the conference today have selectivities to short-chain olefins in a range of up to 10 % - 15 % - i.e. the percentage of the total hydrocarbons produced consists of ethylene, propylene and buthenes.

Modern research says that it is possible to have catalysts which produce, for example, during a lifetime of 2,000 hours, about 50 % of the raw product in this special range. Or, if one produces 150 grammes per normal cubic metre of synthesis gas introduced into the reactor, 75 - 80 grammes of the 150 grammes may consist of these 3 short-chain olefins. The distribution for these are about 40, 35 and 25 percent respectively.

A number of problems are linked with the development of these catalysts:

1) lifetime
2) need for special gas compositions (mainly rich in carbon monoxide) not readily available from the given processes of coal gasification
3) the main problem of removing heat under constant reaction conditions for the catalyst. This has to be solved by technical equipment, which is a very difficult task.
   On the other hand, the phenomenon of catalysis (i.e. the mechanism and conclusions which have to be drawn from this) is not yet clear enough to enable a synthesis to be directed completely in the desired way.

To summarise: Considerable progress has been made, but this provides only an insufficient base for a technical process. More work will be carried out over the next 1-2 years, and the pure research tasks will be more closely linked with engineering tasks. A synthesis of catalyst development and engineering aspects is now necessary.

KÜHN: I fully agree with Dr. Frohning's comments and would like to add one or two points. Unfortunately, parallel to the increase in olefine production, or low-molecular Hydrocarbons production, we must consider the increase in undesired methane formation. Would you subscribe to the same opinion?

GAENSSLEN: A distinction must be made between chemical and fuel production; in the case of the former, selectivity is of vital

importance, because we know how difficult it is to seperate chemicals from what Schering call an "exploded pharmacy", which is what the Fischer-Tropsch-synthesis produces. It produces a little problem created by fuel is not so drastic; the choise of what is burned is not as vital.
A catalyst is needed for the Fischer- Tropsch synthesis which makes a liquid fuel in the range of C4 - C18, and neither methane, ethane nor propane (C18 would be the limit). A catalyst working at around 40 atmospheres at a temperature not higher than 300° C would be an asset to the Federal Republic of Germany. This would lead to a space velocity of over 5 kg per hour and litre (30 lbs. per cu. ft. per hour). It would also lead to a low-viscosity liquid and C4 - C18. Under these conditions, ash could be well separated a d asphaltines attacked.

KNUDSEN: At SASOL much progress has been made in narrowing the band of the spectrum or bell-shape of the products in the carbon range around gasoline. Work is being carried out into the gas and heavy areas.

GAENSSLEN: But the problem of excess methane still exists.

KNUDSEN: Yes, this is true.

KÜHN: By combining two types of Fischer-Tropsch-processes, bringing the desired product pattern in total, they are running parallel to the fixed-bed process, making the long-chain products, and the Synthol or fluidized bed process, which makes high quantities of gas and the low molecules.

KNUDSEN: Long-chain products are made at the first plant, where there is apparent satisfaction with the amounts of wax produced. At the second, larger plant more is made as the process in question is not used. No doubt satisfaction exists with what is produced already.
The question of zeolytic catalysts has attracted much attention and tends to lead to selectivity in that one can control catalyst size. What work is being performed in the Federal Republic of Germany in this field, with regard to either fuel or chemicals?

HOLIGHAUS: Zeolytic catalysts could meet the demands put forward by Mr. Gaensslen.

GAENSSLEN: The Mobil catalyst is a typical example of this; that is why it is so selective for gasoline.

HOLIGHAUS: There is a particular pattern situation showing that difficulties arise in this field.

GAENSSLEN: Does this mean that research is not being carried out because of these patterns?

HOLIGHAUS: We only do some work; but much work is done by industry, e.g. at Hoechst. Is similar work being carried out at Ruhr-Chemie?

FROHNING: No. This principle of synthesis is only valid when one starts from methanol and upgrades this. It does not apply when one starts from syngas and synthesises hydrocarbons directly from this.

KNUDSEN: Such a project exists in the U.S., the most successful being the methanol reformation. However, there are some promising small-scale results for CO and hydrogen.

FROHNING: Maybe some work was carried out 10 years ago (or more) in the Federal Republic of Germany and was discontinued owing to conversion on only a small scale.

KNUDSEN: Several years ago, small groups were established, both of Dupont and Dow chemical companies to look into the possibility of direct hydrogenation of carbon monoxide to valuable chemicals, e.g. high-selectivity ethylene. More experimental groups may be set up.

STÖCKER: In the "International Daily Herald Tribune" of 12. Sept. an article appeared stating that Dow chemicals had found a new catalyst, which they maintain is cheaper than others.

KÜHN: I would like to add that there are several groups in the Federal Republic of Germany which tried to find a new method on this zeolith catalyst basis, but up till now everyone accepts that Mobil has found unique way; its success is really the only one

GAENSSLEN: You mean that this is a single case?

KÜHN: Not exactly, but other successes are surpassed by Mobil.

HILL: I would like to raise the question of the meaning of average cost of the premium gasoline, to which we have arbitrarily assigned the value factor I hereThis means that in this case the price was 40 dollars 82 cents per barrel.
When M-gasoline is compared with SRCI, the latter has a much higher cost than any other gasoline, although it is essentially a lower value product. If one looks at the average cost of the product, it is about 40 dollars (this applies to M-gasoline).
Lower in the table, the cost is approximately 30 dollars; therefore some would conclude that SRCI is preferable to M-gasoline, by 10 Dollars per barrel. However, decision-makers should take into account the fact that one cannot compare the cost of boiler-fuel with the cost of premium gasoline.
We aimed to put everything on a single basis where the value of the product was reflected in the average cost of the product referred to premium gasoline. Another way of reading this is to say that if the SRCII product is taken for refining into premium gasoline (which is a real consideration in the U.S.), then the premium gasoline would cost approximately 35.95 dollars.
The apparent desirability of aiming for a process which leads to a low value fuel must be clarified.

SCHULZE: I would like to raise the question of distributing the costs of the whole production.

HILL: It is impossible, in our opinion, to distribute the cost to the different products. We said that we would assign relative values to the different products based on today's relative costs in the U.S. markte for the various products. We would then arrive at factors which relate one to the other.

We also take into account the total cost of all the products and their quantities, and distribute these costs to the different products according to current market values. This technique is used by many others, too.
The problem of defining methane within a regulated market occurs. Some products become very expensive when it is assumed that methane

is not worth much. No logical basis for cost distribution exists; so if the market continues to value the products in the same ratio, then this would be the price at which one would have to sell them. In our more detailed studies (1977, 1978) we showed that the market values differed between 1970 and 1978 - they did not remain static.

HOLIGHAUS: In the U.S. and the Federal Republic of Germany, different lifetimes for the plant are used. In the U.S. I believe you correspond more to power plants, and use a lifetime of 20 - 25 years, whereas Germany relates more to chemical plants, which have a lifetime of 7 - 10 years.

KÜHN: We talk about basic chemical materials, not pharmaceuticals, which may change from year to year. One can calculate that plants which serve the basic chemical industry can run for 15 - 20 years.

HOLIGHAUS: Other calculations show a lifetime of 20 - 25 years; but some companies' calculations also dealing with more basic refining techniques show a lifetime of only 7 years.

KÜHN: In the case of power generation within such a complex of coal gasification down to Fischer-Tropsch products, a lifetime of 20 - 25 years could be expected.

HOLIGHAUS: In the Federal Republic of Germany, however, we correspond much more to chemical plants - especially Fischer-Tropsch. In the U.S., they correspond to power plants; as these have different lifetimes, different results must be obtained.

HILL: We are developing costing guidelines which can be used uniformly by all people making estimates. One of the parameters which we would like to include in these guidelines is the lifetime that should be used for the different types of plant. 30 years is an expected lifetime for a nuclear plant; with coal gasification plants we use 20 years.

BAKER: The Economic Assessment Service of I.E.A. Coal Research made a review of the practices adopted by different countries in various economic parameters, including the lifetime of plants. A central view (including the German viewpoint) was that a lifetime of about 25 years was expected. For gasification and liquefaction plants, this was about 20 years.

SCHNUR: In our calculation we used a depreciation rate of 7,5 years in order to allowing for the changing market situation for chemicals. All major plants (e.g. SASOL) should operate for over 20 years without having to replace or repair essential sections.

HOLIGHAUS: We should aim towards creating a common basis for calculations.

SCHNUR: If products become obsolete in 5 years, then a depreciation rate of 20 years is unrealistic. This is not the case, however, when products can sold over a period of 15 - 20 years.

HOLIGHAUS: This makes the matter even more complex.

SCHNUR: Of course, one must use various bases for the calculation.

HOLIGHAUS: If there are no more questions or comments on today's papers, we will end this session. It is too early to summarise the papers now, but a resumé will be made tomorrow afternoon, at the end of the workshop. I would like to thank you for your participation and will be pleased to meet you again when we reassemble tomorrow.

19 SEPTEMBER 1978

HOLIGHAUS: I am pleased that we are able to continue our meeting today. The first paper on the agenda for this morning is by Dr. Wolk of E.P.R.I., and will be delivered by Dr. Knudsen.

LECTURE READ BY KNUDSEN

KNUDSEN: I would like to ask Dr. Mc.Neese to discuss the organisation of Oakridge National Laboratory.

TALK AND SLIDES - MC.NEESE

HOLIGHAUS: I would like to thank you for this excellent review of the U.S. situation; no doubt the participants have questions regarding this paper; I would welcome information about systems engineering.

KNUDSEN: Systems Engineering is a division in fossil energy; it comes under the Assistant Secretary of Energy and Technology, which reports to the secretary.

HOLIGHAUS: Who heads this division?

KNUDSEN: I am assistant manager in the division of Systems Engineering; the acting manager is Mr. Laccardi.

HOLIGHAUS: Are the efforts to do fundamental research (so far as these can be related to fossil energy) included within this 700, 000 000 dollars per year programme?

KNUDSEN: No; that is not part of our specific division; the D.O.E. has other activities which cover basic research. Since we are still organising, the situation could change again. There is an Office of Energy Research under another assistant secretary primarily responsible for basic research. In the Office of Fossil Energy we fund basic research as part of the programme division.
Systems Engineering is one of the programme divisions which make up the rest of fossil energy and has its own research programmes. There is also the Assistant Secretary for Energy Research, who has a considerable involvement in this respect. In the past, growth of the previous organisation - The Atomic Energy Commission - took place. Now, however, there is much involvement in fossil activities.

HOLIGHAUS: You also mentioned the Freedom of Information Act, which is of interest to us. If you indicate that information created outside the U.S. as proprietary, will this not be published as a result?

KNUDSEN: The act says that all information in the hands of the Federal Government is public information with certain exclusions, including proprietary information, personnel cards, sensitive internal memoranda, information concerning plans and budget etc.

This information could not be extracted from the Agency. The Act permits people to sue the Agency. They ould request information and then receive it according to a certain procedure; if the information were not forthcoming, they ould have recourse under the Act to sue the Agency for it.
However, there are specific exclusions from the Act - e.g. any proprietary information obtained from our industry or your industry, etc. Information not under the classifications I mentioned would have to be handed over upon demand.
In practice, there is an enormous quantity of information, which has been the concern of the various parties in the International Energy Agency, e.g. in the specific project of the Economic Assessment Service which Mr. Baker heads. No problems exist in that no-one has come forward to ask for notes, memoranda, reports, drafts etc.

HOLIGHAUS: You have clarified the situation very well: you cannot be forced to publish information you receive which is marked "confidential" or "proprietary".

KNUDSEN: Except that the Act takes care that information does not remain withheld by the mere fact that it is stamped "confidential" it has to pass a test to ascertain which type of information it is.

HOLIGHAUS: In principle, one could be forced to impart proprietary information etc. to the public. I suspect that it does not suffice just to say that no confidential information has reached the public yet; in fact, this should be possible.

KNUDSEN: Proprietary information exchanged would be confidentially treated. Before we actually carried out a straight forward protection process, we would need to consult the lawyers at the Agency, who could immediately take us through the right procedures, telling us definitely whether the information could be protected. It is a question of having experts involved in consultative capacities.

HOLIGHAUS: Do you have a steady contract with ESCOE, or more specific contracts for certain tasks within your programme?

KNUDSEN: As Dr. Hill explained, ESCOE was established to bring universities and industry into direct association by arranging fellowships, sabbaticals, etc. This would enable universities to take advantage of industry's expertise and viewpoint; this could be used in the solution of various problems.
One group was set up to attract interest in the scheme. Initially, it was hoped that people from the universities would just be able to joint industries, but government personnel regulations prevented non-federal employees intermingling etc. with us. We therefore established a non-profit-making organisation sponsored by the fundamental U.S. engineering societies, who formed a corporation for writing three year contracts with two year extensions, and developing a costing plan for "bringing on" at least 10 "residents". In order to comply with personnel regulations, we employed Dr. Hill as executive manager for our Washington Office ESCOE was actually established in New York.

In collaboration with the engineering societies, Dr. Hill set up a screening panel and advertiséd for "residents" in the engineering trade journals, larger magazines (e.g. Wall Street Journal, New York Times etc.) and by means of symposia and meetings. Hundreds of applications have been received, from which suitable candidates for the fossil energy programme have been selected.
The term is approximately two years; we are now approaching the two year point of the first three year contract, which we aim to extend for two years. Before the end of the total five year period, we hope to obtain an extension for a further five years from the government.

HOLIGHAUS: Who defines the tasks and work programmes?

KNUDSEN: I was appointed technical manager by the government This does not mean that I am allocated to direct the engineers from my ESCOE office; instead, I deal through the executive manager, who, in turn, acts as chief technical and planning officer.

We write and organise tasks within fossil energy to be worked on specifically and within a set number of hours; I make such negotiations with Dr. Hill, who decides whether his staff can perform the various functions, and also organises the ESCOE work. I coordinate with the government and he coordinates the responses.

HOLIGHAUS: Experience from industry is valuable in decision-making.

GAENSSLEN: I note that you have a group specialising in systems analysis and optimisation; is the latter technical or economic?

KNUDSEN: Its title is "Systems and Optimisation", the latter being economic rather than technical. Part of the group deals with process economic, looking at various types of gasifiers or whole plants. Its information, and other facts, are taken by the systems synthesis group, which attempts to form integrated systems.

GAENSSLEN: We have a similar group in the Federal Republic of Germany. It is an inter-company group working on problems resembling those in the U.S. What are the criteria for optimisation? When one optimises, one needs a "measuring stick" for gauging quality; some kind of value must be applied. Is this value cost, or do you examine other aspects?

KNUDSEN: We are examining the whole picture. Over the past two years, we and the D.O.E. have been involved in an overall effort to make research and development respond more to society and market needs. By integrating and synthesising systems, we mean becoming attuned to market and user specifications, the environmental effects on the infra-structure, i.e. the supporting towns and facilities developing around new energy ventures. The criteria are not well-established yet, but they involve all the activities I have just described as well as economics.

HOLIGHAUS: We should now proceed with the next paper, which will be presented by Dr. Wolowski and deals with the capital concerned if an SRCII plant were built in the Federal Republic of Germany.

RESEARCH OF CAPITAL REQUIREMENTS, COSTS AND ECONOMICS OF A SRC-II-PLANT UNDER CONDITIONS RELATED TO THE FEDERAL REPUBLIC OF GERMANY

by

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SUMMARY

The capital requirements, costs and economics of a 6,000 st/d SRC II plant under conditions related to the Federal Republic of Germany have been investigated. The total capital requirements of a 6,000 st/d SRC II plant have been estimated with an accuracy range of ± 15 % to be more than 800 Mio DM at 1976 money value. The total annual costs on the same pricing basis are 360 Mio DM. This amount includes raw material costs, capital costs and operating costs. The average product price has been estimated to be 272 DM/t. The net costs of production are 90 DM/t higher than this average product price.

The results show that an economical operation of a coal liquefaction plant cannot be realized at present.

1. INTRODUCTION

From the view of process engineering and with regard to the conversion products there are two different coal hydrogenation technologies:

- The catalytic hydrogenation of coal to produce liquid hydrocarbons which can be used as chemical feedstock, fuel oil or gasoline;
- The non-catalytic hydrogenation of coal either to produce liquid hydrocarbons or solid fuels.

One of the most advanced processes of the non-catalytic hydrogenation of coal is the Solvent-Refined-Coal (SRC) process. The so called SRC-I process has been developed for the conversion of coal into a clean burning solid fuel, the SRC-II process for the production of fuel oil.

Based on the SRC-II process GULF and the federal government of the USA intend to build in West-Virginia a demonstration plant for the liquefaction of coal in cooperation with the government of the Federal Republic of Germany and the two German companies Ruhrkohle AG and STEAG AG.

2. OBEJECTIVE AND BASIS OF THE RESEARCH

The major plant streams of a 6,000 st/d = 5,443 t/d SRC-II demonstration plant are shown in Table 1.

The objective of the research was to investigate the capital requirements, costs and economics for a complete SRC-II demonstration plant under conditions related to the Federal Republic of Germany. Therefore technical and economical data - already worked out within the scope of a design study by Stearns-Roger Incorporated, Denver/USA - have been used according to German conditions and adapted to the existing cost and price conditions.

The following assumptions shown in Table 2 are the basis for the economic research.

3. RESULTS OF THE RESEARCH

3.1 Capital requirements

The total capital requirements for a complete 6,000 st/d SRC-II plant shown in Table 3 have been estimated to be more than 800 Mio DM. This amount includes the direct capital costs of 610 Mio DM (items 1 through 7 under Table 3), an allowance of 10 % of this estimate for contingencies and the indirect capital costs of 130 Mio DM (items 1 through 14 under Table 3). The total capital cost estimate has an accuracy range of ± 15 %. All costs shown in Table 3 are based on 1976 money value.

Direct capital cost estimates summarized under Table 3 include offsite facilities.

Indirect capital cost estimates also summarized under Table 3 are defined as costs for initial charge of catalysts (2.5 Mio DM) and chemicals (1 Mio DM), construction time interests, management costs, land costs and working capital.

The working capital cost estimates are summarized by cost components for raw coal inventory (30 days' supply), product inventory (14 days' production), maintenance inventory (2 % of the plant capital), inventory of catalysts and chemicals (60 days' supply), additional working capital (ready money of 1 Mio DM).

3.2 Costs

The annual costs shown in Table 4 are subdivided into capital costs and raw material costs.

The following is a description of how these costs were calculated:

The annuity for the investments, which can be depreciated has been calculated to be 11,47 % with the following assumptions:

calculatory rate: 9 %/y
depreciation : 15 years

The interests for the investments, which cannot be depreciated (interests for the land and working capital) are 9 %/y.

3 % of the direct plant capital costs are provided for maintenance and repair.
Taxes and insurance were estimated to be 2.8 % of direct plant capital costs.
The labor costs are summarized by the costs for the operating and maintenance staff (207 manyears), the administration staff (53 manyears) and contract personnel (60 manyears).

The average annual rate per employee at 1976 prices is 50,000 DM and the average annual costs for the contract personnel are 90,000 DM.

The purchased utility is 28 MW $\hat{=}$ 224.10^6 kWh/y of electrical power at 0.09 DM/kWh.

The annual costs for the replacement of the catalysts and chemicals run up to 1.5 Mio DM/y.

The costs for the ash disposal amount to 18 DM/t of wet ash.

The start-up costs' estimates are based on the assumption that the plant capacity is only 65 % during the first year of operation.

The raw material costs have been calculated for a total annual coal consumption of 1,800,000 tons. This rate is based on 365 days' operation at 5,443 t/d (dry basis), and 12 % moisture.

The feed coal is Illinois No. 6 at 96 DM/t at 1976 money value. This price includes the freight charges.

The total annual costs have been estimated to be 360 Mio DM. 50 % hereof are raw material costs, 37 % capital costs and 15 % operation costs.

3.3 Economics

The basis for the economic research are the 1976 market prices for Fuel Oil, Naphtha, Pipeline Gas and LPG shown in Tabel 5. With regard to the quantitive relations of these products the average product price had been calculated at 272.10 DM/t.

The following points have been investigated in detail:

1. conversion costs = capital costs + operating costs
2. gross production costs = conversion costs + raw material costs
3. net production costs = gross production costs + by-product costs
4. Difference = net production costs - product proceeds.

The costs and proceeds related to 1 t of the products are shown in Table 6.

The raw material costs and the conversion costs, that means the gross costs of production, are 382.00 DM/t. The by-product proceeds are 20 DM/t and the product proceeds are 272.00 DM/t. The net costs of production are 90 DM/t higher than the product and by-product proceeds.

Table 7 shows the detailed cost/proceeds-calculation. The costs and proceeds are tabulated as absolute amount per year (TDM/y) and then related to 1 t of the product.

Figure 1 shows the costs' and proceeds' structure. The gross costs of production consist by 36.7 % of capital costs, by 14.7 % of operating costs and by 48.7 % of raw material costs (coal). These costs are covered by 5.2 % from by-product sales and by 71.2 % from product sales. The difference between the costs and proceeds is 23.6 %.

4. DISCUSSION OF THE RESULTS

The results of the economic research of the 6,000 st/d-SRC-II plant demonstrate that an economical operation cannot be realized at present in the Federal Republic of Germany.

Judging these results one has to consider the following aspect:

The present research is based on the 1976 market respectively price ratios.

In reality such a plant could be operated at the earliest in 5 years with regard to the layout and construction phase. One can certainly say that the rates of price increase for mineral oil and natural gas will be higher than the general rates of price increase. Consequently the economics of the investigated SRC-II plant for an operation period from 1981 will be better than presented here.

The dependence of the economics of a SRC-II plant from the price of the feed coal as well as from the price of the competitive energy mineral oil is shown in Figure 2. It is obvious that an economical operation of a 6,000 st/d SRC-II plant at a coal price of 96 DM/t would only be possible if the mineral oil price would rise up to more than 330 DM/t.

