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APPENDIX 1. COAL MINING

It was not intended in this study to carry out a detailed analysis of coal mining operations but rather to use the results of such studies by other authors. Coal mining by strip and underground methods will be considered separately. One factor that the energy analysis does not take into account is the relative recovery obtainable by the two methods - whereas surface mining of coal will recover of the order of 85% of the resource in place, underground methods may only recover 50% of a deposit(1).

1.1. Strip mining of coal.

Long(1) gives the following breakdown of the energy requirements to recover coal by surface methods:

Process	Energy requirement (MJ(th)/tonne)
Stripping overburden and removal*	190
Replacement of overburden	190
Seeding, fertilizing for land reclamation	?
Loading coal	9
Transportation of coal	46
	435 MJ(th)/tonne

For comparison a study produced by Hittman Associates(3) gives a figure for the weighted average direct energy requirement of coal from surface mines of 222 MJ(th)/tonne. However this latter figure does not seem to include either the energy required to replace the overburden at the mine at the end of its lifetime prior to revegetating or indirect energy requirements due to plant and equipment. If these are accounted for, the two estimates are in good agreement.

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*The average overburden ratio for United States coal mines has been given as 15.1 m^3/tonne of coal (= 26 tonnes overburden/tonne of coal).(2)

1.2. Underground mining of coal.

Long(1) gives the following estimates of the energy expended in underground operations for various methods of coal mining in the United States (in quite good agreement with figures quoted in the study by Hittman Associates(3)).

	Energy expended underground (MJ(th)/tonne)
Long wall mining + transport of coal to the surface	80
Short wall mining + transport of coal to the surface	83
Continuous mining + transport of coal to the surface	85
Conventional mining + transport of coal to the surface	83

When the energy expended on the surface is included, Long(1) gives the average energy requirement for U.S. underground mining of coal as 190 MJ(th)/tonne.

Chapman(4) has examined the 'efficiencies' of the UK energy industries using the Report on the Census of Production for 1968. His analysis relates to "...establishments of the National Coal Board and non-nationalised undertakings in Great Britain engaged in the extraction of coal from deep mines and quarries and in such ancillary activities of cleaning, washing, grading etc. normally carried out at mines".(5) The data also refers to National Coal Board establishments employing 25 or more persons. From Chapman's study one can estimate the net energy requirement (NER) of deep-mined coal in UK in 1968 as 1024 MJ(th)/tonne.

There are probably a number of reasons for the large differences between the results of Chapman and Long. Long's figure is derived from analysis of mines in USA where coal seams are thicker and straighter than in the UK, the source of Chapman's data. Secondly Chapman's study is based on UK energy statistics and probably includes many ancillary aspects of the coal industry not included in Long's process analysis of the operation of a coal mine.

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APPENDIX 2. COAL LIQUEFACTION BY DIRECT HYDROGENERATION

Two processes have received considerable attention as means of converting coal into liquid fuels using direct hydrogenation methods. These are the H-Coal process developed by Hydrocarbon Research Inc (USA) and the Synthoil process developed by the U.S. Bureau of Mines. Although both projects have only been tested at small-scales, there is sufficient published data available to allow a preliminary analysis to be carried out. In fact most of the analysis presented here is based on conceptual designs derived from pilot-plant experiments and as such is open to question.

2.1. H-COAL PROCESS

The H-Coal process for the conversion of coal to liquid products was invented by Hydrocarbon Research, Inc. (USA) and is an extension of the ebullated bed technology developed for the H-Oil process. H-Oil reactors have operated commercially since 1963. The H-Coal process has been operated effectively on two ranks of coal, Illinois No.6 and Wyodak coals, at the bench and process development unit scale (3 tonnes coal/day)and should be effective with all types of coal.(1)

The sequence of operations in the H-Coal process is as follows. Coal is first ground to -40 mesh, dried to 65-95°C and slurried with an approximately equal weight of coal-derived solvent. The coal slurry is then mixed with compressed hydrogen and fed to the preheater and then into the bottom of an ebullating bed reactor where it contacts a cobalt-molybdenum catalyst. The reactor operates at 2700 psig and 450°C. The catalyst is retained in the reactor, and the upward hydrogen flow maintains the catalyst in a fluidized state thus providing good contact between the coal, liquid and catalyst. The coal is catalytically hydrogenated as dissolution occurs.

