

**Aviation Gasoline Technology Transfer during the Second  
World War: Japan, Germany and the U.S.A.**

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## INTRODUCTION

As an example of the reception of *knowledge*, let us consider the aviation gasoline production technologies, which were transferred over the boundaries of Allies vs. Axis Powers during the World War II. It is worthwhile to trace how Japan acquired the overseas methods from a web of newest and complicated technological information then available and developed its own technology. Detailed consideration reveals prejudiced assumptions, misleading reception of *knowledge*, technology transfer from enemy country, and other complex aspects.

Why did Japan, specifically the Imperial Navy, believe that Germany succeeded in coal liquefaction by Bergius Process to produce aviation gasoline, and did not consider using low-temperature coal tar as the raw material? It is necessary to discuss the background and the reasons how the Naval Fuel Depot, which employed the most advanced technical staff in Japan at the time, led this move on the wrong assumption. The Navy doggedly insisted on the liquefaction process, spent enormous resources, and solicited the South Manchuria Railway Co., Ltd. (Fushun) and Nippon Chisso (Hunnam) to prepare for manufacture. The Navy showed interest in the information regarding the isooctane process, which came from the Universal Oil Products Company (UOP), and was actually able to show some results in production. However, it paid no heed to the similar, more efficient alkylation process, which played an important role in increased production of high-octane aviation spirit in the U.S. , in the Trinidad, in Abadan and in Germany during the war. This is a very interesting point as we consider the international transfer of technology over the borders between the Axis Powers and the Allies in WWII. Germany directed its attention on C4 fraction (butane, butane, isobutylene) of low-temperature tar to produce the aircraft gasoline, but the Japanese Navy did not show any interest to applying C4 fraction, which could have produced the material for isooctane by gasification of low-temperature tar. As is well known, V. N. Ipatief of the UOP synthesized the diisobutylene through

polymerization of isobutylene, and developed the method to produce isooctane by hydrogenation, which enabled mass production.

The Navy exaggerated the success of the pilot plant, and persuaded the South Manchurian Railway to build the coal liquefaction plant in Fushun and the Chosen Jinzoku Sekiyu Co., Ltd. to build the Aoji plant, both of which resulted in total failure without quantifiable production.

After the war, Yoshihiko Kanō pointed out the problem of the Navy's prewar coal liquefaction project in a roundabout way. In *Japan Aviation Fuel History*, he writes: "The author is one who predicted from the beginning that our coal direct liquefaction industry would be very delayed even if it might not fail." In 1935, Kanō had visited the Interessen-Gemeinschaft Farben Industrie AG (IG) Leuna Plant in Germany and the Imperial Chemical Industries' Billingham Plant in Great Britain. He writes that "they did not show the paste plant" even though they boasted 2-300,000 kl annual production, and that he "came home with some lingering doubt." Kanō suspected that Germany was producing gasoline by hydrogenation of tar. Kanō probably wanted to argue in detail about the fact that Germany was using the low-temperature tar to produce gasoline for aircrafts during the war. The Imperial Navy tried various raw materials, but failed to notice that the Germans were using the low-temperature tar.

#### 1. An Illusion for Coal Liquefaction

In *Development of the Coal Liquefaction Industry and the Future of Coal Mining*, Kitaru Mizutani, who led the industrialization effort of coal liquefaction for the South Manchurian Railway and the Naval Fuel Depot, wrote: "When the Manchurian Railway entrusted the Navy to carry out the direct coal research, Germany had already industrialized this process and seemed to be producing quite a large amount of synthetic oil already." He also wrote "IG Farben took out a patent that led to their success to industrialize coal liquefaction," and pointed out that Germany's IG, the Standard Oil Co. Inc. of the U. S., Imperial Chemical Industries of the U. K., and the

Royal Dutch Shell formed a patent holding company, International Hydrogenation Patents Co. Ltd. (IHP), which monopolized the coal liquefaction patent. Mizutani mentions further "Japan would had to purchase the patent right from this IHP Co. in order to go in production of direct liquefaction of coals, but that would require an enormous fund."