Table 1 : Feed and Products

Feed		t / d	t / y
Coal (mf)		5,443	1,800,000

Products	wt %	t / d	t / y
SRC II Product	69.3	1,946	650,000
Naphtha	15.7	441	150,000
Pipeline Gas	12.4	348	115,000
L P G	2.6	74	25,000
Total Products	100	2,809	940,000

By-Products		t / d	t / y
Phenols		11	3,600
Sulphur		227	75,000

Table 2 : Basis for the Economic Research

Plant Size	2 Mio st/y Coal Throughput
Location	Federal Republic of Germany
Construction Time	3 Years
Operating Period	8,000 h/y
Depreciation	15 Years
Calculatory Rate	9 %/y
Feed Coal	High-Sulphur US-Import Coal at DM 96/t
Price Basis	1976 Money Value

Table 3 : Capital Requirements

		Mio DM
1.	Coal Preparation and Ash Handling	53.4
2.	Primary Process Plants	149.5
3.	Hydrogen Production Plants	114.0
4.	Gas Plants	50.8
5.	Secondary Recovery Plants	20.7
6.	Utility Systems	124.7
7.	Offsites	96.8
	Σ 1 - 7 (rounded)	610
8.	Contingencies ca. 10 %	60
	Σ 1 - 8	670
9.	Initial Charge of Catalysts and Chemicals	3.5
10.	Construction Time Interests	61.9
11.	License Fees	2.0
12.	Management Costs	4.0
13.	Land Costs	20.0
14.	Working Capital	41.4
	Σ 1 - 14	802.8

Table 4 : Costs

Costs	Amount Mio DM/a	Share %
Capital Costs:		
Service of capital for the plant, construction time interests, license fees, management costs	85.0	
Interests for the land and working capital	5.5	
Maintainance and repair	20.1	
Taxes and insurance	20.6	
Total capital costs	131.2	36.7
Operating Costs:		
Labor costs	20.9	
Energy costs	20.2	
Auxiliary materials and ash disposal	5.3	
Startup costs	5.7	
Total operating costs	52.1	14.6
Raw material costs (coal)	174.3	48.7
Total annual costs	357.6	100.0

Table 5 : Product Prices (1976 Money Value)

Product Proceeds	DM / t
SRC II Product	250
Naphtha	375
Pipeline gas	259
L P G	300

Table 6 : Costs and Proceeds

Costs and Proceeds	DM / t
Raw material costs	186.20
Conversion costs	195.80
Gross costs of production	382.00
By-products proceeds	19.90
Net costs of production	362.10
Product proceeds	272.10
Difference	90.00

Table 7 : Costs and Proceeds Calculation

Costs ,proceeds	Valuation	TDM/a	DM/t
1. Capital requirements	802,8 Mio DM		
2. Capital costs:			
2.1 Annuity capital and initial charge	11.47 %	77,250	
2.2 Annuity construction time interests	11.47 %	7,100	
2.3 Annuity license fees and management costs	11.47 %	688	
2.4 Construction interests	9.0 %	1,800	
2.5 Working capital interests	9.0 %	3,726	
2.6 Maintainance and repair	3.0 %	20,100	
2.7 Taxes and insurance	2.8 %	20,577	
Σ 2.1 - 2.7		131,241	140.2
3. Operating costs:			
3.1 Labor costs and administration		20,925	
3.2 Energy costs	0.09 DM/KWh	20,160	
3.3 Auxiliary materials and ash disposal		5,283	
3.4 Startup expense	11.47 %	5,735	
Σ 3.1 - 3.4		52,103	55.6
CONVERSION COSTS (Σ 1-3)		183,344	195.8
4. Raw material costs (coal)	96 DM/t	174,336	186.2
GROSS PRODUCTION COSTS (Σ 1-4)		357,680	382.0
5. By-products proceeds (Cinders granulate, Sulphur, Phenols)		18,667	19.9
NET PRODUCTION COSTS		339,013	362.1
6. Product proceeds:			
6.1 SRC II product	250 DM/t	162,167	
6.2 Naphtha	375 DM/t	55,125	
6.3 Pipeline gas	259 DM/t	30,044	
6.4 L P G	300 DM/t	7,400	
Σ 6.1 - 6.4		254,736	272.1
DIFFERENCE		84,277	90.0

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6.2 Naphtha	375 DM/t	55,125	
6.3 Pipeline gas	259 DM/t	30,044	
6.4 L P G	300 DM/t	7,400	
Σ 6.1 - 6.4		254,736	272.1
DIFFERENCE		84,277	90.0

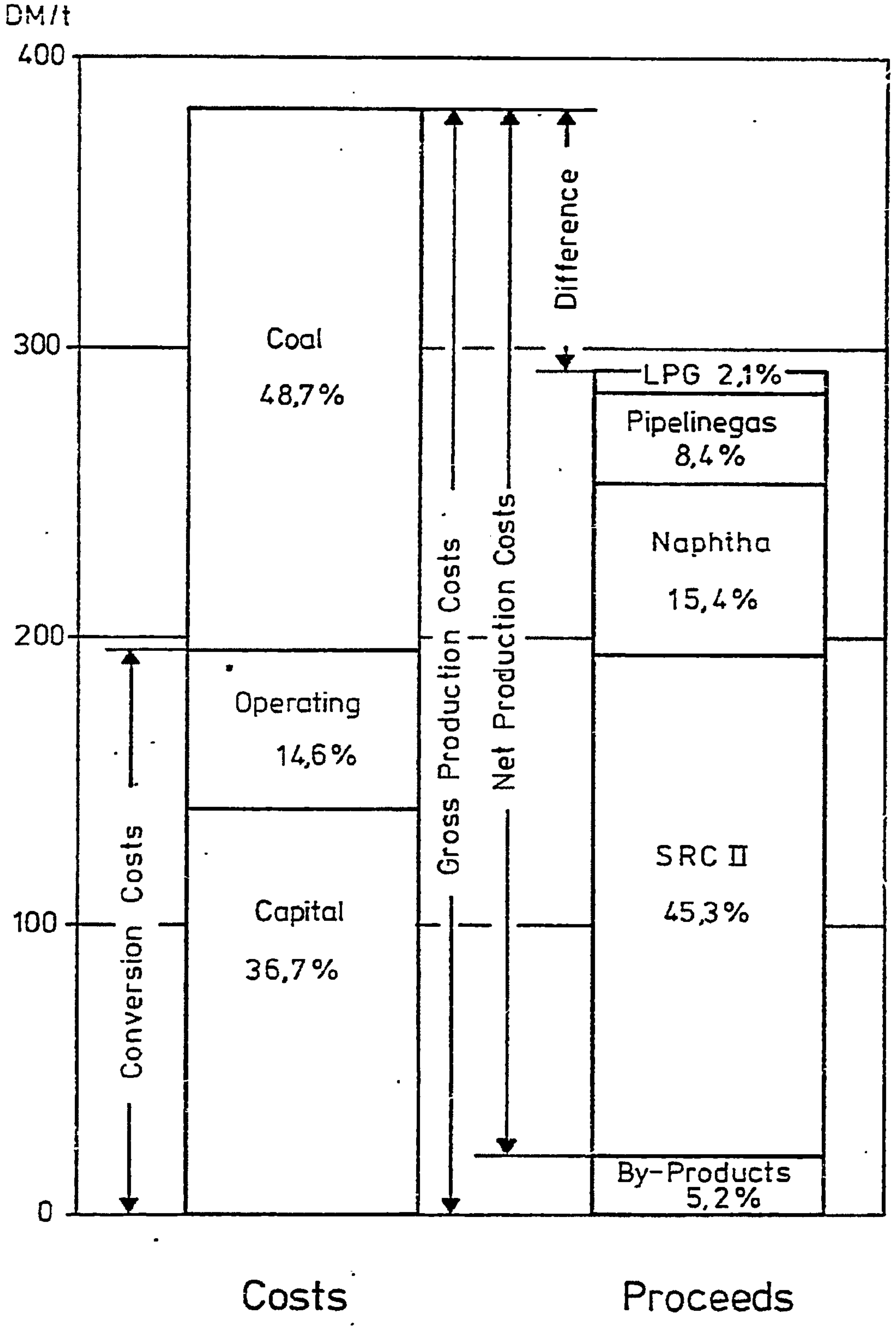

figure 1

Cost and Proceeds Structure
SRC II - plant under German Conditions

GVV

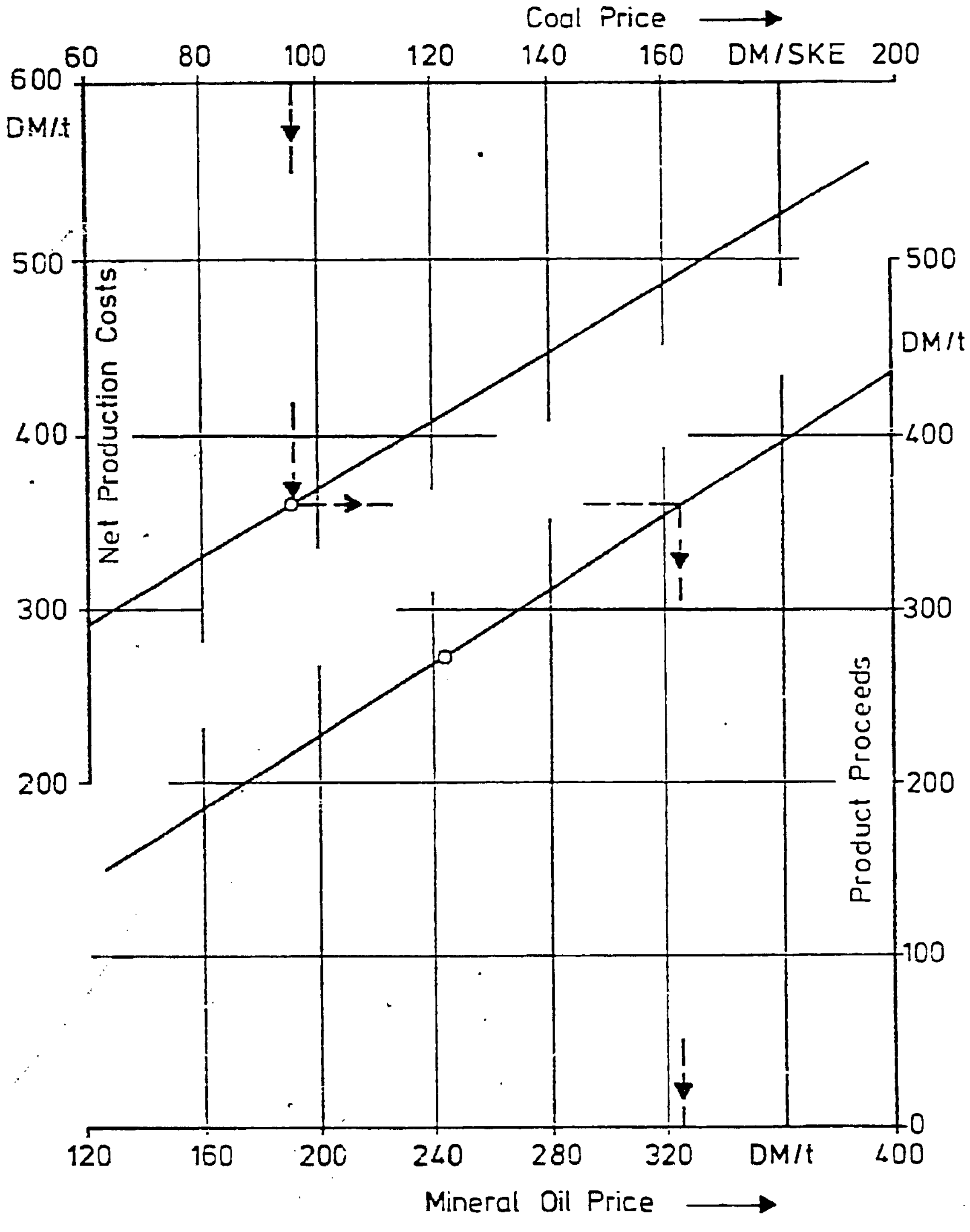

figure 2

Costs and Proceeds in dependence from the coal price and mineral oil price

LECTURE - WOLOWSKI

HOLIGHAUS: It may appear surprising that we in the Federal Republic of Germany examined in such detail a U.S. process; but perhaps you were already aware of our interest. However, the principal ideas concerning modification from SRCI to SRCII come from us rather than from the U.S., where solid products were preffered in about 1974.

KNUDSEN: For many years, Gulf Oil has stressed a liquid version, whereas the Southern Company (a utility) has been interested in a solid one. The former interest has been very strong for a long time, and Guld has been the main investigator, funded by the government, of the process. Its interest in liquid SRCII has carried much weight and influenced matters strongly in this direction; many at the D.O.E. feel that this is very important.

Dr. Wolowski's comment that the differential rate of inflation would make the picture look better in the future was very appropriate. This process could have important applications in various situations in the U.S. over the next 20 years.

HOLIGHAUS: D.O.E. only supported the development of the SRCI process up till now and spent very little money on SRCII. Gulf, I think, developed a process for making liquid products only on a catalytic basis; non-catalytic approaches on a more technical, less advanced scale, were developed about two years ago at Hamarville and Merriam.

We aim to emphasise the SRC process, because we thought from the start that this was more relevant and important for our country, as we can transport the products easily.

KNUDSEN: Coal Research, Energy Research and Development Administration and D.O.E. have been saying officially that we were developing a solid refined coal product, although there are many who have been concerned over the past 4 years about extending the process to put more hydrogen into the material, thus making a liquid process. Then distillation could cause separation instead of filtration and the material would not solidify after completion.

Nearly all the finances for the plant at Fort Louis come from the government. It was supported by the Merriam laboratory and has been

run in a solid mode until the first runs for the liquid about 1 1/2 years ago. It started to run on a Kentucky coal, then an Illinois coal. (This was 1 - 1 1/2 years ago) The so-called solid mode or manner (SRCI) has been adhered to, because we were already considering with Exxon to use H-coal in making liquid fuel type products from coal.
We have always been under pressure from those who maintain that we fund so many identical projects; Exxon is a donor and non-catalytic process, but our extension of SRCI to add more hydrogen and make a fluid causes it to resemble closely the Exxon process. Some maintain that all these so-called different processes will merge in about 15 years and become very similar, incorporating the best aspects of all of them in a final commercial plant. This would be sensible, but one should note that we have funded SRCI and are now funding SRCII. Initially, we treated the two projects separately, as they were similar, but now we agree that we are definitely undertaking both. The SRC project has been sponsored by government funds.
The Hamarville plant, near Pittsburg, Pennsylvania, is a Gulf research and development centre, which performed the catalytic work. They still have small catalytic pilot plant, whereas the process being funded at Fort Louise is the non-catalytic SRC-process.

HOLIGHAUS: The development of the SRC process has been proven at the Tacoma plant, which started working on a proof about a year ago (May, 1977). This has been developed at Hamarville as a non-catalytic process with government participation and support from the Federal Republic of Germany. Without this, data for modifying the Tacoma plant would not have been available.

KNUDSEN: The extension of the process from SRCI to SRCII at Hamarville does not mean that there is a different process; however, the approach is different. Gulf argued strongly that the process should not be referred to as different, maintaining that there is only one process: the SRC process. I would not agree that a process was developed elsewhere and handed to the U.S. government, which has already spent millions of dollars on the process in order to make it what it is today.

HOLIGHAUS: Yet the Hamarville process is run as a totally integrated P.D.U. plant. This is a form of catalytic process, which was reconstructed and rebuilt in order to run the SRCII process. It is a technical question. SRCII is exactly the same as SRCI; only one SRC technology therefore exists. It is good that the U.S. has this definition, but we in the Federal Republic of Germany would prefer the alternative one.

MC.Neese: Exploratory research on SRC-II was done in 1973 at Merriam. Work on the SRC-II type process interms of process variable studies began in early 1975. The Hamarville plant operates at one ton per day and is an integrates system, which allows good material balance closure. The principal advantage of the type of experience which has been obtained in the Fort Lewis plant is that this experience forms a basis assessing the actual mechanical component aspects of the system, as the Hamarville system is very small.

HOLIGHAUS: What is the capacity of the Merriam facility?

MC.NEESE: It is also very small, and is a bench scale facility.

HOLIGHAUS: I believe that the capacity is 1 % at Hamarville; this cannot be a basis for this process to be applied at a 50 tons per day plant. Merriam is so small, that it can only provide certain indications as to what would work in the case of a larger plant.

KNUDSEN: For the non-catalytic work done at Hamarville, the was involved in the funding.

MC.NEESE: The Hamarville work was sponsored by Gulf; there was no U.S. government funding. The SRCII process was certainly developed in part by aid from the Federal Government. It was recognized about two years ago that the Fort Lewis pilot plant information did not provide good closures in terms of material balance information. This was the principal reason for initiating the Hamarville work, which would provide such information and determine the ultimate notential of the process for operating as an SRC-II type plant.

HOLIGHAUS: The difficult matter is really the question of definition. We agree that the basic SRC technology was funded by D.O.E. and developed in the U.S., while SRCII technology was co-funded by Germany .

KÖLLING: Dr. Wolowski's data are the most favourable heard so far during this workshop. I have two question regarding these: firstly, would it be economic with a coal of the same kind as the lignite coal, if this cost only DM 5.00 per Giga calorie? Secondly, what is the difference between calculations in the Federal Republic of Germany and the U.S.?

HOLIGHAUS: This is a very important question.

GAENSSLEN: The sensitivity of the process seems to be quite high, in contrast to the Fischer-Tropsch process, where the sensitivity is much lower. 50 % of the costs are coal costs.

WOLOWSKI: Two tons of coal needed for the production of one ton of the product cost about DM 190. The difference between the proceeds and the overall costs is DM 90. If one halves the coal price, an economic situation results; this is shown by economic analysis.
To answer your second question - in principle, there is no difference between German and U.S. calculations.

HOLIGHAUS: This depends very much on the price basis; in 1976, the U.S. estimates were 360 000 000 dollars, whereas they have now risen to about 620 000 000 dollars. All the nes data we heard about yesterday are based on this much higher estimate for capital costs.

GAENSSLEN: It appears that there is an apparent difference at least between the economic calculations in the U.S. and here in the Federal Republic of Germany. I believe that you were running a non-profit-making organisation when you did these calculations, as no return on investment was shown (only interest on loans being indicated). For the benefit of shareholders, this return should be indicated.

WOLOWSKI: This problem is connected with the model one takes.

GAENSSLEN: In that case, one would not have comparable results.

BAKER: It seems that there was a 10 % discounted cash flow analysis rate conversed into annual terms on the 2.43 rate you were taking. If you did not also enter any inflation rates into your calculations, you would have taken the level of return higher than is usual in the Federal Republic of Germany. In that sense, you would have been guaranteeing yourself a return. You often take 5 % in real terms, I believe.

GAENSSLEN: Normally it is 12 % after tax; 5 % would be too low.

BAKER: In real terms?

GAENSSLEN: Yes.

BAKER: I have seen many calculations suggesting that 5 % in obtained.

WÜRFEL: 1) Is the new product SRCII distillable?
2) What is its boiling range?
3) What is the net oil yield based on M.A.F. coal?
4) Could the results of the 1976 study be confirmed, or have changes taken place? This year, a paper was published containing different data; more C1 (about 60 %) methane was produced than average.

WOLOWSKI: 4) The concept of the plant had been changed in the U.S. to meet actual market conditions. It was found that liquid and gas fuels were marketable products, whereas naphtha was not. Therefore, more gas was produced and naphtha was used in the plant as an internal fuel.

2) The boiling range of an SRCII product is 400° F (about 200° C) to lower than 950° F (510° C).

WÜRFEL: This means that it is an all-distillable product?

WOLOWSKI: 1) Yes, it is a middle and heavy distillate.
3) The concept of the plant is to be self-sufficient as far as possible. The only exeption is the electric power which has to be imported. All produced products derive from the feed coal.

Beside the liquid products there is a non-destillable residue which is fed to a gasifier in order to produce syngas which is shifted and converted in further steps to hydrogen.

WÜRFEL: I was given a balance indicating 69 % SRCII.

KRÖNIG: That percentage was including total gas formation, without gas it was 53 %.

WÜRFEL: So it is about the same with German technology?

KRÖNIG: Yes.

HOLIGHAUS: Does the same apply as for the Fischer-Tropsch-synthesis, i.e. that methane formation makes the process expensive?

WOLOWSKI: Yes; this is true for all direct hydrogenation processes. Any liquefaction process tried to reduce the gas content; also this combination might not be a bad process, but it depends upon market conditions. If a market exists for gas (in the U.S. or in the Federal Republic of Germany), the process might be economic.

SCHULZE: I would like to extend Prof. Köllings remark. We should also consider the possibilities given by higher coal prices. You asked about the lower coal price of DM 5 per Giga calorie; but in the Federal Republic of Germany, the prices are much higher. I wonder why you based you study entirely on U.S. imported coal prices? We are now trying to become less dependent on foreign energy imports; plants should be supplied with our own coal, whose prices are about 50 % higher. (In 1976 these could have been DM 140 or even DM 150 per ton) This is a realistic and more pessimistic view, which applies to all processes, not just the particular SRC process in question.
This leads to a more general question concerning coal supplies in the future; we have insufficient coal to fulfil our needs. We would be unable to rely on the U.S. for supplies, as the same problem exists there - internal demands will have to be met.

Your sales price for the SRC product was up to DM 250 per ton; this is more than the fuel oil prices (DM 180 in 1976). I believe that the higher value margin was given because of the low sulphur content; the sulphurisation processes are not required when buring the synthetic product in industrial power plants. Can this margin be justified by desulphurising heating oil from mineral oil sources?

WOLOWSKI: This price was governed by market conditions in the Federal Republic of Germany in 1976; it was not lower.

HOLIGHAUS: Are you referring to crude oil?

WOLOWSKI: No ;,I am considering a heavy fuel oil.

HOLIGHAUS: The questions which have been raised are rather difficult to discuss, mainly because of doubts concerning the processing of German coal.

WOLOWSKI: The process we are now discussing is unsuitable for German coal; the output would be a solid. Instead, a catalytic process is required in order to produce liquids; higher partial hydrogen pressure is also necessary. These are the technical reasons governing our developments in our country with this special type of coal.

SCHULZE: The consequences of this process would be profitability estimates based on conditions in the U.S., where we could alos build plants instead of investing capital only here, and transport the SRC products to the Federal Republic of Germany. This would be perhaps a more economic prospect than performing the liquefaction process here.

HOLIGHAUS: This was already under consideration half a year ago; much U.S. data has been transferred to your country. The general feeling is that the best site for an SRCII plant would be in the U.S., and that the liquids produced should be transported here. However, one cannot be absolutely certain that this method is best; if the plant were placed here and the cheapest coal bought on the world market, advantages could result. A good site should be chosen in order that the best use of the by-products could be made. One cannot say that a process using U.S. coal should necessarily be situated in the U.S.; this matter needs to be considered carefully.

KNUDSEN: I would like to comment on Prof. Schulze's remarks. He mentioned that the U.S. would probably need all its coal for its own considerable needs. However, I am sure that the National Coal Association the coal industry and various mining concerns would be pleased to provide almost any amount of coal which you would like to buy in the Federal Republic of Germany. I think that the organisations I listed would have the capacity as far as supply is concerned and would be well able to respond to the demand.
The two countries cooperate, and would like to encourage a mutual export and import situation. In the U.S., with regard to mining, we are demand rather than supply limited. Demand is limited by environmental regulations; the ability to burn as opposed to mine comes into question.
I would like Dr. Wolowski to describe how he would break transportation costs; what portion of the DM 96 total costs relates to transportation? This has a bearing on Mr. Gaensslen's comment concerning the fact that this process seems to be 50 % coal related. SASOL is less - about 30 % - 35 %; there the plant is at the mine mouth, whereas the coal now in question is exported, involving much transportation.

WOLOWSKI: If the price of coal was 19 U.S. dollars per short ton.

HOLIGHAUS: In 1976, there were DM 2,5 to the dollar.

KNUDSEN: If it were possible to have a U.S. mine mouth location, with German construction, costs, labour etc. (minus transportation costs) the prices would decrease, becoming more in balance according to your analysis, and the proportions would resemble those at SASOL. The fundamental cost differences relate to transportation only.

HOLIGHAUS: The same product prices for SRC II (DM 250 per ton) would apply - otherwise the difference would remain.

GAENSSLEN: The results depend on the coal prices rather than on the parameters described by Dr. Knudsen. The coal is halved, 20 % less is obtained for the product; then this would be very noticeable.

SCHNUR: About 5.000 tons of sulphur could be obtained; this is 7,8 megatons of coal. The question does not concern the quantity of coal, but the sulphur content.

WOLOWSKI: This was coal of an Illinois type with about 3% - 5% sulphur.

HOLIGHAUS: If there are no further questions, we can proceed with our schedule. The next subject under consideration is pyrolysis; in this country we performed an economic assessment of this process, using the Vernon and Lurgi Ruhr-Gas processes for degasifying the coal, and considered how the coke could be used in a power station.
I would like to ask Mr. V.Diest to present his paper; the paper which follows this deals with the question of what is to be done with the tar obtained during the devolatilisation step.

Essen, den 22. September 1978
vDie/Le

Projektstudie VORENTGASUNG
Workshop Coal Liquefaction 18./19. September 1978
Kernforschungsanlage Jülich
Vortrag / Berichtstext

Obtaining Gas, Tar and Oil by Degasifying of Coal for Power Stations

Vorgetragen: Gerhart von Diest
Jülich, den 19. September 1978

1. Introduction

In 1974/75, the Consortium STEAG AG, RUHRKOHLE AG, RUHRGAS AG in cooperation with BERGBAU-FORSCHUNG mbH, LURGI MINERALÖLTECHNIK GmbH, DEUTSCHE BABCOCK AG executed a Project Study entitled:

> "Gas, Tar and Oil Production by Devolatilization of Power Station Coal".

