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OPTIMIZING THE COMBINATION OF A FISCHER-TROPSCH SYNTHESIS WITH COAL HYDROGENATION FOR THE PRODUCTION OF MOTOR FUELS

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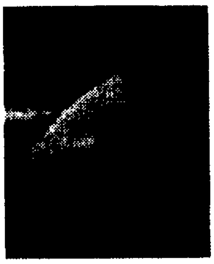

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Technological Research and Development
- Non-Nuclear Energy Technology -

Optimizing the Combination of a Fischer-Tropsch Synthesis with Coal Hydrogenation for the Production of Motor Fuels.

By

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Contents

Part I

1. Introduction

At the request of the Ministry for Research and Technology of the German Federal Republic a seminar on the production of motor fuels from lignites and bituminous coals was given to the Australian Federal States of New South Wales, Queensland and Victoria in March 1976. This seminar was prepared by a German consortium under the leadership of Prof. Dr.Dr. K.-H. Imhausen and was based on the Fischer-Tropsch synthesis.

The following German companies belonged to the consortium:

Imhausen-Chemie GmbH, Lahr
Lurgi Kohle und Mineralöltechnik GmbH, Frankfurt am Main
Rheinische Braunkohlenwerke AG, Köln
Ruhrchemie AG, Oberhausen
Ruhrkohle AG, Essen
Salzgitter Industriebau GmbH, Salzgitter
Uhde GmbH, Dortmund

In May, 1977, the combination of Fischer-Tropsch synthesis, coal hydrogenation and gasification of the hydrogenation residues was proposed to the German consortium in place of a Fischer-Tropsch synthesis for the conversion of coals into motor fuels. This combination has process-technological and economic advantages as compared to a purely Fischer-Tropsch synthesis and is based on modern German know-how.

Although the individual processes are known, their combination in the proposed form strikes out into new technological territory. The consortium therefore proposed that the process combination should be investigated as to its technical and economical aspects in a feasibility study. In order to have the required information available for this feasibility study as well as the most favourable approach, the Federal Ministry for Research and Technology (FMRT) gave, on 1.02.1978, a contract to the German consortium for a preliminary optimization study.

2. Objective

At the suggestion of the FMRT the feasibility study was to be preceded by a stage in which the process sequences were to be optimized.

In agreement with the Australian partner - the Department of National Development (DND) of the Australian Government - and the FMRT the optimization is to be based on a plant with an annual output of 3×10^6 te motor fuels and liquefied gas, with lignite and with bituminous coal respectively as the starting materials. The product distribution is to accord with given market requirements and is to be approximately

45% motor fuel (spark ignition)
45% diesel oil
10% liquefied gas

In the calculations the Fischer-Tropsch synthesis with suitable gasification processes as well as the high pressure coal hydrogenation with hydrogen production, gasification of hydrogenation residues and purification of hydrogenation gas, and their combination, are to be considered and to be presented in a number of variations.

The product distribution, the coal and fresh water requirements as well as the byproducts which cannot be converted into motor fuels are to be shown in the variants, and the production costs are to be worked out using the estimated investment costs and assumed prices for coal. Simplifying assumption are admissible so long as comparability is maintained.

Any location-specific requirements, environmental protection, coal and water supply and infrastructure are left out of consideration.

3. Delimitation of the Study

3.1 Coal Qualities

The study is based on the following coal analyses as representative of the Australian lignites and bituminous coals for the hydrogenation and gasification processes and for the generation of energy.

3.1.1 Lignite

Carbon	22.89 wt %
Oxygen	8.82 wt %
Hydrogen	1.62 wt %
Nitrogen	0.24 wt %
Sulfur	0.10 wt %
Ash	0.34 wt %
Water	65.99 wt %
Calorific value H_u	1610 kcal/kg
Calorific value, dry, H_u	5950 kcal/kg

Coal analysis, dry basis

C	67.98 wt %
O	26.20 wt %
H	4.81 wt %
N	0.71 wt %
S	0.30 wt %

3.1.2 Bituminous Coal

Carbon	77.09 wt %
Oxygen	6.61 wt %
Hydrogen	4.54 wt %
Nitrogen	1.53 wt %
Sulfur	1.52 wt %
Ash	4.33 wt %
Phosphorus and chlorine	0.15 wt %
Calorific value H_u	7329 kcal/kg
Calorific value, dry, H_u	7690 kcal/kg

Coal analysis, dry basis

C	84.30 wt %
O	7.23 wt %
H	4.96 wt %
N	1.68 wt %
S	1.67 wt %
P + Cl	0.16 wt %

3.2 Limitations in Selection of Processes

The study is based on processes which are the property of the consortium partners or which are available to them.

