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Abstract

The technology assessment study of coal-based fuels presented in this report was performed for the Federal Ministry for Research and Technology. Its goal was to support decision-making of the Federal Ministry for Research and Technology in the field of coal conversion. Various technical options of coal liquefaction have been analyzed on the basis of hard coal as well as lignite - direct liquefaction of coal (hydrogenation) and different possibilities of indirect liquefaction, that is the production of fuels (methanol, gasoline) by processing products of coal gasification. The TA study takes into consideration the entire technology chain from coal mining via coal conversion to the utilization of coal-based fuels in road transport. The analysis focuses on costs of the various options overall economic effects, which include effects on employment and public budgets, and on environmental consequences compared to the use of liquid fuels derived from oil. Furthermore, requirements of infrastructure and other problems of the introduction of coal-based fuels as well as prospects for the export of technologies of direct and indirect coal liquefaction have been analyzed in the study.

Technikfolgenabschätzung für verschiedene Kohle-Kraftstoff-Optionen

Zusammenfassung

Die in diesem Bericht dargestellte Technikfolgenanalyse zu Kraftstoffen auf Kohlebasis wurde im Auftrag des Bundesministers für Forschung und Technologie zur Unterstützung der Entscheidungsfindung des BMFT auf dem Gebiet der Kohleveredlung durchgeführt. Es wurden verschiedene technische Optionen der Kohleverflüssigung sowohl auf Stein- als auch auf Braunkohlebasis betrachtet: die direkte Kohleverflüssigung (Hydrierung) und verschiedene Varianten der indirekten Kohleverflüssigung, d.h. die Gewinnung von Kraftstoffen (Methanol, Benzin) über die Weiterverarbeitung von Produkten der Kohlevergasung. Die Technikfolgenabschätzung betrachtet die ganze Kette von der Kohlebeschaffung über die Kohleumwandlung bis zur Verwendung der Kohle-Kraftstoffe im Straßenverkehr. Der Schwerpunkt der Analyse liegt bei einzel- und gesamtwirtschaftlichen Auswirkungen (einschließlich Auswirkungen auf die Beschäftigung und staatlichen Haushalte) und bei den Umweltfolgen. Es werden jeweils Vergleiche zum Einsatz von Mineralölkraftstoffen durchgeführt. Weiterhin werden betrachtet: Infrastrukturelle Erfordernisse und sonstige Realisierungsprobleme für die Einführung von Kohlekraftstoffen sowie Exportperspektiven für Technologien der direkten und indirekten Kohleverflüssigung.

Technology Assessment of Various Coal Fuel-Options

Table of Contents

I. Introduction

1. The analysis of different alternatives of producing fuels from coal in order to substitute liquid fuels derived from oil has been designed as a technology assessment study. In TA studies options which have been formulated on the basis of existing knowledge and certain basic assumptions are analyzed with regard to their preconditions and potential consequences and evaluated with the aid of a wide range of criteria. Thus, the results of TA studies do not consist in forecasts but in the clarification or even the quantification of the positive as well as negative consequences possibly connected with the options selected. This type of analysis aims at supporting decision-making processes in politics and business.

2. The study represents an extension of the study "Methanol for Road Transport" which was carried out by the Department for Applied Systems Analysis (Abteilung für Angewandte Systemanalyse/AFAS) of the Nuclear Research Centre, Karlsruhe together with the Fraunhofer Institute for System Technology and Innovation Research (ISI) and the Technischer Überwachungsverein (TÜV) Rheinland in December 1984. The scope of the study was extended to include additional possibilities for fuel production from coal, namely the gasoline production from hard coal and lignite on the basis of TEXACO or HTW (High-Temperature-Winkler process) gasification and the MTG process (MTG = Methanol to Gasoline) developed by Mobil, and the production of gasoline and diesel fuels by direct liquefaction respectively hydrogenation of hard coal.

3. The TA study is based on the following fundamental assumptions:

(1) it is assumed that the extent of substitution of oil-based fuels by coal-based fuels will amount to 10 % of the fuel consumption expected by the year 2000, (this corresponds to 110 PJ). To achieve this figure, 5 million tons of methanol or 2.5 million tons of MTG gasoline or 2.5 million tons of fuels from direct coal liquefaction are required, depending upon the alternatives chosen. The quantities of coal required to produce these amounts of coal-based fuels fluctuate between 5.8 and 7.2 mtce depending upon the overall efficiency of the options under consideration.

(2) in the reference case, gasoline and diesel fuel derived from mineral oil are replaced at a ratio of 40:60 for private and commercial vehicles by methanol respectively M 100, which can be used as diesel fuel or gasoline. The M 100 fuel contains 93 % methanol plus 7 wt % C_4 and C_5 compounds which improve cold starting conditions. The exclusive substitution of either gasoline or diesel by methanol or M 100 respectively are also considered to be alternative options.
MTG gasoline replaces predominantly oil-based gasoline for use in private vehicles.
Fuels from hydrogenation replace gasoline and diesel fuel (derived from mineral oil) at a ratio of 50:50 in private and commercial vehicles.

(3) as many as eight options (Table 1) are analyzed because firstly, it is assumed that methanol and MTG gasoline are produced from lignite as well as from hard coal, and secondly two alternative sources for the coal required have to be taken into consideration:

- the amount of hard coal required is obtained by additional coal mining
- the amount of hard coal required is replaced by nuclear energy in electricity generation.

Because of ecological restrictions on additional mining of lignite in the F.R.G. it is assumed that the necessary quantity of lignite has to be released from electricity generation in any case where it will have to be replaced by nuclear energy.

(4) The following model technologies have been selected for the different possibilities of coal conversion:

- the "High-Temperature-Winkler" gasification process for methanol and MTG-gasoline production for the options based on lignite
- the "Texaco" gasification process for methanol and MTG production from hard coal

Table 1: Coal-Fuel Options

OPTION 1	M100	from additionally mined hard coal
OPTION 2	M100	from hard coal replaced by nuclear energy in electricity generation
OPTION 3	M100	from lignite replaced by nuclear energy in electricity generation
OPTION 4	MTG	gasoline from additionally mined hard coal
OPTION 5	MTG	gasoline from hard coal replaced by nuclear energy in electricity generation
OPTION 6	MTG	from lignite replaced by nuclear energy in electricity generation
OPTION 7	Direct liquefaction products from additionally mined hard coal	
OPTION 8	Direct liquefaction products from hard coal replaced by nuclear energy in electricity generation	

- the modified IG-Farben process for the hydrogenation of hard coal, supplemented by further process modifications which have been proved under laboratory conditions. The potential of more advanced techniques (Pyrosol process, high pressure hydrogenation) will be discussed within the framework of sensitivity analyses.

For analytical reasons plants which are self-sufficient in process energy supply have been assumed. It should be noted, however, that in individual cases optimizations may be possible using electricity, natural gas or hydrogen from external sources.

The throughput of coal per plant has been fixed at approximately 1 mtce p.a., which means that the plant dimensions selected comply with the requirements of a large-scale technical demonstration. However, economies of scale can still be expected for larger plants.

4. The options selected are analyzed under various aspects - especially with regard to

- costs (section III.A)
- effects on the economy as a whole (employment, public budgets etc.) (section III.B)
- environmental impacts (section IV)
- aspects of industrial policy (section V)
- important preconditions of implementation (section VI).

A subsequent comprehensive evaluation is carried out in section VII.

The following Section II provides some technical explanations regarding the coal conversion technologies considered and the use of M 100 in cars.

II. Technologies for Coal Conversion and the Utilization of Coal Fuels

Options 1 to 6 are based on processes of so-called indirect liquefaction (Table 2), that means the coal is first of all gasified and the resulting "synthesis gas" is then liquefied in further steps. Options 7 and 8 are based on direct liquefaction of hard coal via hydrogenation.

Table 2: Technical Classification of Coal-Fuel Options

		Hard Coal		Lignite	
		Additionally Mined	Replaced by Nuclear Energy in Electricity Generation	Additionally Mined	Replaced by Nuclear Energy in Electricity Generation
Indirect Liquefaction	gasification → methanol → M 100	option 1	option 2	--	option 3
	gasification → methanol → gasoline	option 4	option 5	--	option 6
Direct Liquefaction	hydrogenation - gasoline, middle distillate, liquified gas	option 7	option 8	--	--

(1) Indirect liquefaction

In order to obtain methanol from coal, an intermediate step is required. First, the coal must be gasified. The resulting raw gas is subsequently purified. It then consists of hydrogen (H_2) and carbon monoxide (CO) only and is referred to as "synthesis gas". For the production of methanol it is important that the synthesis gas consists of approximately two parts H_2 and one part CO. As this ratio cannot be achieved immediately during gasification, the CO of the synthesis gas has to be partly converted into H_2 in a converting step with the aid of water vapour and catalysts.

The synthesis gas is then converted into methanol at pressures of 40 to 100 bar in a synthesis reactor with copper catalysts.

Methanol can be used directly as a fuel, e.g. without any admixtures in commercial vehicle engines, as M 100 in spark-ignited engines after blending with some percentage of hydrocarbon compounds [1], or as "diesel engine blend"[2] together with ignition improvers and co-solvents. It can also be used indirectly by

[1] C_4/C_5 cuts
[2] these possibilities are not examined here

converting methanol into unleaded gasoline via the so-called MTG (Methanol to Gasoline) process with zeolite catalysts (Mobil process). This MTG-gasoline can be used directly in spark-ignited engines. Its knock-resistance is superior to the current standard knock-resistance of "Euro-Super", depending upon the mode of operation of the MTG-plant. An MTO (Methanol to Olefins) variation of the Mobil process can also produce a non-sulphurous diesel fuel from methanol.

In the following section the two processes of gasification, which have been assumed as model technologies, are outlined. Other methods of gasification are not described here.

The Texaco process of gasifying hard coal is based on the gasification of pulverized coal, for which very finely ground coal mixed with water is fed into the gasifier. Furthermore, oxygen is added from an air separation plant.

Part of the pulverized coal is burned down with the oxygen producing temperatures exceeding 1300° C. The carbon of the pulverized coal, which has not been burned down, is converted with the resulting water vapour into raw gas. The ash of the pulverized coal is removed from the bottom of the gasifier. In order to improve the process it is planned to increase the pressure under which the gasification takes place from 40 to 100 bar. Virtually all types of hard coal can be used for the Texaco gasification process.

For the gasification of lignite the High-Temperature-Winkler (HTW) process has proved suitable. This is an advanced development of the fluidized-bed-combustion gasification, which is operated at 10 bar and 800 to 1000 degrees celsius. Because of the higher reactivity of lignite vis-à-vis hard coal, the high temperatures of the entrained-flow gasification are not required. By the same token the fusing point of the ash is not reached, which prevents the ash particles from caking in the "more densely packed" fluidized bed. Ground and dried lignite as well as oxygen and water vapour are utilized here. Again the oxygen - together with part of the lignite - serves to produce the gasification temperature, so-called auto-thermal gasification, and to procure the reaction energy. The very process of gasification is similar to the gasification of hard coal, which has been described above.

(2) Direct coal liquefaction (hydrogenation)

As long ago as World War II gasoline for aircrafts was produced by direct liquefaction from lignite and from hard coal. This process was further developed to become the new IG-Farben ("IG-Neu") process. In recent years, however, detailed concepts have been designed in the Federal Republic of Germany for the hydrogenation of hard coal only. For the new IG-Farben process hard coal is finely ground, "slurried" with distillate oil from the hydrogenation process and with a catalyst and then pumped into the "hydrogenation reactors" together with gaseous hydrogen. Temperatures of approximately 450 degrees Celsius and pressures of 300 bar prevail in the hydrogenation reactors.

The resulting vaporous and gaseous products are separated from the heavy vacuum bottoms in downstream separators. These products are further processed to gasoline, middle oil distillate, and LPG (liquified petroleum gas) via different distilling and refining processes. The vacuum bottom still contains carbon, sulphur, and the entire ash. It can be gasified or pyrolized. In the case of gasification, the resulting gases are used for the production of part of the hydrogen necessary for hydrogenation. In the case of pyrolysis, the remaining pyrolized residue is burned by fluidized combustion which produces process energy in the form of steam.

Apart from the coal-oil pilot plant in Bottrop which is operated according to the modified IG-Farben process ("IG-Neu") and has a processing capacity of up to 200 tons of coal per day, two further variations are being developed in the Federal Republic of Germany at present. For the so-called high-pressure hydrogenation pressures of up to 1000 bar are applied. Reaction takes place in long high-pressure tubes of small diameter as opposed to the former large diameter vessels. The carbon is to be completely transformed in these tubes so that the vacuum bottom essentially consists of ash only. For the Pyrosol process (pyrolysis), only very "mild" hydrogenation conditions of 200 bar are selected. Apart from a combustible or gasifiable coke a non-sulphurous middle distillate is produced, which can be used either for blending with highly sulphurous oil, or which can be further processed to gasoline in a special refinery. Either process can bring about higher efficiency and lower capital cost.