(Original: Gas, Teer und Ölgewinnung durch Vorentgasung von Kraftwerkskohle).

This Study was sponsored (Sponsor Mark 316-7291-ET 64) by the BUNDESMINISTERIUM FÜR FORSCHUNG UND TECHNOLOGIE (BMFT) and attended by the KERNFORSCHUNGSANLAGE JÜLICH GMBH (KfA).

Since the Project Study was completed in 1975, and the project program has not been continued till now, no update of the 1975 figures has been made.

The main tasks of the Study were:

- Project Planning
- Review and Evaluation
- Design Concept and Estimate of a Commercial Plant
- Alternative Plant Combinations
- Process Commercial Efficiency Products Market Potential
- Project Continuation

2. Processes and Plant Concepts

The following devolatilization processes were noted and investigated:

- VEW-Kohleumwandlung
- COED
- GARRET
- TOSCOAL
- LURGI-RUHRGAS (LR)

TABLE 1 compares these processes and shows the process steps, the project targets, and also the stage of development.

The project targets vary in greater or lesser degree, and have reached different stages of development.

The LR process is most highly developed. It can process the largest input coal size. Capacities planned or available range from laboratory units with capacities of 1 kg/h up to commercial plants with 2x33 t/h. Materials pyrolized include coal, lignite, oil and gasoline. Certain experience has been made with the link to a boiler unit.

2.1 The LR-Process

FIG. 1 shows principal steps involved in the LURGI-RUHRGAS-Process.

The first process step is accomplished in the devolatilizer, where the volatile matter is rapidly released from the coal by the added hot char. The char so formed is fed to an entrainment tube, where it is propelled upwards by a blast of air. At the same time, combustion takes place. This heats the char. The hot char is separated from the flue gas and fed to the devolatilizer to heat the input coal.

The crude gas contains the products of devolatilization from the coal. These are further separated into tar, oil, gas and water fractions. Surplus char is taken out of the separator for further processing. The flue gas leaving the separator has to be treated before being discharged to atmosphere.

The process as generally described above, has to be adapted to the mode of operation and the coal used, e.g. instead of air blowing, combustion gas may be used. If the coal cakes, screw feeders have to be used for mixing hot char with the coal.

Depending on the mode of operation, liquid products will mainly be produced at 600 ^{o}C and gaseous products will mainly be produced at 900 ^{o}C devolatilization temperature. Up to 180 % of the "Fischer-Teer" is yielled at low-temperature operation. The principal product by quantity is char (semi-coke) at the lower temperature and coke at the higher temperature.

2.2 Combined Systems

As the research showed, the char or coke product of the devolatilization process may be used

- in a power plant as a fuel for the production of electric power
- in a gasifier as feedstock for the production of synthesis, reduction or fuel gas
- in a formed-coke plant for the production of metallurgical formed coke

Since the main target is a high yield of liquid products, the LR Process with low-temperature operation and linked with a power station was selected.

2.3 The LR Process Linked with a Power Plant

FIG. 2 is a block-flow-diagram showing the links and the integration of the combined plant.

1000 - Coal Preparation

Based on an assumed site in the North Ruhr District, a high volatile power plant hard coal with a fraction size of ≤ 10 mm would be delivered by rail.

A coal storage capacity covering 20 days was selected. A pneumatic conveyor drier was selected for reducing the moisture content of the coal to less than 1,5 %.

2000 - LR Devolatilization and Condensation

The dried coal is fed at a temperature of about 90 °C to the screw feeders of the two parallel LR lines. Devolatilization takes place at a pyrolysis temperature of 590 °C. The crude gas is fractionated in the condensation and gas cooling section.

Raw gas containing the light oil fraction, medium oil, tar oil, and the pyrolysis water leaves the condensation and gas cooling plant for further processing.

3000 - Power Plant

The fine LR char is carried over to the boiler in a tube by a blast of LR flue gas at 580 °C. The boiler is a Babcock double slag-tap furnace type equipped with roof burners.

The maximum power generation load is 700 MW.

The boiler flue gas is cleaned using the Bergbau-Forschung active-coke process.

4000 - Product Preparation

The raw gas is compressed to 10 bar and sweetened in a Sulfinol process. The acid-gas fractions are fed to the boiler plant for combustion.

Carbon monoxide, being toxic, is eliminated in a conversion step. The gas is conditioned to pipeline quality and compressed to 30 bar. The light oil fraction is separated in an oil washing stage.

The medium and the tar oil fractions are cleaned in a dedusting step and pumped as a crude tar at 150 °C to the storage tank. The pyrolosis water is dephenolized using the Phenosolvan Process. The acid water is pumped to the steam boiler, where the acid components are decomposed.

3. Economic Evaluation and Further Development

3.1 Combined Plant Estimate

It has been assumed for the plant layout and the estimates, that all processes used in the LR plant combined with a 700 MW power block are commercially available. Technology gaps were described for further process development. The results of the planning, the calculations and the estimates for the outsite and the offsite of the plant are shown in TABLE 2.

The input of 2.3 million t/a (380 t/h) refers to power plant coal with a fraction size smaller than 10 mm, a moisture content of about 8 %, and an ash content of about 12 %. The volatile matter of the MAF coal is 38 %.

The output shows the total liquid products (22 % of MAF coal input) and the gas yielded. The net electricity output of the plant is about 630 MW at full load operation.

For operational reliability reasons, it would appear necessary to operate a combined plant at 8000 h/a instead of the normal peak load operation of a hard coal fired power plants in Germany. 6000 h/a full load operation can be attained by temporarily reducing throughput. A turndown of the combined plant to 60 % load would appear possible. Within the framework of this Study, it was not possible to prove the feasibility of a 30 % load. The energy efficiency turns down with the load factor.

Calculation of investment costs is based on the normal plant component calculation method. Most of the combined plant components are proven, conventional units. Costs for the new process steps were estimated on the basis of generous assumptions.The overall contingency factor for the combined plant has therefore only been taken at 8 %. The plant capital investment is 770 million DM. A plant area of about 750 x 380 m will be required.

FIG. 3 shows an overall view of the total plant.

The environmental impact of this combined plant does not exceed that of a conventional power plant. The LR process and all other chemical steps are carried out in closed systems.

3.2 Product Markets

The concept of the commercial plant is to market the greatest possible proportion of the valuable liquid fractions. If a greater number of commercial plants were in operation, it would be necessary to hydrogenate the crude tar to produce lower boiling point fractions.

The fractions of the liquid products of the LR process are 3.2 % light oil, 10 % medium oil and 87 % tar with about 5 % dust. The 700 MW Combined Plant output of 0.41 million t/a liquid products corresponds to 120 million t/a todays consumption of petroleum product in Germany. This is about 0.3 %.

The biggest tar fraction is pitch, which accounts for 65 % of the liquid products yielded. The pitch is absorbed mainly for the production of electrodes for the aluminium and electric steel industries. Pitch mixed with tar oil is also used in road construction and the building industry.

Today these markets are mainly supplied by the petroleum industry. An increase in the market share of coal derived tar products may not appear possible at the moment, but as the availability of petroleum products decreases, this situation may well change. In a growing market at constant coke oven tar production, a sufficient sales opportunity seems to be possible.

The detected phenols, aromatics, aliphats and bases may be marketed, but no research has been undertaken into the industrial-scale fractionation processes of LR tar.

The 110 million m^3/a SNG produced represent less than 0.2 % of the total gas market in 1980.

Electric energy must be generated as it is needed. Peak load operation is more costly than base load operation because of lower utilization during off-peak periods.

The combined plant calls for continuous operation with load variation over a certain range only. The electric power generated by the plant thus has to be evaluated for different generation times of the day and the year. Peak load is evaluated much higher than base load generation.

3.3 Cost Estimate

The cost estimate is based on the precalculation method. Costs and the revenues are compared. Different full-load operating hours are considered.

TABLE 3 shows the main cost factors employed. The Investment has been given in TABLE 2. Interest on capital is paid until the time of plant startup. The depreciation figures chosen are generally allowed by the tax authorities, Insurance is used to cover the catastrophe risk, and the tax is a general non-income tax. The price of the power plant coal includes freight and carriage to plant. Additional costs are included, e.g. for auxiliary materials, administrative costs.

TABLE 4 shows the revenue factors employed. These factors are all ex-works values, i.e., a consumer has to add the distribution or transmission costs.

The gas price is valued by its gross calorific value. The raw phenol price is based only on the water soluble fractions which can be easily extracted from the pyrolysis water. The tar oil is valued by its calorific content. The power revenues incorporate the estimated figures for peak-load operation. For example, the biggest proportion of base load is at 7 000 h/a full load at a load factor of 60 % turndown.

The results of the cost estimate show no cost recovery. There is an annual minimum loss of 101 million DM at 4 000 h/a full load for the low temperature devolatilization, and a maximum loss of 148 million DM at 7 000 h/a full load for the high temperature operation.

The proportion allocated to the liquid products after low temperature operation results in an average price of 567 DM/t at 4 000 h/a or 451 DM/t at 7 000 h/a full load operation. A sensitivity calculation at a 10 % lower coal price and a 5 % higher power revenue shows an average price of 355 DM/t for the liquid products at 6 000 h/a full load operation.

A dynamic cost analysis was not considered necessary at the time in question. Discounted cash flow calculations would have shown no positive DCF rates.

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3.4 Study Results and Further Development

Under the 1975 market conditions in Germany, the LR-process could not be economical. Nevertheless, it appeared expedient to research and to analyse devolatilization processes for a commercial application to recover substitute products.

In contrast to other devolatilization processes, the problem of coal caking poses no difficulties for the LR process. There are principal solutions for the purification steps of the crude gas. Experience with the LR process development unit linked with a boiler plant had shown that high temperature operation produces a coal fraction fine enough to be burned in linked power plant boilers.

Taking the economic view, only long-range work on the devolatilization problems were recommended in the Project Study. Short-term continuation of the Project would have been practical only for economic reasons or to ensure adequate supplies.

A research and development programm could be continued in three phases:

Phase 1 - the laboratory research program should examine the combustion behaviour of the devolatilization char, the dedusting and hydrogenation of the crude tar, and the conversion of the gaseous devolatilization products.

Phase 2 - the detail engineering of and experiments with a demonstration plant.

Phase 3 - the planning, construction, and operation of a commercial plant.

After each phase, it would be necessary to decide on the continuation of the program. The startup of a commercial 700 MW power plant combined with an LR devolatilizer would be possible at the earliest 10 years following a decision to continue the program.

PROCESS NAME DEVELOPER	PROCESS STEPS	PROJECTS TARGETS STAGE OF DEVELOPMENT
VEW-KOHLEUMWANDLUNG VEREINIGTE ELEKTRIZITÄTS-WERKE, DORTMUND	- DRY INPUT COAL < 0.1 mm - PREOXIDIZING < 500 °C - RAPID DEGASIFICATION WITH PARTIAL GASIFICATION AT 800 - 1000 °C	LOW SULFUR COKE TO POWER PLANT TAR, OIL AND GAS PRODUCTION 1 t/h PDU
COED FMC PRINCETOWN, NEW JERSEY, USA	- DRY INPUT COAL < 0.6 mm - 4 FLUIDIZED BED REACTOR DEVOLATILIZATION AT 290, 433, 565 and 815 °C	GASIFYING OF CHAR PURIFICATION OF TAR OIL AND CRUDE GAS 1,3 t/h PDU DEMONSTRATION PLANT PLANNED
GARRET GARRET-RESEARCH & DEVELOPMENT CO.INC., LA VERNE, CALIFORNIA, USA	- DRY INPUT COAL<0.076 mm - DEVOLATIZING BY HOT COKE MIXING IN AN ENTRAINMENT TUBE REACTOR AT 590 °C	CHAR AS POWER PLANT FEED HYDROGENATED TAR OIL 130 kg/h BENCH-SCALE UNIT
TOSCOAL THE OIL SHALE CORP., GOLDEN, COLORADO, USA	- DRY INPUT COAL - DEVOLATIZING BY CONTACT WITH HOT CERAMIC BELLS IN A ROTATING DRUM REACTOR AT 500 °C	CHAR AS POWER PLANT FEED LIQUID PRODUCT 0,9 t/h PDU
LURGI-RUHRGAS (LR) LURGI MINERALÖLTECHNIK GMBH FRANKFURT, und RUHRGAS AG, ESSEN	- DRY INPUT COAL < 10 mm - DEVOLATIZING BY HOT COKE-MIXING AT 600 °C OR 900 °C	CHAR OR COKE AS FEED FOR POWER PLANT, GASIFIER OR AS FORMED COKE; CRUDE GAS TO BE SEPARATED INTO GAS, OIL AND TAR PLANTS UP TO 2 x 33 t/h
TABLE 1	DEVOLATILIZATION PROCESSES	STEAG 1975

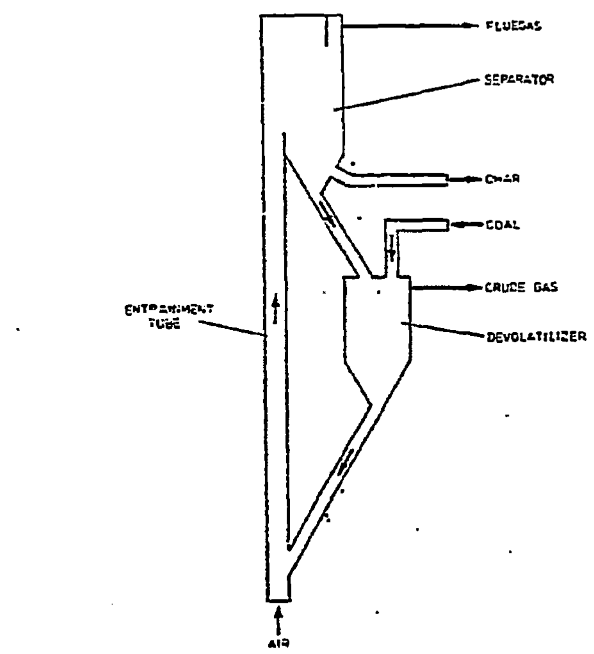

FIG. 1 Diagrammatic Sketch LR Devolatilization Process steag

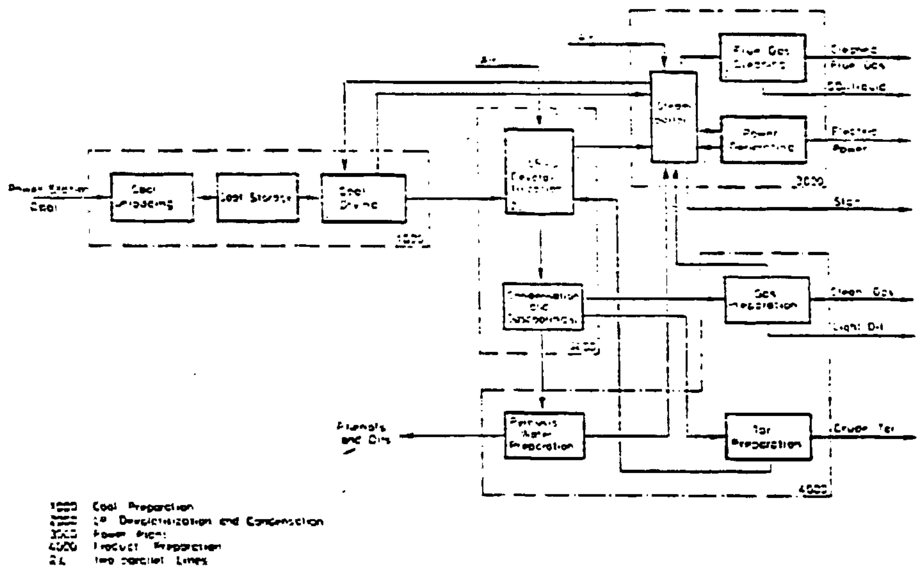

FIG. 2

Block-Flow-Diagramm
LR Plant Combined
with Power Plant

steag

LR DEVOLATILIZATION PLANT COMBINED
WITH A 700 MW POWER PLANT AT 6 000 h/a FULL LOAD

<u>INPUT</u>		
- POWER STATION COAL	MILLION t/a	2.30
<u>OUTPUT</u>		
- LIQUID PRODUCTS	MILLION t/a	0.41
- GAS (SNG)	MILLION m^3/a	110
LOAD FACTOR	PERCENT	100 - 60 (30)
ENERGY EFFICIENCY		0.54 - (0.50)
CAPITAL INVESTMENT	MILLION DM	770
PLANNING, CONSTRUCTION AND STARTUP	YEARS	4

TABLE 2 — PLANT ESTIMATE RESULTS — STEAG 1975

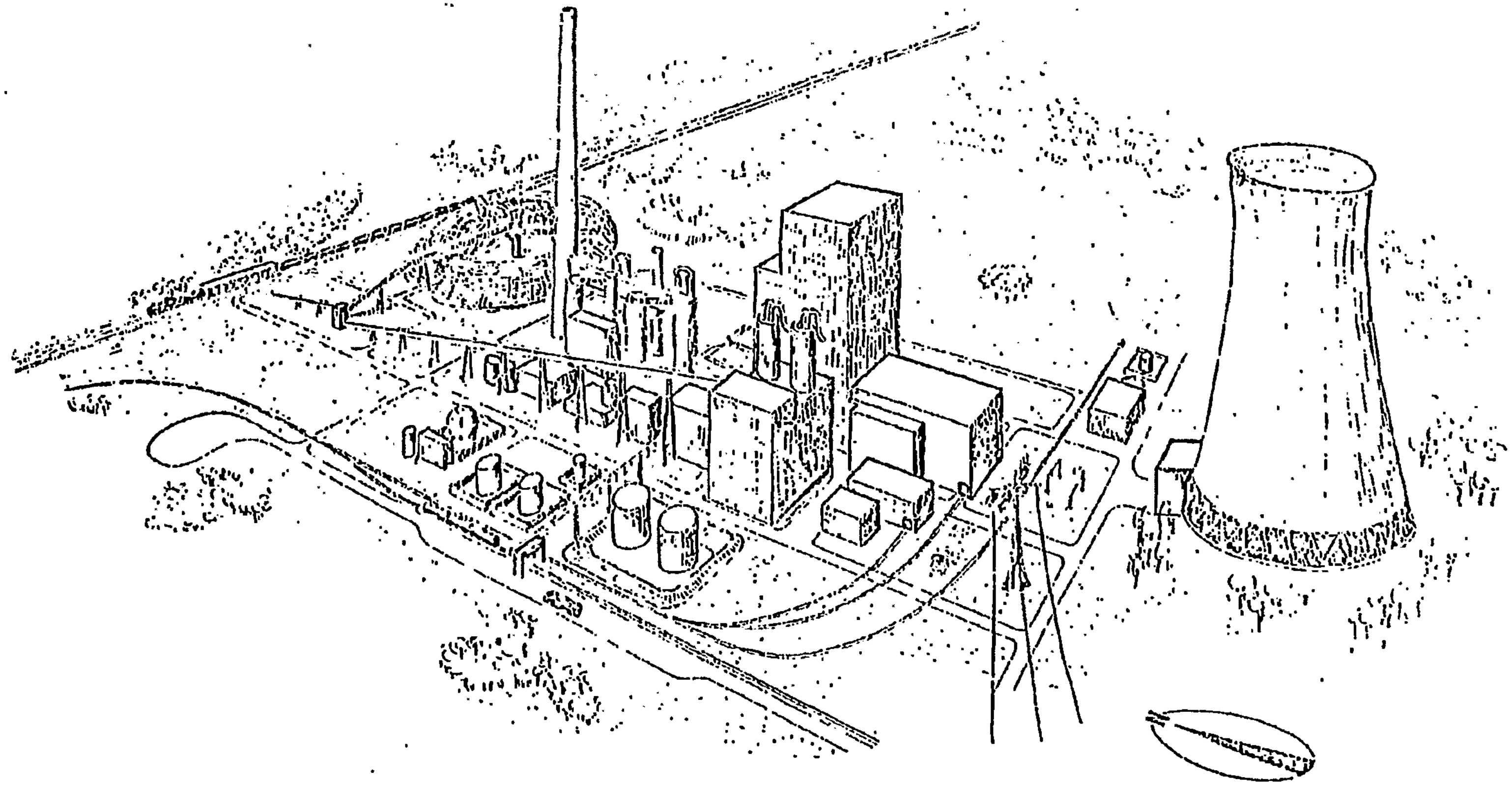

FIG. 3

OVERALL PLANT VIEW
LR Devolatilization Process Combined
with a 700 MW Power Plant

steag
1975

- CAPITAL INTEREST	% p.a.	10
- DEPRECIATION		
POWER PLANT BLOCK	YEARS	20
LR AND CHEMICAL PLANTS	YEARS	10
- INSURANCE AND TAX	% INVESTMENT p.a.	1.8
- MATERIAL		
POWER PLANT COAL	DM/t	134
- SALARIES AND WAGES		
OPERATORS	DM p.a.	24,000
SUPERVISORS	DM p.a.	36,000
ADDITIONAL EXPENSES	% SAL. & WAGES	30
- MAINTENANCE		
POWER PLANT BLOCK	% INVESTMENT p.a.	3
LR AND CHEMICAL PLANTS	% INVESTMENT p.a.	5

TABLE 3 COST FACTORS STEAG 1975

- GAS REVENUE	DM/Gcal H_o	16
- LIQUID PRODUCT REVENUES		
RAW PHENOLS	DM/t	700
LIGHT OIL	DM/t	220
MEDIUM OIL	DM/t	230
TAR OIL	DM/t	185

- POWER REVENUES

FULL LOAD OPERATION	LOAD RANGE 100 - 60 %	LOAD RANGE 100 - 30 %
h/a	DPF/kWh	DPF/kWh
7,000	7.4	7.4
6,000	7.9	8.0
5,000	8.4	8.5
4,000	-	9.3

PERFORMANCE ALLOWANCE 170 DM/kWa

TABLE 4 REVENUE FACTORS STEAG 1975

LECTURE - V. DIEST

HOLIGHAUS: Thank you for your paper; I would like to ask you about the power generation ocsts which would occur if this Lurgi Ruhr-Gas process were not placed in the plant.

V. DIEST: This was a considerable problem for the study itself. We have no free market for power generation in the Federal Republic of Germany; there is an area monopoly on this. Prices are always fixed by individual longterm agreements between the power generator and the supplier.
It is difficult to show figures dealing with these agreements. Therefore, a model based on the idea of a power exchange like a commodity exchange was chosen. If someone makes base load öpwer he will obtain the equivalent for the cheapest power generating process - in case of peak load production the equivalent for the most economic.
This research was undertaken very carefully and no other figures are available. The figures for the production do not relate to a comined system. In this case, they are revenue figures including a IR-system and are the best possible market figures which can be shown.
HOLIGHAUS: This means that you would not decide to build a 7 000 hours per year power plant based on coal?

V. DIEST: No; most of our agreements do not allow us to make a base load currency for 7 000 hours per year full load. Most of the time, we produce less than 4 000 full load operation power.

HOLIGHAUS: Did you also include the so-called "Kohle-Pfennig" for all the coal put in?

V. DIEST: We had no subsidies included in the calculations.

HOLIGHAUS: It is astonishing that the results were so negative, considering that world opinion says that the process in question will maybe be the first to become economic.

V. DIEST: This would depend upon the coal price.

HOLIGHAUS: Yes, but other conditions play a part too. Most of the energy goes into the power stations and one cannot cover the cost of generating electricity.

