THE SYNTHETIC FUELS INDUSTRY IN GERMANY 1927-1945

E. E. Donath

THE SYNTHETIC FUELS INDUSTRY IN GERMANY 1927-1945

E. E. Donath
P.O. Box 1068
Christiansted, St. Croix 00820
USA

The object of this paper is a description of the development of the German synthetic fuels industry before 1945. I shall attempt to describe the general conditions and forces. Although the size of the production of synthetic fuels was small in comparison to present production and the conditions were different, some useful conclusions may be possible. Looking back, there were two distinctly different periods. In short the democratic, free enterprise time until 1932 and the authoritarian regime beginning in 1933.

Germany was after WW1 a country rich in coal but with very small petroleum reserves and production, large unemployment and a chronic shortage of foreign exchange. Therefore with increasing motorization the conversion of coal into liquid fuels was an interesting possibility and in time could become an attractive industry. It had become apparent that the existing high and low temperature carbonization industry could not remain the only source of domestic liquid fuels from coal. Experiments for the direct liquefaction of coal and the conversion of coal-derived synthesis gas into liquid fuels were resumed after WW1

The Bergius-Pier Process (Direct Coal Liquefaction)

First let us look at Table 1 which gives briefly dates of the inputs that were necessary for the development of the direct, catalytic coal liquefaction process. There is in 1910 the commercialization of the ammonia synthesis by C. Bosch of the BASF at Ludwigshafen. This brought high pressure technology and large scale production of hydrogen from coal into industrial use. In 1913 the high pressure hydrogenation of coal was demonstrated by F. Bergius in his laboratory in autoclaves. He built a pilot plant with private financing in 1921. Coal was fed as a slurry into horizontal, heated reactors and converted to oil. The oil yields were low, however, and the quality and stability of the oils made without catalysts were unsatisfactory.

In 1923 in the BASF laboratories at Ludwigshafen, M. Pier found a Zn-Cr-oxide catalyst that produced pure methanol from coal-derived synthesis gas. Industrial production started in the next year in the BASF subsidiary, the ammonia plant in Leuna in Central Germany. In 1924 M. Pier found sulfur-resistant coal hydrogenation catalysts. Large scale experiments in 1926 led to the decision to build the 100,000 t/y gasoline demonstration plant in Leuna which started production in 1927. In 1929 the operating problems of brown coal tar hydrogenation had been solved, and in 1931 the hydrogenation of brown coal itself had reached the same stage of maturity. In the same year a large scale experiment at Ludwigshafen proved the feasibility of catalytic liquefaction of bituminous coal.

The large scale test with bituminous coal was made to prove that the equipment developed for the hydrogenation of brown coal could be used successfully for the liquefaction of bituminous coal. At that time the Imperial Chemicil Industries, Ltd., England had become a licensee and intended to build a commercial plant for the hydrogenation of bituminous coal and creosote oil at Billingham, England.

After this review of dates let us now return to the year 1924 which in retrospect can be called the beginning of the catalytic coal liquefaction industry. Brown coal tar was hydrogenated with a molybdenum catalyst to waterwhite gasoline with 100% yield by volume. This result induced the BASF management to give M. Pier the company standing and the means for a rapid development of the catalytic coal liquefaction process reporting to C. Krauch. Large scale experiments in 1926 gave results that led to the consideration of erecting a demonstration plant. Calculations indicated gasoline production cost for a Leuna plant of 20 Pfennig per liter. This was somewhat above the then existing price for imported gasoline but would still be profitable, since a reduced excise tax for the Leuna gasoline could be expected. It was in the tradition of BASF[1] to enter, based on its research, new fields and markets. At that time the competition in the synthetic ammonia field caused equipment at Leuna to stand idle. This too made a high pressure process using hydrogen interesting, especially since it produced many byproducts that could become starting material for other chemical processes. In view of the existing unemployment and shortage of foreign exchange one could expect that the government would continue to agree to a reduced excise tax for Leuna gasoline. On this basis the then already existing I.G. combine with C. Bosch as president and the driving power decided to build at Leuna a demonstration plant for the production of 100,000 t/y of gasoline.