(3) The use of methanol in vehicles

Passenger cars with spark-ignited engines

At present, methanol is blended with 7 wt% of hydrocarbon compound. In this form it is called M 100. Essentially the blending is supposed to improve cold-starting qualities and to maintain the risk of inflammability of a fuel/air mixture within safe limits.

The vehicle may require further modifications to improve cold-starting qualities. In addition, adjustments are necessary because of the lower heating value of M 100 vis-à-vis gasoline. Fuel tanks will have to be larger, and fuel systems, mixture formation and spark plugs will have to be modified. As a result of the higher knock-resistance of methanol a higher engine compression-ratio is possible, leading to improved specific performance and engine efficiency.

With regard to emissions, spark-ignited engines running on M 100 could comply with the new EEC standards. However, as they emit significantly more formaldehyde than comparable gasoline engines, an oxydation catalyst has to be assumed to be a minimum requirement.

Vehicles with divided chamber diesel engines

Through the admixture of ignition improvers with the necessary co-solvents methanol can be developed into a self-igniting diesel fuel. Research work is still in the laboratory stage, however.

Vehicles with direct injection diesel engines

These engines are used for commercial vehicles (lorries, buses, vans). Various approaches are being pursued by different companies and tested in prototype vehicles. Not only M 100 but also methanol can be used directly as a fuel, without additives.

One of the concepts is based on the vaporization of methanol and its subsequent combustion in a spark-ignited engine running on gas. By comparison with spark-ignited engines running on liquid fuel, a higher compression-ratio can be selected. Another concept provides for a stratified charge engine with direct injection and an electric ignition system whose compression-ratio has been selected according to a diesel engine. A third concept is not based on an exclusive methanol engine, as a diesel jet with the approximate idle fuel quantity of the diesel engine is injected into the combustion chamber with the help of a second injection pump for the ignition of the methanol/air mixture. Thus, in practical operation from 70 % to 85 % of the diesel oil are energetically replaced by methanol depending on the vehicle and its utilization.

In engine concepts using only methanol, NO_x emissions are reduced by at least 50 % vis-à-vis the comparable diesel engine. Soot emissions are almost non-existent. In the vaporization concept aldehyde emissions are lower. In the concept with electric ignition they are limited by the use of an oxydation catalyst. HC and CO emissions are comparable. The dual-jet concept also has environmental advantages which, however, depend upon the respective operating point of the engine due to the diesel fuel component.

III. Analyses of Economic Impacts

This section is subdivided into analyses of costs and effects on the economy as a whole.

A. Cost Analyses

1. Basic technological and economic data

Table 3 provides a survey of the most important technical and economic data of the various processes for producing fuels from coal which have been examined in this study.

The data for hydrogenation plants presuppose that the more recent improvements of the modified IG-Farben process, so far positively tested on a laboratory scale only, will also prove viable in larger plants. These modifications include modified solvents for slurrying coal, which lead to a more effective cracking of the coal, and low temperature pyrolysis instead of the gasification of the vacuum bottoms. Both modifications entail a higher rate of efficiency.

The technical and economic data of hydrogenation plants of the size under discussion are not as well proved as in the case of indirect liquefaction or gasification because of a lack of experience with sufficiently large hydrogenation plants.

The technical and economic data compiled in Table 4 have been used for the calculation of cost differences which result from replacing hard coal or lignite respectively by nuclear energy in the field of electricity generation.

Table 3: Technical and Economic Data for Model Plants of the Various Processes to Produce Liquid Fuels from Coal

		A	B	C	D	E
		Methanol from Hard Coal (Texaco)	A + MTG (Texaco + Mobil)	Methanol from Lignite (HTW)	C + MTG (HTW + Mobil)	Hydrogenation of Hard Coal (Modified I.G.Process)
Coal Throughput	tce/d	3540	3540	3140	3140	4150
Products:						
Methanol	t/d	2500	---	2500	---	---
LPG	t/d	---	130	---	130	310
Gasoline	t/d	---	920	---	920	920
Middle Distillates (Diesel)	t/d	---	---	---	---	550
LHV[3] Products/LHV Coal		0,47	0,46	0,53	0,52	0,64
Investment Costs	million DM[1]	1050	1350	1200	1500	1860
Labour, Maintenance, Insurance	million DM/a[1]	59	72	63	77	132
Variable Operating Costs[2]	million DM/a[1]	22	31	19	28	36

economic and technical data valid for all plants: construction period 5 years, operating life 20 years, 8000 full load operating hours per year

1) money value 1984
2) without coal cost
3) LHV = Lower heating value

Table 4: Technical and Economic Data for Coal and Nuclear Power Stations - Operating Costs for the Year 2000, Money Value 1984 -

	Unit	Hard Coal	Lignite	Nuclear Power
Construction Time	Years	5	5	7
Investment Costs	DM/kWe	1900	2200	3200
First Core Inventory	DM/kWe	---	---	320
Energy Costs	DM/MWhe	105[1]	39[2]	20
Costs for Waste Disposal	DM/MWhe	---	---	20
Other Operating Costs	DM/MWhe	16	16	16

1) cost of hard coal incl. transportation costs: DM 317/tce
2) cost of lignite incl. transport: DM 119/tce

For the purpose of cost analyses all options are based on the economic and energy assumptions shown in Table 6.

For the period of analysis the following price relations regarding crude oil and oil refining products have been assumed in order to compare mineral oil products and coal fuels (Table 5).

Table 5: Price Relations between Oil Products and Crude Oil

Product	Price per ton Oil Product in relation to Price per ton Crude Oil
Middle Distillate	1,2
Gasoline	1,3
LPG	1,2
C_4/C_5 Cuts	1,5

Table 6: Reference Assumptions Regarding Basic Economic Factors

Reference Assumptions for the Cost Analysis		
Interest Rate	8	%/a
Inflation Rate	4,5	%/a
Deflated Interest Rate	3,35	%/a
Taxes	4,4	%/a [1]
Cost Growth Rates		
- Investment costs (deflated)	0	%/a
- Operating costs (deflated) [2]	1	%/a

Reference Assumptions Regarding Energy Prices

	Price Levels 1984 in DM/t	Average Real Price Growth Rate in %/a	Price Levels in 2000 (Money Value 1984) in DM/t
Crude Oil	620	1	726
- Gasoline[3]	830		944
- Middle Distillate [3] (Diesel)	755		871
Domestic Hard Coal	245 [4) 5)]	1	287 [4)]
Lignite	88 [4)]	1	103 [4)]

1) in relation to the (discounted) cash value of the investment
2) other than coal costs
3) refinery prices
4) DM/tce excl. transport costs
5) cost of hard coal for hydrogenation DM 255/tce because of higher quality requirements

2. Method of cost calculation and calculated indicators

For cost calculations, the discounted cash flow method is applied. This allows for taking into account the temporal development of the different types of costs, for example the costs of coal or labour costs. On the basis of the discounted cash flows "average real" costs are calculated at the constant monetary value of 1984. Thus, inflationary effects on the calculation are avoided. For assessing capital costs a minimum interest return on the invested capital is assumed.

While in options 4 to 6 fuels are produced which comply with the specifications for fuels derived from oil, in the case of the M 100 options (options 1 to 3) cost calculations have to take into account cost differences resulting from the use of M 100:

- additional costs are incurred by blending methanol with C_4/C_5 components derived from mineral oil in order to produce M 100
- as far as energy consumption is concerned, M 100 is more efficient than liquid fuels derived from oil especially in spark-ignited engines
- because of the low energy density of M 100, the cost of distribution per energy unit of M 100 is almost twice as high as in the case of fuels derived from oil
- motor vehicles modified for M 100 are technically somewhat more sophisticated and therefore more expensive than conventional motor vehicles.

In options 7 and 8 gasoline from direct coal liquefaction has to be further refined in order to obtain a fuel which complies with the required specification standards.

Three indicators have been estimated to compare the options

(1) production costs for the products in DM per energy unit (GJ) converted product

(2) leading oil prices representing the oil price level in the year 2000[1] above which the respective option would produce cost advantages compared to utilizing liquid fuels derived from oil.

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1) to be more precise - the "average real" oil price between 1990 and 2010

(3) "gross subsidies" representing the cost differences of the options vis-á-vis utilizing liquid fuels derived from oil (the "oil case") in the year 2000 - providing the same amount of oil-based fuels (108,5 PJ) is replaced by coal fuels. In other words, to avoid financial disadvantages in the production, distribution and utilization of fuels derived from coal - compared to the "oil case" - corresponding subsidies will be required covering at least the cost difference vis-à-vis the "oil case". The term "gross subsidies" emphasizes the distinction from the indicator "net subsidies" used in Section III.B.

3. Results of cost analyses for the reference case

(1) Production costs

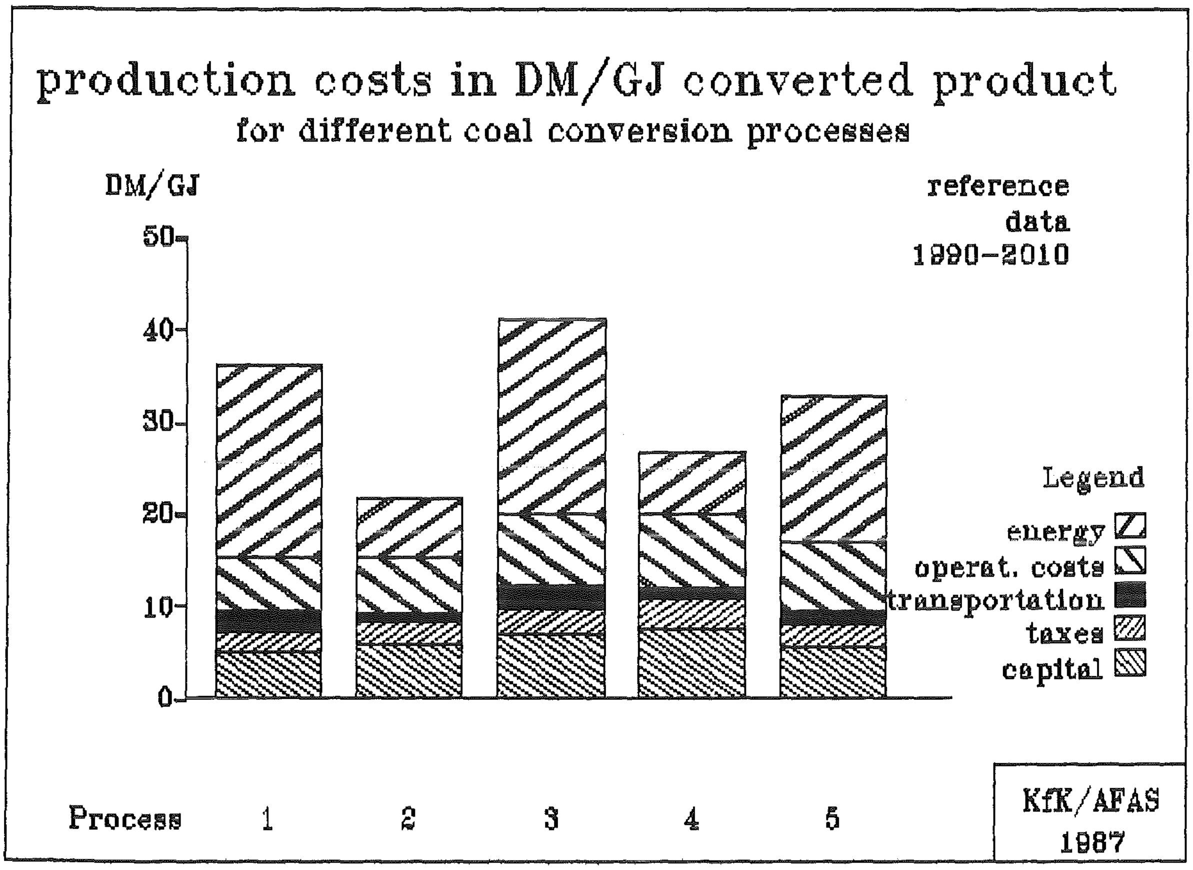
Leaving aside temporarily cost effects resulting from the replacement of the coal required in electricity generation by nuclear power, the pattern presented in Figure 1 results for the production costs of the coal fuels from the different coal conversion plants selected as model technologies.

The importance of coal costs in the case of hard coal conversion plants becomes apparent in the structure of production costs (processes 1, 3, 5). For the processes 2 and 4 production costs are relatively lower because the cost of lignite is significantly lower.

A comparison of the hard-coal-based processes (1, 3, 5) reveals that liquefaction of hard coal is more capital intensive than methanol production from hard coal. However, liquefaction leads to somewhat lower overall costs per energy unit of the products because of the higher rate of conversion efficiency.