GAENSSLEN: A very similar situation exists in combined liquid products, with the production of substitute natural gas. A normal plant making no liquids would have a thermal efficiency of about 38%. As soon as these liquids are made, this rises to 54%. Why is this not economic, in spite of the fact that the thermal efficiency goes up? This is a question of average prices; if one examines the cost of electricity, in terms of cost per BTU, it can be seen that this is rather high when the value 54% is taken. One would find that both prices could never be obtained for the liquid products. An average price of DM 600,- to DM 700,- would have to be obtained for the liquid products in order to break even with the cost of electricity. As one is unable to do this now, the sale of liquid is being subsidised by the cost of electricity; this makes the process inherently uneconomic. It would be different if the products were much more expensive.

HOLIGHAUS: I do not entirely agree; in this case, the liquid products are not being supported by the price of electricity generation. Instead, the reverse is true; in this calculation, the electricity generation costs are not worked out. An energy field of, for example, 38%-54% can be obtained with very little effort from capital costs. This may be economic. The effort put into producing electricity is very high, when compared with work on obtaining liquids.

KNUDSEN: I would like further information regarding differences between plants with and without this facility. The incremental cost and value of the liquid products at market costs today or in the future could be considered.

V. DIEST: The values discussed are market revenue prices. The assumption was that one does not obtain more from the market. If the revenue is compared with the cost in this case, a minimum loss of DM 100 000 000 per year is shown.

KNUDSEN: I would like to know whether this is a comparison of the revenue of the additional liquid products with the additional capital required to process the liquids out.

V. DIEST: No; this is not done by a split plant, but by a total plant with all utilities. Only coal and water (for cooling) are added. Outcoming products, whether marketable or not, are shown as having market prices. Any losses are distributed over the products, in this case, only the liquid products. The aim of the study was to produce liquids and gases.

HOLIGHAUS: The question whether a plant with a 700 megawatt capacity could be constructed to produce suitably priced electricity arise.

KNUDSEN: The additional cost of adding extra equipment is not paid for by the additional liquids produces. Presumably, electricity sold from power stations must pay for them.

HOLIGHAUS: They are supported by the so-called "Kohle-Pfennig" and only run at 4 000 hours per year, and perhaps according to another concept. (For example, the new .... power plant.) It would be very interesting to see whether a 700 or 630 megawatt plant could produce, according to Mr. V. Diest's concept, electricity for the prices introduced in the consideration mentioned.

V. DIEST: It cannot be produced for these prices; these are market prices.

HOLIGHAUS: But then losses are made with electricity generation.

KRÖNIG: Is there any advantage in introducing fine coke instead of the original coal into the boiler? Does the former have less sulphur, or is there any other advantage?

V. DIEST: There is a sulphur distribution between the coke and the liquid products (about half and half). All the sulphur components are ultimately re-introduced into the boiler, so the same situation results. In a general power plant, the flue gas has to be de-sulphurised.

BAKER: I thought that Mr. V. Diest's economic analysis was very interesting but I wonder exactly why the Lurgi Ruhr-Gas process was not paying for itself. I wonder whether an illuminating way of looking at it would be to calculate or divide up the plant investment in such a way that one could actually calculate a transfer price. Has this actually been done? This would perhapt illuminate the fact that investment on the gasifying side is not paying for itself.

V. DIEST: This has been discussed already; if three partners with different market interests cooperate, no real result is obtained. Therefore, the model I described was preferred to cost-sharing with regard to coke - then the price of hot LR flue gas must also be evaluated; this could be done on a heat basis (a Giga calorie might cost DM 20,-), but difficulties would arise.

BAKER: I can appreciate the complications.

KNUDSEN: At the Exon refinery, we are continually evaluating what we have versus what we might add. The new unit would be an independant project. I was interested in the discussion about the "Kohle-Pfennig"; a subsidy for energy produced by electricity (as in the case of combustion plants) would not have to be transferred to the liquid products, as Mr. Gaensslen noted. A more approximate divided transfer type of situation would then arise this happens in an oil refinery, when a new project is considered.

V. DIEST: This concept and the input of coke were discussed earlier today; but while working on the study we could not come to any conclusions or compromises, as the input of wastes was not considered. Some wish to obtain much more revenue from coke, whereas others want to burn waste products.

KNUDSEN: The fact that three people of different interests were working on the project necessitated putting everything into one category, instead of agreeing on transfer prices.

V. DIEST: The revenue of the tar was calculated only by the calorific value. Normally, one cannot say that the tar contains so many products of value, from which revenue can be obtained. We therefore took a lower figure.

GAENSSLEN: Economic analysis in this case was, I believe, based on an extremely expensive coal. (DM 134,- per ton or 2 1/2 dollars per BTU). I wonder whether an economic range could not be achieved using a cheaper coal? Obviously, the cost of the coal will reflect on the cost of the liquid products stemming from it. Cheaper coal would result in cheaper products.

V. DIEST: We made an analysis with a 10% lower coal price and a 5% higher power revenue.

GAENSSLEN: What happens if the price drops by half, as was the case in the U.S. for example?

V. DIEST: This was not investigated.

GAENSSLEN: I think that this is an essential point; it might not work in the Federal Republic of Germany, but it would work very well elsewhere.

KLUSMANN: I agree with Prof. Kolling's earlier comments concerning tar and power production. Such a large project falls under the basic conditions for hard coal electricity sales to the large utilities. If one aims for 700 megawatts project of this type, all the subsidy advantage would certainly be applied, as Dr. Holighaus already indicated. However, we cannot go that far, because confirmation from the utilities is required first.

Such a project would fall under the normal conditions for hard coal electricity sales. The discussion of data dealing with liquid and tar only while ignoring the electricity production is a wrong approach in my opinion.

HOLIGHAUS: This would be a very important condition. How much does the subsidy procedure lower the cost of coal?

V. DIEST: It is basically a subsidy on the investment side which constitutes about 10% (quite a large sum) of the total investment. Then there are the specifics on the coal side.

HOLIGHAUS: This is a very typical German situation; an additional study dealing with the foreign situations would be very useful. Its results might be totally different from those which we have here.
We should now proceed to the next paper, which deals with some efforts made to obtain a saleable product from tar arising from the L.R. process. Other processes, e.g. the Lurgi gasification, which also has a high tar yield, are also discussed.

Frankfurt/M., 11th September, 1978.
DrSi/Mler/KeE

Upgrading of Tar Distillates from Coal Gasification

Introduction

The purpose of these investigations was to determine the yield and composition of products obtained by hydrotreating liquid hydrocarbon by-products from coal gasification. The production of gasoline and fuel oil has been examined in continuous bench-scale tests under specific conditions. This paper presents the conclusions from these test runs as a first approximation related to the pressure gasification tar of the Sigma-type bituminous coal originating from the Republic of South Africa.

Considerable efforts to characterize and classify various tar types obtained by different gasification and carbonization techniques from a representative spectrum of coal grades were followed by studies regarding process selection in the upgrading process scheme. Although final decisions are governed by topical and economical aspects, for example, whether an aromatics recovery or a phenol recovery would be considered or not, the main process route comprises hydrogenation steps to produce automotive fuels.

The route of straight hydrogenation with the exclusive production of gasoline and fuel oil in the diesel oil boiling range were selected as basic criteria for the present work.

Experimental and Discussion

A simplified diagram of the upgrading processes shows Fig. 1. The liquid hydrocarbons which are produced by coal gasification are partly condensed from the produced gas (light & heavy tar) and separated from gas liquor, and partly obtained from

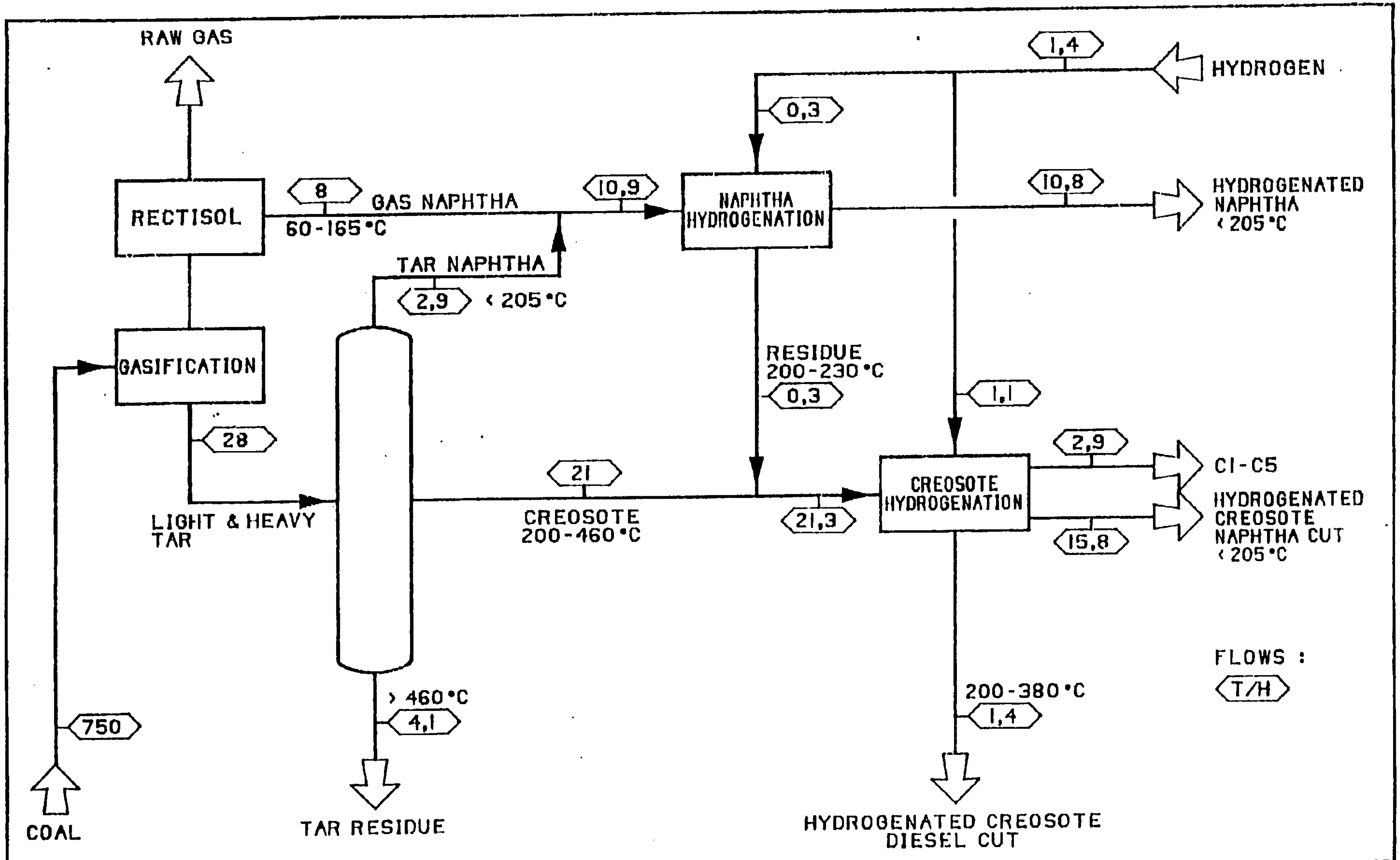

FIG. 1

NAPHTHA AND TAR UPGRADING PLANT

LURGI

LURGI KOHLE UND MINERALOELTECHNIK

the Rectisol purification process (gas naphtha). Solid particulates from the heavy tar condensate fraction are removed and the combined condensates distilled. A first atmospheric distillation stage supplies tar naphtha. This fraction combined with the gas naphtha is processed in the naphtha hydrogenation.

Vacuum and flash destillates in the boiling range 200 - 460°C ("Cresote") are combined with polymerization residues from naphtha hydrogenation and processed in the creosote hydrogenation.

A tar distillation residue in the boiling range above 460°C is recovered and used either by recycling to coal gasification or processed individually for hydrogen production.

Naphtha hydrogenation is operated according to the Lurgi Benzoraffin process which has been applied several times in the last decades in commercial plants. This process yields hydrogenated naphtha ready for reforming and isomerization when premium quality gasoline is required. The light ends (C_1 - C_5) produced here are omitted from this diagram. The chemical hydrogen consumption is 300 - 310 Nm^3/t.

Creosote hydrogenation is a fixed-bed reactor and is operated in the trickle phase using hydrogenated creosote recycle, and yields a naphtha cut produced by hydrocracking besides a fuel oil with 380°C final boiling point, - no residuals - and light ends. Thus, an atmospheric distillation is integrated in the step, producing the net streams as shown. The actual hydrogenated fuel oil stream, that is the residue of this destillation is expanded by the recycle. The chemical hydrogen consumption in this hydrogenation step is 400 - 450 Nm^3/t feed.

The flow data on this diagram refer to a coal gasifying unit fed with 750 tons/hour bituminous coal and reflect actual yields and hydrogen consumption under the particular conditions of creosote hydrogenation. These are tabulated below.

Feed-recycle ratio	1 : 1 by weight
Pressure, total	120 bar
Temperature, max.	490°C
LHSV	0,6 kg/l.h

A commercial hydrotreating catalyst has been used. The temperature maximum indicates the peak temperature in a preselected gradient.

Test series operated with different variables showed that the higher the feed-recycle ratio the lower the specific hydrogen consumption related to the naphtha produced. On the other hand, the investment costs rising with the necessary volume are the upper limiting factor.

The naphtha cut produced by this process is similar in composition to the hydrogenated naphtha (from the Benzoraffin process) and can therefore be readily fed to gasoline finishing. However, the fuel oil cut has a high aromatics content and a relatively low cetane index. A nitrogen content of 0,2 - 0,3% by weight, originating from the respective character of the feed is unusually high although not prohibiting for diesel oil purposes. We believe, for the time being, that this cut can serve as a blending component for diesel oil but that it is less suited as an independent source for the same.

Therefore, the maximization of the naphtha production to the sacrifice of the fuel oil cut should be preferred within the margins of reasonable proportions of light ends.

As a result of these considerations the balances and conditions were selected for demonstration. Variations of the pressure and the LESV change the balances slightly but do not influence the properties of the products substantially.

Characteristic properties of the main product streams are shown on Table 1.

Based upon the yield of the applied hydrogenation processes and using the principle: preferred naphtha production, minimum diesel oil co-production, the output of a naphtha and tar upgrading plant would be as follows:

Feeds	Light & heavy tar	224 000 tons/year
	Gas naphtha	64 000 "
	Chemical hydrogen consumption (cumulative)	11 200 "
Total Feed		299 200 "
Output of Products		
	Hydrogenated naphtha	86 500 "
	Hydrogenated creosote naphtha cut	126 000 "
Total hydrogenated naphtha reformer feed		212 500 "
	Hydrogenated creosote Diesel cut	11 200 "
	Light ends $C_1 - C_5$	23 200 "
	Tar residue	33 000 "
	Total Output	279 900 "
Balance:	losses due to heteroatoms removal H_2S, NH_3, H_2O	19 100 "

Yields based on hydrocarbon feeds:

Hydrogenated naphtha	73 wt%
Diesel cut	4 "
Light ends	8 "
Tar residue	12 "

Summary

In a plant for upgrading coal gasification tar the naphtha (boiling range up to 200°C) and the creosote (boiling range 200 - 460°C) destillate fractions will be hydrotreated separately. The products are hydrogenated naphtha, hydrogenated creosote fuel oil or diesel cut (boiling range 200 - 380°C), light hydrocarbons, as methane and C_2 to C_5.

The hydrogen consumption of naphtha hydrogenation is 300 - 310 Nm^3/t and that of creosote hydrogenation 400 - 450 Nm^3/t. In the case of a representative feed composition: 1 ton naphtha to 2 tons creosote the cumulative hydrogen consumption is 3,9 wt% of the feed. Tar distillation residue (boiling range above 460°C) will be obtained. The hydrogenated naphtha is ready for platforming or for prior aromatics recovery determined by economic aspects. The diesel cut has an aromatics content of 70 - 74 wt% and a cetane index of 30.

The case of upgrading liquid hydrocarbons from coal gasification discussed here yields hydrogenated naphtha of 73 wt% of the feed.

Table 1

	Creosote	Tar Residue	Hydrogenated		
			Naphtha	Creosote naphtha cut	Creosote Diesel cut
Specific gravity g/m	0,996	> 1,0	0,820	0,809	0,930
Boiling range °C	200-460	> 460	60-190	40-205	200-380
Ultimate analysis wt%					
H	8,79	7			9,74
C	88,9	85			90,1
O	4,79	6			< 0,03
S	0,45	0,8		1,5 ppm	0,008
N	1,17	1,2			0,23
Constitutional analysis Vol%					
Paraffines + Naphthene	25		50	53	26
Olefins	15		-	-	-
Aromatics	60		50	47	74
Composition wt%					
Paraffines			25	16	
Benzene)					
Toluene)					
Xylenes)				30	
C_9^+ Aromatics				21	
Total Aromatics			50	51	
Naphthenes			25	33	
Cetane index	-	-	-	-	30

LECTURE BY BARON - READ BY SIMO

HOLIGHAUS: Thank you for reading this paper. Can the hydrogen consumption be covered by gasification of the tar residue?

SIMO: In principle, it is possible to cover the necessary amount of hydrogen with the tar residue by gasification, and to change the amount of residue if more feed for the hydrogen production is required.

HOLIGHAUS: In this special case, if one has 12% of residue, and needs 3.8% - 3.9% hydrogen, it cannot be covered. If this were changed, covering could take place. The yield, however, would go down.

SIMO: If the amount of residue is insufficient, it could be extended.

HOLIGHAUS: Then you would have the same hydrogenation products.

SIMO: Yes; however, this would result in a slightly changed yield.

KRÖNIG: Can the tar residue be recycled into the Lurgi pressure gasification, or must it be gasified in a separate plant?

SIMO: In order to produce hydrogen, a different gasification would be required. It has been proved in a number of cases that it is possible to recycle it in the gasification if one wishes to produce a normal producer gas.

GAENSSLEN: If one wants to make hydrogen for hydrogenation, a high concentration hydrogen is required. Then the Lurgi process, owing to the methane it makes, would not be the mose suitable method. So another type of hydrogen-production might have to be used.

KRÖNIG: Is your hydrogenation one or two step?

SIMO: It is one step hydrogenation.

KRÖNIG: Does your catalyst stand hydrogenation at rather high temperatures (490° C and 120 bars)?

SIMO: This is a peak temperature in a very short part of the reactor. The catalysts have withstood these conditions for up to 500 hours without being damaged in any way.

KRÖNIG: These must be excellent catalysts.

SIMO: One must ensure that the catalyst carrier does not contain hydrocracking compinents.

KRÖNIG: But all materials below 200° C turned by cracking, I would call this hydro-cracking. Have you another explanation for this?

SIMO: Yes, this is hydro-cracking, but under the same conditions, when using a dydro-cracking catalyst, it would be much more severe.

GAENSSLEN: You would make more light products.

KRÖNIG: You had a catalyst which cracked without being a hydro-cracking catalyst?

SIMO: Yes, because of the severe conditions.

WÜRFEL: In the case of the catalyst concerned, is the carrier of the metal components aluminium oxide?

SIMO: Not exclusively.

WÜRFEL: Do you think that the tar from the Lurgi Ruhr-Gas devolataliser is as easy to hydrogenate as the tar from a pressurised gasifier?

SIMO: I believe not.

KRÖNIG: Please could you describe the reasons for this.

V. DIEST: The tar contains many bases. Tar from the Lurgi-gasifier is more stable, and tar from the Lurgi Ruhr-Gas devolataliser tends to polymerise and is therefore unsuitable for certain processings.

WÜRFEL: In hydrogenating this secons type of tar, we must take into account another kind of yield distributions owing to a greater proportion of heavy ends.
When hydrogenating the same fraction of this tar, one must bear in mind the higher hydrogen consumption (in the case discussed, this was lower); this is the main difference. Certainly the production of light ends would be increased too.

KÖLLING: Is the Lurgi gasifier tar here distillable without residues?

WÜRFEL: Only 10% is undistillable. L.R. tar is distillable only to about 30%; the remainder is pitch, and hydrogenation of pitch is an extremely different matter. These figures, I believe, are from SASOL I. What is done there now? Is the tar burned or hydrogenated? Also, what are the plans at SASOL II?

SIMO: Uncertainty as to whether to hydrogenate exists. The main part of the tar is sold at the present coditions with the same properties. This will definitely be done for as long as possible.

KRONIG: To whom is it sold?

SIMO: The sales are domestic.

SCHNUR: I have a question connected with Fischer-Tropsch. It is not necessary to have a minimum of diesel fuel which could be mixed. Do you have rough figures showing the yields if one changes from a minimum to maximum diesel?

SIMO: Yes; this was the other part of the study we carried out. The summary of the balance would be altered so that the diesel yield amounted to 20%-24%. The light ends would amount to 5%, an the residue would of course remain the same.
The main difference concerns the hydrogenated naphtha (we gave about 20% - 22% to the other components, therefore we could say that). The rough yield of hydrogenated naphtha would amount to 50%-60% only. This is the sacrifice when one reduces the light ends and hydrogen consumption.

HOLIGHAUS: Please could you describe the separation steps for dust. Did it become tar and gasify, or was it separated before passing to the distillate corridor?

SIMO: Work with coal gasification tar is fairly effortless, as in this particular case. Pre-sedimentation during the condensation occurs, so the overflow entering the distillation column contain a maximum of 10% solids. We found that it is possible to concentrate these amounts of solids into the residue. Since this is a coal gasification process, the solids are coal too.

HOLIGHAUS: That is no problem; if it is only concentrated there. So much is said about the Lurgi Ruhr-Gas process and its application with oil-shale, tar and coal. You also considered, I believe, how to upgrade those liquid products from the Lurgi Ruhr-Gas process. Could you just give an indication as to what yields you would obtain if you were to make a connection with the paper we heard previously (considering coal in particular)?

SIMO: We could consider only the distillate fraction, which is obtained any way from an L.R. tar. We should allow for an increase of at least 10% in hydrogen consumption and another 10% increase in the production of light ends.
Personally, I don't believe that it would be possible to produce inexpensive hydrogenated products without heavy ends. After hydrogenation, there is certainly remaining a residue fraction. It would be unwise to recycle this into the hydrogenation of the original fraction between 200°-400° C. Further, we would be unable to distill the original L.R. tar up to a final boiling point. However, I assume that it would be possible to do this up to 400° C. These all would influence the yields of plants adversely in comparison with the hydrogenation of coal gasification tars.

HOLIGHAUS: What is done with the large quantity of residue?

SIMO: Hydrogenation of pitch and asphaltenes is a different question and cannot be performed with a fixed bed system. This is a case for liquid phase hydrogenation.

HOLIGHAUS: Looking at the economics of the processes you included a number of relevant figures in your paper; I think you should also indicate the product prices in connection with market competition. What are the raw material prices for this slightly heavy tar?

SIMO: We have considered these questions; I would like Mr. Gaensslen to discuss them.

GAENSSLEN: The cost of the reatment is depandant upon the coal price. Hydrogen cost is a function of the coal used in production. So under German conditions (in the case of an expensive coal, Steinkohle, which costs DM 20,- per Giga calorie and about DM 1,50 per kg of hydrogen) an addition of 1% amounts to at least DM 15,-, on top of which the capital cost of the hydrogenation plant must be added. A 1% hydrogen addition to such a plant in the Federal Republic of Germany would cost about DM 25,-/DM30,-. As soon as the coal price drops, (as under U.S. conditions with DM 5 - DM 7 per Giga calorie) there would be an added cost of about DM 18 - DM 20 per 1%.

HOLIGHAUS: But in the case of diesel, this upgrading process can be balanced; then coal with a mixed price need not be introduced.

GAENSSLEN: This must be introduced, as the hydrogen cost is a function of the coal.

