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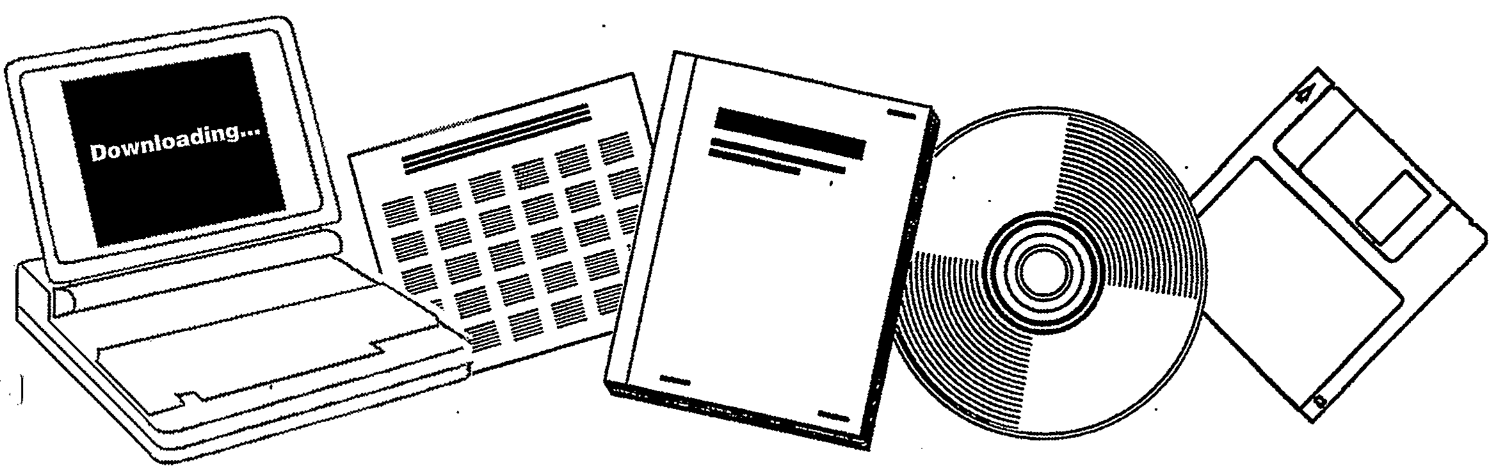

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MOTOR FUELS AND SNG FROM COAL

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Motorkraftstoffe und Ferngas aus Kohle

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POST OFFICE BOX 5500
LIVERMORE, CALIFORNIA 94550

by AD-EX®
3220 ALPINE ROAD, PORTOLA VALLEY
CALIFORNIA 94025 (415) 854-6732

MOTOR FUELS AND SNG FROM COAL

H. [illegible]LLER

Abstract

The classical coal-conversion processes for the production of motor fuels must be adapted to present economic and production conditions. Only the process sequence for Fischer-Tropsch synthesis plants has undergone continuous further development, stimulated by the existence of large industrial plants in this sector. Recently, methanol synthesis based on coal gasification and followed by gasoline synthesis has become possible on a large industrial scale. The economy

of the various processes for converting coal to motor fuels and SNG is compared. It is observed that there are proven conversion processes which guarantee competitive supplies in view of the price trend in the crude-oil market. Immediate construction of such plants to reduce the dependence of West Germany on crude-oil supplies is advisable.

Introduction

The cost of crude oil has risen by a factor of more than ten since 1973. Price discussions of the oil-producing nations against the background of limited worldwide oil reserves are responsible for this increase.

Oil, an easily exploitable and transportable energy source, generally cannot be replaced directly in use by other fossil raw materials -- such as coal and oil shale -- which are still present in greater reserves. Because of the refined present technology for oil use, to which our modern life-style is tuned, it is difficult to imagine, for example, the use of motors running on pulverized coal. Thus the secondary energy sources for the foreseeable period of the

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next decade must correspond largely to those which we obtain from oil refining. In the future, therefore, we shall turn to production from coal and oil-shale feedstocks as well, particularly in the case of motor fuels and middle oil.

The estimated worldwide coal reserves are 5 to 10 times as great as the heavy oil reserves associated with shale, clay or sand, and even more than 10 times as great as the crude-oil reserves.