The additional effect of the conversion of methanol to gasoline increases production costs by additional 5 DM/GJ approximately (converted: approximately 220 DM per ton of gasoline).

Figure 1: Production Costs in DM/GJ Converted Product



Processes

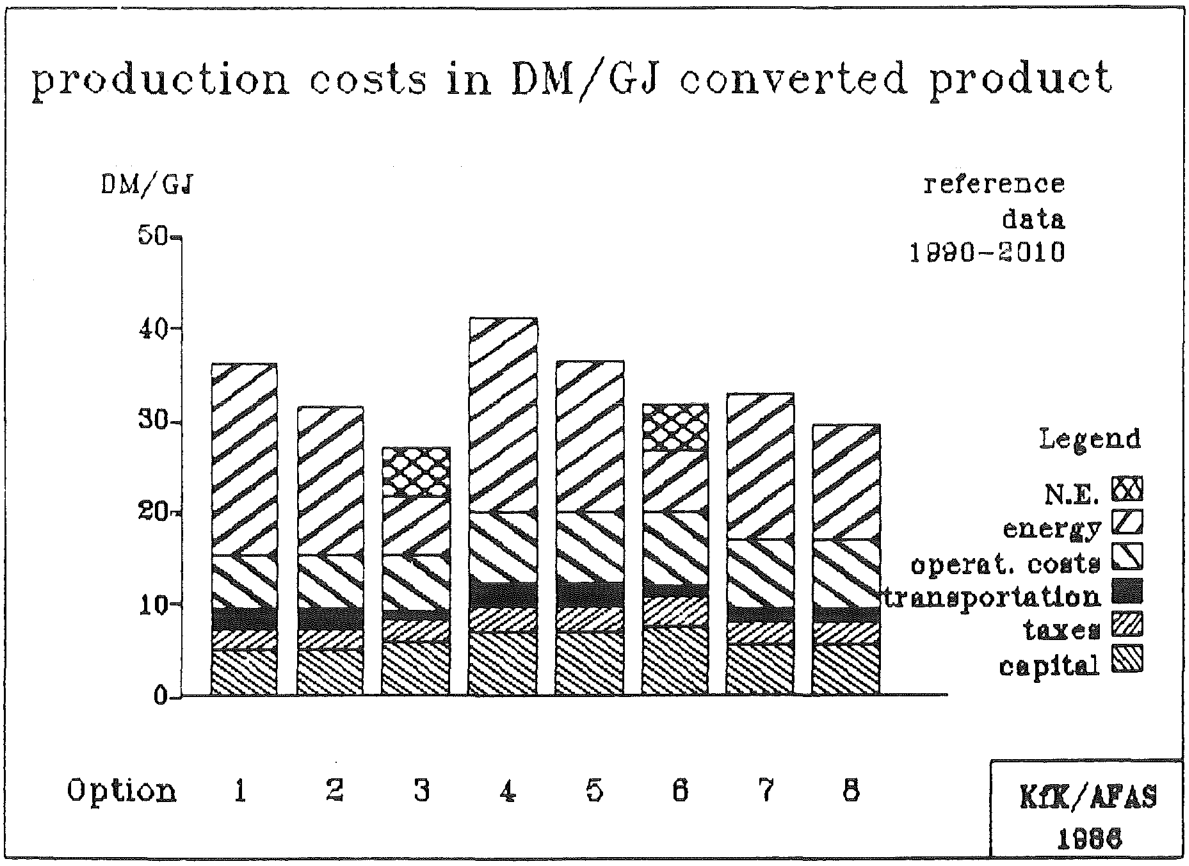
1 Methanol from hard coal using the Texaco process
2 Methanol from lignite using the HTW process
3 Gasoline from hard coal using the Texaco and MTG process
4 Gasoline from lignite using the Texaco and MTG process
5 Direct liquefaction products using the modified IG-Farben process

For options 2, 3, 5, 6 and 8 it has been assumed that the extent of hard coal or lignite mining remains unchanged compared to the "oil case", and that the quantities of coal required are released by a correspondingly increased utilization of nuclear energy for electricity generation. According to the reference data for the years 1990 to 2010 increased utilization of nuclear energy for electricity generation leads to reduced costs vis-à-vis electricity generation from hard coal (because of high prices of German hard coal) and higher costs in the case of electricity generation from lignite. From a business point of view these cost differences are likely to be of secondary importance. However, for an overall economic balance it is appropriate to allocate the corresponding cost increases and reductions to the product costs of the coal conversion plants.

In Figure 2 the comparisons of options 1 and 2, of options 4 and 5 and of options 7 and 8 reveal this bonus in the case of hard coal.

In the case of lignite the additional costs are shown in the cost structure of options 3 and 6.

Figure 2: Production Costs in DM/GJ Converted Product

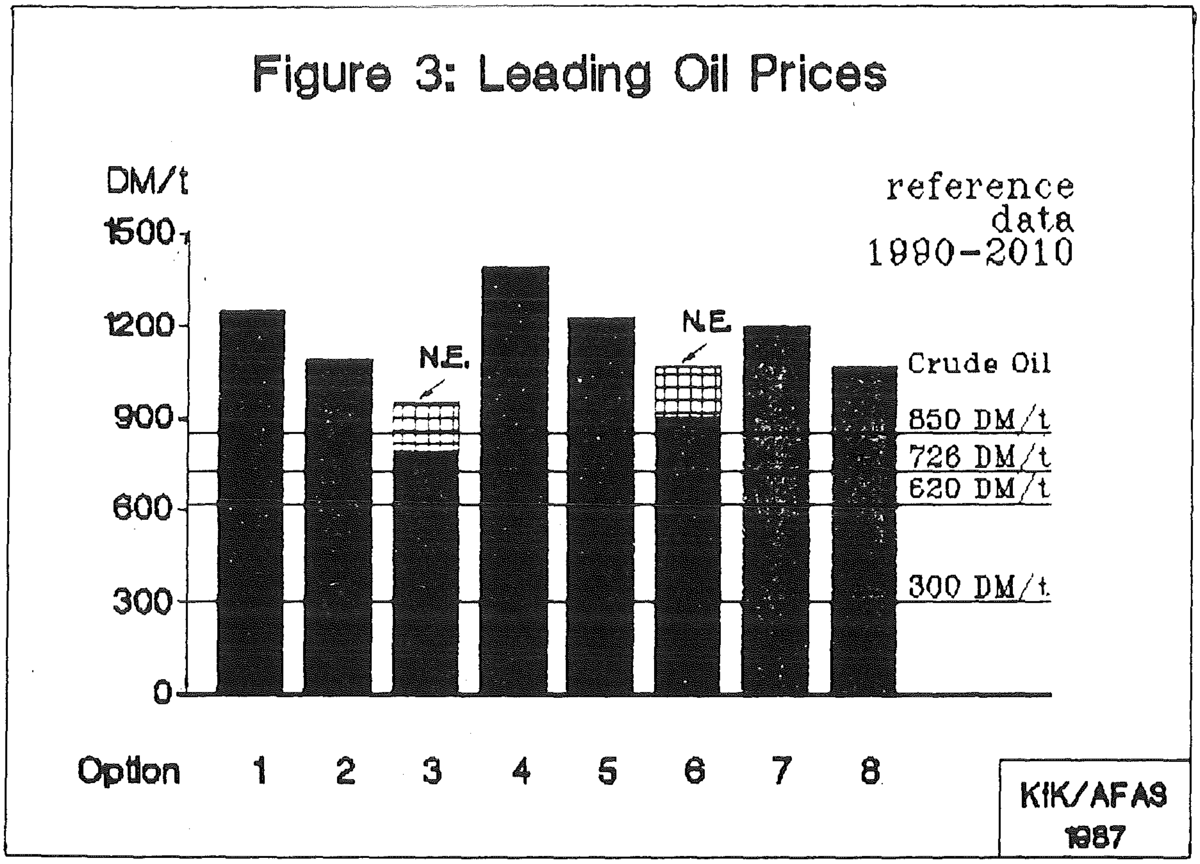


N.E. = Additional costs resulting from the replacement of lignite in electricity generation by nuclear energy

(2) Leading oil prices

Production costs do not yet include those cost differences which occur in options 1 to 3 as a result of the C_4/C_5 components required, the distribution of M 100 and the fuel consumption in vehicles. They are, however, considered in the leading oil prices. In the case of spark-ignited engines the efficiency advantage largely makes up for the cost disadvantages in the distribution of M 100 among the options. For this reason the differences in leading oil prices resemble that of the production costs to a large extent (Figure 3).

Figure 3: Leading Oil Prices



N.E. = Additional costs resulting from the replacement of lignite in electricity generation by nuclear energy

It becomes apparent that for all the options under consideration the deflated oil price level would have to be considerably higher than the price level of 1984 (approximately 620 DM per ton of crude oil) and the current price level in particular (spot prices of beginning February 1987 at approximately 250 to 300 DM per ton; exchange rate ca. 1 Dollar = DM 1,80) in order to bring about cost advantages vis-à-vis the "oil case". In the most favourable case (option 3) average real price growth rates for crude oil would have to exceed 2,5 % p.a. (on the basis of 1984 prices) up to the year 2010. Leaving aside the additional costs of replacing lignite by nuclear energy in electricity generation, the price growth rates would have to exceed 1,5 % p.a. which would equal about 800 DM per ton in the year 2000.

For reasons of comparison three oil price lines have been drawn (Figure 3) which would result for average real growth rates of oil prices of 0 %/a, 1 %/a and 2 %/a between 1984 and 2000.

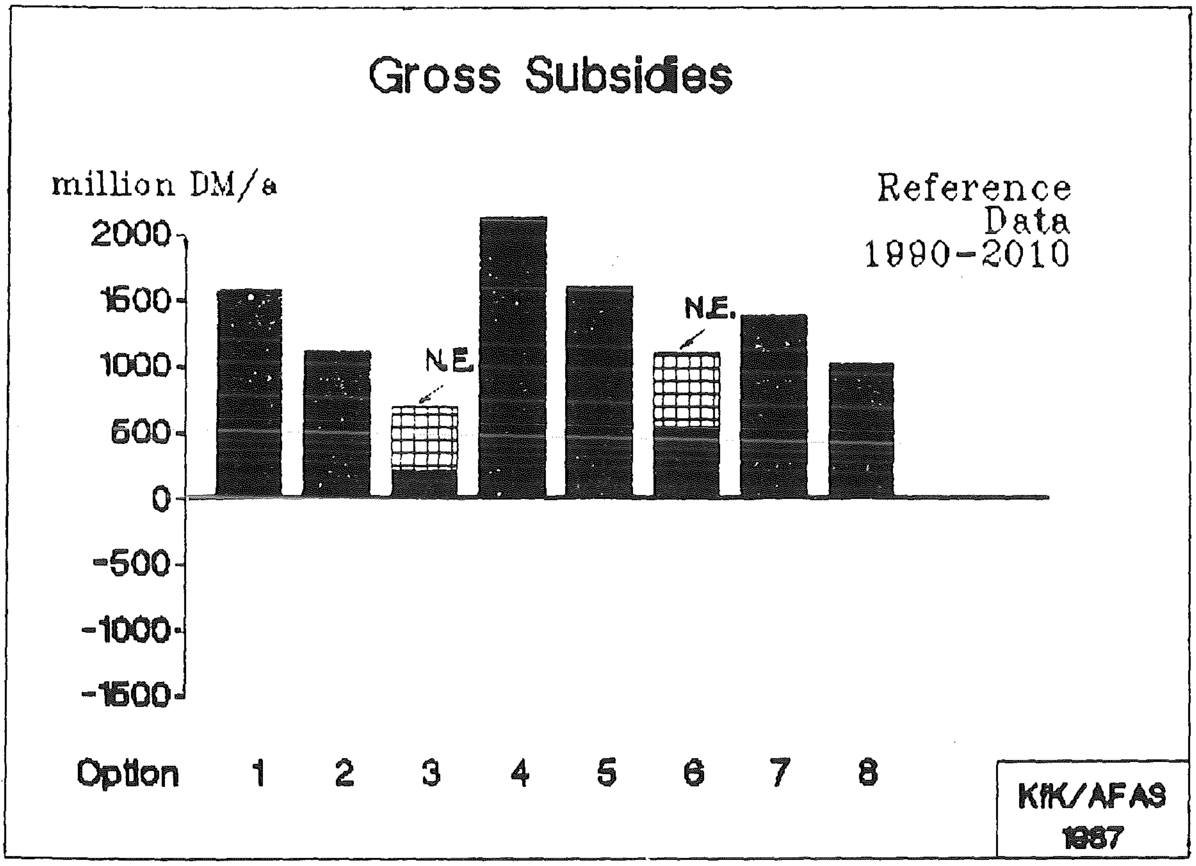
(3) Gross subsidies

If an average real growth rate of oil prices of 1 % p.a. is assumed from 1984 onwards, annual additional costs shown in Figure 4 would occur vis-à-vis the "oil case". They can be interpreted as estimates of the minimum subsidies required annually.