HOLIGHAUS: If the residue is increased and then used for hydrogenation, the upgrading process is closed.

GAENSSLEN: Then the tar would also be a function of the coal, as its cost must be balanced against the Giga calorie cost of tar. However, if the tar is bought, the cost of hydrogen can also be considered.

HOLIGHAUS: Certain prices can be obtained on the market for all these products. With a closed process, the price which can be paid in order to obtain these market prices can be calculated.

GAENSSLEN: The added cost in this country is about DM 30 per 1%. If, for example, the tar is valued at DM 100, the total sum of the products would be about DM 200. (With 3.9%, this would be about DM 220).
The situation would be different if the coal were cheaper and the tar could be valued at a lower price. Finally, it is not merely a question of economics, but also of the amount of such tars available. Our needs in this country can scarcely be met.

HOLIGHAUS: I would now like to introduce the next paper, delivered by Mr. Baker, who is head of one group of the I.E.A. Services dealing with the economic assessment of coal.

Liquefaction Economics
Direct or Indirect Routes?
- Some Considerations

A. Baker
IEA Coal Research
Economic Assessment Service

Paper to Workshop on Coal Liquefaction Economics, Jülich,
18/19 September 1978.

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1. INTRODUCTION

Economic Assessment Service is one of five projects of IEA Coal Research based in England. Though the National Coal Board is "operating agent", the work of Economic Assessment Service is directed by and carried out for representative agencies of eight countries (United States, Federal Republic of Germany, United Kingdom, Canada, Spain, Sweden, Netherlands, and Italy) and the eight technical staff are in part seconded from some of those countries. Economic Assessment Service is concerned with three broad questions:-

a) What are the economic prospects of coal conversion technology (new techniques of power generation, gasification and liquefaction)?
b) What are likely future developments in the cost and supply of coal internationally?
c) How can coal use fit most economically with environmental standards?

One of the tasks in Economic Assessment Service of IEA Coal Research is to examine various liquefaction processes under development in the routes

(a) Pyrolysis
(b) Direct hydrogenation of coal
(c) Gasification + synthesis to liquid

EAS cannot provide its own basic process information. Its purpose is, instead

(a) to review reported information, and accept or adjust it on the basis of developing knowledge of a process.
(b) try to put information on a consistent and relatively independent basis - level of optimism and economic conventions are two examples.
(c) extract "message" free of conventions, pointing out where uncertainty remains.

As an essential step in reviewing liquefaction economics we have surveyed representative processes from the three routes above and produced a report (1) setting out reported performance data and giving our views on them.

These have not yet been translated into economic views, so I will confine this paper to some general observations and then focus on an issue of comparison of direct and indirect processes that appear of interest.

2. LIQUEFACTION ECONOMICS - SOME GENERAL CONSIDERATIONS

Most reported studies (references 2, 3 are examples) tend to quote economic data for plant roughly as:

coal throughput	22-24000 ton/day
liquid yield	50%-60% (thermal basis)
liquid type	various: methanol at one extreme LPG, Naphtha, diesel oil, fuel oils.
plant investment (excluding interest)	$1200-1400 million

At a coal cost of $1/million BTU and real required rates-of-return of 10%/yr, costs are about $5/million BTU for the whole product slate or some $30/barrel of liquid.

All of this is based on projected data and therefore arguably optimistic. In many cases the processes have not been proven to "work". The processes have neither been tested out on any scale nor have they been "closed" e.g. by assurance of hydrogen production from residual char. Some messages seem clear enough.

(a) if gasoline from coal is required, methanol + synthesis looks relatively attractive.
(b) Burning Fischer Tropsch liquids as boiler fuels is very un-economic compared with the intermediate stage of gas use.
(c) In general the hydrogenation processes appear to be resembling each other. Thus Exxon Donor Solvent and SRC II may differ in solvent hydrogenation, slurry recycle and treatment of distillation residuals but each has thoughts of possible process revision in the direction of the other.
(d) The compatibility of many coal-based liquids (at least those from direct production) with traditional petroleum liquids is in doubt. The way coal-based liquids may ultimately penetrate the market requires much study.

Overall it is common knowledge that the projected economics of coal liquefaction mean that it is not a competitive technology at present or within near future, except in special circumstances where very cheap coal and strategic reasons justify the costs.

In this climate, development in IEA countries is aimed at achieving workable processes where all stages are demonstrably in balance, and in the course of this to obtain firmer information where one process clearly dominates another in providing a generally cheaper product range.

As part of this assessment, there is clear interest in finding out under what circumstances different routes to liquefaction (pyrolysis, hydrogenation, synthesis) may be more attractive. As a preliminary stage in our work, an example comparison between hydrogenation and Fischer-Tropsch synthesis is considered.

3. HYDROGENATION V SYNTHESIS - AN EXAMPLE

This example raises the question of how processes giving different products may be compared, and in particular, how an effectively joint process for liquefaction and gasification compares with just liquefaction. It may be immediately objected that process schemes should be taken to produce just liquids. A counter-argument is that coal processes should be allowed to transform the coal into products to best advantage - and then make the comparison on product value.

The choice of process data poses obvious difficulty - it is clearly unfair to compare real SASOL data with projected hydrogenation performance, and we are therefore forced to compare projected results from conceptual plants. To do this I have chosen two schemes, adjusted certain information to attempt to meet criticisms of bias, and then tried to place the schemes on the same economic basis.

For hydrogenation process to produce liquids the Exxon Donor Solvent results reported in reference (2) have been taken. Fischer Tropsch synthesis produce a range of products. As an example of the process forced to maximum energy production the scheme proposed by Parsons (reference 4) has been taken. This has been widely criticised as being optimistic in its heat recovery and coal input required has been adjusted to assume the need for coal-based power generation. Investment costs have been adjusted to adjust the Exxon contingency and incorporate a 35% contingency in the Parsons figure. They have also been up-dated to end-1977 values. Figure 1 shows resulting process data.

It seemed interesting to compare pro-rata investments and coal import with earlier requirement data quoted by Pichler (ref 5). Figure 2 suggest that the Fischer Tropsch data used here is not unfairly favoured, though the difference reflects the SNG production in the Parsons scheme and the investment required to obtain it.

Working capital, insurance, local taxes etc. were put on a similar basis using the set of EAS convention proposed in our report (ref 6). Operating costs were on the reported basis, and coal cost taken at different levels. The economic analysis was carried out on a straight DCF basis, assuming plant construction times of 5 years, operating times of 10 years and plant availability of 80%. Values have been taken in "real terms," excluding the effect of inflation.

From this analysis a cost/million BTU of product can be obtained in each case, and this is shown in Figure 3 (columns 1 and 2). Superficially the figures favour the Fischer Tropsch example, but the comparison is false since products are by no means the same. For example, if the SNG product of Fischer Tropsch is treated as a byproduct to be used at ½ the cost of liquids, the position is reversed and the equivalent liquids of F-T shown in column 3 is higher than from the EDS hydrogenation scheme.

Such a valuation is arbitrary and it seemed that a clearer picture might be obtained by considering that each process has a fuel-type product which eventually has to be compared economically with the use of coal in

	EDS	F-T
Coal Input		
T/D	24000	32 900*
10^9BTU/D	535	825
Products		
10^9BTU/D		
SNG	-	268
LPG	33	14
Naphthas	114	98
Diesel Oil	-	85
Fuel oils	183	28
Alcohols etc	-	12
Thermal efficiency	61.7	61.2
Plant investment (million $)	1520	2000

* Adjusted for power generation

Figure 1: PROCESS DATA ASSUMED

		Hydrogenation	Fischer-Tropsch
COAL REQUIREMENT (million tons/yr hard coal)	Pichler	6.4	9.6
	Present comparison	5.1	9.7
INVESTMENT COSTS (million $)	Pichler(1969?)	770	820
	Present comparison(1977)	1130	2000

Figure 2: VIEWS OF REQUIREMENTS FOR HYDROGENATION AND FISCHER-TROPSCH SCHEMES.

	(1) EDS	(2) F-T	(3) F-T
Coal Cost: $\$1/10^6$BTU			
DCF Return 5%	4.9	3.9	5.3
10%	5.9	4.7	6.4
15%	7.1	5.8	7.9
Coal Cost: $\$2/10^6$BTU			
DCF Return 5%	6.4	5.5	7.5
10%	7.4	6.4	8.6
15%	8.7	7.4	10.1

Note: Column (2): all F-T products valued equally
(3): SNG product valued at ½ liquid product

Figure 3. COST OF TOTAL PRODUCT RANGE $\$/10^6$ BTU

power generation (with flue gas desulphurisation or fluidized bed combustion) or with industrial or domestic gas use, either directly or as natural gas or from coal gasification. The other product is a naphtha or diesel oil product suitable after treatment as transport fuel. These different fractions may be considered to have potentially separate values, and economics have to be considered in two discussions. Their costs in these example processes are linked through the DCF analysis. Thus for a \$1/million BTU coal and 10% DCF yield rate EDS fuel (F) and transport products (T) costs are linked by :

$$350T + 427F = 4556$$

or quoting transport product cost in \$/barrel

$$67.3T + 427F = 4556$$

Figure 4 plots this line. Essentially, for market prices to the right of the line, the process is economic. Figure 5 now adds two more lines for two cases of Fischer-Tropsch.

Case (1) -- all fuel products valued equally
Case (2) - SNG valued at half as much as Fuel oil

How the processes are valued relative to each other can be quantified by

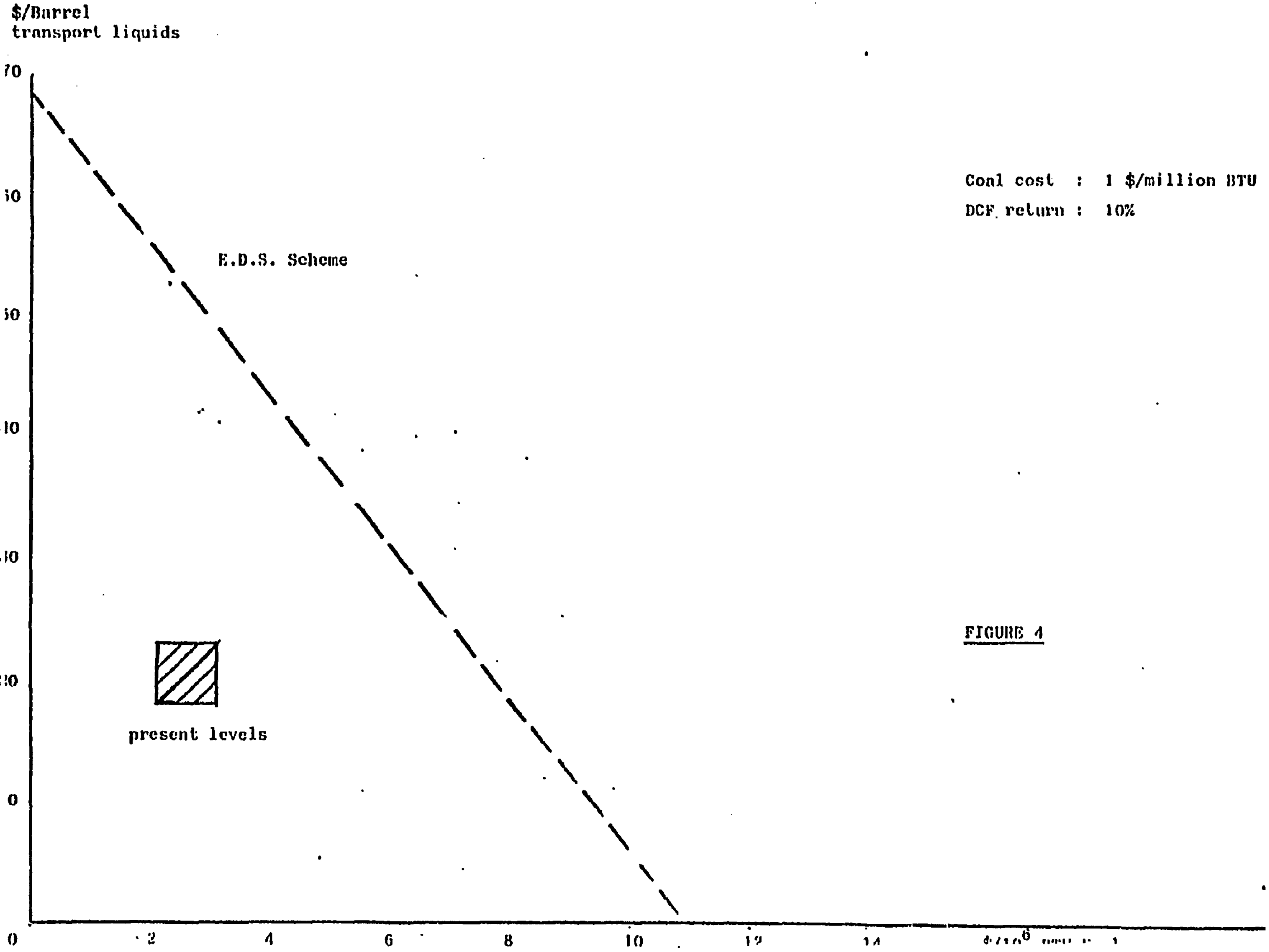
(a) The likely future direction of movement of the fuel price/transport liquid price factor.

(b) The valuation of gas relative to fuel liquids.

If gas is (almost) as highly valued as fuel liquids, then the F-T scheme can be seen to be more economic in general. If SNG is valued low, then EDS would be more economic unless transport fuels become much more highly valued (say 5 times on a thermal basis) than combustion fuels.

Figure 6 shows an equivalent graph for a \$2/million BTU coal together with a 5% DCF rate and the above conclusion is reinforced.

Obviously different processing schemes will alter the slopes of the straight lines and further adjustments can be made to reflect different quantities of transport fuel. However it is hoped that this approach helps to clarify a general debate about different process types.



Coal cost : 1 $/million BTU

DCF return : 10%

FIGURE 4

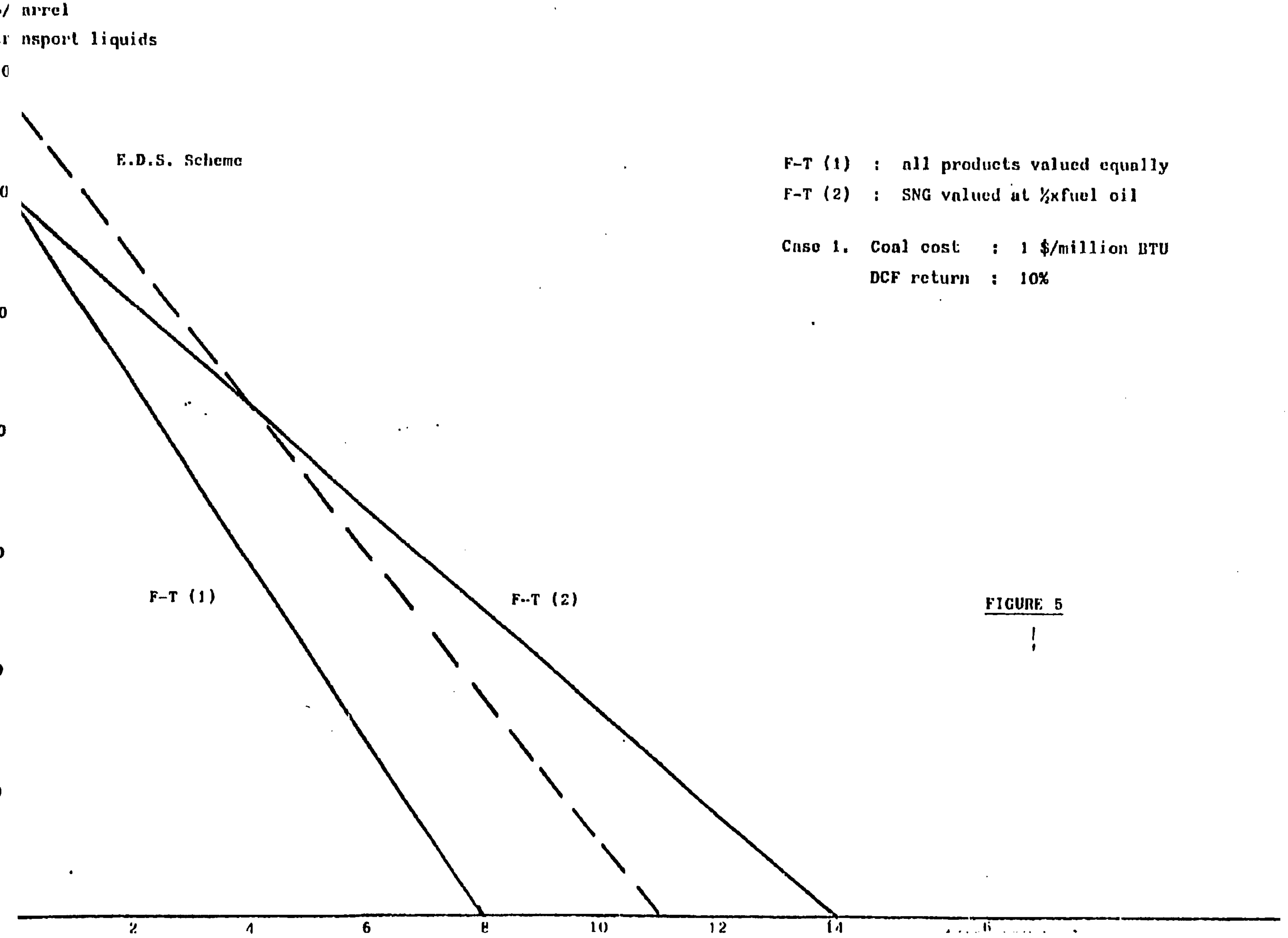
/ arrel
nsport liquids
E.D.S. Scheme
F-T (1)
F-T (2)
F-T (1) : all products valued equally
F-T (2) : SNG valued at ½xfuel oil
Case 1. Coal cost : 1 $/million BTU
DCF return : 10%
2
4
6
8
10
12
14

FIGURE 5

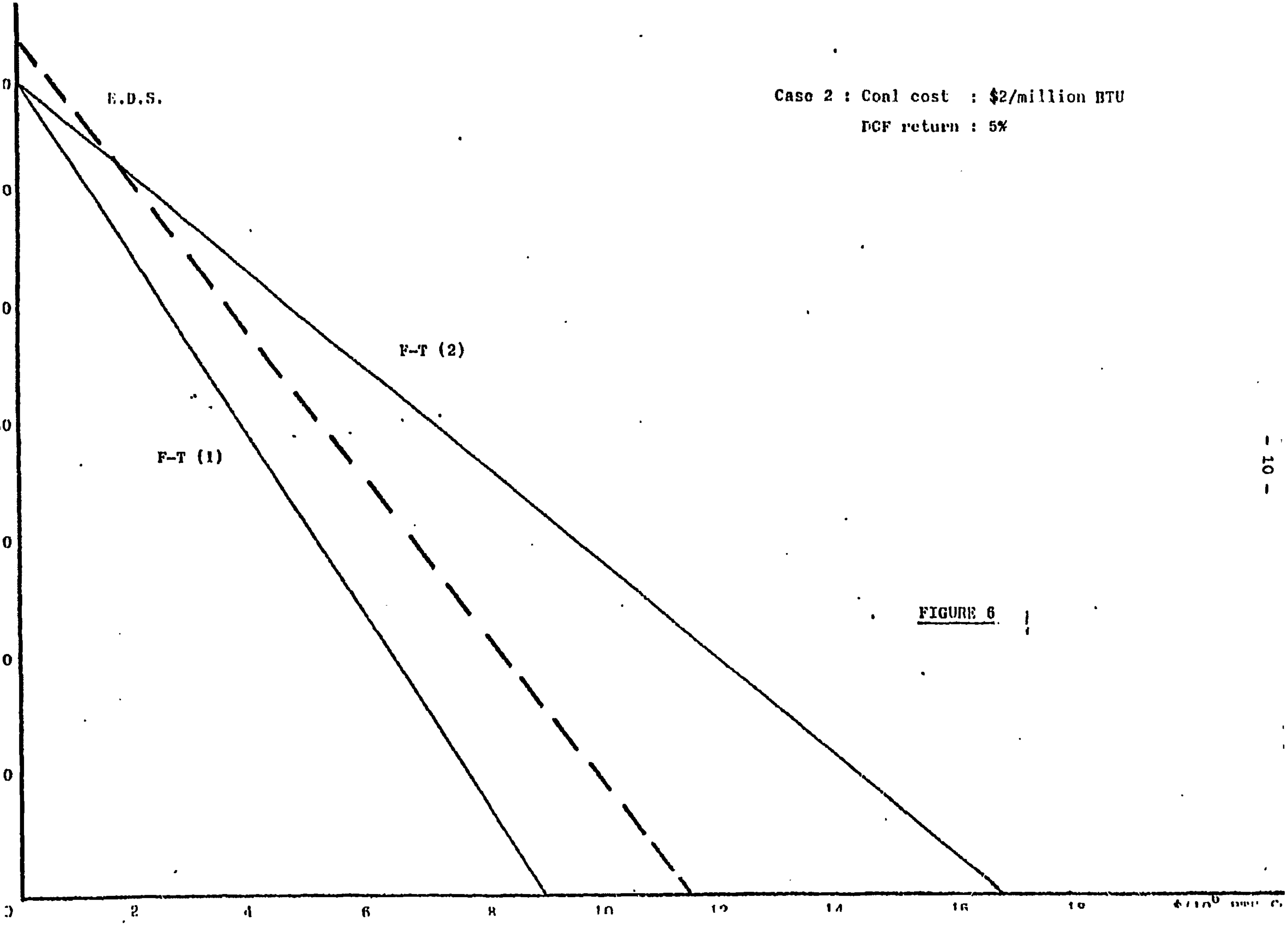

E.D.S.
Case 2 : Coal cost : $2/million BTU
DCF return : 5%
F-T (2)
F-T (1)
0
0
0
0
0
0
0
0
2
4
6
8
10
12
14
16
18
$/10^6 per

FIGURE 6

4. FURTHER CONSIDERATIONS

The above analysis illustrates how a variety of views can be obtained in process comparison by considering product value - an inherent difficulty of liquefaction economics.

There are some extra points which condition any comparison among which are:

(1) The relative status of two technologies. In a sense, with slurry handling and with ultimate reliance on gasification, hydrogenation is essentially a less certain technology than synthesis. Should plant operating factors be taken as the same?

(2) Hydrogenation schemes can also produce gas if more coal is used for heating. A further analysis should include the effect of this and different hydrogen production schemes, (e.g. this EDS scheme assumed reforming of the primary gas product), as well as the possible use of cheaper hydrogen from natural gas.

(3) Are the processes rightly comparable on the same hard coal? The ability of synthesis processes to use cheap lignite effectively should be reflected - as also their potential ability to use a wide range of coals in countries necessary to import coal.

(4) Though developers deny any potentially serious problems, coal hydrogenation involves production, cycling and handling of environmentally unpleasant liquids. Entrained gasification processes linked to synthesis appear less unpleasant here, though it is difficult to quantify this.

5. CONCLUDING REMARKS

Comparison of processes and routes to liquefaction is made very complicated by the variety of product and valuation of their uses. An assessment has to be made on the basis of a fuel product and a potentially high valued transport or chemical product. The examples illustrate what range of views may be obtained when allowing synthesis of a full product range against a narrower liquefaction by hydrogenation. It raises the question of the value of combined gas and liquid production, as well as the relative status of two types of process. Our assessment work of liquefaction in EAS will look further at some the these questions as well as tackle a wider range of process comparison.

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LECTURE - BAKER

HOLIGHAUS: Thank you for your excellent lecture, which gives a good impression of your work and your approach towards the various problems. Now the discussion is open.