Liquid products and gases generated during hydrogenation exit from the top of the reactor and are separated in a series of flash drums and fractionation units. Separations of unreacted solids and liquid products is a problem in the H-Coal process as it is in all other coal liquefaction processes. Although fitering, centrifuging and coking have been evaluated, it appears that the most feasible approach may be to fractionate the mixture from the reactor and send the combined unreacted solids and vacuum bottoms to a partial oxidation unit for hydrogen production(2). The remaining hydrogen required would be generated by steam reforming of process gases.

Compounds containing sulphur, nitrogen and oxygen in the feed coal are largely converted to hydrogen sulphide, ammonia and water in the reactor and removed as sour water in the separation step. Ammonia and sulphur are recovered and sold as bi-products.

Calculations of energy requirements in the H-Coal process are based on a conceptual design presented by Goen et al(2) for processing eastern (Illinois No.6) and western (Wyoming Powder River) American coals. It is assumed that the liquefaction plant is situated at the mouth of the coal mine so that coal transportation is a minor consideration in cost or energy requirements.

2.1.1. CASE I. Illinois No.6 bituminous coal

Goen et al(2) give the following characteristics of feed coal and product syncrude.

	Illinois No.6 Coal			Syncrude
	As received	moisture free	moisture and ash free	
Ultimate analysis(%)				
moisture	10.0			
ash	9.0	10.0		
carbon	62.7	69.7	77.5	86.8
hydrogen	4.8	5.3	5.9	10.9
oxygen	8.9	9.9	11.0	1.9
sulphur	3.5	3.9	4.3	0.19
nitrogen	1.1	1.2	1.3	0.23
Calorific value MJ(th)/tonne	25,530	28310	31,460	42,700*

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*Calculated from Goen's thermal efficiency of the process of 71%

2.1.1.1. INPUTS

2.1.1.1.1. Coal. Goen et al[2] estimated that for a plant producing 100,000 bbls (14,452 tonnes) syncrude/stream day the total requirement of Illinois No.6 coal would be 34,767 tonnes/stream day as received or 31,300 tonnes/stream day for dried coal. It is possible to gain some idea of how this coal is used in the process. By carrying out a carbon balance it can be estimated that in supplying carbon for the production of syncrude, the theoretical minimum (100% conversion) amount of coal required is 17,997 tonnes (moisture free) or 57.5% of the coal feed. This mass of coal contains 954 tonnes hydrogen, so that an additional 621 tonnes hydrogen is required to give the C/H ratio of the product syncrude. Hydrogen is also consumed in reactions with oxygen, sulphur and nitrogen yielding H_2O, H_2S and NH_3 respectively. To reduce the levels of these compounds in coal to the levels required in syncrude requires a theoretical minimum (per stream day) of 188 tonnes hydrogen for oxygen compounds, 42 tonnes hydrogen for sulphur compounds and 73 tonnes for nitrogenous compounds. Thus the total theoretical minimum requirement for hydrogen is 924 tonnes/stream day, compared with 1704 tonnes supplied per stream day. Furthermore, since it is assumed that all hydrogen is generated from either coal or plant bi-products (gases, char or vacuum bottoms), the quantity of coal required to produce hydrogen (whether directly from coal or from coal derived products) can be calculated.

From the general equation (1) below, one can calculate that to supply 1704 tonnes of hydrogen at 100% conversion efficiency requires 4486 tonnes of moisture and ash free (i.e. MAF) coal.

$$1/n \left[CH_{0.9}\right]_n (s) \quad + \quad 2H_2O(l) \rightarrow 2.45\ H_2(g) \quad + \quad CO_2(g) \qquad (1)$$

Furthermore since equation (1) is endothermic, heat must be supplied by the combustion of more coal and in order to exclude nitrogen from the product hydrogen, combustion must be in the presence of oxygen rather than air.