Regarding the options based on hard coal the production of gasoline from methanol (options 4 and 5) shows the highest additional costs and the production of fuels from hydrogenation plants (options 7 and 8) shows the lowest additional costs. However, the small cost advantages of the latter vis-à-vis options 1 and 2 (M 100 from hard coal) may result from data uncertainties.

The results shown in Figures 3 and 4 do not yet take into account that gasoline from hydrogenation would have to be further refined in order to meet fuel specifications. In the case of options 7 and 8 corresponding cost adjustments would increase leading oil prices by approximately 40 DM per ton of crude oil and the gross subsidy requirement by about 80 million DM p.a..

Figure 4: Gross Subsidies



N.E. = Additional costs resulting from the replacement of lignite in electricity generation by nuclear energy

The replacement of the necessary quantities of hard coal by nuclear energy in electricity generation reduces the cost differences vis-à-vis the "oil case" by 380 to 530 million DM p.a. according to the type of process used.

The most favourable that is the lowest cost difference from the "oil case" occurs in option 3 (methanol production from lignite, utilization for M 100 fuel).

4. Summary of the results of the cost analyses and final conclusions

1. Cost disadvantages vis-á-vis the use of liquid fuels derived from oil are to be expected for all options during the period of analysis from 1990 to 2010. At the price growth rates of oil discussed here subsidies would be required for all options if the coal conversion plants started operation at the beginning of the 90s. If around the year 2000 the price of crude oil does not exceed 900 DM per ton, at current monetary value, none of the options will reach cost advantages in the Federal Republic of Germany by the year 2000. For comparison, in 1984 the price of crude oil was at 620 DM per ton, at the beginning of February 1987 spot prices were at 250 DM to 300 DM per ton.

2. Despite the cost disadvantages to be expected around the year 2000, in the long run there are favourable economic prospects for fuels based on coal to replace fuels derived from oil. According to our calculations for most of the options coal fuels would cost roughly 2 DM per litre (gasoline and diesel fuels based on coal at current monetary value). This would entail an increase of 0,06 DM per km for a medium-sized car compared to 1984 when the gasoline price per litre was about 1,40 DM. A comparison with total car costs (1984) of approximately 0,50 DM per km reveals that coal-derived fuels would only moderately increase total driving expenses, and could still be afforded by the average wage earner. It appears to be highly questionable that the use of hydrogen or ethanol from domestic biomass, or electric cars, will achieve cost advantages over fuels derived from coal.

From this angle fuels derived from coal have to be regarded as attractive successors to liquid fuels derived from oil, although from an economic point of view the time is not yet ripe to enforce the introduction of coal fuels.

3. If the options are compared for cost, or from the levels of leading oil prices, and if uncertainty allowances are made, the following qualitative picture emerges:

- because of the large share of coal costs in all options, and because of the cost advantages offered by open-cast lignite mining in comparison to hard coal mining, options 3 and 6 are more advantageous than the corresponding options 1 and 4 on the basis of hard coal. This is still true if cost disadvantages are taken into account which may result from replacing lignite by nuclear energy in the sector of base-load electricity generation. Technical considerations suggest that the favourable position of lignite is also maintained in the case of hydrogenation of lignite not considered here.

- among the options based on the production of fuels from hard coal, these options have cost advantages for which the quantities of hard coal required are not procured by additional mining, but by releasing hard coal in the field of medium-load electricity generation.
- a comparison of conversion technologies produces cost-induced advantages of the M 100 options vis-ă-vis the MTG options. This is largely independent of the question if hard coal or lignite were to be used for conversion purposes. Because of a lack of experience, the options based on liquefaction encompass greater data uncertainties than the M 100 and MTG options. Therefore the differences in costs which have been calculated for the options based on direct liquefaction and the other comparable options should not be overrated.

B. Overall Economic Effects

1. Explanations of the method of calculation

The implementation of the coal fuel options would have diverse effects on the goods and money flows of the overall economic cycle. Such effects can be taken into account by using input-output analysis which permits identification of the effects of changes in final demand on production, income and employment at the level of the direct supplier and his preceding suppliers. On the basis of these results of the input-output analysis effects on private households and government budgets can also be estimated.

For the analyses of this study the scope of the traditional input-output methodology was extended to include, in addition to the primary changes of final demand caused by the options, the following induced changes in final demand:

- reduction of final demand for the oil industries due to the substitution of oil-based fuels
- reduction of final demand for financing the gross subsidies to cover the additional costs of coal-fuel options vis-à-vis the "oil case"
- increase in final demand as a result of option-induced additional income for private households, for example for households of miners. In economic terminology this represents the so-called income multiplier.

- increase in final demand in the public sector, including the social security system, as a result of option-induced additional income, e.g. higher tax revenues, or reduced spending for unemployment payments
- changes in export demand caused by changes in domestic import demand. This means we assume that foreign countries will import less from Germany as a reaction to our import reductions.

As indicators, "additionally employed manpower" and "net subsidies" have been calculated which result from off-setting the gross subsidies defined in the preceding section against the option-induced financial returns to the public sector.

Whether such overall economic effects will in fact occur depends on a variety of factors, some of which will shortly be described hereafter:

- the quantitative importance of changes in demand or income for the economic agents (companies, private households, government budgets). If the changes are minor, it is unlikely that economic agents will react. For example, private households are unlikely to change their consumption behaviour in the case of fairly small income changes.
- the creation of new jobs as a reaction to demand changes depends on the degree of employment of the existing manpower capacity of the companies concerned, or the degree at which the additional demand can be met by working overtime.
- additional income from higher tax revenue, higher social security contributions and lower expenses for employment payments in the public sector, which taken together may be quite considerable, will be distributed over a wide variety of public and social budgets. This means that the effects on individual budgets may be quite minor and may not influence the spending behaviour of the various government agencies.
- moreover, it should be pointed out that the calculated effects are based on production and productivity conditions prevailing at the beginning of the '80s, but the effects of the coal-fuel options would occur towards the end of the '80s and over a further 25 year period. It cannot be expected that the industrial production structure will remain constant for such an extended period of time.

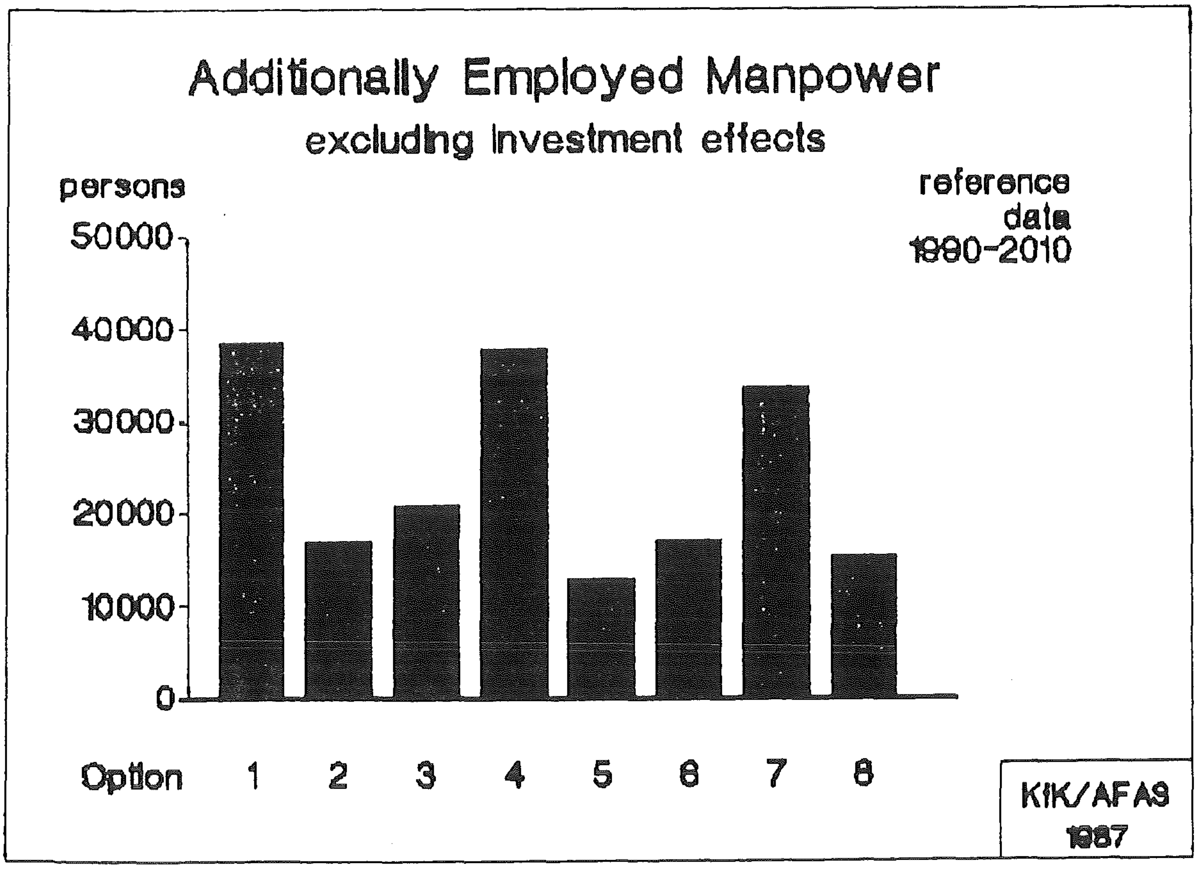
Bearing in mind the uncertainties described above, the results subsequently presented must not under any circumstances be interpreted as reliable forecasts of the overall economic effects of the options discussed. They are primarily supposed to reflect tendencies in the differences in the overall economic effects of the various options.

2. Results for the reference case

(1) Employment effects

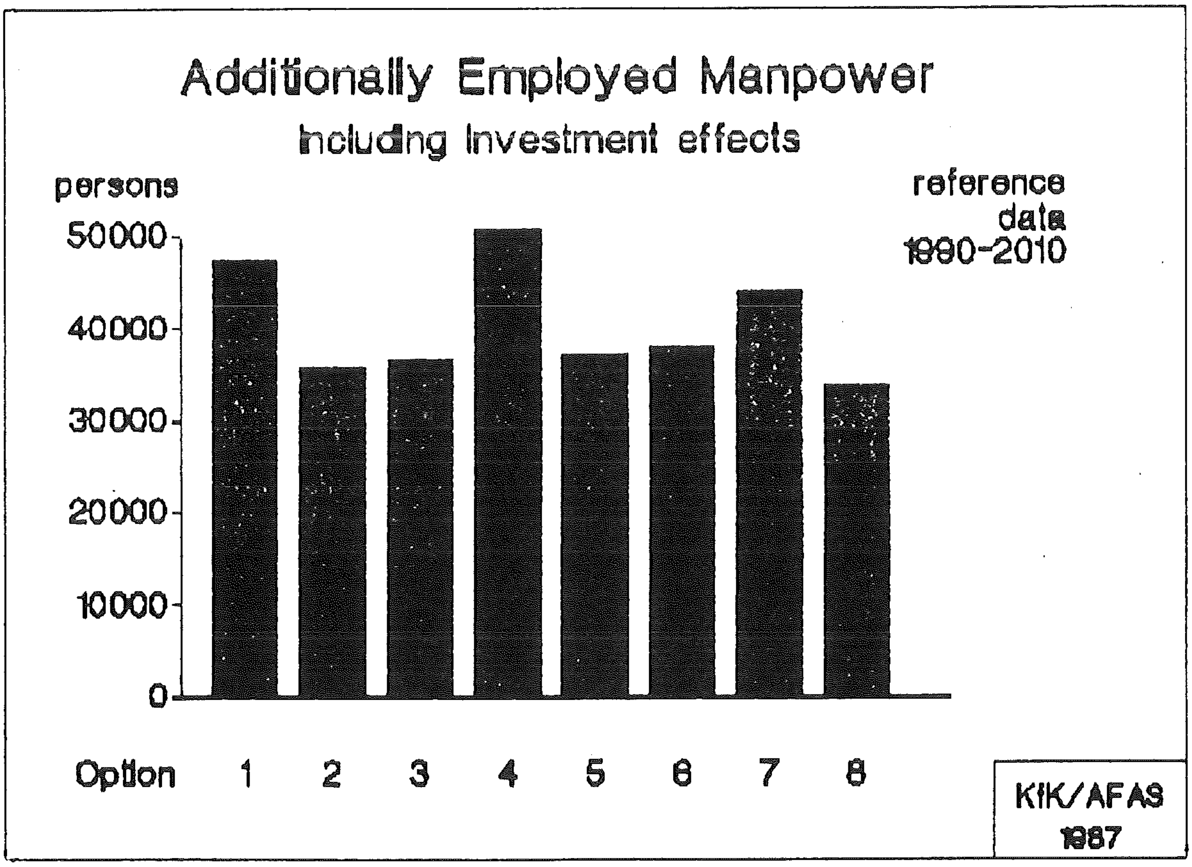
If the operating phase of the plants, without the effects of the investment phase, is examined, considerable differences among the options become apparent (Figure 5). Options 1, 4 and 7, which are based on increased work-intensive coal mining activities would lead to the creation of significantly more permanent jobs than the other options which are more capital-intensive because of the need to build new nuclear power stations. However, this means that the higher capital intensity of the other options will result in higher employment during the investment phase.