These are in particular:

- Methods of coal preparation, drying and briquetting
- Fischer-Tropsch synthesis
- Liquid phase hydrogenation of lignites and bituminous coals
- Pressure gasification of lignite or bituminous coal in lumps
- Pressure cracking of hydrocarbons
- Processes for the production of hydrogen, for gas purification, for gas separation and for gas conditioning
- Hydrorefining and cracking of coal oils
- Reforming of naphtha fractions
- Hydrocracking of higher molecular weight n-paraffins
- Processes for isomerization and alkylation
- Processes for purification of process effluent

3.3 Plant Boundaries

3.3.1 Process and Utilities Plants

These include the process plants, boiler house and power station, production of deionized water and treatment of condensate as well as cooling plant for cooling water. They start at the points of coal and fresh water supply and end at the points of product discharge at the tail end of the last process plant in each line and with the discharge of ash and effluent to outside the plant boundaries. The effluent treatment plant is not included.

3.3.2 General Facilities and Ancillary plant

These include roads, squares, administrative buildings, laboratories, workshops, storage facilities for chemicals, catalysts and spare parts, employee facilities, fire and gas protection and general safety installations, storage of intermediate and final products, loading, general transport installations, mobile lifting gear, sewerage, connecting piping between the process and utilities plants as well as high tension switch gear and electrical distribution installations up to the output side of the low voltage mains distribution.

3.4 Capacity Data, Losses and Consumption Data for Utilities, Raw Materials and Auxiliary Materials

The study is uniformly based on 8000 operating hours per year for both process and utilities plants.

Energy and material balances are worked out without considering transport and distribution losses, unless expressly noted otherwise.

Data on consumption of utilities, raw materials and auxiliary materials and on production of intermediate and final products are in the relevant mass unit per hour. The summary of production rates for main and byproducts and of coal consumption is in tonnes per year.

The term 'mains gas' is used for a mixture of methane and ethane/ethylene, if it is separated from the gas streams and is shown separately as a joint product with motor fuel production. The production rate is shown as the respective mass unit per hour or per year.

The unit 'cal', which since the 1 1 1978 is no longer admissible, as well as its multiples, is used in this study in place of Joule (J) and its multiples.

3.5 Product Specifications

The further processing of the primary products from the Fischer-Tropsch synthesis and the coal hydrogenation is to be of such a nature that the following values are attained.

Spark ignition motor fuel

Density	$d_{15^\circ C}$	not less than 0.72
	RON	not less than 98 (0.15 ml TEL/l)
Diesel fuel	$d_{15^\circ C}$	not less than 0.815 max. 0.845
	cetane number not less than 50	

The other specifications, according to DIN 51600 and 51601, are to be guaranteed: deviations must be identified in detail.

Liquefied gas

Heating value H_u	not less than 10,600 kcal/kg
Butane content	not more than 65 wt %
Methane/ethane	not more than 5.5 wt %

Mains gas

A mixture of methane and ethane/ethylene with a heating value H_u within the limits of 8,550 to 9,600 kcal/m_n^3, free from hydrogen, oxides of carbon and nitrogen

3.6 Estimate of Investment Costs

3.6.1 The investment costs are determined separately for each process plant with an allowable error of 25%. They are to be understood for a turn-key plant in the German Federal Republic and include design and engineering costs. The estimates are based on average prices current in the German FR in 1978.

3.6.2 The investment costs or the investment capital are defined as the sum total of the costs for process plants, utilities and auxiliary plant. The cost of spares, catalysts and chemicals as well as licenses and know-how fees are not part of the investment capital unless specially mentioned. Additions to the investment capital for interest due during the period of construction, erection and commissioning have also been left out of consideration. The same applied to wages and salaries etc during the erection and commissioning period, insurance costs, working capital and coal requirements during the commissioning period.

3.6.3 A productive capacity of 3×10^6 te motor fuel and liquefied gas per annum and a total works area of 2,300 x 1,500 m are assumed for all variants. Costs of land are not included in the investment capital.

3.7 Simplified Cost Calculation

The term 'costs' will here be used for the sum of the annual costs of capital and of coal. The former will be taken as 14.7% of the investment capital, as was done in the 1976 seminar, made up as follows:

depreciation and interest	10.2%
maintenance and repairs	3.5%
taxes and insurance	1.0%

In a further calculation these annual capital charges were taken as 20%, so as to be able to gauge the influence of capital charges on total costs; here 15% was taken for depreciation and interest, 4% for maintenance and repairs and 1% for taxes and insurance.