One can obtain an estimate for the heat of reaction of equation (1) using Hess' law and standard heats of combustion. Thus

$$1/n\left[CH_{0.9}\right]_n + 1.225\ O_2(g) \rightarrow CO_2(g) + 0.45\ H_2O(l)\quad \Delta H = -\ 97.0\ \text{kcal}\quad (2)$$

(from calorific value of MAF coal)

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(l)\qquad \Delta H = -\ 68.3\ \text{kcal}\quad (3)$$

Then, $\left[\text{equ}(2)\right] - 2.45 \times \left[\text{equ}(3)\right]$ gives for MAF coal

$$1/n\left[CH_{0.9}\right]_n + 2H_2O(l) \rightarrow CO_2(g) + 2.45H_2(l)\quad \Delta H = -\ 70.3\ \text{kcal}\quad (1)$$

Thus each tonne of coal used in hydrogen production requires a theoretical minimum of 22,801 MJ(th) or 0.725 tonnes of MAF coal equivalent to sustain the reaction.

According to equation (2), the combustion of 0.725 tonnes of MAF coal requires 2.203 tonnes of oxygen for which Harris has calculated an energy requirement of 6.33 GJ/tonne(3).

To produce each tonne of hydrogen requires a minimum of 4.54 tonnes of MAF coal, 7.35 tonnes process water and 5.80 tonnes oxygen giving a theoretical minimum energy requirement for hydrogen (excluding capital cost of plant, catalyst etc) of 179.5 GJ(th)/tonne. By comparison, Harris (3) gives an energy requirement for the production of hydrogen from natural gas of 245.3 GJ(th)/tonne and Akhtar et al(4), assuming a production efficiency of 60% give the energy requirement of hydrogen from coal as 228 GJ(th)/tonne, and from data given by Lowenheim and Moran(5), hydrogen produced by the shift reaction of coke with steam can be shown to have an energy requirement of 492 GJ(th)/tonne.

Thus the production of 1704 tonnes of hydrogen required for stream day will require a theoretical minimum energy of 1704 x 179.5 GJ(th), equivalent to 10,804 tonnes of moisture free coal.

Additional to the aforementioned requirements for coal, 368 tonnes/stream day of char (100% carbon?) are produced as a biproduct of the process(2). This quantity of carbon is derived from 530 tonnes of coal.

Thus one can estimate that the coal inputs are used approximately in the following ways:

	Quantity of moisture free coal(tonnes)	% of total
Direct conversion to syncrude (theoretical minimum)	17,997	57.5
Hydrogen production (theoretical minimum)	10,804	34.5
Char biproduct	530	1.7
Plant fuel and sundry losses (by difference)	1969	6.3
TOTAL	31300	100

The energy content of the coal feed is $31,300 \times 28310 = 8.861 \times 10^{8}$ MJ(th) per stream day.

2.1.1.1.2. Coal slurry preparation.

Although not mentioned explicitly in the report it seems that energy requirements for drying and crushing coal have been included in the estimate of the overall plant running costs. However no account has been taken of coal losses as dust. In slurry preparation, 164,000 bbls of coal-dervied solvent are required per stream day. Although this will be recycled it would seem that some losses may occur, but again no allowance has been made for make-up solvent in the study(2).