GAENSSLEN: I agree with Mr. Baker's comments. We have done a very similar type of analysis at Lurgi, finding out whether it was possible to make simultaneously fuel gas in large quantities. We were motivated by the Parson's study. The figures of this study disturbed us to some extent, and we did our own re-calculations. We found that the thermal efficiency of the process rises dramatically from 40%-60%.
There is a so-called liquid premium: any liquid fuel commands a higher price than a gaseous product, while in gas, only the heating value is honoured. Our analysis is performed in practically the same way as that done by Mr. Baker's group, and the same conclusions were reached.
We must aim to avoid recycling anything in all our processes; if possible, substances burned should not be products which have passed through the plant. Recycling always carries an energy loss; so if the product can be sold at a reasonable price, this is to be preferred to recycling through the plant.
Finally let us compare hydrogenation and Fischer-Tropsch. There is a fundamental weakness in the latter, which is overcome by one basic strength: Fischer-Tropsch works. The weakness is that the process tries to hydrogenate an "artificially oxidised coal". Carbon monoxide is actually made by taking coal and oxidising it with oxygen made under high energy consumption. It would be the same if Dr. Wolowski were to take a coal for hydrogenation with 57% oxygen. Firstly, this oxygen is added and then removed with hydrogen in the form of a very expensive water. This fundamentally lowers the thermo-dynamic efficiency of the Fischer-Tropsch process. The direct hydrogenation of coal does not have these drawbacks; on the whole, it is more impractical, though.

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BAKER: I agree entirely with your comments.

KNUDSEN: We are pleased with the work of Mr. Baker's group is doing and give our support. We think that his type of examination and results will help us; in the past, we have felt negatively about Fischer-Tropsch, but more are beginning to realise that it is not necessarily on a practical basis (as Mr. Gaensslen pointed out). Theoretically, it might perhaps suffer, but practically, it may be as good and, in some cases, even cheaper. (If some of the filtration problems are not solved.) One must look at the matter objectively.

HOLIGHAUS: We learned yesterday that at least one third of the cost of the coal liquefaction process was related to gasification. A proper development of such a process is not known in the U.S., I believe. However, there are 3 developments in the Federal Republic of Germany: Texaco, Shell Koppers and the Saarberg Otto generator. A good chance exists for us to co-operate with the U.S.

KNUDSEN: We could mention the sliding Lurgi in Ohio which we have taken on and funded. British and German technology were used.

GAENSSLEN: You calculate that there are 2 000 000 dollars for that 2 000 tons per year plant; these figures agree very well with our own estimates. Yours (61%) is probably based on a higher heating value, whereas we refer to a lower heating value and arrive at 59%, the parsons figures are too low.

HOLIGHAUS: Some of the points raised concerning Mr. Baker's paper can be dealt with in this afternoon's general discussion. We should now turn to the last paper by Dr. Hill on the potential of coal liquefaction on the U.S. market.

POTENTIAL FOR LIQUEFACTION

IN THE U.S. ENERGY MARKET

(Presented at the IEA Coal Liquefaction Workshop,
September 18-19, 1978, Jülich, West Germany)

Richard F. Hill
Executive Manager

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During the last decade, there has been a rapidly growing interest in the possibility of using liquid and gaseous fuels derived from coal to partially displace conventional liquid and gaseous fuels in the United States. Interest has been especially strong since the OPEC oil embargo and price jump five years ago. The expectations of the last few years, however, have not yet been translated into plants nor products.

Prior to the OPEC embargo, the general belief was that the market price of crude oil would have to about double to make coal liquefaction competitive in the United States. Five years later now, the average market price for crude oil in the United States has about tripled, but the general belief still is that the market price of crude oil must about double if coal liquefaction is to become competitive.

To better understand the various factors that contribute to this phenomenon, we examine the market prices of crude oil and raw coal in the United States since 1970 and compare these with the expected prices for crude oil equivalent that would be obtained from coal liquefaction. The rate of inflation is also examined and its impact on the expected prices of liquefied coal is estimated.

Figure 1 is the average wellhead price of crude oil (expressed on an energy content basis, $\$/10^6$ Btu) in the United States from 1970 to 1978(1). The points on the curve are calculated assuming an average energy content of 6 million Btu per barrel. The wellhead price is presently subject to Federal price control for "old" crude oil and thus the average wellhead price is less than the world market price. At present, in 1978, the average U.S. wellhead price is about 2/3 of the world market price.

Figure 2 is the average minemouth price of bituminous coal (also expressed in $\$/10^6$ Btu) in the United States from 1970 to 1978(2). The points on the curve are calculated assuming an average energy content of 10,850 Btu/pound.

Whereas the average prices of oil and coal in previous years are quite precise because they are based on actual prices paid for known quantities, the expected prices for liquefied coal are much less precise because no product was made during those years in the U.S. To make our best estimate of what was generally perceived to be the expected cost of liquefied coal during the period from 1970 to 1978, we examined five different reference(3-7) to obtain values of $4.50 per barrel anticipated in 1970, $5.00 per barrel anticipated in 1972, $8.00 per barrel anticipated in 1974, and $21.00 per barrel anticipated in 1978.

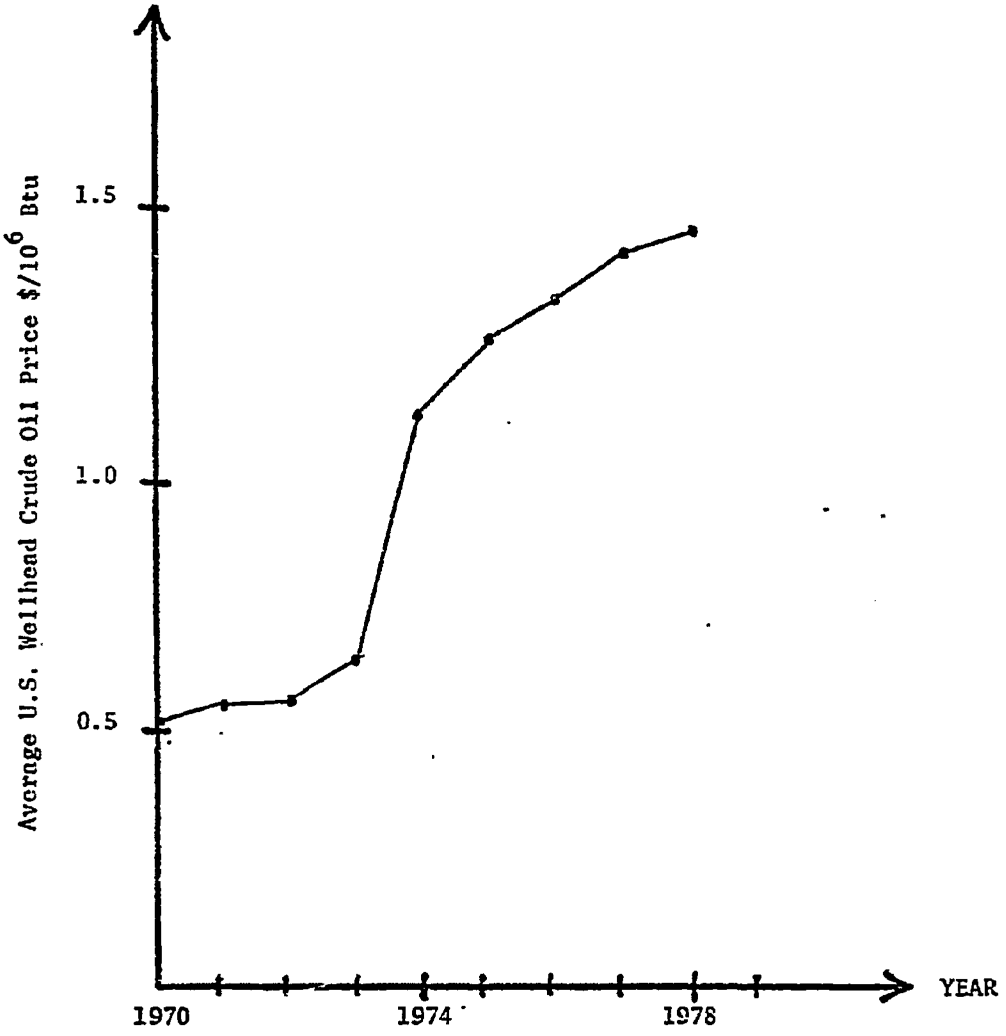

FIGURE 1: U.S. CRUDE OIL PRICE

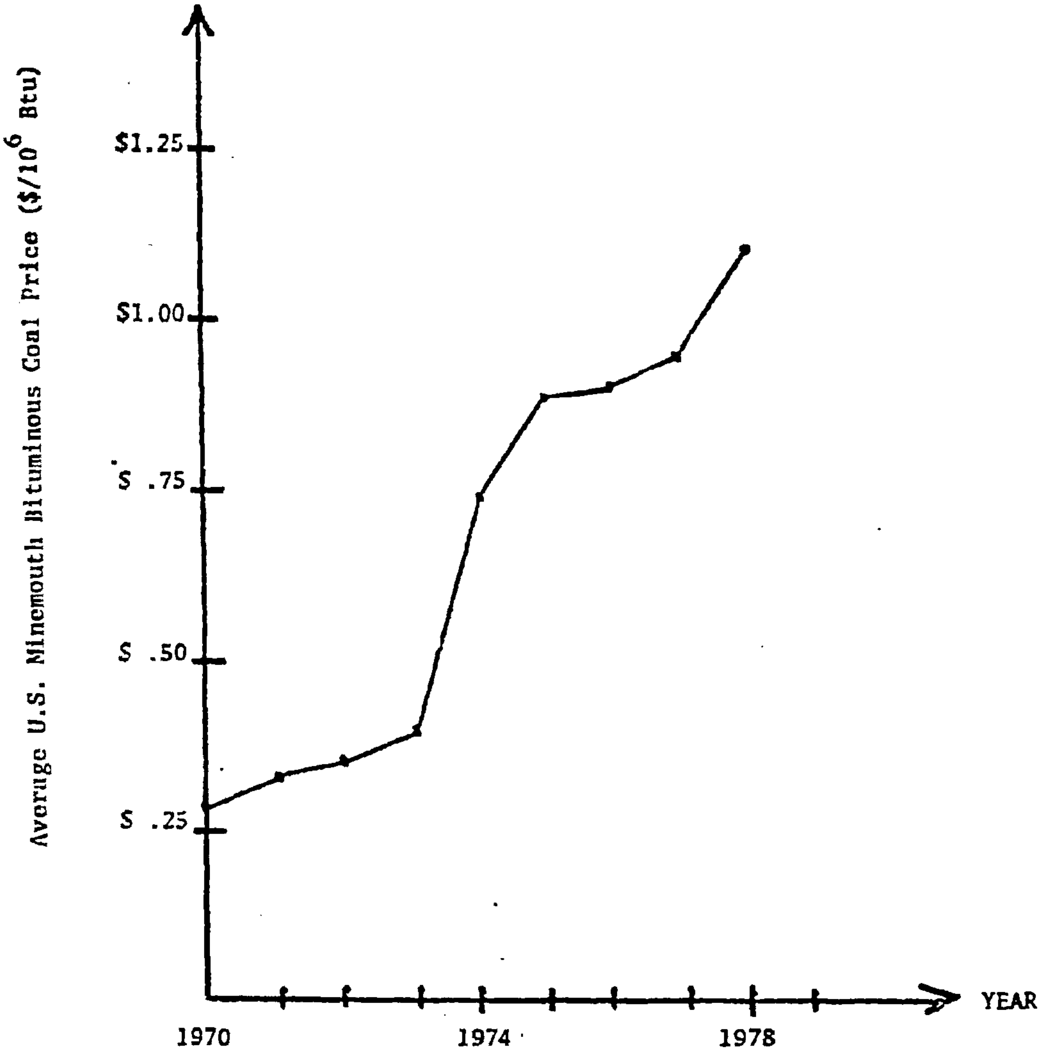

FIGURE 2: U.S. COAL PRICE

Figure 3 shows how the prices of U.S. coal and U.S. crude oil and the expected cost of liquefied coal have increased since 1970. All prices here are shown relative to the 1970 price of each. In addition, Figure 3 includes the U.S. Inflation Index, relative to 1970, as reported by the U.S. Department of Commerce.

Since 1970, the average price for crude oil at the wellhead in the United States has increased from about \$0.54/10^6 Btu to about \$1.52/10^6 Btu, some 180%; the average price of bituminous coal at minemouth in the United States has increased from about \$0.28/10^6 Btu to about \$1.10/10^6 Btu, some 290%; whereas the anticipated cost of crude oil equivalent obtained by liquefying coal has increased from about \$0.75/10^6 Btu to about \$3.50/10^6 Btu, some 360%. During that time, the U.S. consumer price index increased about 80%.

The increase in the expected cost of coal liquefaction products is, of course, due to a number of factors -- the two most obvious being the large increases in coal prices and general inflation.

Figure 4 shows the expected cost for liquefying coal (cost less fuel). This expected cost of liquefying coal is obtained by subtracting the coal cost component from the expected cost of liquefied coal. The coal cost component is calculated for any year from the average reported price of coal by using a nominal coal liquefaction efficiency of 67%.

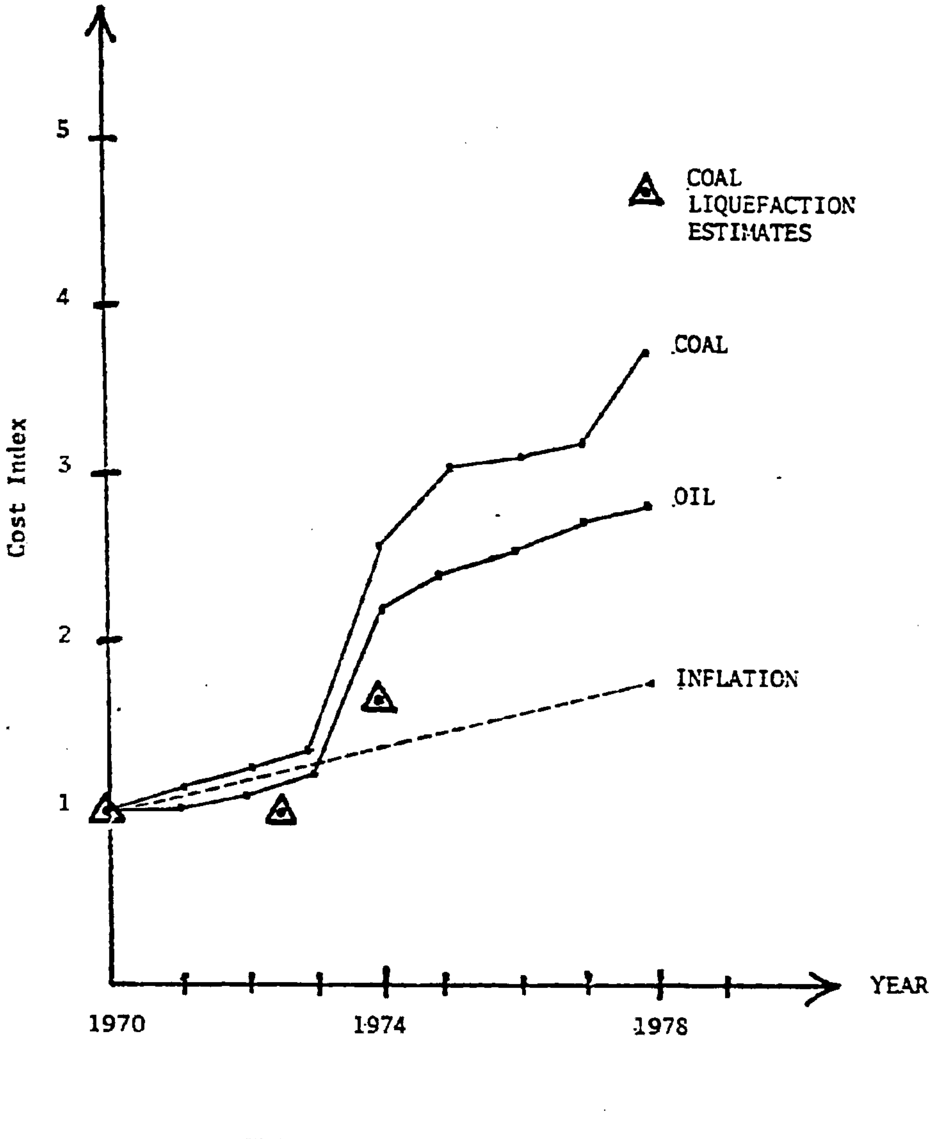

FIGURE 3: RELATIVE PRICE INCREASES

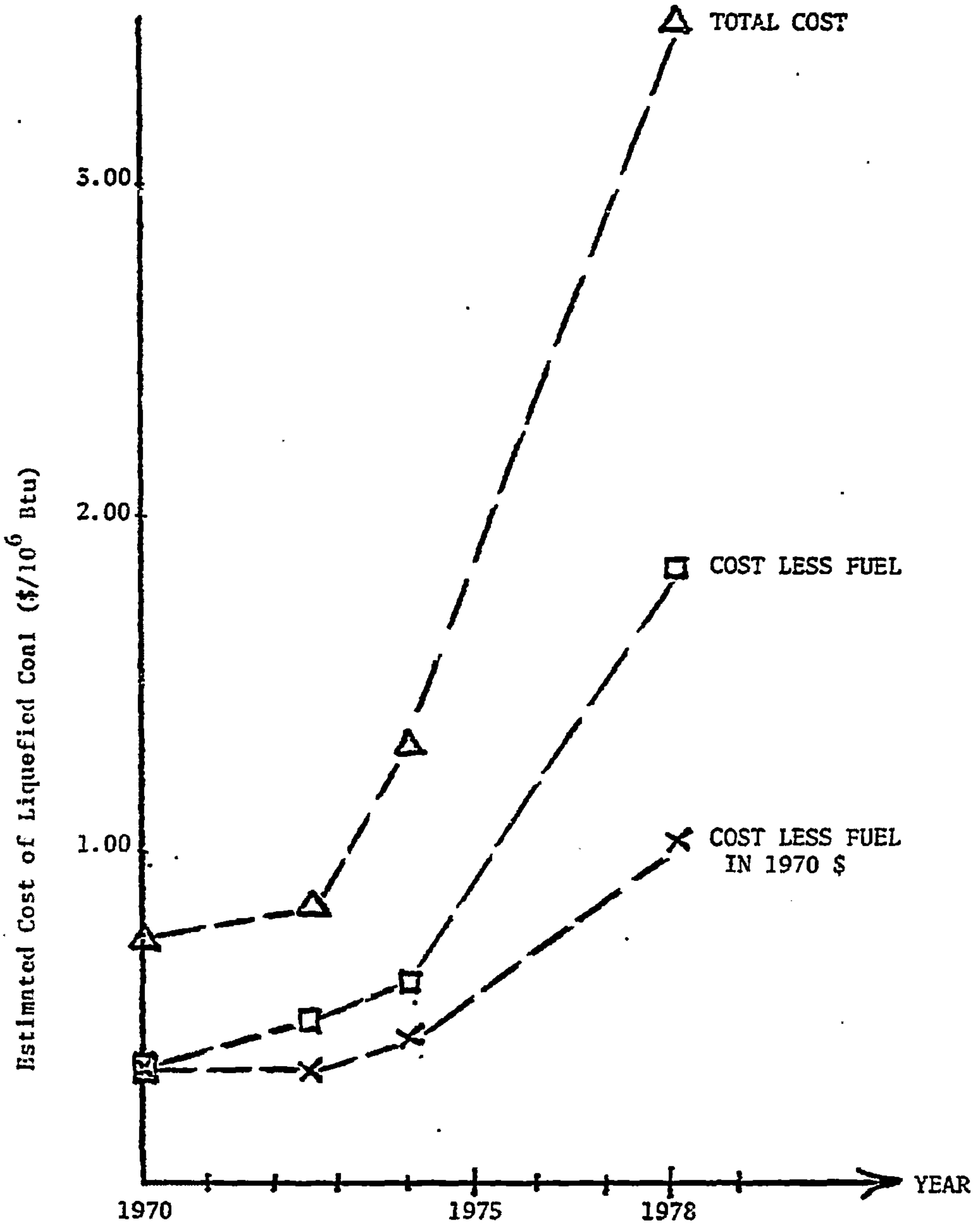

FIGURE 4: ESTIMATED LIQUEFACTION COSTS

Figure 4 also shows the expected cost of liquefying coal in constant 1970 dollars. This constant dollar cost is simply the estimated cost for liquefying coal reduced by the inflation index shown in Figure 3.

After deducting the effects of coal price escalation and general inflation, the estimated real cost of liquefying coal has still increased from about \$0.35/10^6 Btu to about \$1.05/10^6 Btu (both in 1970 dollars), some 200%. This increase probably is due mostly to the inevitable rise in cost estimates for new technologies as they evolve from the concept stage to the commercial demonstration stage. In all fairness, although the figure of \$0.75/10^6 Btu for coal liquefaction was generally quoted in 1970, there were some who cautioned at that time that the estimates were probably much too low because of the usual optimism in estimating commercial-size plant costs based on conceptual designs.

While recognizing the various factors that have contributed to the rising price projections for coal liquefaction, it is most important to appreciate the fundamental contribution of coal prices. Because of the basic market competitiveness of coal with crude oil, liquid fuels from coal will always be more expensive than crude oil in a free market. As crude oil prices increase, coal prices also are going to continue to increase in a free U.S. market in the foreseeable future.

For coal liquids to become competitive, some governmental initiatives must be taken to recognize -- and then buy out -- the inherent additional cost for converting the solid fuel, coal, to the preferred liquid.

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LECTURE - HILL

HOLIGHAUS: Thank you for your paper, which presents a realistic view rather than an optimistic picture. It shows how much effort we must make in order to come down from 30 to 28. Please raise any questions or comments.

BAKER: I think that Dr. Hill's paper certainly gives us some interesting food for thought for this afternoon's discussion. On the whole, I agree with his comments, am concerned about the problems he describes, and welcome a full discussion this afternoon. You showed that the cost of effectively processing coal to obtain syn crude in U.S. dollars (1970) has risen from about 1/2 a dollar per 1 000 000 B.T.U. in 1970 to about I dollar per 1 000 000 B.T.U. in 1978. Why is this? Is it just because of a greater knowledge of the difficulties, or is there another reason?

HILL: A number of reasons exist. For one, certain costs involved in building the facilities have risen faster than average inflation - cost of capital and labour for example. Our simple deflation exercise does not recognise these differences.

I think the largest factor is the one you pointed out and which Dr. Knudsen showed in his first presentation today: namely, that larger contingencies are needed in the earlier design stages. As engineers, we are always over-optimistic about making our first cost estimates; we almost always add rather than subtract as we perfect our designs. The figures which we are seeing today are more realistic. I would caution that the last curve must not be extrapolated.

BAKER: This has also happened with competing technologies whether nuclear, solar, etc.

HILL: Yes, except that the nuclear in the U.S. is proven technology. There are many nuclear plants in the U.S. Certains increases are inevitable as we deal more realistically with the fuel cycle, but certainly the contingency question and the uncertainty of cost connected with actually building and operating nuclear plant should not be inhibiting factors.

KNUDSEN: The estimates have changed 2-3 fold. I was one of the engineers in a group about 6-10 years ago; we were trying to indicate that the government estimates were out by about 2-3 fold lower than our estimates.

We were using the types of contingencies described, and apparently some of this has now made an impression. There have been symposia and discussions about the real cost. As long as people try to take the primary data and do the secondary analysis separately, we will realise this more and more. I would like to point out several things in this connection. Firstly, there are groups in the U.S. which have been making realistic calculations, in the 1970s. However, these calculations were not communicated and understood at a political level, ad Dr. Hill pointed out.