The question is being increasingly raised in public of whether we now have technologies capable of operationally safe and nonpolluting production of the above-mentioned petroleum products from coal and oil shale. Moreover, the price level for crude oil at which such a process becomes economic is an open question.

The present discussion will deal only with the conversion of coal to motor fuels and to SNG. It will not touch on the feedstock situation of the chemical industry, which at present consumes only 6% of the crude oil produced worldwide (ca. 13% in West Germany). Thus the production of synthesis gas from coal, which is undoubtedly a topical problem for this branch of industry, will not be treated here either.

Classical coal-conversion processes

There are two classical methods for converting coal to oil:

- Fischer-Tropsch synthesis, and
- high-pressure hydrogenation according to Bergius.

Both methods of coal liquefaction had attained great importance in Germany in the thirties and forties. Up to 1945, 12 high-pressure hydrogenation plants and 9 Fischer-Tropsch plants producing 4.5 million tons per year of motor fuels were operating in Germany. The basis of the hydrogenation plants were low-ash bituminous coals, lignites and their tars. The basis of the Fischer-Tropsch synthesis plants were lignites, bituminous-coal coke and coking-furnace gas.

After 1945 only a few plants continued to operate and, in early 1950, an abundant supply of cheap petroleum rendered coal liquefaction uneconomic and thus meaningless.

The principle of the *Fischer-Tropsch synthesis* consists in converting synthesis gas (i.e., hydrogen + carbon monoxide) at low or medium pressures (e.g., 25 bar) and preferably over iron catalysts into liquid hydrocarbons of paraffinic or olefinic character, and dissipating the resulting heat of reaction. Characteristics of its range of products are an excellent diesel oil, a medium-grade gasoline and the simultaneous production of some valuable chemical feedstocks. The synthesis gas can be produced by gasification of coal of any origin. It must be refined for use in the synthesis. The bottleneck in the plants of the forties was insufficient capacity of the gas generators and very expensive, but technically unsatisfactory purification of the gas from gasification to obtain the necessary synthesis-gas quality.

In *coal hydrogenation*, molecular hydrogen or hydrogen as a substituent of solvents (coal extraction) is brought into direct contact with a coal slurry (sump-phase* reaction). under high pressure (300 to 700 bar), and usually in the presence of finely powdered iron catalyst. The considerable heat of reaction produced is removed by cold circulating gas. The products of this stage, i.e., gas and light, middle and heavy oil, as well as the sludge, which contains coal residues, ash and catalyst, must be subjected to further treatment and upgrading.

The IG process of the forties is still the only process in the world by which oil has been produced on a large industrial scale by coal hydrogenation. For renewed application of this process, s me process steps must be improved and made nonpolluting, particularly upgrading of the residue and production of hydrogen. To achieve economy, the high pressure level and the high specific hydrogen consumption must be lowered and the limited throughput capacity increased. A special feature of this process is that it requires the use of low-ash and dry coals.

* Translator's note: There is a distinction in German between liquid phase and sump phase.

Status of further and new developments

Fischer-Tropsch process

Development studies on this process have continued without interruption since the end of World War II. They have been concerned in particular with increasing the gas-generation capacity and designing an efficient gas-purification system. The SASOL fuel plant which started operation in South Africa in 1954 contained elements of these new developments: Lurgi pressure gasifier with considerably increased diameter and capacity as well as the newly established Rectisol process, in which all impurities in the crude gas, particularly the sulfur compounds, were eliminated almost completely in a single purification stage. Units with larger dimensions were also used in the actual synthesis part of this plant, and a new variant of the Fischer-Tropsch synthesis was introduced for the first time in the form of the Synthol process, in which conversion of the synthesis gas to liquid products occurs in flight-stream* reactors. The SASOL II plant, which is 10 times larger and is now being started up, has to exhibit further improvements in technology and apparatus. It will have a simpler flow chart. The new gas-generator design permits coal throughputs per unit of ca. 1000 tons

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* Translator's note: Literal for the German "Flugstrom" -- "Flug" = flight, flying; "Strom" = stream, current, flow.

per day, and even the Rectisol and Synthol units have been considerably enlarged and thus specifically give lower plant costs and consumption factors. No wastewater is discharged to the outside from this plant, with consequent ecological advantages. The entire wastewater is worked up and recycled to the overall process, particularly as cooling water.