2.1.1.1.3. Electricity

In the analysis of Goen et al(2) it was assumed that electricity was bought from an external utility and the annual requirement was estimated to be 10.304×10^8 kWhe. However in this report it will be assumed that al electricity is generated on-site from a coal-fired plant operating at 30% generating efficiency with no transmission losses. Assuming that the plant is on-stream for 90% of the time, electrical requirements of the plant are given (in primary energy terms) by

$$10.304 \times 10^8 \times 3.6 \times \frac{100}{30} \times \frac{1}{365} \times \frac{100}{90} = 0.376 \times 10^8 \text{MJ(th)/stream day.}$$

2.1.1.1.4. Plant and Capital Equipment

Goen et al(2) estimated the cost of a H-Coal plant producing 100,000 bbls/stream day as $(US1974) 533m. (not including on-site plant for electricity generation). From U.S. wholesale price indices(6) for the machinery and equipment sector $(US1974) 1.0 = $(US1968) 0.74 and

$(US1968) 2.4 = £(S1968) 1.0

Also Casper et al(7) give the energy intensity of the outputs of a number of heavy engineering sectors as about 220 MJ(th)/£(S1968). Thus if it is assumed that the plant is on-stream for 90% of its 10 year lifetime, and 50% of initial costs are allowed for maintenance then,

energy requirement of plant and equipment

$$= 1.5 \times 533 \times 10^6 \times \frac{0.74}{2.4} \times 220 \times \frac{1}{20 \times 365 \times 0.9}$$

$$= 0.083 \times 10^8 \text{MJ(th)/stream day.}$$

2.1.1.1.5 Catalysts and chemicals

Goen et al(2) estimated the annual cost of catalyst and chemicals as $(US 1974) 10.37m. Using US Wholesale price indices(6) for "chemicals and allied products" gives $(US 1974) 1 = $(US 1968) 0.68

and $(US 1968)2.4= £(S 1968) 1.0

Casper et al(7) give the energy intensity of "general chemicals" as 702 MJ(th)/£(1968), and thus, assuming that the plant is on - stream for 90% of the time,

$$\text{energy requirement of chemicals} = 10.37 \times 10^6 \times \frac{0.68}{2.4} \times 702 \times \frac{1}{365 \times 0.9}$$

$$= 0.063 \times 10^8 \text{ MJ(th)/stream day}$$

2.1.1.1.6 Ash disposal

As the plant is assumed to be at the mine mouth and no account is taken of coal transportation, similarly no account will be taken of the removal of small amounts of ash generated by the process.

2.1.1.1.7 Water requirements

Goen et al(2) give the following water requirements:

cooling water	2.845×10^6 tonnes/stream day
boiler feed	2.289×10^4 tonnes/stream day
steam	3.055×10^4 tonnes/stream day
raw water	9.810×10^4 tonnes/stream day

Summary of energy requirements of a H-Coal plant producing 100,000 bbls syncrude/stream day from Illinois No. 6 coal

	x 10^8 MJ(th)/stream day
Coal for supplying carbon for syncrude (theoretical minimum)	5.095
Coal going to char biproduct	0.150
Coal for hydrogen production (theoretical minimum)	3.059
Coal for plant fuel and sundry losses (by difference)	0.557
Coal for electricity generation	0.376
Plant and capital equipment	0.083
Catalysts and chemicals	0.063
	9.383 x 10^8 MJ(th)/ stream day

2.1.1.2 OUTPUTS

In the conceptual design of a H-Coal plant presented by Goen et al(2), where 31,300 tonnes ofdry Illinois No. 6 coal are processed per stream day, the following products are obtained:

Product	Production Rate
Syncrude	100,000 bbls or 14,452 tonnes/stream day
Coal char	368 tonnes/stream day
Ammonia	378 tonnes/stream day (i.e. 90% recovery)
Sulphur	925 tonnes/stream day (i.e. 80% recovery)

By convention, the energy requirements of a process are partitioned between fuel products according to calorific values and between non-fuel products according to replacement energy requirements.

From Goen's(2) quoted thermal efficiency for the H-Coal process, the calorific value of syncrude produced can be estimated as 42.7 GJ(th)/tonne. Coal char is assumed to be 100% carbon and as such will have a calorific value of the order of 33 GJ(th)/tonne (cf heat of combustion graphite = 94 kcal/mole). Harris(3) gives the energy requirement of ammonia as 55.71 GJ(th)/tonne. It is difficult to assign a replacement energy requirement to sulphur because of the wide variety of methods used for its production, but, as it is a low value product, here it will be given an energy requirement of 400 MJ(th)/tonne as an approximation to a mined and crushed product.