To indicate the size of the research effort that supported this decision, the size of Piers department in 1927 had a strength of more than 1000 people, including about 70 chemists and engineers, and including operators for the Leuna plant which were trained by running large scale pilot units at Ludwigshafen.

One other factor in favor of erecting the synthetic gasoline plant was a 1926 prediction of the Washington Oil Conservation Board that the U.S. oil reserves would only last for seven more years.

The development of sulfur-resistant catalysts for the hydrogenation of coal, tar, and oil at Ludwigshafen was therefore of interest to the Standard Oil Company of New Jersey. After licensing the hydrogenation patents, two oil hydrogenation units were erected and operated in the U.S. The cooperation between the two companies was expanded to other fields. This led later, among others, to the transfer of Buna Rubber information which had been developed by the I.G. The Buna process in turn had profited from high pressure coal hydrogenation technology.

The process development continued in the Leuna plant and at Ludwigshafen. It took more time and was more costly than BASF anticipated after the smooth and rapid commercialization of the methanol process. In 1929, with the beginning of of the economic depression, the hydrogenation of brown coal tar was a smooth process. At about the same time the price of imported gasoline dropped sharply. Although gasoline from brown coal tar barely covered its out of pocket production cost, the I.G. management decided, against internal opposition to continue production in order to avoid dismissing experienced personnel. Direct brown coal liquefaction was also continued but on a severely reduced scale.

In 1930 a new catalyst was found at Ludwigshafen. It gave a threefold increase of the throughput in the coal oil hydrogenation step and a reduction of the hydrogen consumption. This promised considerably reduced gasoline production costs, and was most timely since it helped continue development through the worst depression years of 1931 and 1932. In these years the direct, catalytic brown coal liquefaction became a mature process. The gasoline production in Leuna increased from 28,000 t in 1928 to 108,000 t in 1931. The conditions under which this development was achieved were discouraging. The employment in I.G. fell from 114,000 people in early 1929 to a low of 64,000 in September 1932. During the same time the number of unemployed people in Germany increased from 2.9 to 5.8 million.

Thus the coal hydrogenation process was in a precarious and dangerous position. It produced no profit and depended on the high gasoline import duty which the automobile industry wanted reduced. Therefore in 1933 the efforts of the Nazi government to reduce unemployment and alleviate the foreign exchange shortage coincided in this respect with the desire of the I.G. to increase gasoline production at the Leuna plant to make it profitable. Near the end of 1933 a contract was signed with the government which provided a gasoline production increase at Leuna to 350,000 t/y while the government agreed to buy the produced gasoline at the cost of production plus adequate depreciation. During the first years of this contract the I.G. received a total subsidy of about 5 million Marks. The production increase to 350,000 t/y was reached in 1935 and the capacity later increased to 650,000 t/y. As a result of the decreased production costs I.G. paid about 90 million Marks to the government in the following years. The gasoline production cost of 18.5 Pf/l in 1933 was decreased to 13.6 Pf/l in 1943.

After the success of the Leuna plant, I.G. was ready to license the catalytic coal hydrogenation process and provide performance guarantees and technical assistance to licensees.

In 1934 the government issued a decree "For the Formation of Economic Organizations with Mutual Participation of the Brown Coal Industry". As a beginning the companies had to provide 100 million Marks in liquid assets as capital for the "Braunkohlen Benzin A.G." (Brabag) which erected three large hydrogenation plants for brown coal tar. Similar orders and agreements led to the erection of hydrogenation plants for bituminous coal on the Ruhr and in Silesia. Table 2 gives the main cost figures[2] for three early hydrogenation plants. It is significant that the cost of the Boehlen plant, built by the Brabag which had government people on the board and in top management, is nearly as high as the cost of the bituminous coal plants with their much more complex and costly process. The Scholven and Gelsenberg plants were owned, built, and operated by coal companies. All companies had price guarantees for their gasoline product.