This writing of the Naval Vice Admiral, Kitaru Mizutani, who also served as the Advisor to the Manchurian Railway, stands on the incorrect assumption that Germany had already succeeded in industrializing coal liquefaction. That is how the outlook that Japan surely could industrialize synthetic oil as well continued to be believed. Because the patent was under the joint management by IHP, it could not be helped if Japan could not obtain the right to it, and this fact might have even spurred the belief that the patented process must be an incredible technology for getting high quality gasoline.

Why did the Japanese Navy and the coal liquefaction researchers pay no heed to hydrogenation of low-temperature tar?

I shall trace how the assumption about Germany's success on coal liquefaction came to be formed through period sources.

In July 1939, the Ministry of Commerce and Industry, Bureau of Fuel produced an article titled "Status of Synthetic Oil" for distribution at the Ministry of Navy, Bureau of Munitions. It reports: "Germany's IG Farben. built the first plant in 1927. After that, a group of influential businesses from the U. S., Netherlands, U.K. and others formed an international technical pool under the name of an international hydrogenation patent holding company, and the so-called IHP Method is incorporated for production in Germany, England, Italy and others. In our country, we have about 20 years of the research history, and developed our own unique method that resulted in the construction of the aforementioned Hoeam and the Fushun plants." What we can ascertain from this report is that, just as Iwajima, Kameyama and Mizutani referenced earlier, it is also based on the premise or assumption that the method was industrialized first by Germany's IG and

in Germany, England, Italy. It stands to reason that they believed Japan to be able to develop the coal liquefaction method single-handedly, if other countries have already industrialized it.

## 2. Isooctane Production Process: Technology Transfer and Material Supply from the U. S.

When the octane value of the aviation gasoline became a huge issue in the U. S. Army and Navy, Japan could not remain indifferent. The "General Progress Summary" section of the Naval Fuel Depot's *Operation Progress, Fiscal Year 1934* mentions: "There is a desperate demand for more anti-knock aviation gasoline." The isooctane is mentioned in the "General Progress Summary" of the *Operation Progress, Fiscal Year 1936*: "We started to work on synthesizing a new type of compound fuel. Per request of Aviation Depot, we are also engaged in the research for producing gasoline with isooctane and solvent, and are designing to build mid-scale experimental equipment. In addition, mid-scale experiments to produce special additive were conducted, and in case an urgent situation arises, the fundamental values were attained for plant construction." Let us look more in detail.

"Research Experiments for Aviation gasoline" in *Status Report of Naval Fuel Depot Research Department*, dated May 20, 1935, makes a case for urgent research development of "gasoline for hydrogenation," "quality improvement of cracked gasoline" and "discovery of antiknock agent" by stating "Recently, the demand for aviation gasoline with greater knock resistance is growing ardent, and we are faced with a need to resolve this rapidly." Following year, "synthesis of isooctane" was added in the *Status Report of Naval Fuel Depot Research Department*, issued on May 20, 1936, and it specified "we are researching aviation gasoline for diesel engine as well as fuel with high cetane value." It is clear that the Navy was paying close attention to the production technology for fuel with high octane (antiknock) and cetane value.

A special feature article on 100-octane fuel from New York Times, "Power Increasing New Fuel" (translated by Sakuichi Igasaki) and "Synthesis of Isooctane (C<sub>8</sub>H<sub>18</sub>)" (translated by Keisaku Mitsui) were published in volume 22 of *Digest*, a publication that introduced translation

of articles from foreign journals, issued on June 25, 1935 by the Naval Fuel Depot Research Department. The next vol. 23, issued on September 20, contained "Producing One Billion Gallon Motor Fuel by Gas Polymerization" (translated by Kazuyoshi Sasaki), which was co-authored by V. N. Ipatiev and Gustav Egloff on National Petroleum News, published on May 15 of the same year. *Digest* vol. 41, issued on November 10, 1937 included an article translated by Hiroshi Nishioki, entitled "Present and Future of Aviation gasoline Standards". These are evidence that the Imperial Navy of Japan was highly interested in the articles on high-octane aviation gasoline, especially on the state of octane values for aircraft gasoline in the U. S.