Methanol synthesis

Up to now the use of methanol has been limited almost exclusively to the chemical industry. Around 10 years ago, the production of methanol from synthesis gas was basically improved and made less expensive by the development of low-pressure processes (ICI, Lurgi), which supplanted the previously used high-pressure processes with pressures around 300 bar. In this way the use of methanol as an energy source became extremely interesting, because of the advances described in both coal gasification and gas purification. The technology is one in which all parts are already being operated in large units. Since methanol is formed very selectively in the conversion of synthesis gas on special catalysts -- in contrast to the Fischer-Tropsch reaction -- and thus fairly extensive secondary processing is unnecessary, the capital investment costs are also correspondingly lower.

In experimental long-term tests in the automobile industry, methanol has been mixed with conventional fuels for commercial internal-combustion engines, and has exhibited economic (and ecological) benefits in concentrations up to 15% by volume. The use of methanol alone is even being considered, since only slight changes to the carburettor and also preheating of the mixture are necessary. Usable designs exist to prevent disadvantages resulting from the fact that methanol is more soluble in water than are the conventional fuels.

A promising variant for the use of methanol as fuel has been developed by Mobil Oil. Methanol has successfully been transformed to high-octane gasoline with an efficiency of more than 90%. The development is so advanced that, by using certain reactor systems, this process can be applied immediately on an industrial scale as an adjunct to coal-methanol plants.

High-pressure coal hydrogenation

In contrast to the above-mentioned processes, the development of coal hydrogenation has not been continuous. Only in the course of the seventies were development projects of consequence carried out -- at fairly high cost -- on the basis of the old Bergius and IG processes and pilot plants constructed. As a result, the process ought to be improved in terms of economy and nonpolluting capability as well as of the possibility of building larger units.

The common goal of the various projects is mainly to lower the hydrogenation pressure, if necessary by omitting hydrogenation of the less reactive coal components. Efforts are being made to use distillation for separation of the larger quantities of residue which would then be expected. The bottom product discharged from distillation in the form of a pitch-like distillation residue with high melting point and considerable mineral content is then to be gasified with oxygen to obtain the hydrogen necessary for hydrogenation. This gasification system itself is a part of development projects.

Instead of undertaking separation of the solid by distillation, some developments have retained the old IG principle of filtering and centrifuging. Another variant under study is separation by gravity sedimentation.

Research concerned with the use of new catalysts is also to be mentioned.

The numerous R&D projects in progress still have to be proved in terms of engineering and mechanical reliability of the chosen layouts.

In 1977, an experimental plant for continuous production of coal oil was started up in West Germany at the Bergbau-Forschung in Essen. The next step is a semi-industrial demonstration plant for a capacity of 120 tons per day of coal oil. This is now being constructed in Bottrop, and is to be operated jointly by Ruhrkohle AG and Veba Oel AG. Saarbergwerke AG is building a pilot plant for a capacity of 6 tons per day in Völklingen-Fürstenhausen. Numerous developments are proceeding in the USA, and the following seem to stand out:

- Solvent-Refined Coal (SRC)-II process of Gulf Oil Corporation.
  The construction of a demonstration plant for 6000 tons per day of coal throughput, with participation of Ruhrkohle AG and a Japanese group, is planned. The intention is to produce coal oil there as fuel for power plants and industrial furnaces.

- H-Coal process of Hydrocarbon Research Inc.
  Catalytic hydrogenation of coal slurries in reactors with bubbling catalyst bed. A pilot plant for a coal throughput of 600 tons per day is under construction.

- Synthoil process of the Bureau of Mines.
  Special reactor engineering and separation of the liquid products from the solid fraction by centrifuging and low-temperature carbonization. A pilot plant for 8 tons per day is under construction.

- Exxon Donor-Solvent process.
  Hydrogenation of the coal by hydrogen-donating solvents without catalyst (Pott-Broche method). A pilot plant for 250 tons per day of coal throughput is under construction (Ruhrkohle AG is participating).

In all coal-hydrogenation processes, the coal must -- in contrast to coal liquefaction by the Fischer-Tropsch synthesis and to coal-based methanol production -- be specifically suited to the process being used and to its system components. The influence of the coal on the process cannot be estimated reliably without extensive preliminary tests.