The cost of coal in the cost calculations was taken as DM 5.00/Gcal in the first instance. Suitable graphs make it possible to estimate how far the price of coal has to be reduced in order to produce motor fuels and liquefied gas at the same 'costs' in a plant with a higher capital cost and also a possibly higher coal consumption as in a plant which is less capital-intensive and perhaps also uses less coal.

OPTIMIZING THE PRODUCTION OF MOTOR FUELS FROM COAL

- RESULTS OF THE ANALYSIS -

PART II

CONTENTS

PART II

1. Objective

The objective was the technical and economic investigation of the production of motor fuels from lignite and from bituminous coal. An annual plant capacity of three million tonnes of motor fuel was chosen as the model unit. The products were to comprise 45% motor fuel (spark ignition, RON 98), 45% diesel oil (cetane number 50) and 10% liquefied gas.

For lignite comparisons were to be made of

> the high pressure hydrogenation with the Fischer-Tropsch synthesis

and for bituminous coal of

> the combined process, consisting of high pressure hydrogenation and Fischer-Tropsch synthesis, with the Fischer-Tropsch synthesis

It was not at first the objective to produce mains gas with the motor fuels. Work on the project indicated, however, that the simultaneous production of motor fuels and mains gas has particular economic advantages. The mains gas variant has therefore been included in the scope of the analysis.

2. Procedure and Limitations

For various reasons the possibilities for the achievement of the objective had to be limited. The processes had, therefore, to be selected to a certain extent from the start, particularly from the point of view of process technology.

The characteristic features of the process sequences investigated are shown in Tables 1 and 2, using relevant abbreviations.

Table 1

Process Features in the Processing of Bituminous Coal

	Process	Production of	Synthesis gas produced		Provision of hydrogen	
			from	process	recovery	process
Fischer-Tropsch synthesis						
Bit. Coal I	FT	MF	Coal	Texaco	L.T.S.	-
Bit. Coal II	FT	MF	Coal	Lurgi	L.T.S.	-
Bit. Coal III	FT	MF + MG	Coal	Lurgi	L.T.S.	-
Combination process						
Comb. Installation I	HPH+FT	MF	Coal+ Hydrog.	Texaco	gas scrubbing	autotherm cracking
Comb. Install. II	HPH+FT	MF	Residue	Texaco	L.T.S.	steam reforming

Abbreviations

FT = Fischer-Tropsch synthesis
HPH = High pressure hydrogenation
MF = Motor fuels including liquefied gas
MG = Mains gas
L.T.S = Low temperature separation

The variant "Combined installation I" has only been investigated from the process technological side. From this it appeared that its energy consumption is less favourable than the variant "Combined installation II" investigated in parallel.

Table 2

Process Features in the Processing of Lignite

	Process	Production	Synthesis gas production		Hydrogen supply	
			from	process	from	process
Fischer-Tropsch Synthesis						
Lignite I	FT	MF	Coal	Lurgi	-	L.T.S
Lignite II	FT	MF + MG	Coal	Lurgi	-	L.T.S
Lignite III	FT	MF	Coal	Lurgi	-	L.T.S
High pressure hydrogenation						
Hydrogenation, autothermal cracking	HPH	MF	Coal	Lurgi1)	Hydrogen residues residual gases	Texaco autothermal cracking
Hydrogenation, steam reforming	HPH	MF	Coal	Lurgi1)	Hydrogen residues residual gases	Texaco steam reforming
Combined process						
Comb. Installation I	HPH + FT	MF	Coal	Lurgi2)	Hydrogen residues residual gases	Texaco autothermal cracking
Comb. Installation II	HPH + FT	MF + MG	Coal	Lurgi2)	Hydrogen residues residual gases	Texaco autothermal cracking

Notes:

1) Only production of heating gas
2) Production of synthesis gas + heating gas

The variant Lignite I has been completely worked through from the process technological point of view. It was not investigated further because of the extremely low octane number of the motor fuel due to the absence of a naphtha reformer as in Lignite III.

3. Tabular Summary

Tables 3 - 6 give brief information about the results of the work. Here Tables 3 and 4 indicate the product distribution, the product properties and the thermal efficiency. Tables 5 and 6 then give a summary of capital investment and coal consumption. Details, particularly the analysis, are reserved for the following sections.