The capital for the Poelitz plant on the Baltic sea, originally designed for the hydrogenation of petroleum residues, was provided by the German affiliates of Standard Oil and Shell Oil. These companies were not permitted to transfer their profits from Germany to their mother companies, and used them for the erection of the hydrogenation plant in cooperation with I.G.

Later an engineering company was formed, the Mineraloelbau G.m.b.H., for the erection of all liquid fuels plants. It was staffed partly by I.G. engineers. In close cooperation with Ludwigshafen and Leuna, it had access to all data necessary for design and construction.

As Table 3 shows, a total of 12 hydrogenation plants with a combined capacity of 4 million tons per year or nearly 100,000 barrels per day was built.

All the licensees of I.G. held regular meetings in which new developments were disclosed and operating experience and problems discussed. This helped greatly in improving the performance of operating plants. Most of these meetings were held at Ludwigshafen under the chairmanship of M. Pier. This exchange of information began in 1927 with the Standard Oil Company. It included later in addition to the German licensees, the ICI and other licensees of the hydrogenation patents. For the design of hydrogenation plants outside of Germany, U.S.A. and the U.K., the IHEC company in the Hague was established.

The Fischer-Tropsch Process (Gas Synthesis)

The reactions of CO (or CO_2) with hydrogen, Table 4, have a history that goes back to 1902 when Sabatier obtained methane on Ni or Co catalysts at atmospheric pressure and 250-300°C. In 1913 BASF obtained liquid, oxygen-containing compounds at pressures above 100 atm and 300-400°C with a variety of catalysts. Similar results were obtained by F. Fischer and H. Tropsch at the government-supported Kaiser Wilhelm Institut (KWI) fuer Kohleforschung in Muelheim/Ruhr. In 1923 the above mentioned methanol synthesis was found. In 1925 Fischer and Tropsch obtained a mixture of liquid and solid hydrocarbons at about 250°C, atmospheric pressure and with catalysts that contained Fe and Co. A 1926 publication of these results can be considered the beginning of the Fischer-Tropsch process.

A major progress was achieved in 1930. Kieselgur as support for Co and Th gave a superior catalyst, and a small pilot plant was built at KWI. Similarly progress was made in the purification of the synthesis gas, especially the removal of trace organic sulfur compounds. Thus in 1934 the process was ready for commercialization.

The potential in the then existing economic climate was recognized by the managements of the coal mining companies at the Ruhr. They were especially interested in new outlets for surplus coke. Thus the Ruhrchemie A.G., a company founded by the Ruhr Coal Syndicate, acquired the licensing rights for the process. The Ruhrchemie operated ammonia and nitric acid plants at Oberhausen-Holten. It erected there a pilot plant with a throughput of 100 Nm^3/h of synthesis gas at atmospheric pressure. In 1935 in Castrop-Rauxel, a second pilot plant with ten times greater throughput was started. An important step was the startup of a commercial catalyst plant in 1936.

In the same year the competitive development of medium pressure processes began by several organizations in various locations. These pilot plants used iron catalysts in part. Among others Ruhrchemie and Lurgi developed a medium pressure process and reactor system. It was later improved further and used in the Sasol plant in South Africa.

The pilot plant at the Ruhr supplied data for proposals for erection of commercial plants. At that time the government asked the coal and steel companies at the Ruhr for proposals for the production of 500,000 t/y of liquid fuels. Company owned and operated plants were expected to cost less and operate more efficiently. In actuality the first 4 Fischer-Tropsch plants and all the later synthetic fuels plants came under stricter government control within the "Four Years Plan".

