

TABLE 19. - Estimated operating personnel and materials requirements for the 30,000-bbl.-per-day coal-hydrogenation plant

	Bureau of Mines data ^{1/}	N.P.C. data ^{2/}
-Coal..... tons/day (as received)	<u>3/</u> 11,820	12,990
Hydrogenation..... do....	6,142	6,422
Fuel..... do....	3,330	3,800
Gasification..... do....	2,348	2,220
Hydrogen production..... million cu. ft./day	242	239
Low-temperature separation..... do....	39	38
Off-gas conversion ^{4/} do....	117	80
Coal gasification..... do....	86	121
Hydrogen consumption..... do....	242	239
Liquid phase..... do....	165	-
Vapor phase..... do....	77	-
Oxygen (95 percent)..... tons/day	1,952	2,615
Electric power..... kilowatts	194,710	213,880
Steam..... 1,000 lb./hr.	-	5,214
High-pressure..... do....	2,700	2,634
Process and heating..... do....	<u>5/</u> 556	2,580
Cooling water..... gal./min.	250,000	227,555
Fresh water..... do....	18,263	19,616
Operating labor and maintenance (plant).....	2,400	3,349
Total (including supervisory).....	3,020	<u>6/</u> 5,250
Construction metals:		
Tons.....	<u>7/</u> 173,267	188,600
Tons per bbl.-day.....	5.8	6.3

1/ Bureau of Mines data (6).

2/ Based on National Petroleum Council Committee Report (10).

3/ No loss included.

4/ Bureau of Mines by steam cracking, N.P.C. by partial combustion with O₂.

5/ Does not include extracted steam.

6/ Includes 605 miners.

7/ Steel only.

TABLE 20. - Estimated power requirements for 30,000-bbl.-per-day coal-hydrogenation plant

	Bureau of Mines data ^{1/}	N.P.C. data ^{2/}
	<u>Kw.</u>	<u>Kw.</u>
<u>Hydrogenation section, total</u>	54,730	49,995
Coal-preparation plant.....	6,120	5,025
Paste-preparation plant and high-pressure injection....	36,930	34,715
Delayed-coking unit.....	9,070	5,070
Product distillation and phenol recovery.....	2,610	5,185
<u>Gas-production section, total</u>	114,600	127,460
Low-temperature, off-gas separation.....	7,460	13,170
Hydrocarbon-steam cracking.....	11,640	4,400
Coal gasification.....	12,660	3,490
Oxygen plant.....	26,580	45,200
Hydrogen compression and purification.....	56,260	61,200
<u>General and auxiliary plant section</u>	25,380	36,424
<u>Power required, grand total</u>	<u>194,710</u>	<u>213,879</u>
Per barrel of gasoline..... kw.-hr.	216	239

^{1/} Bureau of Mines data (6).

^{2/} Based on National Petroleum Council Committee Report (10).

TABLE 21. - Estimated costs (1952) for coal-hydrogenation gasoline
(single plant)

	Bureau of Mines data ^{1/}	Ebasco Services data ^{2/}	National Petroleum Council data ^{3/}
Plant size..... bbl./stream-day	33,000	33,000	30,000
Stream year..... days	330	330	330
Total investment..... dollars	414,400,000	403,827,000	437,300,000
Operating cost annual dollars (including depreciation).....	53,199,500	58,753,000	68,060,000
Production, annual:			
Gasoline..... bbl.	6,773,800	6,815,800	7,113,900
L.P.G..... do.	2,590,480	2,590,480	2,332,350
Benzene..... gal.	11,750,000	11,750,000	-
Toluene-xylene..... do.	39,350,000	39,350,000	-
Phenol..... lb.	43,800,000	43,800,000	31,025,000
Cresols..... do.	71,000,000	56,600,000	50,370,000
Xylenols..... do.	25,000,000	25,000,000	66,430,000
Ammonium sulfate..... tons	131,000	131,000	-
Sulfur..... do.	17,100	17,100	-
Cost of total liquid products..... cents/gal.	10.2	11.4	16.4
Value of byproducts..... annual dollars	48,559,000	44,692,000	16,487,000
Cost above byproducts returns..... do.	4,640,500	14,061,000	51,573,000
Cost of gasoline, cents/gal.:			
Before profit and income tax.....	<u>4/</u> 1.6	<u>4/</u> 4.9	17.3
At 6% return on total investment after 50% income tax.....	19.1	21.8	34.8

1/ Bureau of Mines estimates (1).

2/ Based on Ebasco Services, Inc., estimates (3).

3/ Based on National Petroleum Council Committee Report (10).

4/ These low gasoline costs result from the high returns assumed for byproduct chemicals.

TABLE 22. - Types of Fischer-Tropsch processes^{1/}

Type	Stage of development	Status (1958)	Hourly space velocity	Temp., °F.	Calculated heat-transfer coefficient, B.t.u./hr.-sq. ft.	Catalyst	Principal products
Early fixed bed	Commercial, but obsolete	2 plants still in use for chemicals in West Germany	100	To 520	6	Precipitated cobalt or iron	Gasoline stock, chemicals, and heavier hydrocarbons (wax). 40% of liquids as gasoline; 60% heavier hydrocarbons.
Modern fixed bed	Commercial	Used as first stage by Sasol, in South Africa	500	To 520	30	Precipitated iron	Gasoline and chemicals.
Fixed fluidized bed	do.	Used by Amoco Chemicals, in Texas; now inactive	2/500	570-645	100	Mill scale or similar iron oxide	Do.
Entrained fluidized bed	do.	Second stage by Sasol	2/400	570-645	100	Fused magnetite	Do.
Oil circulation	Pilot plant	Development completed by Bureau of Mines	600	To 535	40	Fused iron oxide or steel lathe turnings	About 70% gasoline.
Slurry	do.	Development continuing by Bureau of Mines and at British Fuels Research Station	300	To 535	40	Precipitated or fused iron or mill scale	50 to 70% gasoline.
Hot-gas recycle	do.	Development continuing by Bureau of Mines	1,000	570-645	50	Steel lathe turnings	Gasoline.