Table 3

Bituminous Coal - Processing

Product distribution, RON4), CN5), efficiency

	Production in %						
	MF1)	DF2)	LPG3)	RON4)	CN5)	therm. effy. %	mains gas supplied
Target	45	45	10	98	50		-
Fischer-Tropsch synthesis							
Bit. Coal I	40	54	6	93	75	42.4	-
Bit. Coal II	44	50	6	95	71	46.0	-
Bit. Coal III	46	49	5	96	69	57.2	+
Comb. process							
Comb. Inst. I	48	41	11	98	51	-	-6)
Comb. Inst. II	48	41	11	98	51	52.3	-

Notes:

1) Spark ignition motor fuel (RON 98)
2) Diesel oil
3) Liquefied gas
4) RON 98 with 0.15 ml TEL/l
5) Cetane number
6) See section 6.2.2 - mains gas

Table 4

Lignite Processing

Product distribution, RON, CN, efficiency

	Production as %					Therm. efficiency %	Mains gas supplied
	MF	DF	LPG	RON	CN		
Target	45	45	10	98	50	-	-
Fischer-Tropsch synthesis							
Lignite I	47	48	5	92	73	-	-
Lignite II	47	47	6	96	72	58.4	+
Lignite III	45	50	5	95	73	46.9	-
High pressure hydrogenation							
Hydrogenation autothermal cracking	40	45	15	99	52	52.2	-
Hydrogenation steam ref.	41 (54)	47 (29)	12 (17)	99 (98)	52 (53)*	51.6 -	- -
Comb. process							
Comb. Inst. I	43	47	10	97	60	49.9	-
Comb. Inst. II	42	48	10	97	60	54.4	+

*The figures in ( ) show the maximum possible quantity of MF

Table 5

Bituminous coal processing

Capital investment and coal consumption

3,000,000 te/yr liquid products 1)

	Capital investment 10^6 DM for				Coal consumption te/yr
	Process plant	Utilities	Offsites	Total	
Fischer-Tropsch synthesis					
Bit. Coal I	3,116	1,093	1,169	5,378	9,380,250
Bit. Coal II	2,741	1,127	1,094	4,962	8,647,775
Bit. Coal III	3,041	1,239	1,171	5,451	12,163,120 2)
Comb. proc.					
Comb. Inst. I	-	-	-	-	-
Comb. Inst. II	2,560	785	951	4,296	7,910,000

Notes:
1) Liquid products = MF + DF + LPG
2) With mains gas 2,355,800 te/yr

Table 6

Lignite Processing

Investment costs and coal consumption

3,000,000 te/yr motor fuels and liquefied gas

	Investment costs in 10^6 DM for				
	Process plant	Utilities plant	Offsites	Total	te/yr Coal consumption
Fischer-Tropsch synthesis					
Lignite I	-	-	-	-	-
Lignite II	4,041	1,865	1,444	7,350	62,248,000 1)
Lignite III	3,391	1,386	1,233	6,010	40,976,000
High Pressure Hydrogenation					
Hydrogenation autotherm cracking	2,767	1,050	924	4,750	36,600,000
Hydrogenation, steam reforming	2,750	957	908	4,615	37,000,000
Comb. Proc.					
Comb. Inst. I	-	-	-	5,215	39,000,000
Comb. Inst. II	3,523	1,345	1,118	5,986	46,800,000 2)

Notes: 1) 2,355,800 te/yr mains gas
2) 895,200 te/yr mains gas

4. Analysis of the Production of Motor Fuels and Liquefied Gas from Bituminous Coal : Details

4.1 Production of Motor Fuels and Liquefied Gas from Bituminous Coal

4.1.1 Fischer-Tropsch Synthesis

The two versions have the same concept of the synthesis with the subsequent processing - also called refining - and are distinguished only by the method of synthesis gas production. Bituminous Coal I is based on the Texaco process while in Bituminous Coal II the synthesis gas is produced by the Lurgi Pressure Gasification Process. In the latter case there are oily byproducts, which are hydrogenated. The equipment for the synthesis in Bituminous Coal II is thus smaller. The target product distribution cannot be achieved.

As can be seen from Table 7, diesel oil production preponderates in both cases. This can be reduced with a consequent increase in the quantity of (spark ignition) motor fuel, but then both the density of the latter and its octane number are lower.

In both cases the liquefied gas production is 6%, which is less than the target figure of 10%. Production cannot be increased since propylene, butylene, butane and isobutane are used for the production of alkylate.

The motor fuel does not meet target figures for either density or octane number.

The diesel oil has an excellent cetane number, see Table 7, but its density is below the norm. However, the density is compensated by a high heating value, so that the volumetric heating value of the diesel oil corresponds to that of a petroleum product.

Table 7

Fischer-Tropsch Synthesis based on Bituminous Coal

	Distribution wt. %1)			Motor Fuel (Spark ignition)		Diesel Oil		Therm. Efficiency %
	MF	DF	LPG	Density	RON2)	Density	CN	
Target	45	45	10	>0.72	98	>0.815	50	
Bit. Coal I (Texaco)	40	54	6	0.696	93	0.767	75	42.4
Bit. Coal II (Lurgi)	44	50	6	0.708	95	0.788	71	46.0

1) MF = Motor Fuel (spark ignition)
DF = Diesel Fuel
LPG = Liquefied Gas

2) RON = Research Octane Number with 0.15 ml TEL/1

4.1.2 High Pressure Hydrogenation

High pressure hydrogenation of bituminous coal produces a motor fuel which corresponds to the norm and a diesel fuel which does not.