The coal oil produced in coal hydrogenation is rich in aromatics and is thus particularly suitable for the production of high-octane fuel for internal combustion engines.

The renewed activity now occurring in coal hydrogenation and in its adaptation to modern, high-capacity industrial production conditions does not promise widespread industrial use of this process before the end of the eighties.

The situation is different for tars produced during low-temperature carbonization or gasification of coal. Commercial plants for hydrogenation of tars or tar fractions fall within the scope of the state of the art. Depending on the sphalt content, this process operates in the gas, liquid or sump phase.

Methane synthesis

In common with the worldwide oil reserves, the reserves of natural gas are also very limited. The production of methane (SNG*; piped gas) from coal is therefore an urgent topic. Light fuel oil can be saved, particularly in the industrial countries, by expanding the supply of natural gas. In this way the fuel market for diesel oil can be relaxed.

Since 1972, numerous large-scale projects on the basis of the LURGI pressure-gasification process have been in the planning stage in the USA. The decision to proceed with one of these projects has now been made, and ordering of the equipment has begun. Start-up of this first commercial SNG plant will take place as early as mid-1983. A serious start to the construction of SNG plants has also been made in West Germany and in the Netherlands.

The technology of these plants is based on the development work and improvements of recent years in the known coal-gasification process and in gas purification, particularly with respect to the construction and operation of large units for the individual parts of the plant. In this context it was possible to take advantage of experience from the construction of the SASOL plant, since the head end of the overall process used there can be adopted almost without change for SNG plants.

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* Note in original: SNG = substitute natural gas.

It is advantageous for an SNG plant that as much methane as possible is produced in the primary stage of the coal-gasification plant, so that only a small additional part of the gas (Co, H_2 and CO_2 fractions) is converted to methane in a methane-synthesis stage in the last step of the process. This stage is also commercially available following years of operation of a demonstration plant.

Economy of coal conversion

Useful statements on the question of economy can be made only regarding processes for which there is complete clarity about the technological flow chart and whose industrial design on the basis of such a flow chart exists in detail, with references to operational trials if at all possible.

The economy of coal conversion to liquid and gaseous products depends categorically on the following factors:

a) cost and quality of the coal,

b) thermal efficiency of the conversion,

c) capital investments.

From these it is possible to calculate the production costs.

a) Cost and quality of the coal

For coal-conversion plants using the Fischer-Tropsch synthesis, the methanol synthesis and the methane synthesis, no special requirements are imposed on coal quality.

In these processes, the coals are first converted to gas by means of gasification plants. Such plants (in contrast to the process of high-pressure coal hydrogenation) permit the use of inexpensive, low-grade coals. For example, a geologically young bituminous coal with ca. 30% ash content is used in the SASOL plant.

A price of DM 100.00/ton, corresponding to ca. DM 15.00/Gcal, can be assumed for imported coal. Rhine lignite can also be estimated at this price, while the Ruhr and Saar coals are much more expensive.

Since the capital investment costs of every coal-conversion plant are around 5 times higher than those of a petroleum refinery because of the more expensive process for production of fuels from solid coal, the price per calorie of the coal must, if for no other reason than this, basically lie well below that of crude oil in order to achieve profitability.

b) Thermal efficiency (relative to lower calorific value)

This efficiency indicates the fraction of the heat content of the assumed coal (bituminous coal with 20% ash and 5% moisture) found in the end products. The difference from 100 represents losses occurring during conversion. Thus the efficiency is defined as the caloric value of the production (gasoline, diesel oil, liquefied petroleum gas, SNG) relative to the caloric value of the coal used for conversion and production of working stock.

For comparison, it is worth mentioning that a refinery designed for fuel production has a thermal efficiency of ca. 85%.

The following efficiencies are obtained for the process variants mentioned above:

1.	Fischer-Tropsch synthesis	
1.1	Production of motor fuels*	40%
1.2	Production of motor fuels* and SNG	58%
2.	Methanol synthesis	
2.1	Production of methanol	49%
2.2	Production of methanol and SNG	62%

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* Note in original: Motor fuels: gasoline, diesel oil and liquefied petroleum gas.