Figure 5: Additionally Employed Manpower (Excluding Investment Effects)



In order to further take into account the employment effects of the investment phase, too, we have chosen the following procedure. The employment effects of the investment phase have been evenly distributed over the life-time of the plants (20 years). Thereby the total employment can easily be compared. The results of this calculation are presented in Figure 6 which shows that the preferential position of options 1, 4 and 7 is maintained, but less obviously than when only taking the operating phase into account.

Figure 6: Additionally Employed Manpower (Including Investment Effects)



(2) Net subsidies

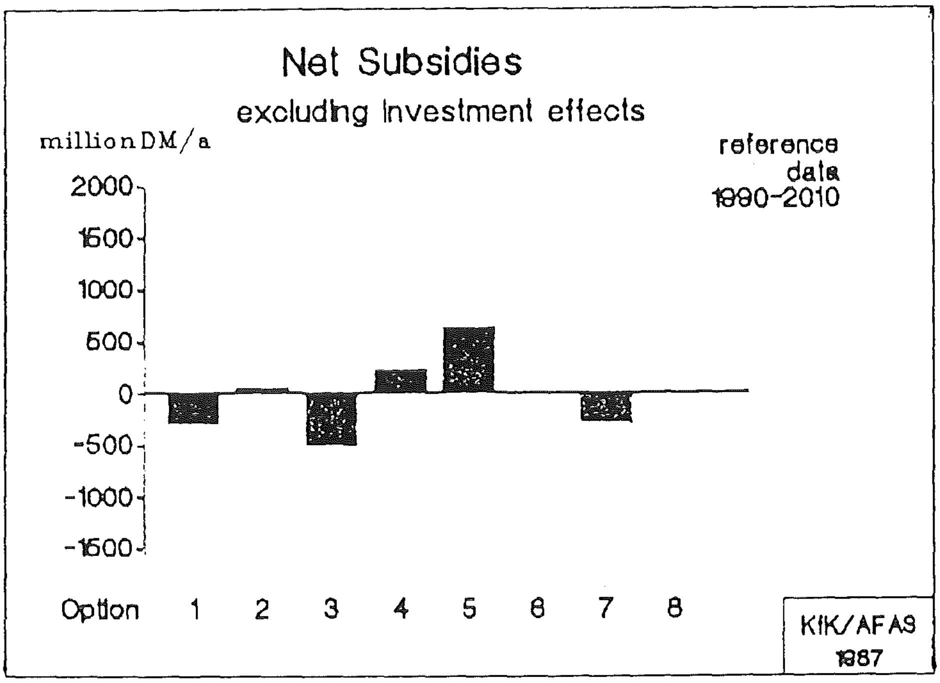
The fluctuations in final demand discussed in section III.B1 would lead to an increase in the value added for all options compared to the "oil case". This entails positive secondary effects on the public budgets

- additional income from production taxes
- additional income from taxes on wages and salaries
- higher social security contributions as a result of higher incomes and higher employment
- reduced social security expenditure because of lower unemployment figures.

The term "net subsidies" describes the balance between gross subsidies, according to the cost difference compared to the "oil case", and the positive secondary effects on the public budgets.

If, as in the case of employment effects, only the operating phase is looked at, the pattern shown in Figure 7 emerges. The dominant position of options 3 and 7 can be explained by two different factors.

Figure 7: Net Subsidies (Excluding Investment Effects)

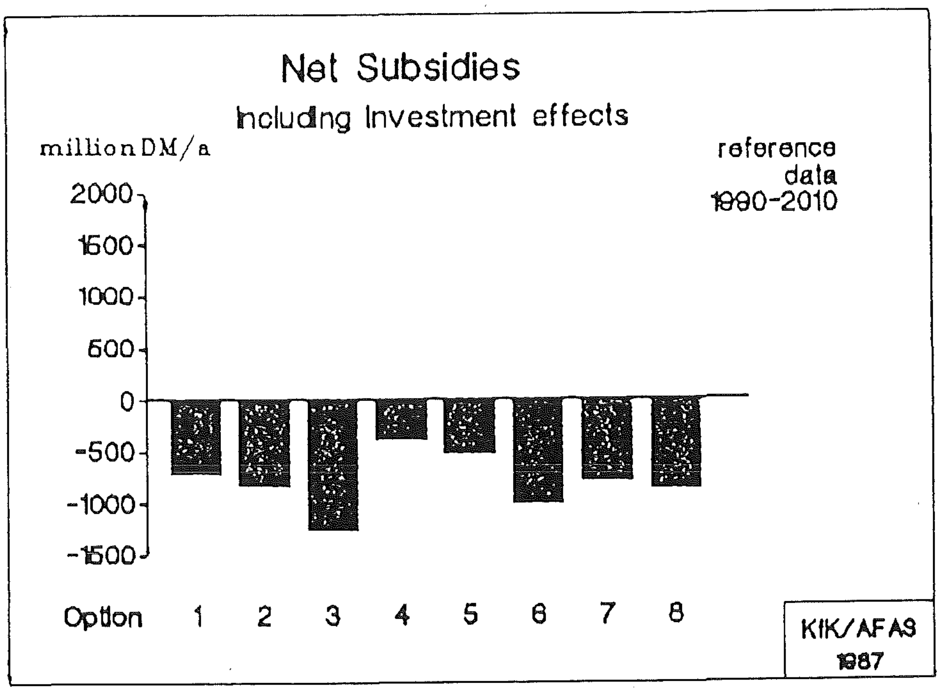


* For options 6 and 8 net subsidies result which are near zero. For technical reasons they cannot be shown in the figure.

In option 3 the relatively small gross subsidies are reflected. In option 7 the gross subsidy disadvantages vis-à-vis option 3 (see Figure 4) are almost offset by the advantages which accrue to the public budgets as a result of the higher employment effects during the operating phase.

If the effects of the investment phase are also considered, using the same procedure as for the calculation of total employment effects, the pattern presented in Figure 8 results. It appears surprising at first that negative net subsidies, i.e. net advantages for the public budgets, result for all options. This is because in all options oil imports are replaced by domestic production to a large extent thus leading to increased domestic income. This means that income previously earned by foreign countries is now earned domestically. In option 4 the economic advantages hereby obtained domestically are clearly far more impaired by the cost disadvantages of this option as opposed to option 3. Furthermore, the pattern in Figure 8 is characterized by differences in the labour intensity of the induced net value added. This explains that the method of supplying hard coal - by additional mining or replacement by nuclear energy in electricity generation - has a far smaller impact on the net subsidies than on the gross subsidies (see also Figure 7).

Figure 8: Net Subsidies (Including Investment Effects)

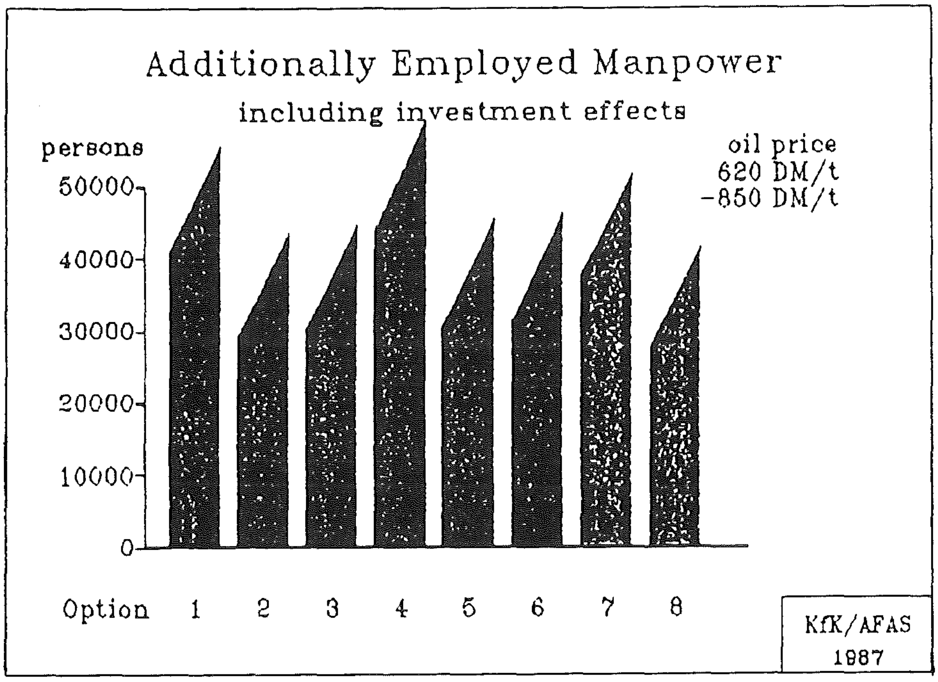


3. Summary of the results of analyses regarding the overall economic effects

During the operating phase the employment effects are far stronger in options 1, 4 and 7 than in other options because of labour intensive hard coal mining. However, they are weaker during the investment phase because of lower capital intensity. Therefore the differences in employment volume are weaker if the operating and investment phases are considered together.

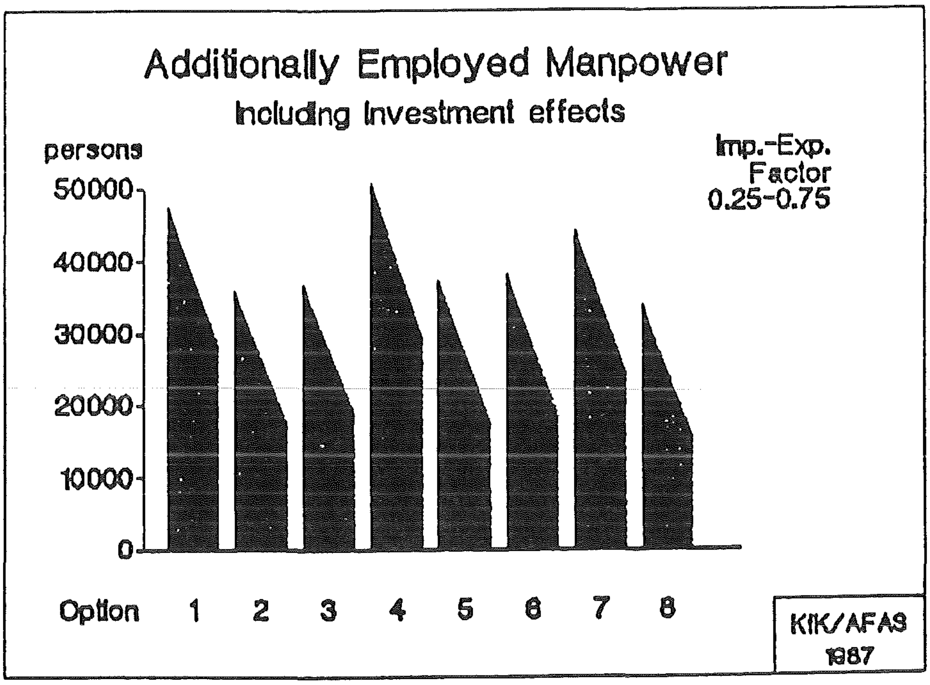
The scope of the employment effects depends on the oil price level around the year 2000 to an extent which is similarly large for all options (Figure 9). It also relies heavily on the extent of potential negative impacts on exports resulting from the reaction of oil producing countries, vis-à-vis diminishing oil imports by the Federal Republic of Germany shown in Figure 10. It is therefore by no means apparent that all options would entail positive employment effects especially in the case of low oil prices and a strong reaction of oil producing countries on import reductions.

Figure 9: Additionally Employed Manpower (Including Investment Effects) Depending upon the Oil Price Level



The left sides of the columns refer to the lower oil price level.
The right sides of the columns refer to the higher oil price level.