Secondly, regarding synthetic fuel; other companies, including Lurgi, appreciated these differences even before we began to be concerned about them. Certain U.S. industrial groups (including U.S. Lurgi) have been waiting patiently for people to become more aware of the expenses involved and that there are not magic breakthroughs.

GAENSSLEN: The outlook is rahter gloomy but realistic, and we subscribe to it. There has been a tendency over the past years to "chase after the break even point" (in other words, to obtain the same cost as in the case of oil), which is somewhat futile. One can see that it is impossible to reach this point; optimisation does not become a question of reaching the same cost, but of looking at the total cost entered. For example, one has to examine the balance of payments, whether foreign policy can be carried out independantly, etc. This kind of context is the social impact of such a liquefaction policy.

Great difficulties arise if one considers the costs only, as coal costs have increased more rapidly than those of oil over the past 8 years. So "chasing after the break even point" is doomed to failure, and we must convince politicians that it is wrong to look at cost only.

I mentioned in my lecture that cost is determinded by thermal efficiency of the process; but we have reached a point where improvements in thermal efficiency are unlikely and could only be margial. Therefore, the costs are relatively fixed at a certain value, which will only change with inflation. Other "measuring sticks" must be applied.

HOLIGHAUS: Your comment and figures would not apply in the case of the lower priced German brown coal; however, they are applicable to German hard coal.

GAENSSLEN: In this country, coal was comparatively expensive from the start. Therefore, price increases over the years could not be as steep as in the U.S., where coal costs were low compared to oil.

HOLIGHAUS: If there are no further questions, I would like to thank all the speakers.

GENERAL DISCUSSION

HOLIGHAUS: I would now like to open the general discussion, which is the last item on our agenda. A summary of the workshop, consideration of the results and the raising of general points would be welcomed. Are there any general operning remarks on what we have heard and discussed during our two day workshop?

KNUDSEN: I would like to thank everyone for this outstanding symposium organized by our German colleagues. In particular, I would like to complement Dr. Holighaus, who has enabled our meeting to take place by suggesting, promoting and lending us his support. We are very pleased that he has instigated this and done such a marvellour organisational job.
On behalf of our American group and Mr. Baker of Great Britain, I would like to say how much we have learned from all of you and how much more we think we will learn in the future. We hope that our assiciation will grow and be of as much benefit to you as we are sure it will be to us.

HOLIGHAUS: Thank you for your kind remarks. I would also like to thank all the participants very much.
We still have a very important function to perform, but it seems to me that this has been a very successful meeting up to now, largely owing to your very good contributions.
I would like to return to discussion of a more technical kind and comment on my impressions of what has already been discussed and presented, as far as the figures and cost estimates are concerned. The last paper, by Dr. Hill, is very impressive in so far as it shows clearly that all optimism based on calculations which do not take into consideration all the influences and aspects of costs which may occur have no realistic basis and must be revised.

He showed very well that there has been no chance up till now of doing this and creating a more economic picture for the future. I believed that all participants agreed on the omportance of Dr. Hill's results.
Other questions which should be discussed in more detail are the difficulties involved in making mixed calculations, and whether the U.S. cost calculations could be transferred and applied to the situation in the Federal Republic of Germany. (Assumptions, frame conditions etc. must be examined.)
Are there any further comments on the topics I have mentioned?

BAKER: I wonder whether we could spend some time discussing three topics which I thought would be of particular interest in summary. Firstly, the question: have we really imprived upon past performance and experience. We could discuss lower pressures, higher throughputs and better gasification methods. The development of new processes, e.g. the methanol and Mobil could also be discussed.

Secondly, do we really see more breakthroughs in the pipeline? Dr. Kühn was saying that there would be improvements in the chemistry of coal utilisation if a methanol chemistry could be devised, rather than discarding the oxygen only to have it reappear.
I would also like to see a question explored which Mr. Gaensslen mentioned this morning: is cost everything? We have been anxious and pessimistic about costs - is the concept of a "ceiling price" important?

GAENSSLEN: When we make comparisons of results it is important to have some standard of comparison which is the same. It became obvious that the figures we were presenting had no link up at times. This was partly owing to the fact that we were looking at German conditions, and other participants were examining U.S. or British conditions.
This is not the only difference, however; we are also applying different basic economic parameters. I wonder whether we should not have a standardised procedure of agreeing on interest rates

depreciation time etc. for future workshops. Thus figures presented would be truly comparable except, for example, in the case of low priced coal and certain special conditions. They would not fail to tie up because of different calculation parameters.

KNUDSEN: Your idea is excellent, but I would like to add that it requires some special co-ordination to carry it out. Some discussion must take place to reach an agreed standard; maybe we are not so far from this and have a vehicle to do so, namely the E.A.S.

BAKER: My only comment on that would be that we at E.A.S. recognise the problem you have outlined. We tried to look at standards which occured under the various conditions, e.g. lifetime of plants, time taken to build these up etc.
On the whole, we found more disagreement within, rather than between countries. We issued a report on this, the first part of which has been circulated within the Federal Republic of Germany through Dr. Holighaus. It describes the set of standards I used in presenting my figures this morning.

KNUDSEN: I am interested in the longer range trends of how economic comparisons could be made. We all agree that we should be consistent, but what will the trend of economic analysis be within the next 10 years? I think that it will take at least 10 years for some of the early coal plants to arrive.
Assuming industry is becoming more closely related and more plans are being made, what will be the trend of activities such as economic analysis? Mr. V. Diest and I were talking about the problems for lunar type works, where a large gasifier is connected with a large turbine. As load varies, the response characteristics of these large coupled machines change.
New ideas regarding economic analysis, areas needing improvement beyond consistency and engineering problems now being glossed over should be considered if the industry is to become a more realistic proposition.
As Exxon became more detailed in its engineering, I was not surprised to find out certain things which arose at a more detailed

HOLIGHAUS: If there are not further points for discussion in addition to those already mentioned, we should deal in more detail with the problem of making mixed calculations. We have very different spproaches for different products, e.g. electricity.

SCHULZE: These are different approaches to the same thing; one cannot make any substantial gain by altering just the method of calculation. It is useless to contemplate just certain aspects and contexts of influencing factors. One can retain with the most simple method of calculation, which I believe is the right approach.
Typical of the coal liquefaction process is the joint production of different co-products. These stem from the same process, and we know that it is impossible to distribute the cost to the single split products in a way which is rational. Economists have attempted to solve this problem by cost accounting, etc. The cost can be calculated for only one complex of equipment and then the whole cost on input must be compared with the output. This can be done in a simple way; surely there are some measures of distributing the cost over the split co-products? The cost could be distributed according to the value of the co-products, but this is not a rational method and affords no new insights.

HOLIGHAUS: Cannot we agree upon a standardised procedure of making results comparable?

SCHULZE: The Americans have made better progress in this respect" at the congress of the American Society, a symposim on coal liquefaction and coal chemistry was included. A draft paper was shown dealing with the fundamental methods of cost calculation. It was stated, for instance, that 10% depreciation and 3% maintenance costs must be taken into consideration. Different papers had to be based on cost elements fixed from methodical points of view.

This is the right approach, which should also be used in this country, where there is no standardisation in the cost estimation procedure at present. We should use the same terms, which would enable us to compare results of studies more effectively. Our calculations do not differ very much from those in the U.S., we usually also use the 10% depreciation rate - an agreement which was reached without standardisation.

GAENSSLEN: The problems of simultaneous production of several products is an old one, which cannot be solved in principle as a number of unknowns and only one equation are required. One equation can be solved, leabing all the others open. An arbitrary limit must be agreed upon. We can only decide how to set about this, i.e. define how we are going to distribute it. There is not objective in a mathematical way.

HOLIGHAUS: My views on this matter are the same.

KNUDSEN: I would suggest that this could be done; a simple distribution might be laid out for those groups which do calculations where they cannot go into process design trade-offs. In a large engineering organization, all this happens as a matter of engineering course and does not require any artificial means, e.g. in a large study design of a coal liquefaction plant which I was associated with, the basic choices for the U.S. economy were hydrocracking and catalytic cracking. Differences appeared for these two cases for the coal liquids refinery.

We have discussed a coal liquefaction evaluation model, nicknamed C.L.E.M.,which is a linear programme containing information about relative costs and price values of different fuels. We could design a sensible way of goint through the refinery and work with this model to determine the best means of optimising the materials, e.g. in the entire context of coal liquefaction, the question of buying power versus making one's own, selling the gas or using it for process heat or power generation, etc. These would depend on the relative values of the products and their proceeds.

This matter is not easy, but in a specific case, it is straightforward. It is difficult to make a general case comparison, but in a real case, where one is looking at a plant, the estimated market in 5 years time, and talking to real customers, one has a very definite idea about the value of the gas and whether it should be burned or sold, or whether the hydro-cracker should be driven harder, more naphtha versus less naphtha, etc.

HOLIGHAUS: We now want to compare on a more abstract basis; this is our problem, which was made clear in the paper by Dr. Rogers presented by Dr. Hill.

GAENSSLEN: There is a way of tackling the problems, but it is rather difficult and would involve analysing the system exergetically. Then one may succeed in assigning some costs to one product and some to another on a more rational basis. The concept of exergy has been of little practical use so far and has hot gained much popularity.

KNUDSEN: From an industrial point of view, whenever one has a new process, new ideas are developed and even patented. As soon as the idea to improve the gasification scheme came into existence, a change in equipment was generally required. Many times, preliminary engineering obviously took place. In the case of such ideas the devolatilisation of coal to obtain premium liquids before gasification, the value of the resultant additional liquid would not pay for the equipment.
Things were continually reducing to simple terms. In the case of a refinery, where saleable products are actually being made, one looks at trials and errors and it breaks down to a base case; even better products could be made from a chemical or fuel if just a little processing were added.
The question is whether the additional equipment will actually be worth the additional improved product. I do not believe one has to enter into thermo-dynamics, etc.; it all amounts to hard engineering and we must work some general cases through and set some guidelines. Also, more detailed cases are needed for the setting of guidelines in the U.S., Federal Republic of Germany,

and Great Britain, so that relative prices can be obtained. The market is dictated largely by our own needs and by the characteristics of petroleum. Coal does not necessarily come into the same category; this is owing to all the internal trade-offs in the refining of coal products. We must bring into operation the incremental effects of cost benefit to have more, or less gas, etc. (the linear model we developed proprietarily, which I referred to earlier).

HILL: I would like to emphasise what Dr. Knudsen said.

In industry, of course, one optimises to maximise profit or return on investment. If there are various options as to what one can produce, one naturally starts with what the market is going to pay for the products. Then one attempts to maximise the products which are going to bring the largest returns.
In the case of day-to-day engineering jobs, one is dealing with the real market (or one's anticipation of it) in order to maximise the process accordingly.
I would like to recite briefly some details concerning the question: how does one distribute the costs in a multiple product process? This is connected with what we were discussing earlier: the manner in which the U.S. has regulated the well-head price of natural gas. We all agree that the price is artifically low, because is was worked out on a limited cost basis. The Federal Power Commision has always been under the mandate of the courts to set prices which are equal to the cost of the product. One of the factors causing this distortion is the question as to which portion of the expenses goes towards oil, and which towards gas (when both come from the same well).

Attributing costs between oil and gas on a BTU basis, was not done by the Federal Power Commission until about 5 years ago for the first time. Prior to that, it was not done on a BTU basis. Even this is probably not weighted heavily enough in favour of the additional expense of natural gas, because it is generally considered a premium product. The distorted natural gas price arose, historically, from natural gas being a waste product. Initially, the cost basis assumed that gas was a waste product and all investment went into obtaining oil; therefore, the gas was free. Through the years, some of the costs of producing gas in a mixed well were beginning to be attributed to the actual cost of the gas. It is an intriguing area - with an embarrassing history - as to where the costs should be attributed in a multiple product system.

KRÖNIG: I think the matter can be seen in the following way: One can take the coal hydrogenation and make raw gasoline, middle and heavy oil distillate, and CI, C2, C3 and C4. The latter (especially C2, C3 and C4) have value as feedstock for making ethylene. CI has a value for making methanol. In the case of gasolene, the costs of hydro-refining to naphtha, which has a value, have to be deducted. Now one has middle and heavy oil; if one decides not to progress further, then these only have the value heavy fuel. If one does go further in order to produce motor gasolene from this, the cost of transformation is known and must be added to the fuel value to make another value.

HOLIGHAUS: Costs cannot be calculated in this way; one can only see whether prices obtainable on the market for the products cover the expenses for the plant used in the operation.

KRÖNIG: We have discussed the question of product evaluation.

HOLIGHAUS: But then one has to compare what value the products would have in order to cover all the costs of running the plant. From an economic point of view, it is correct for the value to be below the break-even point; however, the method cannot be applied in the case of all the coal conversion processes.

KLUSMANN: In such a case, the losses would be calculated.

HOLIGHAUS: We could compare, to take a simple example, Fischer-Tropsch and coal hydrogenation. There are different figures, and everyone maintains, that it is impossible to compare as in one case there is a very high value product in the mixture, and in the other case a low value product. However, our problem is that we would only like a basis for comparison.

SCHRAMM: If one is working with fixed prices for all outcoming and incoming materials, one obtains, at least, a comparison of the efficiency of the differnent processes which have been taken into account. This is the only thing we have wanted up till now; later, the price can be corrected by market prices. However, we cannto fix prices for every product and make all the processes comparable in order to see easily which is the most advantageous.

KNUDSEN: I agree with this straightforward approach. I would like to describe briefly the procedure for the mor complex approach which I proposed earlier, and to obtain a reaction from the group.

A particular temperature and pressure of coal liquefaction was explored in the laboratory and the sensitivities of the basic data around these temperatures and pressures with certain catalysts etc. were understood as well as possible. So a yield structure could be defined at a given temperature and pressure for given liquefaction conditions: space velocity, temperature and pressure, and catalyst system. This was based on what could be distillated in a pilot unit, and what could actually be more practically separated rather than theoretically separated. I am not referring to separation by extraction, but separation in pilot equipment. With these conditions and yields, one then has an estimate of the investment and operating costs of a barrel of oil with a given number of BTUs which can then be refined.

We then developed a model sumulating the linear programme of a petroleum refinery, where every day the oil which can be bought is taken (50 refineries in the U.S. may have as many different crude oils to choose from) and related to the market conditions of that particular day. All the input and output information is fed into the linear programme, which states whether or not more should be run through hydro-cracking, etc. and can change the whole mix.

The same was done with a very straight forward coal liquefaction refining model, based on a hypothetical coal refinery, so as to take the characteristics of the oil produced (we knew these, as we had the basic data relating to that temperature and pressure) with mass spectrometry, etc.

We tried to characterise the strange large compounds in the heavier materials and how they might react to either hydro-cracking or catalytic cracking, and to build some simple simulations of these things into this linear programme. Then we told it which certain characteristics were coming into the refinery, and what the perceived relative market prices were. It then distributed the amount of things going into the gas through the catalytic cracker to come up with a spread that gave the largest difference between cost in the refinery and the value of the products in the refinery; in other words, the largest margin given the constraints of a refinery fed this particular material.

It redesigned a refinery, in this case a different one from the petroleum refinery, where the question was what could be done with the existing refinery. This task had less constraints, and involved redesigning a plant to optimise the conditions. What emerged was nor more perfect than the assumptions fed in, but it provided the ideal forecasting approach.

The procedures is much more complicated, particularly with regard to co-ordinating between two groups according to new bilateral agreements (between the U.S. and Germany). We are interested in co-operating and communicating; I wonder whether this would be possible? I would like to know what the group feels about this matter.

BAKER: I would like to add to Prof. Schulze's, Dr. Krönig's and Dr. Knudsen's earlier comments. I think I agree with Prof. Schulze in that if one tries to allocate the co-products on a cost basis, one is really trying to produce arguments, which only turn out to be meaningless. I would certainly agree that there is no cost accounting way; I would be extremely suspicious of such an approach, which would just replace one set of arbitrary conventions by another. I think that ultimately one would probably be left (in any situation) looking at what the market place does. One can be forced into presenting the value factors (as in Dr. Roger's paper) or one can add an extra dimension, as I did this morning. However, this is not progressing much farther, and still leaves the question open.

If one insists upon having a split in costs, then perhaps Dr. Krönig's idea would help: inside one brad process, one can imagine variants as to how far one could go (whether one would upgrade middle distillates and heavy fuel oils, reform natural gas produced and how hydrogen could be produced in the gasification process). One can obtain some kind of trade-off between different products and the process. If one foregoes so much SNG passing out, one can obtain so much extra liquid. I think your linear programming approach would do that, but I think you have got to try perhaps about 10 schemes around the margins of a particular processing scheme, before actually obtaining the data for that linear programme and optimising the difference between the revenues and the cost.

The 10 schemes would include, so much for coal goint through a particular gasifier into a particular synthesis, so much for coal going into a hydrogenation scheme, various adjustments about what should be done to the bottom end, and how the process heat would actually be generated. There are about 10 different variants inside some broad margin of investment and process. These are internal trade-offs between the products we can obtain.

KNUDSEN: I was actually suggesting that with regard to the standard edition of the process you were discussing, we might wish to agree upon a description or characteristic of our liquid products. Firstly, to say something about them besides the BTU content - namely regarding boiling range. We have progressed a long way if we just start discussing the shape of the boiling curve. One a boiling curve is being considered, one can start thinking about refining a given boiling range or feed, and coming to a standard agreement between our several groups. Then we could determine very quickly whether a tendency towards cracking exists. The procedure is not particularly complicated.

KLUSMANN: After hearing all these comments, I recommend that we should follow the methods of the refinery industry for the light fractions. No great difficulties should arise, work could be undertaken on an international basis.
We were in agreement about the heavy fractions. Their value must be discussed, and it should be elaborated whether more hydrogen should be added or whether the heavy fractions should be fed to the power stations. International prices exist and it is known what the utility industry is paying for the heavy fractions.
A standard set of figures to calculate what the utility industry can pay in this area was recently worked out jointly by Mr. Baker and ourselbes. Therefore I would propose a split betweeen products goint to the refineries and to the utilities.

KNUDSEN: I agree, and would like to add that one could then complete this. Instead of bing sold to the utilities, the material could be cracked and put into the refining case. We should be able to agree on some fairly straight forward costs of taking a heavy material with minimum characterisation and suggesting what the cost of transferring it or breaking it down into lighter material would be. This would bring more money into the refinery. A comparison between selling to the utility, and this procedure can be made.

KRÖNIG: The saleable product should be examined, as should the costs involved in transforming the intermediate to the end product. These costs shoudl then be deducted. In this way, one can find out exactly the value of the intermediate product.

KNUDSEN: If we treat the conversion of heavy to light material as two separate parts and know the cost of this, we can look at the entire possibilities.

KRÖNIG: We would also know the value of the intermediate product.

SCHULZE: The simplification is only valid if there are two parts (the key product being light fractions, fuel oil or electricity). What happens, though, when we produce raw materials for the chemical industry? There is a list of different products; there is no main product with subsidiary products. For example, in the case of the production of olefins, there are many different products.

KNUDSEN: But a refinery does that very well.

SCHULZE: I was thinking of a refinery aiming at naphtha. Revenues for fuel oils etc. can be deducted from the cost block. In the case of producing chemical raw materials by the Fischer-Tropsch synthesis there are maybe 10 valuable fractions: oxygenated products, alcohols, olefins, raw materials for plasticisiers, etc. All co-products must be valued according to the market value, put together and counted together. The revenue and cost sides must be compared. The same considerations must be made with every alternative process developed.

KNUDSEN: This does fit in with the refinery on the lighter side. I was not a member of the group which did this particular trade-off, but I did work at the Exon refinery in Bay Town which is a very sophisticated refinery consisting of all kinds of products: benzylene, xyolene and many other petro-chemical intermediate products. These were made in addition to basic fuels. Their main taks was constantly trying to make their margin as high as possible.
Regarding the lighter ends, including chemicals: initially, compexity is not possible, but as one gains experience, one can pick up some of the more important things missed previously, and build up. This is not easy, yet there are those who belong to the petroleum industry and could teach us.

HOLIGHAUS: But this is a totally different situation, because normally the costs are covered, and we are only covered by about 50%. The question is whether one process is covered by 40% or by 70%.

KNUDSEN: What happened in this calculation was that real market values were taken and put into this linear programme. In this case, the programme calculated a negative DCF; the situation with the smallest one was the "winner".

HOLIGHAUS: That would be a basis for comparison. A different method is where some examples refer to a leading material and some by-products, which have a market price. If certain prices for the by-products were obtained, then the prices of the leading products could be determined.
The other method deals with the market prices for all the products, and looks at how far costs are not covered. U.K. Wesseling, I believe, had a different approach , taking into account that the market mechanism may make some constraints. If 50% of the E.E.C. market capacity is exceeded, then there would be not fixed prices.

We should now turn to a different theme, and take advantage of the fact that two representatives from the former development of the two different processes are present at this workshop: Dr. Krönig is concerned with the hydrogenation process, and Dr. Schnur with Fischer-Tropsch. It will be possible to discuss the question (raised earlier by Mr. Baker) as to whether any real improvement upon further developments in both processes haven taken place.

BAKER: I wonder whether Dr. Krönig and Dr. Schnur could provide us with some views about lower pressures, better gasification processes and lighter throughputs, and say whether these are real improvements.

HYDROGENATION - KRÖNIG

HOLIGHAUS: I would like participants to ask questions or make comments regarding Dr. Krönig's observations. The process described works; there is also a significant improvement upon former technology so far as the steps mentioned are concerned. There will be no improvements upon the reactor itself; from the economic point of view, there is an improvemtn but no breakthrough (as Dr. Hill noted).

KRÖNIG: There is a breakthrough; we would not be able to build a large plant of the old scheme.

HOLIGHAUS: Now I should like to ask Dr. Schnur to comment on the Fischer-Tropsch synthesis, which is the alternative to hydrogenation.

DIRECT COAL HYDROGENATION - KRÖNIG

The I.G.-process of making gasoline from coal by direct coal hydrogenation consisted of the coal phase and the gas phase. I will leave out the latter and discuss only the coal phase.

The German Government had demanded, that as much gasoline as possible should be made from one ton of coal. Therefore recycling of heavy materials, especially asphalts, was used in order to botain the highest possible yield.

The quantity of coal available in Germany was restricted on accound of the war and also the pre-war situation; therefore we had to do everything we could in order to recycle. This recycling - called sludge treatment - was done with the sump product from the hot separator, containing heavy oil, asphalts, unconverted coal, ash and catalysts. This sludge was centrifuged. The larger parts of unconverted coal, ash and catalysts went into the residue, smaller parts of these into the filtrate. This filtrate returned as slurrying oil for the coal. The residues had about 38-40% of solids and was thermally cracked (coked) in a so-called "ball-furnace", heated from outside. There was obtained distillate and coke, containing unconverted coal, the ash, the catalysts and newly formed coke. This coking was not a good process. There was a limit; is there was too much asphalt, the coking process did not work. Also the remaining coke was high in sulphur content and could not be disposed of anywhere; it had to be burned in the power station and this proved to be difficult. The operators did not want this coke as it contained much iron from the catalyst which coated the tubes with molten Fe_3O_4.

The total process worked, and the highest possible yield was obtained. Howecer, it has some drawbacks, especially for very large plants. So it was decided, not to work on highest possible yields, but to produce only such a quantity of oil, that a process suitable for very large plants can be used. Thus asphalt-containing oil is not recycled as slurrying oil, but only practically asphalt-free distillate oil. Using this proceeding there are better conditions for hydrogenation because the recycled asphalt and unconverted coal are more difficult to hydrogenate than the original coal. This improvement enabled the coal hydrogenation at 300 bar and lower compared with 700 bar in the previous process, and furthermore higher coal throughputs.