There is at present no process which at the same time lowers the diesel oil density and raises the cetane number. It is only possible, at the present time, to use this diesel fraction which does not correspond to the norm for the production of additional motor fuel which does. Thus it is not possible to produce the required fuels - diesel oil and motor fuel - solely by pressure hydrogenation of bituminous coal.

4.1.3 Combination Process

This consists of the combination of a high pressure hydrogenation with a Fischer-Tropsch synthesis. Here the synthesis is arranged in such a way that it produces a proportion of diesel oil which is equivalent to that from the high pressure hydrogenation, in order to achieve a cetane number of 50 in the mixture. Synthesis gas is produced partly from the hydrogenation residue and partly from bituminous coal by the Texaco process. Methane and ethane from the high pressure hydrogenation and the synthesis are converted to hydrogen.

Table 8

Combination Process

Bituminous Coal

	Distribution wt. %			Motor Fuel		Diesel Oil		Therm. Efficiency
	MF	DF	LPG	Density	RON	Density	CN	
Target	45	45	10	>0.72	98	>0.815	50	-
Comb. Inst. II	48	41	11	0.76	98	0.84	51	52.3

When production is divided as between 62% hydrogenation and 38% synthesis, the combined installation has a consumption of 7,910,000 te coal p.a. and an efficiency of 52.3%. This division of the production does not quite agree with that aimed at. The quality of the products corresponds to requirements as concerns spark ignition motor fuel and diesel oil.

If necessary, the ratio of spark ignition motor fuel to diesel oil can be adapted to suit requirements. In this case less middle oil is hydrocracked in the high pressure hydrogenation. The contribution of the synthesis to the total production then has to be raised from 38% to 41% in order to maintain the cetane number of the mixture at the same level. In this case one must accept a minor reduction of the octane number of the spark ignition motor fuel.

4.1.4 Installation Costs and Coal Consumption

The installation costs calculated for the three variants, the coal consumption and the specific parameters derived from these are collated in Table 9:

Table 9

Investment Costs and Coal Consumption

	10^6 DM	DM/te MF + DO + LPG	Coal consumption 10^6 te/yr	Coal consumption Gcal/te*)
Fischer-Tropsch synthesis				
Bit. Coal I	5,378	1,792	9.38	23.9
Bit. Coal II	4,962	1,654	8.65	21.1
Combination process				
Comb. Inst. II	4,296	1,432	7.91	19.3

*) per tonne MF, DO, LPG

The above data show that the combined installation represents the only possible solution in respect of product quality and that, furthermore, it has the lowest coal consumption and also the lowest capital cost.

4.2. The Production of Motor Fuels and Liquefied Gas from Lignite

4.2.1 Fischer-Tropsch Synthesis

The methane produced in the production of synthesis gas by Lurgi pressure gasification is separated and then partially oxidized to synthesis gas. The fixed bed synthesis is conventional (ARGE-type). Tar and naphtha, occurring as byproducts of the gasification, are hydrorefined.

Table 10

Fischer-Tropsch Synthesis based on Lignite

	Distribution wt. %			Spark ignition motor fuel		Diesel oil		Thermal efficiency %
	MF	DO	LPG	density	RON	density	CN	
Target	45	45	10	>0.72	98	>0.815	50	-
Lignite III	45	50	5	0.719	95	0.773	73	46.9

The specification for spark ignition motor fuel is not satisfied.

The diesel oil has a high cetane number. The explanation in 4.1.1 applies to its density, which is below the norm.

The consumption of raw lignite is taken as 40,976,000 te/yr.

4.2.2 High Pressure Hydrogenation

Here two versions are treated, which differ only in the method of hydrogen production from the gasification products of the hydrogenation. In both cases the hydrogenation residue is gasified in accordance with the Texaco process.

The result is shown in Table 11:

Table 11

High Pressure Hydrogenation of Lignite

	Distribution wt. %			Spark ignition motor fuel		Diesel oil		Thermal efficiency %
	MF	DO	LPG	density	RON	density	CN	
	45	45	10	>0.72	98	>0.815	50	-
Hydrogenation with autotherm cracking	40	45	15	0.767	99	0.845	52	52.2
Hydrogenation with steam reforming	41	47	12	0.767	99	0.845	52	51.6
Variation	54	29	17	0.764	98	0.835	53	-

It must be stressed that motor fuels can be produced from lignite which correspond to the specifications in the spark ignition motor fuel range as well as in the diesel oil range.