Figure 10: Additionally Employed Manpower (Including Investment Effects) Depending upon Foreign Reactions to German Import Reductions

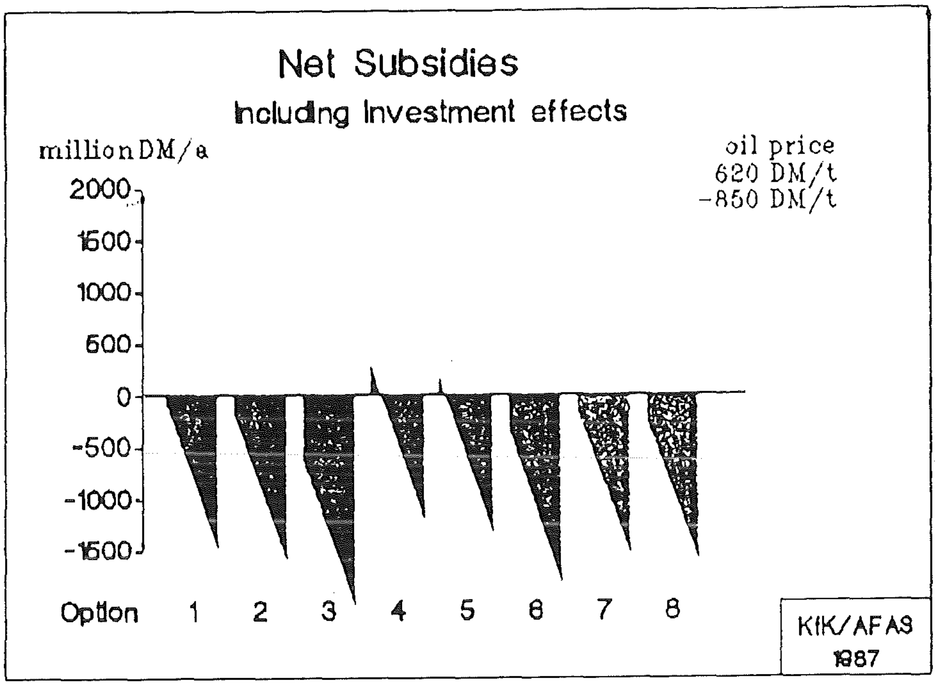


The left sides of the columns refer to the lower import-export factor (y = 0,25).
The right sides of the columns refer to the higher import-export factor (y = 0,75).

It is also valid for all options that the net subsidies, i.e. the balance of gross subsidies required and positive secondary effects on public budgets, strongly depend on the oil price level around the year 2000, and on secondary effects which the diminishing oil imports will have on exports in all options (Figures 11 and 12). The lower the interdependence between import and export changes is rated, the more favourable the net subsidies turn out for all options in comparison with the gross subsidies required.

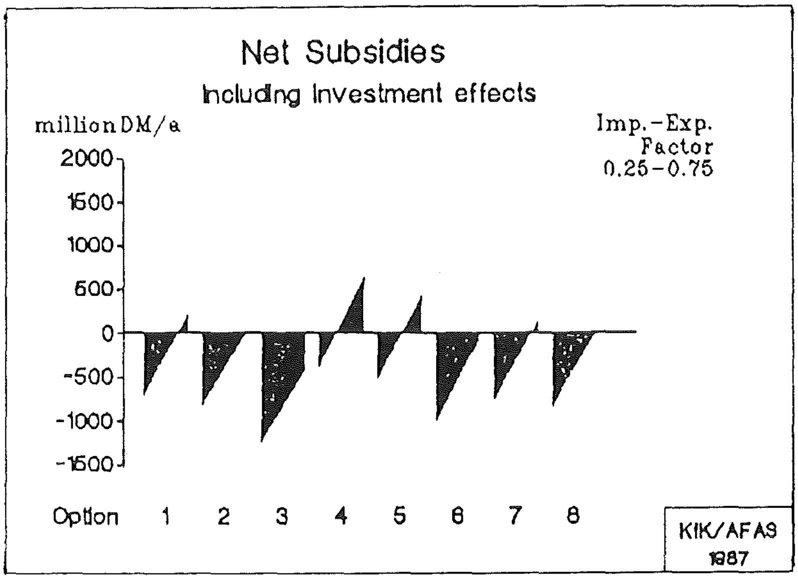
A comparison of the options reveals a pattern similar to that of the cost analyses (section III.A). The only qualitative difference results from the fact that for the hard coal options the disadvantage of options 1, 4 and 7, with additional mining of hard coal, vis-à-vis those options replacing hard coal by nuclear energy in electricity generation (2, 5 and 8) at the cost level (gross subsidies) is by and large balanced by stronger employment effects and the resulting positive effects on social security budgets.

Figure 11: Net Subsidies (Including Investment Effects) Depending upon the Oil Price Level



The right sides of the columns refer to the lower oil price.
The left sides of the columns refer to the lower oil price level.

Figure 12: Net Subsidies (Including Investment Effects) Depending upon Foreign Reactions to German Import Reductions



The right sides of the columns refer to the higher import-export factor (y = 0,75)
The left sides of the columns refer to the lower import-export factor (y = 0,25)

IV. Analyses of the Environmental Impacts of the Coal-Fuel Options

Within the framework of the studies of environmental impacts an attempt has been made to determine all relevant positive and negative impacts on the environment compared to the use of liquid fuels derived from oil. This required:

- on the one hand analyzing the entire chain from coal supply via coal conversion up to the utilization of fuels derived from coal and
- on the other hand analyzing the equivalent chain in the "oil case". This involves analyzing the positive impacts as a result of reduced domestic crude oil processing and the diminished use of liquid fuels derived from oil for road transport. *

For those options in which the necessary amount of coal is made available by replacing coal in electricity generation by nuclear energy, the positive and negative effects which result from this replacement have also been assessed.

The analysis includes emissions of atmospheric pollutants, waste waters and solid wastes, potential risks of accident for persons employed in mining and, partially, risks of accident to the population at large.

Before special positive and negative environmental impacts (SO_2 and NO_x emission) are examined in greater detail, an overview of the range of positive and detrimental effects on the environment is presented in Table 7.

In Table 7 positive and negative environmental impacts are differentiated with regard to aspects of:

- supply of coal,
- conversion of coal,
- distribution and utilization of coal fuels.

As far as supply is concerned those options with hard coal procured from additional mining (options 1, 4 and 7) entail the following risks:

- additional mining wastes
- additional saline pit waters and
- additional accident and health risks to the manpower employed in the mining industry.

* Environmental impacts and risks of the procurement of crude oil (e.g. sea transport of crude oil) however, are not considered here, although there are certain significant risks (e.g. oil spills, SO_2 emissions of oil tankers)

Table 7: Potential Positive and Negative Environmental Impacts of Coal-Fuel Options vis-à-vis the Utilization of Fuels Based on Mineral Oil

	Option 1 (M100/ Hard Coal/ Additional Mining)	Option 2 (M100/ Hard Coal/ Nuclear Energy)	Option 3 (M100/ Lignite/ Nuclear Energy)	Option 4 (MTG/ Hard Coal/ Additional Mining)	Option 5 (MTG/ Hard Coal/ Nuclear Energy)	Option 6 (MTG/ Lignite/ Nuclear Energy)	Option 7 (Hydrogenation/ Hard Coal/ Additional Mining)	Option 8 (Hydrogenation/ Hard Coal/ Nuclear Energy)
1. Supply-Induced Environmental Consequences and Risks	- colliery - saline pit waters - accident and health risks in mining	- slightly increased radiation exposure from nuclear energy - nuclear energy accident risks - higher specific cooling water consumption by nuclear power plants as opposed to coal power plants - nuclear waste + reduction of SO_2, NO_x, CO_2, dust, ash; residuals and waste water from flue gas cleaning	- slightly increased radiation exposure from nuclear energy - nuclear energy accident risks - higher specific cooling water consumption by nuclear power plants as opposed to coal power plants - nuclear waste + reduction of SO_2, NO_x, CO_2, dust, ash; residuals and waste water from flue gas cleaning	- colliery - saline pit waters - accident and health risks in mining	- slightly increased radiation exposure from nuclear energy - nuclear energy accident risks - higher specific cooling water consumption by nuclear power plants as opposed to coal power plants - nuclear waste + reduction of SO_2, NO_x, CO_2, dust, ash; residuals and waste water from flue gas cleaning	- slightly increased radiation exposure from nuclear energy - nuclear energy accident risks - higher specific cooling water consumption by nuclear power plants as opposed to coal power plants - nuclear waste + reduction of SO_2, NO_x, CO_2, dust, ash; residuals and waste water from flue gas cleaning	- colliery - saline pit waters - accident and health risks in mining	- slightly increased radiation exposure from nuclear energy - nuclear energy accident risks - higher specific cooling water consumption by nuclear power plants as opposed to coal power plants - nuclear waste + reduction of SO_2, NO_x, CO_2, dust, ash; residuals and waste water from flue gas cleaning
2. Conversion-Induced Environmental Consequences	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- somewhat higher SO_2- und NO_x-emissions compared to mineral oil processing - ash and sewage sludge; residuals and waste water from flue gas cleaning processes	- higher SO_2- and NO_x-emissions from the combustion of highly sulphurized vacuum bottoms - ash and sewage sludge; residuals and waste water from flue gas cleaning	- higher SO_2- and NO_x-emissions from the combustion of highly sulphurized vacuum bottoms - ash and sewage sludge; residuals and waste water from flue gas cleaning
3. Distribution and Utilization-Induced Environmental Consequences	- higher formaldehyde emissions from stop-and-go traffic in winter - quantitatively higher evaporation emissions of hydrocarbons + reduced NO_x-emissions + reduced soot (particles) emissions + reduced emissions of polycyclic aromatic hydrocarbons + reduced SO_2-emissions	- higher formaldehyde emissions from stop-and-go traffic in winter - quantitatively higher evaporation emissions of hydrocarbons + reduced NO_x-emissions + reduced soot (particles) emissions + reduced emissions of polycyclic aromatic hydrocarbons + reduced SO_2-emissions	- higher formaldehyde emissions from stop-and-go traffic in winter - quantitatively higher evaporation emissions of hydrocarbons + reduced NO_x-emissions + reduced soot (particles) emissions + reduced emissions of polycyclic aromatic hydrocarbons + reduced SO_2-emissions	(+ reduced SO_2-emissions at additional MTO-operation for substituting oil-based sulphurous diesel)	(+ reduced SO_2-emissions at additional MTO-operation for substituting oil-based sulphurous diesel)	(+ reduced SO_2-emissions at additional MTO-operation for substituting oil-based sulphurous diesel)	+ reduced SO_2-emissions as a result of substituting oil-based sulphurous diesel	+ reduced SO_2-emissions as a result of substituting oil-based sulphurous diesel

+ = positive; - = negative

These risks, however, do not appear prohibitive bearing in mind the extent of additional mining under discussion. Corresponding quantities of mining waste and pit waters have been disposed of in the past without great problem at a previously higher level of coal mining. The specific accident and health risks (occupational risks) to coal miners (per 1 mt of useful hard coal mined) will doubtless diminish as a result of further progress in the field of occupational safety.

In those options which presuppose the replacement of coal by nuclear energy in electricity generation (options 2, 3, 5, 6 and 8) the following environmental effects occur as far as supply aspects are concerned:

- the diminished use of hard coal or lignite in electricity generation reduces pollution through SO_2, NO_x, CO_2 and dust emissions as well as reducing amounts of ash and solid wastes and wastewater from flue gas cleaning.

This is counteracted by

- minor additional radiation exposure through the operation of nuclear plants and the facilities of the nuclear fuel cycle
- risks of nuclear accidents albeit of a very small probability of occurrence
- additional nuclear wastes and
- the increased specific consumption of cooling water for nuclear power plants, compared to coal-fired power plants, which might lead to problems in finding suitable sites for nuclear power plants.

A quantitative balance of these highly different positive and negative impacts which result from substituting coal by nuclear energy in electricity generation and a quantitative environmental evaluation compared with the options based on coal from additional mining, meet with insuperable data problems or information gaps about cause-effect-relationships, as well as essential problems of methodology which cannot be discussed here in detail.

If the SO_2 and NO_x emissions, which will be discussed later, are put aside for the time being, there would not be any important differences among the options according to our subjective qualitative assessment.

At the <u>conversion level</u> SO_2, NO_x, CO_2 and dust emissions are higher on balance in all options than in the "oil case". This means that the SO_2, NO_x and dust emissions essentially resulting from the production of process energy for the conversion processes exceed the reduced emissions of these pollutants resulting from diminished crude-oil processing in refineries. Furthermore, coal conversion will lead to additional amounts of solid wastes, such as ashes from gasification plants, vacuum bottoms, residuals from wastewater treatment and other types of waste, e.g. from flue gas treatment. Because of a lack of relevant experience in the field, a definite evaluation of some aspects of solid waste disposal from coal conversion is not yet possible. This largely concerns residuals from wastewater treatment and the solid wastes from the High-Temperature-Winkler gasification which, according to Uhde/Rheinbraun, are to be disposed of by combustion. This does not concern the residues from Texaco gasification in the form of leach-resistant melting granulates, for which there are promising recycling prospects. According to the original conception of the modified IG-Farben process this Texaco process should also be used for the gasification of vacuum bottoms. If these residues, however, are pyrolized, as is at present being discussed, coke with a high sulphur content would result. The disposal of the wastes resulting from fluidized-bed combustion of this coke (as it is planned) has yet to be fully clarified.