It stands to reason that the Navy was interested in the UOP's isooctane production technology. UOP's Dr. Ipatief developed the industrial production method for isooctane by polymerizing isobutene contained in the cracked gas and hydrogenating it, and announced this in the summer of 1935. Finding out how to obtain isobutene to produce isooctane became the most urgent problem for the Navy. The Navy attempted to collect information from all sorts of sources, and endeavored to produce isobutene needed for isooctane manufacture.

The U. S. Department of Justice, Office of Economic Warfare performed thorough analyses of the data materials confiscated from the Japanese trading companies in U. S. shortly after Japan launched the attack on Pearl Harbor. We shall clarify the intentions of the Imperial Navy from these documents.

Asano Bussan Co., Ltd. received a request from Tokuyama Naval Fuel Depot, and the company's headquarter in Tokyo sent a message to the New York branch on November 14, 1936, asking "to what degree can you expect to increase the yield of isooctane by making improvements on the gyro plant?" Receiving this request, the New York Branch of Asano Bussan put the question to the American Locomotive Company ("Alco"). On February 25, 1937, the New York Branch contacted the Headquarters with the opinion and suggestion from Alco: "It is possible to change the gyro plant design of Tokuyama Naval Fuel Depot, but you may not get

enough C4 fraction. For this reason, a place where there are several oil refineries such as Tsurumi in Yokohama may be better.

The fact that the Imperial Navy was searching for a way to increase isobutylene yield from gyro plant is clear. We can construe that the Navy attempted to produce isooctane by trying to get as much C4 fraction isobutylene as possible with vapor-phase decomposition gyro plant and hydrogenating its compound.

The idea of isobutylene from cracking gas persisted in the Navy. Moreover, they focused their interest in getting a yield from the oil's waste gas. Also suggested the possibility of boosting the octane value by augmenting the aromatic compound yield through changing the temperature and the pressure in this process, but there is no record of the Japanese Navy's reaction. I suspect that they dismissed the aircraft gasoline that is rich in aromatic compound at an early stage, due to the fact its lead susceptibility is low and adding the tetraethyl lead as antiknock agent cannot expect to raise the octane value by much. They were trapped by the textbook notion that coals have high fraction of aromatic compounds, and thereby could not conceive of taking these very coals with high aromatic compound, gasifying low-temperature carbonization, and using isobutylene from C4 fraction. Even though the Navy was trying all different types of materials, the fact that they completely dismissed the process Germany was using, namely the utilization of low-temperature tar, becomes clear repeatedly through these documents. They made all types of judgment from a single viewpoint and failed to consider the issue from various angles.

We can see how the Navy studied the U. S. oil refinery techniques in detail to pursue industrialization.

About the same time, Japan Gasoline Corporation (JGC) also proposed a plan to the Navy to jointly produce isooctane with the UOP's patent, using the exhaust gas from the Tokyo-Yokohama area refineries. This plan was also abandoned due to the insufficient amount of the exhaust gas, and as a result, it was decided that Mitsubishi Oil Co., Ltd. and Nippon Oil Corporation would each produce 100 barrels and 50 barrels of isooctane per day, respectively.

The five-refinery joint plan became extinct. Mitsubishi Oil completed building the isooctane synthesizer in April 1940, and started the isooctane production. Nippon Oil completed the plant construction in September 1940, and after trial runs, succeeded in producing isooctane in September 1941.