Table 5 lists the 9 Fischer-Tropsch plants built in Germany, their capacity and start-up dates: in 1936 four plants started operation, three using coke and coke oven gas for synthesis gas generation. The fourth, in Central Germany built for the Brabag company, gasified brown coal briquets. Four plants which started operation from 1938 to 1940 again used coke and coke oven gas. The last plant with a start-up date in 1943 used raw brown coal for the gas production. The total design capacity of these plants was 740,000 t/y of primary product and the actual production reached in 1943 and 1944 corresponded to around 570,000 t/y or about 14,000 barrels per day.

The development of the production[3] of the German synthetic fuel plants is shown in Fig. 1 beginning with the year 1938. Looking first at the graph for the hydrogenation plants, production increases steeply as new plants came on line and older plants increased their service factor until a maximum production of close to 4 million tons per year or 100,000 barrels per day is reached in 1943, even before the last plant at Blechhammer in Silesia began production. In May 1944 begins the catastrophic drop in production due to destruction by air attacks. The graph also shows that part of the total was obtained as aviation gasoline.

During the war almost all of the aviation gasoline came from the hydrogenation plants.

On top of Fig. 1 is the production trend of the Fischer-Tropsch plants. It is similar to that for the hydrogenation plants in the period of the graph, but on a much smaller scale.

This description would not be complete without at least mentioning producer gas powered vehicles. They used wood or brown coal briquets as predominant fuels. It was estimated that in 1943 they brought a saving corresponding to 500,000 t (about 12,000 bbl/d) of liquid fuels.

Summary

Looking first at the catalytic coal hydrogenation or direct coal liquefaction process we see its development beginning with the first sulfur-resistant hydrogenation catalyst as the result of the private incentive of a large company which expected to enter new markets through its research. It took three years from 1924 to 1927 to advance from a small-scale test to the operation of a demonstration plant. Another two years were necessary to make brown coal tar hydrogenation to gasoline and diesel fuel a mature process. Then the economic depression slowed down development work but nevertheless in another two years, in 1931, the hydrogenation of brown coal was a reliable commercial process. Commercial production was made possible by government support in the form of a reduced excise tax for Leuna gasoline. This precarious position ended in 1933 when a contract with the government provided for an increase in production and guaranteed purchase of the gasoline at a price that covered the manufacturing cost.

The development of the Fischer-Tropsch process at the Kaiser Wilhelm Institute began in 1925 with catalysts that produced higher hydrocarbons. It was the result of many years of work with synthesis gas. Improvements of the catalysts and gas purification continued and, in 1934, the process was ready for the pilot plant. Operation of commercial plants started two years later.

The building of commercial plants after 1933 was, for both processes, the result of government decrees or of urging private industry. In all cases the government gave price guarantees for the products which made financing of the plants possible. Direct catalytic coal liquefaction was and remained the preferred and dominant process because of cost, product quality and the ability to adapt readily to changing requirements.

Acknowledgment

The author thanks Dr. Maria Hoering, Heidelberg, for many valuable suggestions and Mr. E. L. Grumer, St. Croix, for a review of the manuscript.

References

General: W. Birkenfeld, "Der Synthetische Treibstoff 1933-45"; Musterschmidt Verlag, Goettingen 1964
F. Ter Meer, "Die IG Farbenindustrie"; Econ Verlag, Duesseldorf 1953, p. 82 ff.

1) T. P. Hughes, "Technical Momentum in History: Hydrogenation in Germany 1898-1933: Past and Present No 44, August 1969, The Past and Present Society 106-32.

2) J. F. Ellis, BIOS Final Report 977, (1947)

3) K. Gordon, "Report on the Petroleum and Synthetic Oil Industry in Germany, London 1947.