As far as distribution and utilization of the fuels are concerned only the M 100 options show significant changes compared to the "oil case".

Additional potential detrimental impacts could result:

- from higher emissions of formaldehyde at cold running phases, e.g. during stop-and-go traffic in winter because during cold running the catalyst which we assume for the gasoline spark-ignited engine, as well as for the M 100 spark-ignited engine, remains ineffective. If and to what extent this is a relevant environmental problem cannot be evaluated as yet because
- on the one hand, there are no measurements available of formaldehyde emissions for the relevant weather conditions and driving cycles,
- on the other hand, the evaluation of detrimental health effects of low concentrations of formaldehyde on man is still a subject of controversy.

Furthermore, there are larger quantities of evaporation emissions of hydrocarbons because of the larger quantities of M 100 to be distributed. Hydrocarbons derived from M 100 are rated as less hazardous than those derived from gasoline, however.

Reduced pollution levels occur in the case of

- emissions of polycyclic aromatic hydrocarbons
- particle emissions
- $S0_2$ emissions
- $N0_x$ emissions.

Under environmental aspects it is especially the latter emissions that make up the differences among the options. This is shown by the overall balances of $N0_x$ and $S0_2$ emissions which are presented in Table 8. These overall balances are based on the assumption listed in Table 9 regarding emission standards and emission factors.

The overall balances of $N0_x$ and $S0_2$ emissions are briefly explained:

(1) on the level of coal supply $N0_x$ and $S0_2$ emissions are reduced in those options which assume the replacement of coal by nuclear energy in electricity generation. In the case of options 2, 3, 5, 6 and 8 reductions through diminished utilization of coal in power plants fluctuate between 17.000 and 28.000 t/a for $S0_2$, and between 10.000 and 18.000 t/a for $N0_x$ (see row 1, Table 8).

(2) the emissions of these pollutants at the conversion level, which mainly result from process energy generation, are higher for all options than the emissions which would result from processing crude oil. However, the difference is insignificant for the options 1 to 6 based on gasification (see Table 8, rows 2 and 3).

By comparison, hydrogenation (options 7 and 8) produces significantly higher $S0_2$ and $N0_x$ emissions because of the combustion of the highly sulphurized residues which result from the pyrolization of vacuum bottoms.

Table 8: Balances of NO_x- and SO_2-Emissions for Various Coal-Fuel Options (in t/a) a)

	Option 1 (M100/ Hard Coal/ Additional Mining)		Option 2 (M100/ Hard Coal/ Nuclear Energy)		Option 3 (M100/ Lignite/ Nuclear Energy)		Option 4 (MTG/ Hard Coal/ Additional Mining)		Option 5 (MTG/ Hard Coal/ Nuclear Energy)		Option 6 (MTG/ Lignite/ Nuclear Energy)		Option 7 (Hydrogenation/ Hard Coal/ Additional Mining)		Option 8 (Hydrogenation/ Hard Coal/ Nuclear Energy)	
	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x	SO_2	NO_x
1. Replacement of Coal by Nuclear Energy in Electricity Generation	-	-	- 24900	- 15700	- 17700	- 13600	-	-	- 28300	- 17900	- 20100	- 15500	-	-	- 16850	- 10600
2. Coal Conversion	+4600	+ 1550	+ 4600	+ 1550	+ 4250	+ 4200	+5200	+2200	+5200	+ 2200	+ 4850	+ 4850	+ 20800 b) + 11200 c)	+ 13050 b) + 5600 c)	+ 20800 b) + 11200 c)	+ 13050 b) + 5600 c)
3. Crude Oil Processing	- 3000	- 800	- 3000	- 800	- 3000	- 800	- 3000	- 800	- 3000	- 800	- 3000	- 800	- 3000	- 800	- 3000	- 800
4. Operation of Motor Vehicles	- 5200	- 34800	- 5200	- 34800	- 5200	- 34800	-	-	-	-	-	-	- 4400	-	- 4400	-
5. Total	- 3600	- 34050	- 28500	- 49750	- 21650	- 45000	+ 2200	+ 1400	- 26100	-16500	- 18250	- 11450	+ 13400 b) + 3800 c)	+ 12250 b) + 4800 c)	- 3450 b) - 13050 c)	+ 1650 b) - 5800 c)

a) calculations are based on existing or planned emission standards; in many cases it is technically feasible to stay below these standards, which means that further reductions of emissions could be possible
b) it is assumed that after pyrolizing the vacuum bottoms the remaining coke is burned in a fluidized bed combustion plant, which is treated as a single plant according to the Regulation on Large Boilers. As the Regulation differenciates between plant sizes, this fluidized-bed combustion plant - as a fairly small plant - would only require comparable weak sulphur retention (75 %)
c) it is assumed that all combustion plants belonging to the conversion plant (power plant, the fluidized bed combustion plant for the combustion of the coke and other combustion plants) are regarded as one plant thus requiring a very high sulphur retention according to the Regulation on Large Boilers.

Table 9: Emission Standards Applied

- for combustion plants (power plants, process energy production for coal conversion and crude oil conversion resp.):

  specifications of the Regulations on Large Industrial Boilers and the supplementary resolution of the conference of the Ministers on Environmental Affairs of April 1984

- for gas cleaning plants in gasification and hydrogenation plants:

  1 wt% of the sulphur contained in the coal is emitted

- for motor vehicles

  passenger cars and small lorries < 3,5 tons of total weight

  US 49-states-standards, which means at present state of technology cars running on gasoline and M 100 have to be fitted with three-way catalytic converters with closed-loop systems

  commercial vehicles > 3,5 tons

  for NOx: 1200 g/GJ fuel (emission factor applied by the Federal Environmental Agency minus 20 % according to the concept of the Federal Government of August 12, 1985 to reduce pollutant emissions from commercial vehicles and motor bicycles)

  for particles: 10 g/GJ fuel (emission factor of the Federal Environmental Agency minus 80 % by using trap oxidizers)

  sulphur content

  0,15 wt% in oil-based diesel (zero in gasoline)
  no sulphur in coal-based diesel fuel

(3) The most relevant effect on the environment is to be found at the level of coal fuel utilization (Table 8, row 4). The M 100 options would entail considerable reductions in $N0_x$ emissions - as many as 6 % of $N0_x$ emissions expected for the year 2000 from total road transport or 3 % of the total $N0_x$ emissions of 1.1 million tons expected for the year 2000 for the F.R.G.. This effect results from the substitution of oil-based diesel fuel in the sector of commercial vehicles larger 3,5 tons which would simultaneously reduce particle emissions.
There would be a considerable potential for reducing environmental pollution if a substitution strategy were set up with the aim of substituting the entire consumption of diesel fuel by methanol in the sector of heavy commercial vehicles. Thus, a reduction of at least 200 000 t/a of $N0_x$ and approximately 3500 t/a of particles could be achieved. In the case of $N0_x$ this would cover almost 20 % of the $N0_x$ emissions expected by the year 2000 for the F.R.G.
Substituting oil-based diesel fuel would also bring about reduced emissions of $S0_2$. This applies to the substitution by M 100 or methanol, as well as to the substitution by diesel fuel derived from direct coal liquefaction, since neither contains any sulphur, or traces in negligible quantities only. There is no $S0_2$ bonus for the MTG option here as it is assumed that gasoline alone is substituted. However, a high-quality diesel fuel could be produced in the future by an MTO (methanol to olefins) operation of an MTG plant as has been shown successfully in the MTG demonstration plant at Wesseling. Thus, options 4, 5 and 6 would also obtain corresponding sulphur bonuses.

(4) The M 100 spark-ignited engine has also a more favourable emission behaviour with regard to $N0_x$ and other legally restricted pollutants as compared to gasoline spark-ignited engines. However, the M 100 spark-ignited engines would also require specific adjustments of exhaust gas cleaning in order to comply with the US standards which, for the calculations of this study, have been assumed as valid. In the field of legally restricted pollutants the standards approved by the EEC for cars under 2 l total piston displacement, however, could be met by M 100 spark-ignited engines more easily than by gasoline spark-ignited engines without special exhaust gas cleaning modifications. It might be expected on the other hand that the introduction of M 100 will entail legal provisions for the use

of open-loop catalysts because of the significantly higher formaldehyde emissions.

(5) As far as NO_x emissions are concerned, the overall balance shows a definite bonus for M 100 over both the "oil case" and the other options. Only those options in which coal required for conversion is replaced by nuclear energy in electricity generation show reduced levels of SO_2 emissions of any significant extent. The liquefaction option, option 8, is an exception. Here these reduced levels are counteracted by additional SO_2 emissions of about the same order as a result of the combustion of highly sulphurized wastes from pyrolization. In the case of the liquefaction option based on coal from additional mining, option 7, the SO_2 emissions would even be considerably higher than in the "oil case" because of the waste combustion.

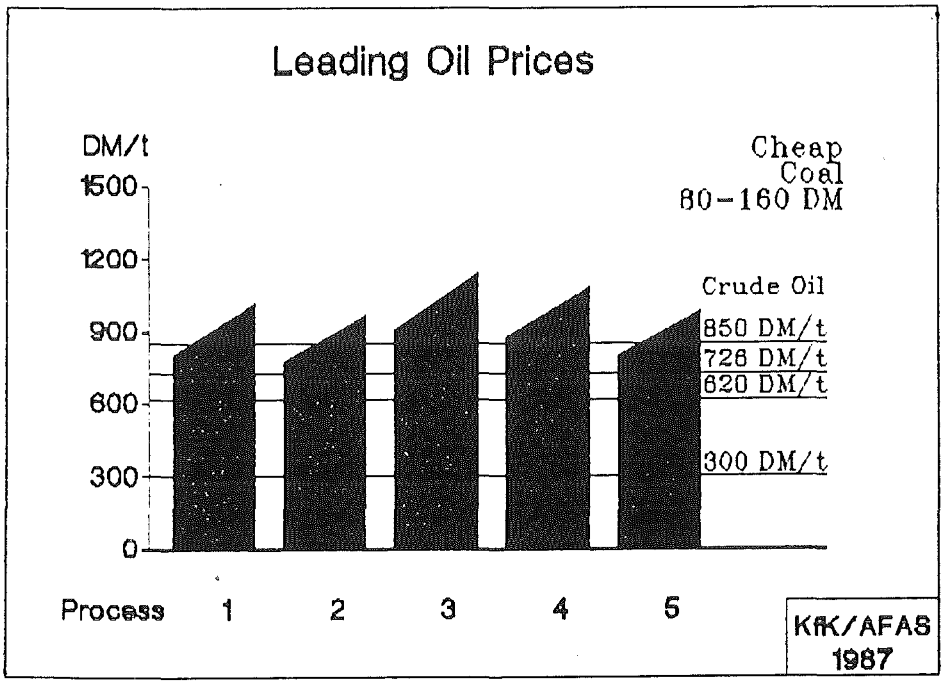
Although an overall environmental evaluation is difficult because of the diversity of positive and negative impacts on the environment we would, however, give preference to the M 100 options. This assessment is based on the potential for reducing environmental pollution, firstly in the case of NO_x emissions, and secondly of particle emissions resulting from the replacement of diesel fuel by M 100 in heavy commercial vehicles. In evaluating this potential it should be kept in mind that there are at present no other technically feasible and economically acceptable solutions for comparable improvements of the emission behaviour in diesel lorries.

V. Perspectives for the Export of Coal Conversion Technologies

Cost analyses reveal that cost advantages vis-à-vis liquid fuels derived from oil cannot be expected to be achieved by any of the options under discussion in the Federal Republic of Germany by the year 2000. However, thinking about possibilities of exporting coal conversion technologies, it is interesting to look at conditions prevailing in countries where cheap coal is available from open-cast mining.

Figure 13 provides an answer to this question which can serve as a guideline. Here leading oil prices are represented which result for hard coal prices between DM 80 and DM 160 per tce. In this case, too, the price of crude oil would have to far exceed the 1984 level, approximately 45 $ per barrel, in order to achieve cost advantages over liquid fuels derived from oil. A deflated oil price of 45 $ per barrel by the year 2000 cannot be ruled out. However, this is certainly within the upper range of price developments which can be envisaged at present.

Figure 13: Leading Oil Prices



Processes
1 Methanol from hard coal using the Texaco process
2 Methanol from lignite using the HTW process
3 Gasoline from hard coal using the Texaco and MTG process
4 Gasoline from lignite using the Texaco and MTG process
5 Direct liquefaction products using the modified IG-Farben process

The left sides of the columns refer to a coal price of DM 80 per tce
The right sides of the columns refer to a coal price of DM 160 per tce

In clearly defined individual cases the situation may be distinctly different because a series of economically relevant conditions differ from country to country such as

- costs of investment and operation. Because of long distance transportation of building materials and equipment, or the necessary recruitment of qualified personnel for assembly and maintenance, costs may be considerably higher than in the Federal Republic of Germany. But they may also be lower because of especially favourable production conditions for assembly parts, or because of lower environmental and safety standards.
- the adjustment of the technical layout of the conversion plants to the coal price level. It may under certain economic considerations, e.g. in the case of very cheap coal, be reasonable to reduce technical sophistication as a means of reducing investment costs.