In *Report on ACTIVITIES OF UNIVERSAL OIL PRODUCTS COMPANY AND THE JAPAN GASOLINE COMPANY*, dated April 7, 1944, the U. S. Department of Justice reports in the section "Plant Sales Activities between UOP and JGC" that Fukio Horie relayed their interest to produce 100-octane aviation gasoline production to UOP, starting in January 1938. In a letter dated March 7, 1938, the president Hiroyoshi wrote to UOP, requesting patent license for polymerization and isooctane process, but there was a difference of interpretation for the extent of the license agreement between JGC and UOP. Both companies were aware of the vagueness of the agreement. In the previous year, the president of UOP, Hiram J. Halle wrote a letter, dated April 12, 1937, to president Hiroyoshi, pointing out that the license is not clear whether it includes polymerization, catalytic cracking, and isooctane production process. The license agreement drawn in 1928 between the two companies included only the Dubbs thermal cracking, and did not include polymerization or hydrogenation. JGC paid an additional one million dollars to purchase the license for various processes to produce isooctane. The portion for the isooctane production technology was \$600,000. Upon reaching the new inclusive agreement in August 1938, Mitsubishi Oil and Japan Oil started producing the isooctane.

Rear Admiral Isabur Watanabe wrote regarding these circumstances in his *Memoir*: "At the time, the only manufacturing system for isooctane synthesis was the UOP method and that the situation of our country's oil industry at the time allowed to synthesize only a few thousand kiloliters of isooctane annually, even if we were to utilize all of the waste gas from cracking available in the entire country." He further wrote that only a small amount of waste gas was produced from cracking, compared to that in the U. S., and to scrape up enough butylene from it to synthesize isooctane was impossible.

The Navy, which considered that the butane-butylene fraction in exhaust gas was insufficient, attempted to develop various other methods such as fermentation method (at Taiwan Sixth Naval Fuel Depot) and acetylene method (at Nihon Chisso Hungnam Plant, the Second Naval Fuel Depot, and Army Fuel Depot) to produce butanol, which would then be dehydrated and isomerized to produce isobutylene. This would lead the Navy to tackle an extremely complex method to synthesize isooctane. In addition to the acetylene method, the Yokkaichi Second Naval Fuel Depot also produced butane-butene fraction from the cracking gas developed in the process of cracking gasoline by thermal and catalytic cracking. This is a highly technical process.

The Navy researched the method of isooctane synthesis from butanol, examined the feasibility of plant manufacturing with mid-size experimental equipment, and performed engine test with the trial isooctane to confirm its performance quality to be the same as the isooctane imported from the U. S. Further, the Navy considered a wide variety of vegetable and mineral resources to find materials for isooctane production from sugar, starch, cellulose, natural gas, coke oven gas, oil waste gas, carbide from coals or cokes, and other possible materials.

Let us examine the well-known example of the isooctane synthesis method of Nihon Chisso (Chosen Chisso). Nihon Chisso aimed to mass-produce isooctane by combining several processes, namely synthesis of butanol from the company's acetaldehyde, dehydrogenation and isomerization method developed by an engineer, Takashi Eguchi (to produce isobutylene-rich compound gas from butanol), and the UOP's isooctane production method. The company constructed an isooctane synthesis plant in Hungnam with Chosen Chisso for a projected annual production of 30,000 kiloliters. Synthesis of isooctane from carbide requires a long series of processes. It is illuminating to see the complete list: carbide→acetylene→(acetylene purification→acetylene hydration→acetaldehyde refinement)→acetaldehyde→(aldol condensation→aldol thermal cracking→crotonic aldehyde refinement)→crotonic aldehyde→(crotonic aldehyde hydrogenation)→butanol→(butanol dehydration)→butene→(butene isomerization)→butene

polymerization→polymerized oil refinement→isooctane hydrogenation)→isooctane. This is a highly complex string of processes like bonsai tree pruning. It is estimated that this isooctane production cost would have been 15 times that of the American method.