Table 1

COAL LIQUEFACTION DEVELOPMENT

1910	F. Haber and C. Bosch, Ammonia synthesis, High pressure technology, hydrogen from coal
1913	F. Bergius, coal liquefaction without catalyst in slurry with oil in autoclaves
1921	Bergius pilot plant, low oil yield and quality
1923	BASF, Mathanol synthesis, M. Pier, oxide catalyst
1924	BASF, M. Pier, molybdenum and other sulfur resistant coal hydrogenation catalysts
1926	BASF at Ludwigshafen, semicommercial, two stage catalytic coal liquefaction
1927	100,000 t/y Demonstration plant start-up at Leuna
1929	Leuna, gasoline from brown coal tar mature process
1931	Leuna, gasoline from brown coal mature process Ludwigshafen, semicommercial bituminous coal liquefaction successful

Table 2

HYDROGENATION PLANT INVESTMENT COSTS

Plant:	Boehlen	Scholven	Gelsenberg
Raw material	Brown coal tar	Bituminous coal	
Capacity t/y	250,000	280,000	400,000
Barrels/day	5,800	6,500	9,300
Investment Cost excl. power gener. Million of 1935 M	80	117	166
Marks/annual ton	320	418	415
$/annual bbl (1$=2.50 M)	15.1	19.6	19.5

Table 3

GERMAN HYDROGENATION PLANTS

Startup Year	Location	Raw Material	Product Capacity t/y 1943/44
1927	Leuna	Brown Coal & Tar	650,000
1936	Boehlen	Brown Coal Tar	250,000
1936	Magdeburg	Brown Coal Tar	220,000
1936	Scholven	Bituminous Coal	280,000
1937	Welheim	Coal Tar Pitch	130,000
1939	Gelsenberg	Bituminous Coal	400,000
1940	Luetzkendorf	Tar, Oils	50,000
1940	Zeitz	Brown Coal Tar	280,000
1940	Poelitz	Bit. Coal & Oils	700,000
1941	Wesseling	Brown Coal	250,000
1942	Bruex	Brown Coal Tar	600,000
1943	Blechhammer	Bit. Coal & Tar	420,000

Total 12 plants: 4.23×10^6 t/y or about 100,000 bbl/d

Table 4

GAS SYNTHESIS DEVELOPMENT

1902	P. Sabatier, Methanation, Ni, Co, 1 atm
1913	BASF, Oxygenated compounds, 100 atm+
1922	F. Fischer & H. Tropsch, Oxygenated Cpds, 150 atm
1923	BASF, Methanol, 200 atm
1925	Fischer-Tropsch, Higher hydrocarbons, 1 atm
1927	Fischer-Tropsch, Pilot plant at KWI
1930	Kieselgur as support for Co/Th
1934	Licensee: Ruhrchemie AG, 100 m^3/h pilot plant
1935	Castrop-Rauxel, Pilot plant 1000 m^3/h
1936	Ruhrchemie, Commercial catalyst plant for 1 atm Beginning development of medium pressure synthesis Processes at KWI, Ruhrchemie, BASF, Lurgi