The bottom line in Table 11 illustrates the possibilities of variation in the high pressure hydrogenation. The yield of liquefied gas is higher than target requirements. However, it is typical for lignite and can be reduced by gasification.

4.2.3 Combined Installation

In the case of lignite a combination of high pressure hydrogenation and Fischer-Tropsch synthesis is not required, since, in contradistinction to bituminous coal, the diesel oil resulting from the hydrogenation conforms to the specifications. The combination of a high pressure hydrogenation with a Fischer-Tropsch synthesis has been worked out for the purpose of comparison.

4.2.4 Installation Costs and Coal Consumption

The installation costs are shown in Table 12 as the total for process installations, utilities plants and offsite facilities. The coal consumption is shown in addition.

Table 12

Investment Costs and Coal Consumption

	10^6 DM	DM/te MF+DO+LPG	coal consumption	
			10^6 te/yr	Gcal/te
Fischer-Tropsch Synthesis				
Lignite III	6010	2003	40.9	21.9
High pressure hydrogenation				
Hydrogenation, autotherm. cracking	4750	1585	36.6	19.7
Hydrogenation, steam reforming	4615	1535	37.0	19.9
Comb. Installation	5215	1738	39.0	21.0

Capital requirements as well as coal consumption favour the high pressure hydrogenation of lignite as against a Fischer-Tropsch synthesis or against a combination of high pressure hydrogenation with Fischer-Tropsch synthesis.

5. Estimation of Costs

For comparing the different processes it can be assumed to a first approximation that the costs for staff, catalysts and chemicals are of comparable magnitude, so that the capital-dependent costs and the coal costs remain as the dominant items. For the purpose of comparison one can furthermore exclude working capital, because this, too, will be about of equal magnitude for equal size of installation.

The capital-dependent costs are taken as 14.7% of investment capital (interest and depreciation 10.2%, maintenance 3.5% and insurance + taxes 1%). In addition, the cost of coal is assumed as DM 5.00/Gcal. The term "costs" is used for the sake of simplicity for the sum of capital and coal costs in the following discussion.

5.1 Costs of Production from Bituminous Coal

Using the above assumptions, costs calculated for the synthesis and for the combined installation are shown in table 13.

Table 13

Costs per Tonne Product*)
(based on bituminous coal)

	Capital costs DM/te	Coal costs DM/te	Total DM/te
Fischer-Tropsch synthesis			
Bituminous Coal I	264	120	384
Bituminous Coal II	243	106	349
Combination process			
Combined Installation II	211	97	308

*) sum of MF, DO and LPG

These figures, too, show the superiority of the combined installation.

5.2 Costs of Production from Lignite

The same assumptions give the following results:

Table 14

Costs per Tonne Product
(based on lignite)

	Capital costs DM/te	Coal costs DM/te	Total DM/te
Fischer-Tropsch synthesis			
Lignite III	294	110	404
High pressure hydrogenation			
Hydrogenation, autotherm. cracking	233	99	332
Hydrogenation, steam reforming	226	100	326
Combined Installation I	255	105	360

The costs also reinforce the preference for the high pressure hydrogenation as compared with a Fischer-Tropsch synthesis or a combination of high pressure hydrogenation with a Fischer-Tropsch synthesis.

6. Analysis of the Production of Motor Fuels, Liquefied Gas and Mains Gas : Details

The additional production of mains gas offers advantages particularly where synthesis gas, hydrogen or heating gas is produced by the Lurgi pressure gasification process. The methane resulting as the primary product from coal gasification can be separated by physical methods from the purified synthesis gas, can then be compressed and finally supplied as mains gas. The methane formed in the Fischer-Tropsch synthesis as well as the ethane-ethylene mixture represent additional mains gas components.

In principle the supply of mains gas is also possible in high pressure hydrogenation installations. Two alternative approaches are available here. The methane separated from the hydrogenation let-down gas can be supplied as mains gas instead of converting it to hydrogen. In that case an equivalent quantity of hydrogen must be produced from coal. Alternately, the heating gas required for bottom heating can be produced by Lurgi pressure gasification and the methane separated from it before its use as a fuel.

A further possibility has arisen during the work on the mains gas version. A plant designed for the production of liquid products can later be converted to the additional supply of mains gas. There is thus the possibility of developing a market for mains gas and to adapt to a rising demand.