Thus in calculating the energy associated with the production of syncrude (only), one must apportion to syncrude a fraction of the total plant energy requirements equivalent to

$$\frac{14452 \times 42700}{14452 \times 42700 + 368 \times 33000 + 378 \times 55710 + 925 \times 400}$$

$$= 0.949$$

2.1.2 CASE II Wyoming Powder River subbituminous coal

Goen et al$^{(2)}$ give the following characteristics of the feed coal and product syncrude

	Wyoming Powder River coal			
	As received	moisture free	moisture & ash free	Syncrude
Ultimate analysis (wt %)				
moisture	33			
ash	5.8	8.7		
carbon	45.7	68.2	74.7	86.0
hydrogen	3.2	4.8	5.2	11.6
oxygen	11.1	16.6	18.2	2.1
sulphur	0.5	0.7	0.8	0.11
nitrogen	0.7	1.0	1.1	0.23
Calorific value (MJ(th)/tonne)	18,100	27,100		42,700*

*As before (cf. Appendix 2.1.1)

By comparing the characteristics of the subbituminous western (USA) coal given above with those previously given for Illinois No. 6 coal - a typical high-sulphur eastern bituminous coal, one can make the following generalisations. Because western coal (as received) has a much higher moisture content than eastern bituminous coal, more western coal must be mined, and additional water removed before the coal is processed. In hydrogenation, western coal generally consumes more hydrogen than eastern coal; while western coals contain less sulphur and nitrogen which consumes less hydrogen, this effect is more than offset by the high oxygen content in the western coal that must be removed by reacting with hydrogen to form water. The amount of ash in western coal is also lower and it can generally be returned to worked out mines. The problems of ash disposal in eastern underground coal mines is not solved so easily.

Calculations of process energy requirements for western subbituminous coals have also been based on the work of Goen et al$^{(2)}$ and a summary of the energy requirements for a H-coal plant producing 100,000 bbl/stream day is given below.

<u>Summary of energy requirements of H-Cola plant producing 100,000 bbls syncrude stream day from Wyoming Powder River Coal.</u>

	x 10^8 MJ(th)/stream day
Coal for supplying carbon for syncrude (theoretical minimum)	4.611
Coal going to char biproduct	0.099
Coal for hydrogen production (including an estimate of plant losses)	3.454
Coal for other plant fuel and sundry losses (by difference)	0.915
Coal for electricity generation	0.410
Plant and capital equipment	0.082
Catalysts and chemicals	0.072
	9.644 x 10^8 MJ(th)

In the conceptual design of a H-Coal plant processing Wyoming Powder River coal presented by Goen et al$^{(2)}$, the design output is 13,538 tonnes syncrude/stream day. In addition 248 tonnes of char, 188 tonnes sulphur and 289 tonnes of ammonia are produced per stream day.

As before (Appendix 2.1.1.2.), the fraction of the total plant energy requirements apportioned to the production of syncrude is given by

$$\frac{13{,}538 \times 42700}{13{,}538 \times 42700 + 248 \times 33000 + 289 \times 55710 + 188 \times 400}$$

$$= 0.960$$

2.2 THE SYNTHOIL PROCESS

The US Bureau of Mine's Synthoil process is similar in principle to the H-Coal process describedabove. Detailed descriptions of the Synthoil process appear elsewhere(8,9). The process is being developed primarily to convert low quality, high sulphur coals to low sulphur heavy fuel oil suitable for burning in power stations. Because the primary product of the Synthoil process has a higher C to H ratio than the syncrude produced by the H-Coal process, the hydrogen consumption of the latter is of the order of 50% higher than that of the former(2,4). Thus although the two processes are not directly comparable it is interesting to note that Akhtar et al(4) quote an energy efficiency of the Synthoil process producing heavy fuel oil of 75% - very similar to that for H-Coal(2).