The U. S. Department of Justice, Office of Economic Warfare investigated the relationship between UOP and JGC, and reported that Mitsui Mining Company's Fischer-process plant for coal gasification in Miike was also conducting negotiations to introduce nonselective polymerization, hydrogenation, and dehydrogenation methods in order to effectively utilize C3 and C4 fraction. Mitsui Mining sent the money to New York to purchase equipment on December 29, 1939, but no equipment was sent due to the moral embargo. Had the purchase been made successful, it would have been possible for them to produce high-octane gasoline using the Fischer-Tropsch Process. Mitsubishi Oil purchased a set of equipment just before the moral embargo was placed and was able to have it sent to Japan, but Mitsui Mining could not.

UOP had already provided the hydrogenation technique and the nonselective catalytic polymerization process to two Fischer-process plants in Germany at Essen and Bochum. Mitsui Mining probably followed suit to Germany in accessing the same technology from UOP. No mention of this is found in the UOP's company history record. Had UOP's isooctane production method been introduced along with this, they probably would have looked to coal gasification for aviation gasoline manufacture even with the Fischer-process gasification.

Another interesting point in the investigative report of the Office of the Economic Warfare is that we can see how much Japan was interested in the alkylation method. Simply speaking, the biggest difference is that the UOP's method is a two-stage process involving polymerization and hydrogenation of isobutylene dimer, whereas the alkylation process can omit the hydrogenation stage. Knowing this should suffice to understand the situation further.

Training sessions on catalytic cracking for Japanese engineers were offered from August 21 to the end of December 1939 at the UOP's laboratory in Riverside, Illinois, outskirts of Chicago.

(See Table 2.) The topics included catalytic cracking, polymerization, hydrogenation, dehydrogenation of butane, isomerization, hydrogen production method, catalyst production, gas separation, and technology related to alkylation.

In 1939, the alkylation technology and the knowhow were held solely by Shell. There is a possibility that alkylation was included in the Item No. 10 of the 1938 contract, but UOP still lacked the technology to commercialize the alkylation method. According to the USDJ's investigative report, President Hiroyoshi of JGC met M. B. Cooke, an engineer of M. W. Kellogg Company, which was the contractor for the Shell's plant, in December 1938. Cooke's anecdote is relayed in the report about Hiroyoshi having considerable knowledge about not only the UOP's method but also about the Shell's alkylation process.

UOP did not have the ability to commercialize the alkylation technology yet in 1939. Therefore, JGC could not provide alkylation method to other Japanese corporations or Army and Naval Fuel Depots through UOP. Even though UOP had not acquired enough knowhow of the alkylation technique, it did possess the patent right, because a cross-license among Shell, Anglo-Iranian Oil Company, Standard Oil of New Jersey, Texaco, and a little later, UOP was drawn in 1939 that allowed the companies to utilize each other's patents.

At the time, the Naval Fuel Depot's engineers, Kazuo Nomura and Captain Haruki Fujimoto were conducting technology research in the U. S., but they were mainly concerned whether the Houdry Process of catalytic cracking or the UOP's catalytic cracking process was better for producing the base gasoline for aviation gasoline. They did not collect any information about the alkylation process developed by Shell. To reiterate, the Navy had interest in two methods of UOP. First was the isoctane production process, which was to address the 100-octane value issue that became a big problem in 1935. The other was the catalytic cracking (fixed catalyst), which was still at a pilot plant level. For the latter catalytic cracking, the Houdry process was being utilized commercially. The UOP process had not entered into commercial production yet. The Navy and T a Nenry K gy Co., Ltd. intended to introduce the Houdry Process, but the moral embargo

that started on December 20, 1939 prevented further development. The two Navy engineers hardly attended any of the UOP's training sessions in Riverside. It could be interpreted that the Naval Fuel Depot engineers had that much discerning eyes. Because the Houdry process plant could not be imported due to the moral embargo, the Navy settled on incorporating the UOP method of catalytic cracking still under development.

