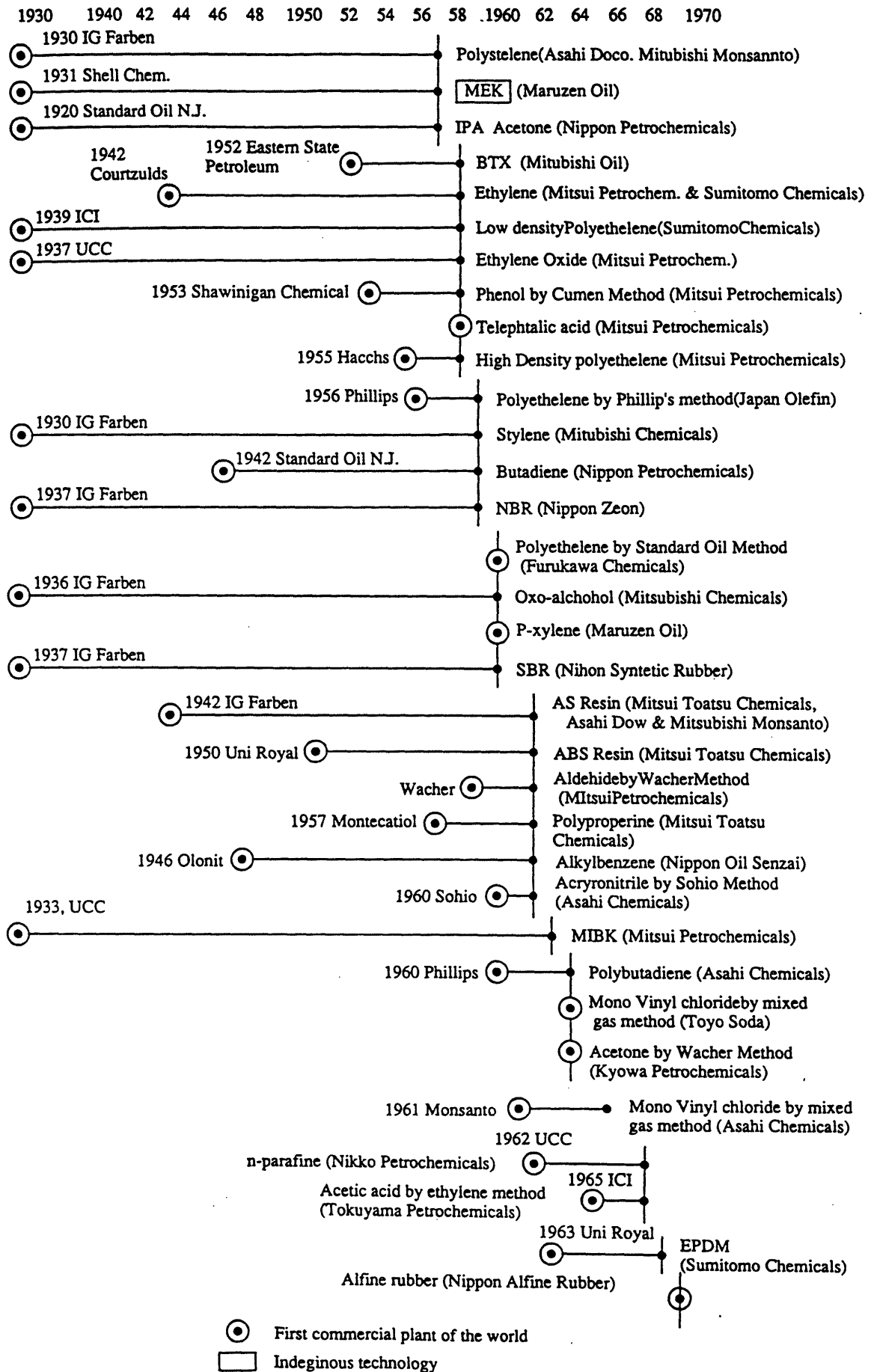


Figure 2 COMPARISON OF COMMERCIALIZED YEAR BETWEEN JAPAN AND OTHER COUNTRIES



Source : Twenty Years History of the Petrochemical Industry.  
 Petrochemical Industry Association

Table 1 THE EVOLUTION OF THE PETROCHEMICAL INDUSTRY

year	Production	Import	Export	Price	Utilization of (Naphtha)	Investment
1957	1,739			213		240
1958	1,096	16,047		189		234
1959	29,527	25,507		189		276
1960	63,123	27,505	582	172	48.5	385
1961	84,483	30,816	1,016	147		664
1962	132,746	27,178	2,824	126		559
1963	139,090	24,995	4,590	116	74.2	620
1964	251,486	30,023	6,191	107	72.5	912
1965	339,576	18,108	25,921	100	73.1	1,109
1966	437,750	16,916	38,606	92	78.5	772
1967	557,784	19,882	34,844	86	80.9	1,092
1968	705,331	25,272	41,854	83	82.8	2,028
1969	940,045	18,942	68,282	79	88.9	2,372

Unit of Products , Export and Import : million yen

Price 1960=100

utilization of naphtha : (%)

unit of Investment : 100 million yen

Source : Twenty Years Hisytory of The Petrochemical Industry  
Petrochemical Industry Association, 1981

Table 2 PETROCHEMICAL INDUSTRY PLANS

Plans for the		Second Period	Third Period	Fourth Period
First Period		1960-1964	1965-1968	1968-1973
New entry & number of center firms	4	4	4	4
Major contents of plan	Implantation of petrochemical industry. Manufacturing of polyethylene.	Conversion of carbide and fermentation industries. Utilization of used fractions.	Large-scale comprehensive use of derivatives. Combination with oil refinery.	Large-scale comprehensive use of derivatives. Combination with oil refinery.
Minimum capacity Etylene ton/year	5,500	40,000	200,000	300,000
Accumulated capacity of ethylene Etylene 10,000 tons/year	About 8 (1959)	80 (1964)	176 (1968)	481 (1973)

Table 3 PLANS AND RELEVANT COUNCILS

<p>Plan for the first period</p>	<p>Countermeasures for nurturing petrochemical industries. (MITI 1955.7)            Council of Petrochemical Industries. (1954.11)            Round-table Conference for Petrochemical Technology</p>
<p>Second period</p>	<p>Guidelines for treating manufacturing plans for petrochemical industries. (MITI 1959.12)            Round-table Conference for Basic Issues related to Chemical Industries. (1961.11)            Research Group for Chemical Industries. (1960.5)</p>
<p>Third period</p>	<p>Guideline for new and increasing facilities related to ethylene plants. (1965.1)            Petrochemical Cooperation Division Group.</p>
<p>Fourth period</p>	<p>Guideline for new facilities related to ethylene plants. (1967.6)            Petrochemical Cooperation Group.</p>