6.1 Fischer-Tropsch Synthesis with Mains Gas Supply

6.1.1 Bituminous Coal Basis

Tables 15 and 16 below are based on the Lurgi pressure gasification and on the supply as mains gas of all the methane from the coal gasification together with a mixture of methane, ethane and ethylene from the synthesis. Here about nine tenths of the heating value supplied originates from the Lurgi pressure gasification.

Table 15

Composition of the Liquid Products

	Distribution wt. %			Spark ignition motor fuel		Diesel oil		Thermal efficiency %
	MF	DO	LPG	density	RON	density	CN	
Specification	45	45	10	>0.72	98	>0.815	50	-
Fischer-Tropsch synthesis Bituminous Coal III	46	49	5	0.713	96	0.783	69	57.2

The thermal efficiency relates to the sum of the products :

liquid products	3,000,000 te/yr
mains gas	1,753,800 te/yr
	= 300,000 m_n^3/h

Installation costs and coal consumption are shown in the following table.

Table 16

Investment Costs and Coal Consumption

	10^6 DM	DM/te LP*)	DM/te total**)	Coal 10^6 te/yr	Coal/te LP*)	Coal/te total**)
Fischer-Tropsch synthesis						
Bit. coal III	5451	1817	1147	12.2	29.7	18.8

*) LP = liquid products (MF + DO + LPG)

**) total = liquid products + mains gas

From these figures and using the assumptions given in section 5 the costs are arrived at as follows

Table 17

Costs per Tonne of Liquid Product and per Tonne of Liquid Product + Mains Gas

	Capital costs DM/te		Coal costs DM/te		Total DM/te	
	LP	total	LP	total	LP	total
Fischer-Tropsch synthesis						
Bit. Coal III	267	169	149	94	416	263

Additional capital amounting to 489 million DM is required for the production of 300,000 m_n^3 mains gas; this is a specific investment of DM 280.00/te/yr mains gas. The additional consumption of coal amounts to 3,515,345 te/yr or 2.02 te coal/te mains gas. The efficiency for mains gas production separately is thus 87.8%.

The costs for the production of mains gas can be calculated from the differences between Tables 17 and 13 (Bit. Coal II):

Capital costs : 267 - 243 = DM 24.00
Coal costs : 149 - 106 = DM 43.00
DM 67.00/0.59 te mains gas per 1 tonne liquid product

or as DM 114.00/te mains gas (equal to DM 9.00/Gcal), while the costs of production of liquid products alone amount to DM 349.00/te (Bit. Coal II).

6.1.2 Lignite Basis

In like manner the production of liquid products and mains gas is presented in the following table.

Table 18

Composition of the Liquid Products

	Distribution %			Spark ignition motor fuel		Diesel oil		Thermal efficiency %
	MF	DO	LPG	density	RON	density	CN	
Specification	45	45	10	>0.72	98	>0.815	50	-
Fischer-Tropsch synthesis Lignite II	47	47	6	0.726	98	0.778	72	58.4

The high yield of byproducts in the Lurgi pressure gasification, which are then hydrogenated to motor fuel and diesel oil, leads to an improvement in the quality of the petrol, although the RON of 98 given as the norm is not attained. The capacity of the synthesis plant can be lowered.

The thermal efficiency refers to the sum of :

liquid products	3,000,000 te/yr and
mains gas	2,355,800 te/yr.

This corresponds to a mains gas production of 400,000 m_n^3/h. The following table gives the installation costs and the coal consumption.

Table 19

Investment Costs and Coal Consumption

	10^6 DM	DM/te		coal	Gcal/te	
		LP	total	10^6 te/yr	LP	total
Fischer-Tropsch synthesis Lignite II	7350	2450	1372	62.2	33.4	18.7

From the assumptions of section 5 the costs are calculated as follows :

Table 20

Costs per Tonne Liquid Products and per Tonne Liquid Products + Mains Gas

	Capital costs DM/te		Coal costs DM/te		Total DM/te	
	LP	total	LP	total	LP	total
Fischer-Tropsch synthesis						
Lignite II	361	202	167	93	528	295

For an hourly production of 4,000,000 m^3 the additional capital amounts to DM 1,340 million and an additional 21.2 million te lignite have to be processed. This is equivalent to a specific investment of DM 569.00/te mains gas/yr and to a specific coal consumption of 9 te/te mains gas, with an efficiency of 84% for mains gas production alone.

The costs for the production of mains gas can be calculated from the differences between Tables 20 and 14 (Lignite III) :

Capital costs : 361 - 294 = DM 67.00
Coal costs : 167 - 110 = DM 57.00
DM 124.00/0.783 te mains gas/1 te liquid products

or DM 158.00/te mains gas (equivalent to DM 12.00/Gcal), while the costs for the production of liquid products alone amount to DM 404.00/te.