With regard to perspectives for the export of coal conversion technologies, it must also to be pointed out that in some countries, economic aspects may not be the only motives for coal conversion. Aspects of foreign trade, for example the currency situation, or security of supply may be of importance. The apparent interest of some foreign companies in establishing joint ventures with German firms in the field of coal conversion has to be viewed against this background.

With rising oil prices this interest will grow especially if further progress is made in research, development and demonstration in the Federal Republic of Germany.

Considering the results presented in Figure 13 for the case of cheap coal, a definite preferential position does not emerge at present for any of the different conversion technologies.

The potential for technological development has not yet been fully exploited in any of the conversion processes presented. The examples of the novel concepts of hydrogenation (high pressure hydrogenation and the Pyrosole process), which are still being developed on a small scale, indicate that there is potential for more than marginal technical and economic improvement.

In a longer-term perspective the chances for exports of hydrogenation technology seem to be favourable because higher oil prices and correspondingly higher coal prices can be expected which would bring to bear more clearly the efficiency advantage of hydrogenation. Hydrogenation appears to be interesting for countries which have a high import demand for the entire range of mineral oil products and which also suffer from a lack of hard currency, for example Eastern bloc countries. Furthermore, in our opinion the Federal Republic of Germany has a leading position in the technological development of hydrogenation which is not true to the same extent in the field of gasification.

In a medium-term perspective there seem to be some advantages in fuel production on the basis of gasification

- compared to direct liquefaction, gasification is a relatively simple technology which is more suitable for export to countries which do not have highly qualified technical manpower resources
- gasification for methanol production is less capital intensive than direct liquefaction, which means it might be easier for countries with a shortage in capital to overcome the investment threshold
- gasification can be carried out with almost any quality of coal, even very cheap coal, which can make up for its efficiency disadvantage when compared to direct liquefaction where higher standards of coal quality are required.

In general, all countries with cheap coal resources are potential candidates for gasification technologies because of the simpler technology involved, lower capital costs and lower quality standards of the coal required. Providing the fuel market does not open up for methanol, it should be stated, however, that the advantages in capital costs of the options based on gasification could turn into disadvantages if a subsequent conversion of methanol to gasoline (MTG process) is required.

VI. Analyses of Implementation Problems of Coal-Fuel Options

At present the biggest implementation problem of all coal-fuel options discussed here is the lack of economic profitability. Further problems of implementation concern the M 100 options most of all, as the introduction of a new fuel requires considerable efforts in adjustment, regulation and coordination. This does not apply to the MTG and hydrogenation options since they produce fuels which largely correspond to oil-based fuels as far as fuel specifications are concerned.

The following problems of implementation would be connected with the introduction of M 100 in particular:

(1) various legal regulations in connection with safety questions and health protection would have to be altered. Until now, methanol is subject to the regulations on poisonous substances of the Länder. It would have to be exempted from these regulations. In a study carried out on behalf of the Federal Ministry for Research and Technology in 1983 such an exemption would be considered acceptable providing that adequate measures of protection were taken, such as identification by colouring, spoiling or constructive measures against tapping.

(2) modifications of international regulations, especially EEC regulations, would be required. The problems with the introduction of unleaded gasoline in all European countries may serve as the best example of potential difficulties. In the case of M 100, however, problems should not be quite as severe since it would not be introduced mandatorily as an exclusive fuel but optionally as an additional fuel.

(3) it should be emphasized that a special regulation would have to be introduced into German mineral oil taxation. Apart form the fact that for fiscal reasons M 100 could not be exempted from taxation, it falls under the Mineral Oil Taxation Law because of the admixture of C_4 and C_5 compounds derived from mineral oil. At the prevailing volumetric taxation, M 100 would be taxed almost twice as high, with regard to the energy content, as gasoline or diesel because of its lower specific energy content. Therefore, a special agreement would have to be reached, as was the case during the test operation of M 100 motor vehicles, i.e. half the tax rate should be fixed as for mineral oil fuels which would roughly correspond to an equal taxation in terms of energy content.

(4) A new infrastructure would also be required such as additional storage facilities for methanol and a sufficiently dense supply network not only nationally but in all European countries, as use of M 100 only for fleet or regional supply purposes is ruled out in view of the quantities discussed here. Regional supply and/or fleet concepts, however, can be of great importance within the framework of introduction strategies.

(5) Modifications of vehicles would also be necessary. For example, larger tanks would be required to achieve the same range as motor vehicles using mineral oil fuels. This could possibly entail reduced space and comfort and might provoke problems of acceptance on the part of the buyer.

(6) During the introduction phase of a new fuel economic problems may occur, which have not been considered within the cost analyses such as gaps in supply and demand for M 100. Whereas lacking quantities could be supplied by the international markets, an excess in supply from domestic production would create greater problems. Partial load operation of the production plants, or various possibilities of using the surplus of methanol for other purposes, blending of gasoline in low concentrations, further processing to gasoline via the MTG process, utilization in the space heating market or for export, will entail economic disadvantages as a rule. Reduced employment of infrastructure capacities are also to be expected during the introduction phase. After all a propensity of the automobile industry, the fuel trade and the service stations to invest in M 100-technologies cannot be readily assumed.

(7) Incentives will be required at least in the initial phase for purchasing M 100 cars or M 100 commercial vehicles as long as M 100 does not offer any economic advantages, because disadvantages from service station supply might discourage potential buyers during the initial phase.

(8) Finally, the supply of C_4/C_5 cuts from domestic production could be jeopardized if domestic crude oil processing is further reduced. The import of these compounds would again entail a stronger dependence on foreign sources.

These problems of implementation are not insuperable. The introduction of a new fuel like M 100 presupposes, however, well coordinated action by public authorities, industry, commerce, service stations and also by the EEC.

It should be mentioned that the introduction of a methanol fuel for heavy commercial vehicles may cause less problems as more than 90 % of the fuel is supplied by on-site service stations of the transportation companies. If they could be convinced to switch over to methanol, the requirements with respect to the density of the supply system would be much lower. Furthermore, for technical reasons an admixture of C_4/C_5 cuts is not required for the substitution of diesel fuel which would avoid problems of this nature. The substitution of diesel fuel by methanol is, however, economically less advantageous for commercial vehicles than the substitution of gasoline by M 100 in the sector of private motor vehicles.

As a summary it can be said that the M 100 options produce significant disadvantages compared to the other options as far as implementation problems are concerned. The liquefaction options seem to be the least problematic in this respect. The implementation of the MTG options without MTO operation, in which case diesel fuel would not be substituted, might entail structural problems in the market for mineral oil products, especially if a larger substitution volume is assumed.

VII. Overall Evaluation of Options

1. Because of the same substitution volume, all options more or less live up to the primary objective which is to reduce the dependence of fuel supply from mineral oil by producing coal-based fuels. Therefore, a discriminating overall evaluation requires additional criteria of assessment.

The following six criteria have been selected: economic profitability, overall economic effects, employment effects, environmental effects, aspects of implementation and potential for export. The rating of the options with regard to these criteria as "relatively favourable", "occupying a middle position" and "relatively unfavourable" reflects, unless based on quantitative assessments exclusively, the evaluation of information and the weighting of various aspects from the viewpoint of the study group (see Table 10).

2. The evaluation aspects chosen and the rating of the options by the study group will be briefly explained.

(1) The aspect "economic efficiency" evaluates the profitability of the individual options or the extent of public subsidies required (gross subsidies). As opposed to the "oil case", cost disadvantages are to be expected for all options. That means public subsidies would be required for all options. The classification of the options in Table 10 is based on Figures 3 and 4.

Table 10: Evaluation Criteria of the Options

Classification [1]	Comparatively Favourable	Middle Position	Comparatively Unfavourable
Economic Efficiency	options 3, 6	options 7 and 8, 1 and 2	options 4 and 5
Overall Economic Effects	option 3	options 8, 7, 6, 2, 1	options 5, 4
Employment Aspects	options 1, 4,7		options 3, 2, 6, 8,5
Environmental Effects	options 2, 3, 1	options 5, 6, 8	options 4, 7
Implementation Aspects	options 7, 8, 4, 5, 6		options 1, 2, 3
Significance for Industrial Policy	Methanol and MTG medium-term, hydrogenation long-term		

[1] the positioning of the options within the categories reflects minor differences of evaluation.

Option 3 (M 100 from lignite) has the best rating; option 6 (MTG from lignite) the second best if the additional costs resulting from the replacement of lignite by nuclear energy in electricity generation are neglected which is justifiable under profitability aspects. The next positions are taken by options 7 and 8 followed by options 1 and 2 which are based on the hydrogenation of hard coal and the production of M 100 from hard coal respectively. The slightly more favourable results of hard coal hydrogenation should not be overrated because the difference compared to the M100 production from hard coal lies within the range of uncertainties of such calculations. By comparison the most unfavourable results are obtained by the MTG options on the basis of hard coal (options 4 and 5).

(2) The evaluation aspect "overall economic effects" produces a somewhat different rating. Here the overall economic effects to be evaluated are mainly caused by substituting import of crude oil and mineral oil products by fuels from domestic production based on domestic coal. As a global indicator of this effect in section III.B, the balance of positive and negative financial effects on the public budgets, called net subsidies here, was selected. The classification can be deduced from Figure 8.

(3) On the one hand employment effects can be regarded as being part of the overall economic effects. On the other hand, regional and social components have to be included in the evaluation. This is because the employment effects of the options, in particular those options based on coal additionally mined, would occur with a high regional concentration in mining areas where very high structural unemployment prevails at present. Hence the employment effects are treated as independent evaluation aspects. Although the quantified differences in employment effects cannot be rated as very significant compared with the present total unemployment of roughly 2 million people, see Figure 6, judged by regional economic aspects they could be of considerable importance. Figure 5 "additionally employed manpower, excluding investment effects" could serve as an evaluation basis in this context because this concerns mainly permanent jobs (for coal mining and the operation of the plants) in the mining regions. There are definite advantages for options 1, 4 and 7 whose production basis is hard coal which has to be additionally mined. The differences among the other options are relatively minor.

(4) The evaluation of environmental effects has to take into account that the environmental anlyses of this study have been based on emissions only. Quantitative analyses of pollution levels and damages have not been carried out. This is because it can be expected from the results of another AFAS study [1] on the consequences of an increased use of coal that hardly any effects on regional pollution levels or damages can be identified. This is due to a fairly modest sensitivity of the available methodology with respect to the minor changes of emissions under discussion here. Therefore the environmental consequences have been evaluated on the level of emissions. The classification of the options was based primarily on changes of the emissions of NO_x, particles and SO_2. If these effects are emphasized the M 100 options appear the best, whereas the hydrogenation options have the least favourable results if the positive effects of the replacement of coal by nuclear energy in electricity generation leading to reduced SO_2 and NO_x emissions are disregarded. Taking into consideration these positive supply aspects leads to a further differentiation. However, it does not jeopardize the preferential position of the M 100 options.
In our opinion, however, some points have not yet been sufficiently clarified for a comprehensive environmental evaluation - the relevance of formaldehyde emissions in the case of stop-and-go traffic in winter and the disposal of special types of solid wastes (residuals from wastewater treatment and solid wastes from coal conversion).

(5) With regard to implementation, the M 100 options get the most unfavourable rating because of the considerable efforts of regulation, coordination and adjustment required for the introduction of a new fuel.

(6) With regard to export potentials, gasification technologies may have advantages in a medium-term perspective because coal of low quality, that is to say cheap coal, can be used. Moreover these technologies being comparatively simple can also be more easily implemented by countries which are not highly industrialized.
In a long-term perspective, assuming significantly higher oil and coal prices, direct coal liquefaction should have good chances for export because of the higher rate of efficiency.

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1) R. Coenen (ed.): Steinkohle - Technikfolgenabschätzung ihres verstärkten Einsatzes in der Bundesrepublik Deutschland, Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1985

3. Summary

Our discussions have shown that none of the options can be rated favourably under all different evaluation aspects.

The M 100 options offer definite advantages as to environmental aspects; with regard to cost, only if methanol is produced from lignite. As to the implementation, however, there are distinct disadvantages for these options.

On the whole, hydrogenation of hard coal assumes a middle position. Its slightly unfavourable rating with regard to environmental effects should not be overestimated; there may be technical possibilities for mitigation measures.

Under all aspects of evaluation the MTG options should possibly be given the most unfavourable rating. This certainly applies to the MTG options based on hard coal whereas MTG-gasoline on the basis of lignite could gain importance within the framework of an introduction strategy for M 100.