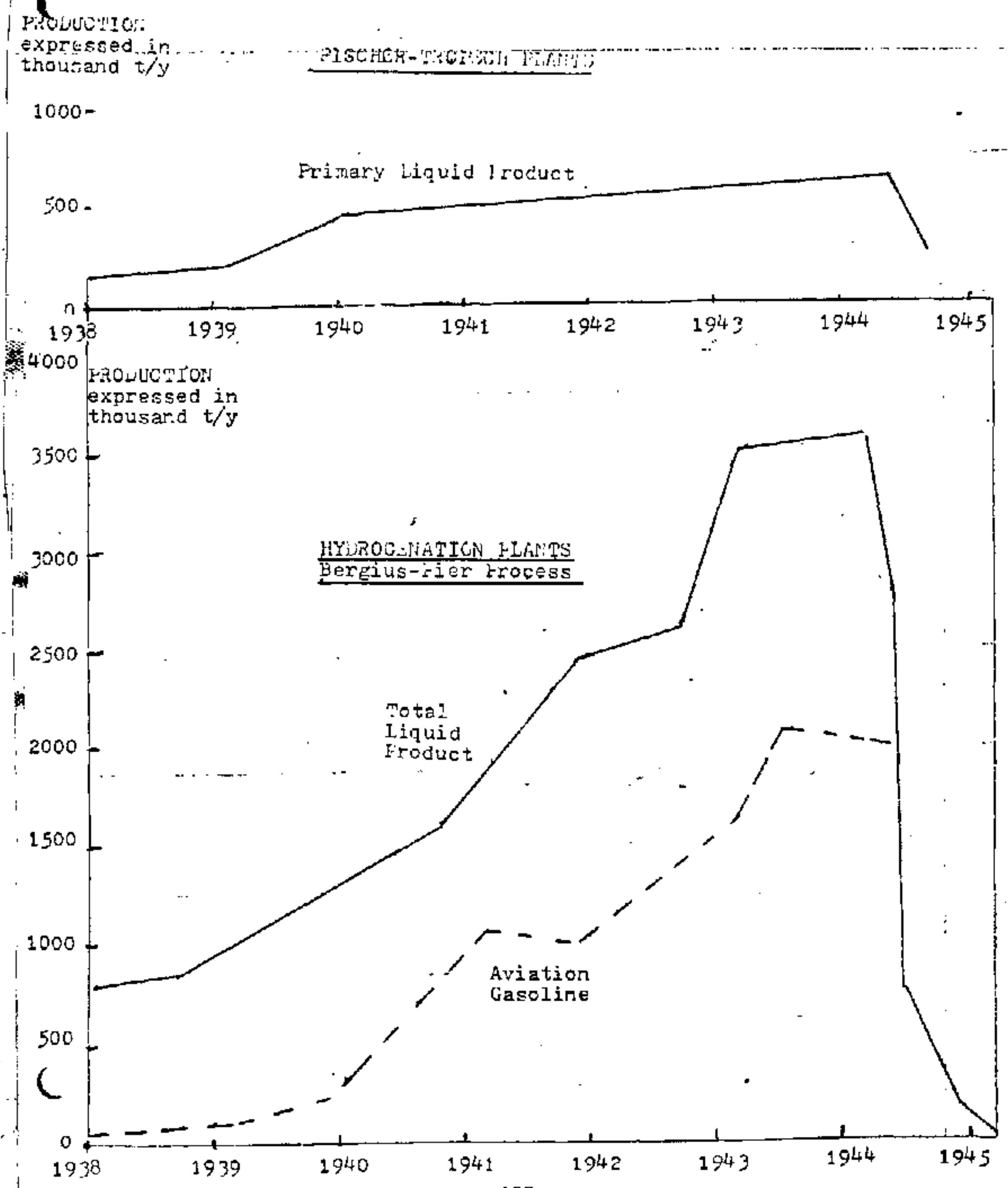
Table 5

GERMAN FISCHER-TROPSCH PLANTS

Startup Year	Location	Raw Material	Product Capacity t/y design
1936	Holten	Coke	70,000
1936	Moers	Coke, Gas	75,000
1936	Castrop-Rauxel	Coke, Gas	50,000
1936	Schwarzheide	Brown Coal Briq.	210,000
1938	Wanne-Eickel	Coke, Semicoke	60,000
1938	Bergkamen	Coke, Gas	75,000
1939	Dortmund	Coke	60,000
1940	Beuthen	Coke, Gas	60,000
1943	Luetzkendorf	Brown Coal	80,000

Total 9 plants: 740,000 t/y or about 18,000 bbl/d

Fig. 1.


PRODUCTION
expressed in
thousand t/y
FISCHER-TROPSCH PLANTS
1000
500
0
Primary Liquid Product
1938
1939
1940
1941
1942
1943
1944
1945
4000
PRODUCTION
expressed in
thousand t/y
3500
3000
2500
2000
1500
1000
500
0
HYDROGENATION PLANTS
Bergius-Pier Process
Total
Liquid
Product
Aviation
Gasoline
1938
1939
1940
1941
1942
1943
1944
1945