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APPENDIX 3. LIQUIDS FROM COAL BY EXTRACTION HYDROGENATION (SOLVENT REFINING).

Extractive hydrogenation processes involve the partial or complete solution of coal in a coal-derived solvent. The Pittsburg and Midway Coal Mining Company (PAMCO) have developed a solvent refined coal process whereby coal is dissolved in an organic solvent in the presence of hydrogen under high pressure (2500 psi). The product is a semi-solid, low-ash, low-sulphur fuel suitable for steam boilers but not as a refinery feedstock. A second system is the hydrogen-donor process in which coal is dissolved in a solvent at low pressure (300 psi) with the hydrogen addition being accomplished by transfer from a hydrogen-donor solvent rather than directly as in the PAMCO process. This permits less severe operating conditions to be used i.e. lower pressure and temperature. The Consol Synthetic Fuels (CSF) Process uses the hydrogen-donor principle to produce a de-ashed extract which is subsequently upgraded by catalytic hydrogenation (cobalt-molybdenum catalyst at about 450°C and 3000-4200 psi) to yield a medium quality synthetic crude suitable as a feedstock for a conventional refinery. The CSF Process was the basis of 'Project Gasoline', a project sponsored by the Office of Coal Research in the United States to develop a process for converting coal to motor spirit economically. A pilot plant designed to process 18 tonnes of coal/day was completed by February 1967 and was operated until February 1970, but the plant was plagued by mechanical failure and was closed down for engineering evaluation and modification before sufficient data had been obtained to enable the design of commercial facilities. An independent evaluation was carried out by the Foster Wheeler Corporation who concluded that the CSF process was technically feasible and suggested a number of modifications to the pilot plant(1).

3.1. MOTOR SPIRIT FROM COAL BY THE CSF PROCESS.

Since the development of the CSF process has been heavily funded under 'Project Gasoline' most of the published data relates to the production of motor spirit from coal. The summary report of the work carried out for 'Project Gasoline' has been used in this report(2). The plant considered in the report(2) converts coal to a synthetic crude which is then refined to produce motor spirit. All plant fuel requirements (mainly as methane and hydrogen) were assumed to be met by char and coal gasification using the CO_2 Acceptor Process. Unfortunately it was not possible to disaggregate the information sufficiently to enable the production of synthetic crude oil by the CSF process to be examined. Two coals were investigated - Illinois No.6 coal (typical of the deep-mined, highly volatile, bituminous eastern coal), and a Montana coal (representative of the strip-mined, subbituminous western coals).

3.1.1. Illinois No.6 Coal.

Calorific value of dry coal = 27,170 MJ(th)/tonne

Moisture content of coal (as received) = 14.4%

3.1.1.1. Inputs.

According to the report of Project Gasoline(2), the following inputs would be required to a plant producing 7667.3 tonnes of motor spirit/stream day.

3.1.1.1.1.Coal.

It was estimated that 21,800 tonnes of dry coal would be required to fuel the plant. Of this, 1486.4 tonnes are gasified for plant fuel together with 8,339.8 tonnes of char (calorific value, 20,280 MJ(th)/tonne) and unspecified quantities of process gases.

Calorific value of coal input = 21,800 x 27,170 = 592.31×10^6 MJ(th)/ stream day.

3.1.1.1.2.Electricity.

From the economic analysis, the estimated electrical requirement was calculated as 1.552×10^6 kWhe. If it is assumed that this electricity is generated on-site from coal then the additional amount of coal that would be required is given by

$$1.552 \times 10^6 \times 3.6 \times \frac{100}{30} \times \frac{1}{27170} = 685.5 \text{ tonnes dry coal.}$$