From this it follows that a coproduction of liquid products and mains gas is sound if a market for the mains gas exists.

The method used for determining the costs of an additional mains gas production is not quite exact. It is based on using the differences between invested capital and coal consumption of two variants which are not quite equivalent for the cost calculation and then applying this to the mains gas production. A correction factor should be taken into account, since in the respective variants different quantities of byproducts are produced in the Lurgi pressure gasification and then converted to spark ignition motor fuel and diesel oil. The efficiency of this conversion is known. The conversion costs, however, must be dealt with separately in another calculation. However, the costs shown here for a mains gas production form a reliable basis for comparison and are suitable as an aid to decision making.

6.2 Combination Process with Mains Gas Supply

6.2.1 Lignite Basis

From the example of a combined installation based on lignite it can be shown that here, too, the supply of mains gas is possible. In this variant 62% of the motor fuels are produced by high pressure hydrogenation and 38% by synthesis. The synthesis gas is produced in a Lurgi installation, which supplies about 152,000 m_n^3 mains gas/h. This version is explained by means of the following tables.

Table 21

Collation of the Liquid Products

	Distribution %			Spark ignition motor fuel		Diesel oil		Thermal efficiency %
	MF	DO	LPG	density	RON	density	CN	
Specification	45	45	10	>0.72	98	>0.815	50	-
Combination process Lignite basis	42	48	10	0.74	97	0.813	60	54.4

At 54.4% the efficiency of the combined installation with mains gas production is more favourable than that with high pressure hydrogenation alone. The products almost conform to the specification.

The distribution can be further corrected in favour of the spark ignition motor fuel. The thermal efficiency of 54.4% relates to the production of :

liquid products	3,000,000 te/yr	and
mains gas	895,200 te/yr	

Table 22

Investment Costs and Coal Consumption

	10^6 DM	DM/te		Coal	Gcal/te	
		LP	total	10^6 te/yr	LP	total
Combination process II Based on lignite	5986	1995	1537	46.8	25.1	19.3

Under the assumptions made in section 5 this leads to the following costs :

Table 23

Costs per Tonne of Liquid Product and per Tonne of Liquid Products + Mains Gas

	Capital costs DM/te		Coal costs DM/te		Total DM/te	
	LP	total	LP	total	LP	total
Combination process II						
Based on lignite	293	226	126	97	419	323

The costs of mains gas production as part of the combination process can be obtained analogously to 6.1.1. Using the values thus obtained as a basis, DM 771 million of the invested capital and 7.8 million te of the lignite consumption can be charged to the mains gas production.

The costs relating to the mains gas production can be calculated from the differences between tables 23 and 14 :

capital costs : 293 - 255 = DM 38.00
coal costs : 126 - 105 = DM 21.00
DM 59.00/0.30 te mains gas/1 te liquid product
or DM 197.00/te mains gas (equivalent to DM 16.00/Gcal)

6.2.2 Bituminous Coal Basis

The plan of the combined installation II described in section 4.1.3 can also be changed over to the supply of mains gas. In this case the synthesis gas and the hydrogen would be produced by a Lurgi pressure gasification. The methane would be scrubbed out from the gas stream purified by the Rectisol process. Methane and ethane/ethylene would be separated from the residual gases of the hydrogenation and the synthesis and, together with the methane from the gas production, supplied as mains gas.

In this way it would be possible to make available about 800,000 to 850,000 te/yr mains gas from a 3,000,000 te/yr unit. The capital requirements for the mains gas production is estimated as DM 360 million. From this one can obtain a specific investment of DM 450.00/te mains gas/yr, which is larger than for the case of a Fischer-Tropsch synthesis with mains gas supply, cf 6.1.1 - DM 280.00/te mains gas/yr.

From capital-related and coal costs the costs of mains gas production can be calculated in the above case as about DM 135.00/te (DM 11.00/Gcal) mains gas, if an efficiency of 80% is assumed.

7. Conclusions from the Analysis

Based on the analysis, the following process pathways are arrived at for coal conversion to motor fuels and liquefied gas :

LIGNITE :	The high pressure hydrogenation yields motor fuels conforming to specification. It has a high thermal efficiency and the lowest capital cost of all the lignite variants investigated.
BITUMINOUS COAL :	Here only the combination of high pressure hydrogenation and Fischer-Tropsch synthesis leads to products conforming to specification. This combination has the advantage that a considerable proportion of high ash, low quality coal can be used as raw material.

The analysis further shows that in both cases the combined production of motor fuels, liquefied gas and mains gas can be economically attractive if there is a market for mains gas or a market can be developed and if the net financial return for this mains gas covers the production costs.

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