3. Methanol synthesis and Mobil Oil process

3.1 Production of gasoline and liquefied petroleum gas — 45%

3.2 Production of gasoline, liquefied petroleum gas and SNG — 61%

4. Methan synthesis (SNG)

With Lurgi pressure gasification — 63%

This list shows that the efficiency depends strongly on whether secondary products formed, especially the SNG (methane fraction), can be made directly accessible for use. Since most industrial countries, including West Germany, have established piped-gas systems, this is probably true in general.

The efficiency of high-pressure coal hydrogenation to motor fuels and liquefied petroleum gas is calculated for comparison as 56%, assuming that the goal of development is reached for this process (in particular: 300 bar pressure; separation of residue by distillation; gasification of the residue with remaining hydrogen balance). Because of the sensitivity of this process to the coal used, higher coal costs must normally be expected. The coal with 20% ash assumed here is in no case usable in this process. Preliminary ash removal would be necessary.

c) Capital investments

The costs for a turnkey plant, including the necessary secondary plant and plants for production of power and working stock on the basis of bituminous coal, were determined for the individual process variants. A plant size of 2 million tons liquid product per year was assumed. In determining the fixed production costs, 15.4% of the invested capital was assumed with straight-line depreciation for amortization and interest. Including personnel, general expenses, repairs and maintenance, insurance, and interest on floating capital, the total comes to 24.2% of the invested capital.

Production costs

The above basis assumptions (including coal price of DM 15.00/Gcal) and calculations lead to the following production costs per heat unit in the product:

		DM/Gcal product
1.	Fischer-Tropsch synthesis	
1.1	Production of motor fuels	90
1.2	Production of motor fuels and SNG	53

		DM/Gcal product
2.	Methanol synthesis	
2.1	Production of methanol	70
2.2	Production of methanol and SNG	48
3.	Methanol synthesis and Mobil Oil process	
3.1	Production of gasoline and liquefied petroleum gas	79
3.2	Production of gasoline, liquefied petroleum gas and SNG	50
4.	Methane synthesis (SNG)	
	With Lurgi pressure gasification	44

For comparison, it is worth indicating the estimated figures which would be obtained for high-pressure hydrogenation, assuming that the goal of development is reached for this process (in particular: 300 bar pressure; separation of residue by distillation; gasification of the residue with remaining hydrogen balance). Because of the requirements of this process for special coal types and the addition of special coal preparation, higher coal costs must be expected. The evaluation of the hydrogenated coal was based on prices of DM 20.00/Gcal and DM 25.00/Gcal (this is approximately the value of German bituminous coal).

The following production costs were obtained for high-pressure hydrogenation of coal to motor fuels and liquefied petroleum gas:

- for DM 20.00/Gcal coal: DM 63.00/Gcal products;
- for DM 25.00/Gcal coal: DM 71.00/Gcal products.

If the above list of prices for the heat content of the resulting product is expressed in prices per unit weight of liquid product (gasoline, diesel oil, liquefied petroleum gas), the values below are obtained. It is to be noted that these prices are averaged for the gasoline, diesel-oil and liquefied-petroleum-gas fractions. Where SNG occurs as a by-product, it is included in the calculation with the same price per unit heat as the liquid products.

		DM/ton product
1.	Fischer-Tropsch synthesis	
1.1	Production of motor fuels	940
1.2	Production of motor fuels and SNG	570
2.	Methanol synthesis	
2.1	Production of methanol	336
2.2	Production of methanol and SNG	270
3.	Methanol synthesis and Mobil Oil process	
3.1	Production of gasoline and liquefied petroleum gas	820
3.2	Production of gasoline, liquefied petroleum gas and SNG	540

	DM/ton product
4. Methane synthesis (SNG)	
With Lurgi pressure gasification	524
For comparison:	
High-pressure coal hydrogenation	
(coal price DM 20.00/Gcal	680
High-pressure coal hydrogenation	
(coal price DM 25.00/Gcal)	770

If the proceeds for the SNG lie below the price per unit heat for the sum of the products, the liquid products must naturally compensate for the difference. With a credit of DM 40.00/Gcal for SNG, the production costs for gasoline, diesel oil and liquefied petroleum gas would increase to DM 730.00/ton in case 1.2 (Fischer-Tropsch synthesis) and DM 580.00/ton in case 3.2 (methanol-Mobil-Oil synthesis).