3.1.1.1.3. Catalyst and Chemicals.

It was estimated that the annual cost of chemicals/catalyst for the plant would be \$(US 1969) 7.52m. From US wholesale price indices(3) for "chemicals and allied products",

$$\$(\text{US } 1969)\ 1.0 = \$(\text{US } 1968)\ 1.0$$

and

$$\$(\text{US } 1968)\ 2.4 = £(1968)\ 1.0.$$

Casper et al(4) give the energy intensity of "general chemicals" as 702 MJ(th)/£(1968), so that, assuming that the plant is on-stream for 90% of the time,

$$\text{energy requirement of catalyst and chemicals} = 7.52\text{x}10^6\text{x}\frac{1.0}{2.4}\text{ x } 702 \text{ x } \frac{1}{365\text{x}0.9}$$

$$= 6.70\text{x}10^6 \text{ MJ(th)/stream day.}$$

3.1.1.1.4. Capital Equipment.

The cost of the plant and equipment (excluding on-site electricity generation) was estimated as \$(US 1969) 239.6m. From US wholesale price indices for the machinery and equipment sector(3)

$$\$(\text{US } 1969)\ 1.0 = \$(\text{US } 1968)\ 0.97$$

and

$$\$(\text{US } 1969)\ 1.0 = £(1968)\ 2.4.$$

Casper et al(4) give the average energy intensity of the outputs of a number of heavy engineering sectors as about 220 MJ(th)/£(1968). Thus if the plant is on-stream for 90% of its 20 year lifetime, and 50% of initial costs are allowed for maintenance,
energy requirement of plant and equipment =

$$1.5 \text{ x } 239.6 \text{ x } 10^6 \text{ x } \frac{0.97}{2.4} \text{ x } 220 \text{ x } \frac{1}{20\text{x}365\text{x}0.9}$$

$$= 4.86 \text{ x } 10^6 \text{ MJ(th)/stream day.}$$

3.1.1.2. Outputs.

It was expected that the products from the conceptual plant per stream day would be 61,400 bbls or 7667.3 tonnes of motor spirit (calorific value of 46830 MJ(th)/tonne(5), 32.7 tonnes phenol and cresols (estimated replacement energy requirement of 50 GJ(th)/tonne(6)), 176.6 tonnes ammonia (replacement energy requirement of 55.71 GJ(th)/tonne(6)) and 555.8 tonnes sulphur (replacement energy requirement 400 MJ(th)/tonne for mining and crushing). According to the conventions adopted here, the fraction of the plant energy requirements apportioned to the production of motor spirit is given by

$$\frac{7667.3 \times 46830}{7667.3 \times 46830 + 32.7 \times 50000 + 176.6 \times 55710 + 555.8 \times 400}$$

$$= \quad 0.968.$$

The overall thermal efficiency (i.e. including coal for electricity generation) of this process for producing motor spirit from Illinois No.6 coal can be shown to be 60.3%.

3.1.2. Montana Coal.

The summary report of 'Project Gasoline'(2) activities also considered a plant processing a western coal and since calculations were analogous to those for Illinois No.6 coal, they will only be summarised here.

Calorific value of dry coal = 27,360 MJ(th)/tonne

Moisture content of coal (as received) = 24%

It was estimated that 21,469 tonnes of dry Montana coal would be required to fuel the plant. In addition, if it is assumed that electricity is generated on-site from coal, a further 774 tonnes of dry coal will be required giving a total calorific value of coal intake of 608.57×10^6 MJ(th)/stream day. Annual cost of chemicals was estimated at $(US 1969) 6.37m. equivalent to an energy requirement of 5.67×10^6 MJ(th)/stream day.

Capital cost of the plant was estimated at $(US 1968) 258.2m. equivalent to an energy requirement of 5.24×10^6 MJ(th)/stream day.

The products from the plant per stream day were expected to be 7607 tonnes of motor spirit (60,824 bbls), 32.8 tonnes of phenol and cresols, 139.3 of ammonia, and 122.2 tonnes sulphur. As before, the fraction of the plant energy requirements apportioned to the production of motor spirit is calculated to be 0.974. The overall thermal efficiency (including coal for electricity generation) of this process for Montana coal can be calculated as 59.3%.

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