Japanese Navy did not conduct sufficient research on the alkylation using catalyst of hot sulfuric acid as developed by Shell. Navy did not pay attention to alkylation process at all.

It was not until September to November of 1942 that the Japanese Navy actually witnessed the Shell's alkylation process, when the reports of the Palembang refineries in Dutch East Indies reached them. The alkylation equipment was installed at the Yokkaichi Second Naval Fuel Depot, following the alkylation plant designs of the Shell-related BPM and the Standard(New Jersey)-related NKPM. After observing the BPM's plant in Palembang, the Army Fuel Depot also constructed an exact copy of the alkylation plant by following the confiscated blueprints, specifications, various standard specifications, and calculation manuals. The Army Fuel Depot's plan took in the UOP's isooctane production method as is. The Army Fuel Depot later tried to construct another plant incorporating the BPM plant's alkylation ideas, but the war came to the end. At the plant seized from BPM, the Army and Nippon Oil technicians produced high-octane aircraft gasoline from the crude oil from the South Pacific.

### **3. German Isooctane Technology and American Petrochemical Technology**

We shall now examine Germany's aviation gasoline production with a focus to the isooctane production technology.

According to the Evaluation Report 36 completed by CIOS, Sholven Plant was producing isobutylene by separating isobutene and dehydrogenating. Isooctane was produced by polymerization and then hydrogenated. The report suggests that this was a copy of the UOP's

process, and notes that isooctane plants were located in Oppau, Leuna, Heydebreck and Auschwitz.

PB Report, ̈PB1657: The Manufacture of Aviation Gasoline in Germanÿ lists the two processes of isooctane synthesis: 1) isobutylene polymerization and hydrogenation, and 2) alkylation of butylene and isobutene. The alkylation process was introduced in 1943. Prior to that, the plants in Leuna, Politz and Scholven produced isooctane by dehydrogenating isobutene to produce isobutylene for polymerization. UOP's isooctane production method was incorporated at Fischer-process plants in Germany, and the technology was probably transferred and applied. The research on alkylation was already begun by 1940 and production started in 1943. In Germany, isobutene was manufactured by dehydrogenation of n-butane as well as isomerization of n-butane. Alkylation plants were built in Blechhammer, Bohlen, Leuna and Scholven. High-octane aromatic compounds were used as the base for aircraft gasoline in Germany, and isooctane was added to this. For the ̈C-3̈ grade aircraft gasoline, approximately 10 to 15% of isooctane was added. DHD process was applied to gasoline with high aromatics, but detailed discussion will be omitted here.

According to the U.S. senate Patent Hearings (77 Congress), Standard Oil(New jersey) paid much attention to the development of alkylation of both Shell and Anglo-Iranian Oil Co in July 1938. I think that Standard(NJ) did not inform I.G. Farben that how important both alkylation and catalytic cracking were.

Let us briefly examine the British isooctane production. Shell's alkylation plants were constructed involving a number of UOP engineers. UOP got first involved in the construction of alkylation plant in the British territory Trinidad, and obtained various knowledge and skills regarding alkylation plant through this process, which were very helpful in building alkylation plants in the U. S. The engineers involved in the Trinidad plant construction were brought back to the U. S., and their invaluable expertise obtained by this experience was applied to the

installation of alkylation facilities at refineries in the U. S. The isooctane and aircraft gasoline produced in Trinidad was supplied to the British Air Force.

In addition to undertaking the construction, UOP proceeded with further research on alkylation process, and was able to lower the production cost by utilizing hydrofluoric acid as a new catalyst with Shell's alkylation plant, and dramatically increased the production output. Cross licensing of patents played an important role in advancement of manufacturing technology for aviation fuel, synthetic rubber and others in the U. S. during wartime.