In doing so the sludge from the hot separator has to be disposed of. The hot sludge is concentrated by flashing into distillate (as slurrying oil) and pumpable topped sludge to be gasified at about 1 300^{0} C and 40 to 80 bars to synthesis gas. The obtained sulphur-free molten residue is easily disposed of. The synthesis gas is converted to hydrogen, satisfying about 75% of the hydrogen need for the coal phase. Naturally the oil yield in the coal phase is lower: about 53% compared with 61% (calculated as C_{5+}-distillate from waf-coal). But this sacrifice allows to use a process suitable for very large plants. (Details on the new process - for which a pilot plant for 200 mt coal/d is being built in the Federal Republic of Germany - are published in "Forschung aktuell. Kohleverflüssigung. Umschau-Verlag, Frankfurt 1978, page 105-117.)

FISCHER-TROPSCH-SYNTHESIS: Dr. Schnur

The original aim of the F.T.-synthesis was to supply motor fuels. Later, the production of chmical feedstocks - boiling point range light petrol to hard wax - also gained in improtance. Since 1973, catalyst development work and process studies has been conducted with the object of developing a process for preferential production of short chained defins - if possible in accordance with market demands. Significant advances have already been made and I have the impression that we are reaching a stage approaching technical feasibility.

The main problem confronting future developments is to lower the production costs for the F.T.-products, these being dominated by capital and coal costs. The latter are determined by the syngas costs.

Dr. Knudsen showed yesterday the results of studies indicate that the investment costs are shared equally between syngas production, the synthesis and energy generation.

If the investments for energy generation are distributed amongst the production plants according to energy requirements, then, 2/3 would be allotted to the syngas manufacture (purification and conversion) and 1/3 to the synthesis and product recovery.

As far as coal is concerned, about 90% of the energy is required for syngas production and only around 10% for the synthesis and product recovery. Thus, when coal costs ' DM/Gcal then 75% of cost of the F.T.-products stem from syngas costs, consequently, when coal is more expensive this value is correspondingly greater.

Therefore, the availability of cheap syngas is one of the most important starting points for reducing the production costs of the F.T.-products. There are a number of promising projects with this end in view-particularly in the USA and West-Germany.

In future F.T.-production plants, coal gasification units will be required possessing essentially greater capacities than has been the case so far. In my opinion a gasifier should supply several hundred thousand cubic meters of gas. The latest developments involving the gasification of coal dust with oxygen (at raized pressures) suggest that such capacities are feasible. They are largely free of constraints such as type of coal, baking tendency and ash content and do not require any mixing unit to be present in the gasifier. The specific investment costs should therefore be lower.

The thermal efficiency of the process - which became more significant with increasing coal costs - can only be basically improved via the choice of process for syngas production and the utilization of process heat for energy generation.

The calorific value of the F.T.-products, including the methane formed in the syngas, amounts to 78-79% of the calorific value of the unconverted syngas. This value cannot be altered as the thermal efficiency of the F.T.-synthesis itself - not including gas production - is a little higher when excess energy is available from the heat of reaction after covering energy requirements.

In future synthesis plants, gas generators - as proposed in the Parssons Study - should be treated like power stations. The sensible heat from the raw gas should be used to supply super heated high pressure steam for the process heat required for the conversion and synthesis. In this way, the energy requirement of the whole plant can be completely or almost totally covered. If, for example, the calorific value of raw gas from a gasification process is around 70% of the calorific value of the coal feed, then the thermal efficiency of the total process largely depends on the extent to which the remaining 30% - present in the raw gas as sensible heat - can be utilized.

The thermal efficiency of 66% relative to the lower calorific value, while being theoretically possible, would be difficult to achieve. Moreover, this value relates to Parssons Study in which 56% of the total production (including excess energy and sulphur as by-product) is SNG.

So far we anticipate thermal efficiencies of 46-48% - assuming no SNG is to be produced and all resulting methane is to be cracked to syngas leading to sole production of motor fuels. In the case of SNG production with the Lurgi pressure gasification, the values would be around 56-57%. The question is, of course, whether the CO-Production of SNG is desiable.

In my view, the main problem is not so much the further development of the synthesis but the production of cheap syngas and a realization in the optimal heat economy. I would be pleased to hear the views of our american colleagues regarding the possibilities of producing cheaper gas and the potentially significant future process.

FISCHER-TROPSCH - SCHNUR

HOLIGHAUS: I would like to thank you for your comments and in particular for your description of the past years' activities. I would like to ask whether any study has already been carried out or is under way which deals with the combination, for example, of the Texaco gasifier and the Fischer-Tropsch synthesis, and making the best use of all the heat.

SCHNUR: This is being considered, but problems exist. It is uncertain at the moment as to how far exactly the work has progressed.

HOLIGHAUS: We should consider that in the case of Texaco, for example, the gases leave the gasifier at a temperature of 1400° C-1 500° C. I agree with you in that this is a power station. Steam can be produced without the aid of an additional power station; maybe a surplus of energy is even produced which could be used within the process. As far as I know, no real study on this combination is yet under way.

SCHNUR: The operation conditions and any necessary changes must be studied.

GAENSSLEN: I would like to raise a point concerning exergetic analysis. Dr. Schnur discussed the improvement of the overall efficiency by making good use of waste heat which would normally emerge having a very low value and could not be used. This is a typical example of looking at a process from an exergy point of view. If such an analysis were done, when and where improvements were possible could be pinpointed very quickly. This could not be done by examining merely the place of heat loss; one should also consider the conditions under which it is lost. This leads actually to an exergy analysis. By using this process, the kind of efforts to be made in research can be determined quickly and easily; this is very important.

HOLIGHAUS: I think that the only study in this field is by Parssons (even taking into account all the new developments); but the by-gas from the gasifier was taken; I believe Texaco or Shell Koppers would be more suitable than by-gas. Such a combination would be very attractive. What is the American attitude towards this?

KNUDSEN: We would like cheaper gasification, and certainly agree that this is the main cost for indirect liquefaction. This view was not expressed earlier, but mainly in the past six months by those funding the programmes and directors of the gasification group.
Some of the most optimistic studies indicate improvements within a wide range of assumptions, economic bases, etc. Most of the improvements are 10%-25% and indicate potential. On a realistic level, if 10% improvements can be made, one should be pleased.
At SASAL, great strides are continually being made, as they are now at the so-called "mark 5" stage of gasifier development and have learned to raise the operating time of the single gasifier to 90%, eliminated gas losses and made all kinds of system engineering improvements.
The Dry Ash Lurgi is its own competitor as it keeps changing.
The British modification, the Sliding Lurgi, is perhaps considered to be the most likely new gasifier, which we are not thinking about yet. Maybe there is not enough knowledge about Shell Koppers, owing to the proprietory nature of information regarding this.
The sliding Lurgi has the potential for making the percentage improvement.

HOLIGHAUS: In the context of producing sythesis gas: this is only for simple considerations. Reactors like Texaco should be far less expensive. We have pilot plants of the same size. Looking at the investment costs for the total plant, including gas clean up, there is a significant difference.

KNUDSEN: This is a matter of opinion and judgement. The Fortuna plant in South Africa is a new amonia plant built about five years ago. After a long decison-making between a Dry Lurgi and Koppers, a was chosen.
Difficulties were experienced; a coal just like a Zambian coal was used, which had been performing very well on a new Koppers unit. This would have looked similar, except in minor details. On paper, one is slightly influenced by the fact that one does not want methane; in practice, however, this is different. At Texaco, for example, much water is used to slurry the feed.

This creates the use of much oxygen; the amount of oxygen fed for a certain amount of coal is high, and oxygen is expensive. There are so many different things to trade off; ideally, CO and hydrogen of the right mixture and no methane are needed. I am not convinced that there is a project sufficiently developed which makes just CO and hydrogen without methane.

GAENSSLEN: The Lurgi gasifier is actually an excellent system if one wants to make a high or medium BTU gas, but as soon as it comes to chemical production, methane and some other by-products, e.g. tar, can become something of a handicap.

HOLIGHAUS: To return to Texaco. I think you are right in so far as you have to evaporate the water with a very high value of oxygen and energy. But no more water is needed than in the case of gasification. In one case, it is not mixed and low quality energy can be used; however, in the case of Texaco, the highest quality energy must be used. This is the only difference.

KNUDSEN: I have never seen a case which did not have a high share of Texaco with a relatively high oxygen and coal ratio.

HOLIGHAUS: Are the current figures for oxygen consumption relating to the operating plant proprietary?

SCHNUR: As far as I'm aware, these figures are not available. However, in any case, the main problem is to lower costs and to raise the thermal efficiency via gas production in gasification plants which operate like power stations.

There are not basic cost differences when the three different processes - i.e. the liquid-phase, the entrained-bed and the fixed-bed synthesis - are compared.

Another question is: What type of products are to be expected from the ghree processes? The entrained - bed sythesis can only produce relatively low boiling products as the catalysts is recycled necessitating the maintainance of certain conditions. Very little diesel-oil is produced and no paraffin. On the other hand, premium motor fuel can be more readily produced by this method due to the aromatic content in gasoline fraction from the entrained-bed synthesis. In the liquid-phase and fixed-bed synthesis, the primary product distribution can be adjusted in favour of either predominantly lower boiling or higher boiling products. This is achieved by varying reaction conditions.

In my view, it should also be possible to increase the specific reactor output in the liquid phase synthesis on applying a higher synthesis pressure. In the fixed-bed synthesis, the specific reactor output can probably be raised on increasing the reaction temperature to that of the liqzid-phase synthesis (around 270°C). This is a measure which would be necessary in any case when producing short chained olefins. The specific investments can be partially reduced in this way. In both processes, the heat of reaction is removed via production of saturated steam. If this steam can be superheated via utilization of the sensible heat of the raw gas from the gasification, then the thermal efficiency of the total process will increase correspondingly.

HOLIGHAUS: These points do not constitute a really significant change.

SCHNUR: No.

HOLIGHAUS: It is important to examine the economics of the overall process.

SCHNUR: As far as chmicals are concerned, there is a greater prospect of success with the fluidized-bed or fixed-bed liquefaction processes than with the entrained bed process.

HOLIGHAUS: We should consider the energy supply side more; chemical and raw materials form only a small part of this. We should also examine the yield of usable liquids or gases. In this respect, I think that our only hope is that there will be improvements in the gasification and heating-up systems.

SCHNUR: Around 95% of the primary products (C_{3+}) are obtained as final products in product processing plants. In this respect, there is no great difference between the three processes.

SCHULZE: I would like to put a question to our American colleagues: so much research work has been done on liquefaction processes, but until now, everything has been confined to hydrogenation and gasification. No experimental work has been done on the Fischer-Tropsch synthesis in the U.S., I believe? The last was performed at Brownsville, which was closed down in 1955. However, we are quite active in this field in the Federal Republik of Germany; there are various chemical concern and university institutes working on Fischer-Tropsch.

HOLIGHAUS: As Dr. Knudsen mentioned, this situation changed half a year ago.

KNUDSEN: Work is being carried out at Pitsburg Energy Research Centre.

SCHULZE: Is there any experimental pilot plant?

KNUDSEN: They have been doing some small scale catalyst work. After the war, they did an extremely comprehensive study of all the patents and known information about U.S., German and other Fischer-Tropsch catalysts. A small effort has been continued over the past 30 years. It was a matter of a few hundred thousand dollars most of the time, but this figure may now have increased to about one million.

SCHULZE: How does this compare with the larger pilot plants?

KNUDSEN: The effect is nil in comparison.

HOLIGHAUS: The relationship is not quite balanced; the question also applies to Renton plug: is it right to push indirect synthesis?

BAKER: The results from the Pitsburgh work are in fact included in the Parsons study. I wondered whether there may be a scheme, if not to base it on BiGas, to actually build some small plant based on that work.

KNUDSEN: I doubt whether that has been considered.

HOLIGHAUS: If there are no further questions, I think we should discuss the requirement of having standardised parameters for making cost estimates. Prof. .Schulze already mentioned that some parameters had been prepared in connection with a conference.

SCHULZE: In the U.S. it is quite usual to have standardised procedures and during conference it is emphasised that these should be used so that all papers presented have a common basis.

HOLIGHAUS: This should be done at the next workshop; I should like to promote a habit of doing this.

KNUDSEN: We have made an effort to develop these standardised procedures for each of the different technologies: gasification liquefaction, etc. These would differ somewhat: unique standardisations would have to be made for each one. Those helping us to do this include ESCOE and TRW Energy Systems Group (with whom we have a contract). We will publish some of our findings next month. Perhaps all present could react to these, and something could emerge; or we could use the excellent work done by Mr. Baker's group as a basis.

BAKER: We have made a consensus based partly on the U.S. and German experience, and some work done in the U.K. and the Netherlands. However, this is nor more than a consensus. Differences are greater within than between countries.

KNUDSEN: We are resolving our differences in the U.S.; at least, we are going to suggest what people should do.

BAKER: The averages which every country sets may be different.

HOLIGHAUS: These are good suggestions and we can take care that papers presented at future meetings use the same procedures, figures, parameters, etc. so that the results are more comparable than they have been today.

SCHULZE: There are two considerable differences in the profitability estimates between the German and U.S. calculations. We have seen during the presentation of different cost tables that the U.S. engineers very often use a certain financing scheme, they distinguish between capital funds provided as equity and long-term debt. In the Federal Republic of Germany, we mostly neglect this completely. We do not take into consideration the method of financing, because we want to show the profitability and attractiveness of a process according to the technical features and not financial influences. (These are kept out of the results.)

Income tax deduction is correlated with this; we normally account return on investment figures and discounted cash flow figures without considering income tax deduction. We should deduct 50% but this is not normally done. Only a certain interest on the capital investment included and the income tax normally is not deducted.

BAKER: I would like to confirm this; I think it is common European practice to leave out income tax. It is also common in the U.K.

KNUDSEN: It is a typical practice to understate the cost by the additional cost of tax. We do not really try to compare directly with a market price.

SCHULZE: It is more realistic to deduct income taxes. We do not wish to make the figures dealing with the cost of coal conversion processes appear even less attractive.

HILL: In the U.S., the inclusion of the tax is very necessary because this is one of the techniques of encouraging the development of new technologies. (This is one of the major considerations being dealt with by Congress.) There would be certain tax incentives; in order to make comparisons as to what would be the impact of these, it is obviously necessary to include them in the analysis. This is also necessary for policy reasons.

HOLIGHAUS: Could we now turn to the next point; I understand Dr. Knudsen would like to consider what is to be done in about 10 years time im pioneer plants in operation for coal liquefaction, for example, and if there is no longer a need for cost estimates, because costs being real are no subject for speculation. What kinds of tasks would groups like ourselves have to undertake?

KNUDSEN: I hope there will be a few more demonstration plants. I think the answers regarding costs would be far from clear when a demonstration plant is built. I agree with those who think that it is difficult to pin down the costs of a process until the first commercial plant has run for a number of years; it would be easier to go to South Africa with the right team and determine in five years what the real cost of SASAL 2 would be. But I think that even to obtain a picture of SASAL 1 would at present require many assumptions, because it does not resemble its original form. The same applies to SASAL 2, as it takes a considerable time to make a plant operate at "full steam", which is the only stage at which one understands the full cost.
In the case of pioneer plants, I believe that there will still be many challenges, and even those processes which are at that point will not be the subject of much argument about the real costs.

I suggest that we might take a different trend, like the questions of control and reliability. One of the things which seems to me to be most overlooked (and perhaps one of the biggest sources of cost escalation in a plant) is the casual assumption that the plant will operate at 90% of the time at its design rate and without any particular analysis of that equipment as to its expected maintainance, without any systems study as to how the maintainance interacts and is carried out, how the forced outage interacts with the expected plant outage to give a total outage and therefore some expected rate for different plants with varying complexity.

BAKER: It seems to me that we must talk about the problem. We cannot assume a 90% load factor of plant availability. In Dr. Hill's case yesterday, I think there were xs in columns on relative complexity of plants. One ought to be identifying processes according to problems of this type as well. We have done a little in our surveys of this status. There is certainly a case for differentiating between the difficulties to be expected in the different processes, and trying to assign (perhaps whitowiles by quantative method) different plant availabilities (where there is clearly going to be some marked difference), and argue about the matter.

KNUDSEN: During the past two days, we have touched upon the ideas of contingencies, and we are just now touching upon an idea which Dr. Hill talked about yesterday. The final result is how much the plant runs, because of the disadvantage of a highly complex plant, which is difficult to maintain.

The idea of contingency never arouses much enthusiasm because of its difficult and abstract nature. I suggest that the whole idea of process economics arouses little enthusiasm as the results are often presented without showing the projects, real technical problems alongside which still need to be solved, how the difficulties compare with another process estimate, etc.

If we were to look at parallel difficulties in technology, we would move into assigning contingencies and move into questions of maintainability and reliability in plant operation. I feel that, if we are not careful, it will be said at future meetings that we have all used common standards and have many estimates, but still have many vastly different undefined uncertainties and technical difficulties etc.

GAENSSLEN: For this, we would need much more detailed technical information than is usual. Speaking for Lurgi processes: we are aware of the advantages and disadvantages. Unfortunately, our competitors do not provide us with their data. Therefore, as an engineering company, we are not in the privileged position of making comparisons between other processes. Such a task could only be undertaken by someone in a neutral position, who would not disclose the information.

HOLIGHAUS: Then I think that a sensitivity analysis has to be made in this respect. When the information is obtained, its availability can be calculated.

GAENSSLEN: But take, for example, the case of Koppers Totzek or Texaco and Lurgi gasification: we are competitors in a number of fields of gasification. Perhaps only people in your position can collect all the information and evaluate it in a neutral way, because you would not disclose it. However, an engineering company, at least in the Federal Republic of Germany, is not in such a privileged position.

HOLIGHAUS: I think that we should bear your good suggestions in mind; the aspects you mentioned should be emphasised more in the future. Calculations and cost estimates have already been made for commercial plants, but I think you intend to stress this field.

KNUDSEN: I agree with the point made by others that the economics should contrast the technical difficulties, while at the same time trying to represent the market need and balance these factors. Perhaps we should stay with an equity situation in some comparisons. Then the issue would not be confused with technical comparisons we are trying to make.

We have a considerable weakness in that we do not discuss reliability and plant operation. We have some beautiful examples of pilot plants etc., which we have built. If a reliable engineer were sent there, he would not be able to imagine why people with his expertise were not involved with the design work. I do not mean that it is impossible to design a power plant which works, but there are many cases where reliability, contingency, and layout could have been closer to the mark.

We need to work towards laying out the technical problems and complexities of an estimate somehow alongside all these capital operating cost breakdowns, so that comparisons can be made.

GAENSSLEN: In order to work along the lines you were describing, I suggest that we could look at things in a similar way, but in a different field. We have a very complicated system in all these coal liquefaction plants; at least 30 independant and interdependent units would have to work simultaneously. One can use very large units, with the inherent danger of losing much production, or a multitude of smaller units. In the latter case, if something failed, it would not be such a large part of the whole complex system. This would be an optimization of another kind: of reliability and size. Taking, for example, the Mark 5: more is lost if this fails than with Mark 3. In my opinion, this would be one point against the work.

KNUDSEN: That is a good question - we could take a specific problem. The trend of some engineers to say that they need 2, 3, 15 or 40 big units exists. Which would be the correct way of looking at this?

GAENSSLEN: Then one would have to offset higher investment against higher reliability in one case. In the other case, there is a lower investment, but there may be a higher unreliability factor. This would be an interesting problem to study in the near future.

HOLIGHAUS: I think that this is done in nuclear gasification; whether one big gasifier or a number of smaller ones should be used is considered.

GAENSSLEN: It is a question of redundancy.

HOLIGHAUS: This task should be tackled in the future.
We should now turn to the last point in the discussion, which Mr. Baker raised again; is cost everything? Are cost estimation and costs the only scale for our judgements?

BAKER: I was following up the remark made by Mr. Gaensslen this morning that we should in fact consider coal liquefaction as a strategic, rather than economic option. This is essentially why the processes are being developed.
We may say that effectively a ceiling on oil prices is provided.
I think there is an argument about the future relationship between oil and coal prices through a combination of fuel markets; what would this do for our liquid products?

Perhaps my earlier unfavourable prediction about the relative size of liquefaction costs in relation even to the newly projected oil prices may be reduced by considerations of this kind, as well as considerations about improvements, which Dr. Knudsen mentioned earlier. It is rather an unquantifiable subject, but it should certainly occupy some of our attention.

HILL: I agree; what you have said is one of the reasons for the type of analysis I presented this morning. In the U.S., for example, a complete agreement exists that we need to move to coal liquefaction and gasification industry as displacements for some of our imported oil.
However, a belief exists that it is a matter of waiting for the price of raw oul to rise high enough so that the industry could see the profit to be made and then move in. We need to recognise that this will not happen on a simple free aconomic basis, because, among other things, the price of coal continues to go up as the value of oil goes up. In the U.S., the government must put aside the simple assumptions and recognises that it has to make a set of deliberate decisions to "buy out" the economic differences. U.S. consumers or taxpayers will somehow have to "buy out" that difference if we are to achieve the public and national benefits of reducing oil imports.
The point here is that recognition has to be made, and certain action has to be taken before this can take place.

The possible actions are various: the simplest one is a subidy by the Federal Government - dollars per barrel for synthetic oil as a subsidy. Then there are all types of tax credits; government ownership of plants etc.; The recognition must be made that simple economics will not bring synthetic oil into the market place.

GAENSSLEN: The iedea of "buying out" something is not unusual; for esample, this is done in the cases of unemployment and defence. We must look at our problems in the same way.
In South Africa, when we discussed the viability of building SASAL 2, it was said that 3 or 4 warships could be built for the same sum. However, the money would be better invested in the plant, as warships cannot supply oil. This kind of matter should be recognised in the context of the national policy of a country.
It must be offset against the possibility of a war; if there were suddenly an embargo, there would be two options: the economy could be allowed to go to ruin, or the countries refusing to supply oil should be occupied. The optionf of "buying out" would perhaps be to build suitable plants. The problem, in my opinion, must be seen in this context.

BAKER: The argument against your last point is one of timing, it is one thing to say we will demonstrate the technology and say that after a 5-10 year period we will in fact produce a reasonable amount of liquids and substitute oil. However, this would not help in an embargo situation, where one has to be prepared almost overnight.

GAENSSLEN: Such plants must exist, in order to make an embargo useless. It is too late if one starts taking steps after an embargo has begun.

CIRKEL: I would like to add to what has been said by Dr. Hill, Mr. Gaensslen, and Mr. Baker. During the past two days, we have only talket about efficienca, costs, prices and the market for the products of our technologies. However, I think that it is the task of the chemical industry, the engineering supply industry and the engineering companies to deal with these questions.
The questions which governments have to deal with go further; their normal tasks include providing the population against things which may happen in the future. Therefore, I believe that it is

necessary for the governments to spend money on the development of the new technologies in coal liquefaction and gasification, as something may happen in the future. We are unsure as to the timing and nature of such an event - but it may be that the costs for imported energy rise so steeply that the damage to our whole national economy would be too great; therefore, the government must do something.

The situation would resemble that of an insurance tax; all people could pay taxes as an insurance for the future. I think that organisation of this is the task of the government.

HOLIGHAUS: This is a good remark, and I gould like to ask whether there are further comments. To summarise: some methods and examples of cost estimation have been presented during this workshop. There were only small differences in the results, in so far as these all showed today's prices for those energy sources are half of those for substitutes. Then we looked at the range of the figures.

The more strategic point of view is to look to the future - the task for governments is to ensure that no crisis will occur in the future. This is important in connection with the continuation of developments and programmes. Although we cannot see this at the moment, we will come into the market on a competitive basis.

I would like to thank you all very much again; in particular, Mr. Bertram, who organised this meeting. I wish our American and British colleagues a pleasant stay here and a good return journey; I also wish the German participants a safe return.

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