By comparing these values to those for production of the above-mentioned liquids from crude oil at the present international prices, we obtain:

base crude-oil price: US $30.00/barrel = DM 610.00/ton;
base crude-oil price: US $35.00/barrel = DM 700.00/ton.

As already obvious from the list of thermal efficiencies, the tables of production costs also reveal the significance of selling the methane formed as a by-product in the Fischer-Tropsch and methanol products for piped-gas supplies.

How many coal-conversion plants for West Germany?

To answer the question of how many coal-conversion plants ought to and can be built in West Germany, the possibility of obtaining the necessary coal must first be discussed. As far as German coal is concerned, it must be pointed out that, within the existing production capacities, the flexibility for increasing production is naturally limited. The development of new bituminous-coal mines requires at least 8 years. Since more than 60% of German coal is used for power generation, decisions on the construction and operation of nuclear power plants are important for easing the future demand for coal. This is particularly true for German lignite. Imported coals, which are usually much cheaper than German bituminous coals, could be converted in coal-conversion plants on sites near the coast. These coals can even be procured in large quantities and with long-term contracts, although at present there are still no international commercial undertakings of the scope that exist for petroleum.

In early 1979 the International Energy Agency (IEA) set a target of 5% reduction in petroleum consumption for 1979. Instead of a reduction in oil consumption, West Germany had to report a 3% increase. At the total petroleum consumption of ca. 140 million tons per year, a 5% reduction would correspond to an equivalent of ca. 20 million tons of coal for conversion plants. This quantity ought to be obtainable without great difficulties from the German mines together with coal to be imported. In the first stage of construction of plants to produce motor fuels and SNG, 2 to 4 plants would have to be installed, depending on boundary conditions, to process the above-mentioned quantity of coal. The capital required would run to between 12 to 16 billion DM (price basis at the end of 1979). Between 7 and 10 million engineering manhours would be required and ca. 300,000 tons of equipment and material would have to be installed.

Thus substitution of 5% of the petroleum by conversion of coal to usable finished products such as motor fuels seems possible. At the same time, the combustion of oil for power generation must be greatly reduced, the production of light oil fractions from heavy oil in cracking plants must be intensified, and further prospects for replacing fuel oil type EL by natural gas must be created. Regarding these possibilities for saving oil, a strategy would have to be worked out to reduce the dependence on foreign oil.

Substitution of the major part of the German oil consumption of 140 million tons per year by coal will not be feasible by coal-conversion plants in Germany even in the long term, as can easily be seen by extrapolating the above-mentioned figures representing the demand for 5% substitution. For economic and ecological reasons, plans for the long-range future must be aimed at construction of coal-conversion plants in the immediate proximity of coal occurrences in the world. It is easier to transport liquid products than coal.

Conclusions

- Proven coal-conversion processes exist which justify immediate use on an industrial scale.
- The costs of producing motor fuels and SNG from coal are already in range of profitability, given the present price of crude oil. The rate of 15.4% for amortization and interest used as basis for the calculations could be improved above all by government action, which would provide an incentive for the immediate construction of coal-conversion plants.
- The construction time for coal-conversion plants must be estimated as 5 to 6 years. Given the distribution of ownership of petroleum and coal, it is to be expected that the price for petroleum will increase faster than that for coal within such a period. Moreover, because of permanent inflation, plants built now will require lower capital investments than plants to be built later. Both argue for an early decision to start construction.

- Both domestic and foreign coals are to be considered as the feedstock basis for such plants. The economy of the project and the choice of location are influenced in particular by such considerations.

- A 5% reduction of petroleum consumption in Germany seems possible by producing motor fuels from coal by several plants constructed at the same time.

- For example, the production of 5 million tons per year of methanol, which would be mixed with motor fuel in a proportion of 15%, could save ca. 3 million tons per year of gasoline. An additional 4 million tons per year of gasoline could be produced by the methanol synthesis and Mobil Oil process. The SNG formed as by-product would, if used for heating purposes, liberate diesel fuel.

- To maintain the leading role which German technology still commands in the research field of coal conversion, appropriate large plants ought to be built in Germany at an early date. This will also help our export trade (export of technology), which seems particularly important considering the increasing expenses for importation of crude oil.

- Legislative action is needed to simplify the acquisition of construction and operating licenses for energy-important plants by clear regulations, so that the cumbersome procedures and the very long processing time in the preparatory stages can be shortened.

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