## REMARKS

Japanese Navy tackled oil liquefaction based on the assumption that Germany was actually producing aircraft gasoline by liquefaction. Germany used high-octane aromatics and the tar from low-temperature coal carbonization and produced isooctane from the C4 fraction by gasification in order to manufacture aviation gasoline with high-octane value. Navy kept pursuing the illusion of coal liquefaction without realizing this. The Navy promoted the construction of the Manchurian Railroad's coal liquefaction plant in Fushun and the Chosen Synthetic Oil's Agochi plant, but the result was dismal as they both failed to produce hardly any aircraft gasoline. PB reports reveal clearly that Germany was manufacturing aviation fuel, using the tar they obtained from carbonization of coals.

The belief that "coal liquefaction is already commercialized" was wide spread among the Japanese scientists and engineers before the war. The misconception was not limited to the Navy.

Japan acquired isooctane production technology by purchasing the patent from UOP through Japan Gasoline Corporation, and the equipment and the knowhow were obtained. Mitsubishi Oil and Nippon Sekiyu purchased the equipment and the technical knowhow prior to the moral embargo, and were able to produce isooctane. Through occupation of the southern region, the Imperial Navy secured aviation gasoline by utilizing Shell and Standard groups'

refineries. The technical team of the Imperial Navy had to struggle to secure raw materials and develop techniques appropriate for the available materials.

Germany imitated the American isooctane production method skillfully by gasification of low-temperature tar to produce isooctane from the C4 fraction. They also derived a better efficiency alkylation from the UOP's two-stage process. The American technical knowhow circulated to Germany, and Germany produced aviation gasoline by adopting the technology to the available coal resource.

Great Britain produced isooctane at the alkylation plant in Trinidad. They imported a great amount of aviation fuel from the U. S. in addition to the isooctane produced in Trinidad, which enabled them to carry out the air battles over the command of air against Germany.

Japan was indifferent to the information about the alkylation technique. Producing isooctane with UOP's already outdated production method was their main focus, and exhausted all efforts to produce the isobutylene necessary but failed to notice the effectiveness of the low-temperature tar that Germany was already using.

There was a same tendency with respect to catalytic cracking. This point is not discussed in the present paper, but suffice to say, Japan did not manage to utilize the most advanced Houdry process but kept using the UOP's outdated catalytic cracking process to produce base gasoline. Germany did not produce gasoline by catalytic cracking.

The aviation gasoline manufacturing technology before World War II was essentially proliferation of the American technology, which can be equated to the "acceptance of *knowledge*". Germany adopted it to work with coals. Japan doggedly tried to pursue the American method, secured crude oil from the occupied refineries in the southern region, and supplied aviation fuel for the warfare against the U. S. However, neither Germany nor Japan reached anywhere near the U. S. in quality or quantity of the gasoline. The octane-value of the aircraft gasoline manufactured by Japan and Germany was 10 to 15 lower than American gasoline. The U. S. production output for aviation fuel was 85,000 kiloliters per day, whereas the peak German consumption of aviation

gasoline was 150,000 ton per month, and the Japanese Navy's monthly average consumption in 1943 was 53,450 kiloliters (about 50,000ton per month). The U. S. far surpassed both countries.

Production of aircraft gasoline by Japan peaked in 1943, and as the command of the air and the sea were lost, import of crude oil was hindered. By 1944, they were struggling to secure enough amount of gasoline, even as they dropped the octane-value from 92 to 91. The supply route to the southern region was cut off in 1945, and the production practically stopped. The Navy adopted an American method, and produced leaded 92-octane aviation gasoline by hydro-cracking light kerosene and cracked gasoline under high temperature and high pressure at the Naval Fuel Depots within the country. The Japanese refining technology was mainly dependant on hydro-cracking of kerosene and gas oils.

Japan's technical standards and production technology ranked much lower compared to the U. S., but I would like to add in conclusion that their ranking was comparative to European countries.