^{1/} From Field, Benson, and Anderson (4).

^{2/} Includes disengaging space; about double this value when based on catalyst space.

TABLE 23. - Distribution of products from Fischer-Tropsch synthesis^{1/}

	Oil-circulation process	Slurry process	Hot-gas-recycle process
Catalyst.....	Reduced, fused iron	Nitrided precipitated iron	Oxidized and reduced iron turnings
Temperature..... °F.	490	500	600
Fresh feed..... H ₂ :CO vol. ratio	1:1	1:1	1.3:1
Liquid product, total..... wt.-percent	100.0	100.0	100.0
Gasoline + L.P.G. (to 204° C.) .do..	55.3	} 45.4	83.7
Diesel oil (204° - 316° C.) .do..	13.5		10.7
Fuel oil (316° - 450° C.) .do..	10.7		.1
Wax (above 450° C.) .do..	9.9		.6
Oxygenates, total.....do..	10.6	54.5	4.9
Oil-soluble.....do..	5.2	36.4	-
Water-soluble.....do..	5.4	18.2	-
Refinery yields, total ^{2/}			
..... bbl./ton raw coal	1.91	1.55	1.68
L.P.G.....do..	.11	.25	.37
Blended gasoline ^{3/}do..	1.06	1.10	1.21
Diesel oil.....do..	.28	.09	.06
Fuel oil.....do..	.21	.07	.03
Wax.....do..	.25	.04	.01
Gasoline octane No., by research method			
Gasoline (clear).....	81.2	92.9	84.8
Gasoline + 1 ml. TEL/gal.....	-	98.5	91.2
Gasoline + 3 ml. TEL/gal.....	92.4	-	-

^{1/} Based on Bureau of Mines unpublished reports.

^{2/} Assumptions: 57,600 cu. ft. (CO + H₂)/ton coal and 90-percent conversion in synthesis.

^{3/} Gasoline contains light alcohols and other reformed oxygenated products.

TABLE 24. - Estimated process conditions and main flow streams
for a 30,000-bbl.-per-day Fischer-Tropsch plant
using Western Kentucky high-volatile A
bituminous coal^{1/}

<u>Gasification - 30 atm., 2,400° F.</u>	
Pulverized coal.....	tons/hr. 649
Oxygen (95 percent).....	do... 476
Steam.....	lb./hr. 430,000
Oxygenates and water.....	do... 106,000
Gas produced.....	million cu. ft./hr. 40.6
<u>Purification - 29 atm.</u>	
Raw synthesis gas.....	million cu. ft./hr. 40.6
CO ₂ removed.....	do... 3.4
Sulfur recovery.....	thousand lb./hr. 43.6
Synthesis:	
1st-stage gas.....	million cu. ft./hr. 61.4
CO ₂ removed.....	do... 6.9
2d-stage gas.....	do... 18.9
CO ₂ removed.....	do... 1.7
Total CO ₂ removed.....	do... 12.0
<u>Synthesis - 28 atm., 500° F.</u>	
1st-stage feed.....	do... 35.8
Recycle.....	do... 43.6
2d-stage feed.....	do... 10.8
Recycle.....	do... 12.9
Products from synthesis, lb./hr.:	
Oil condensate to distillation.....	249,000
Tail gas to light-ends recovery.....	268,000
Oxygenates and water to gasifier.....	106,000
<u>Refinery</u>	
<u>Polymerization plant</u>	
Total feed.....	lb./hr. 77,525
C ₃ + C ₄ unsaturates.....	do... 52,110
L.P.G. product.....	gal./hr. 2,755
Gasoline product.....	do... 7,955
<u>Butane (gasoline) product</u>	do... 2,765
See footnote at end of table.	

TABLE 24. - Estimated process conditions and main flow streams for a 30,000-bbl.-per-day Fischer-Tropsch plant using Western Kentucky high-volatile A bituminous coal^{1/} (Con.)

<u>Refinery (Con.)</u>	
<u>Catalytic reforming</u>	
Total feed.....	lb./hr. 148,040
Debutanized bottoms.....	do... 140,950
Gasoline product.....	gal./hr. 24,100
<u>Catalytic cracking</u>	
Total feed.....	lb./hr. 142,570
Gas oil and heavy distillate.....	do... 104,235
Wax.....	do... 33,670
Reforming and polymerization bottoms.....	do... 4,665
Gasoline product.....	gal./hr. 6,740
Fuel oil product.....	do... 8,205
<u>Overall plant</u>	
Fuel coal.....	tons/hr. 126
Total coal.....	do... 775
Thermal efficiency.....	percent ^{2/} 38

^{1/} Based on National Petroleum Council Committee Report (10).
^{2/} 100 x calorific value of liquid product/calorific value of total coal used.

TABLE 25. - Estimated requirements for operating personnel and materials for the 30,000-bbl.-per-operating-day Fischer-Tropsch plant^{1/}

Coal.....	tons/day (as received)	18,900
Gasification.....	do...	15,875
Fuel.....	do...	3,025
Oxygen (95 percent).....	tons/day	11,700
Electric power.....	kw.	96,800
Steam.....	1,000 lb./hr.	2,900
Cooling water.....	gal./min.	555,750
Fresh water.....	do. ^{2/}	3,240
Personnel ^{3/}		6,442
Construction metals.....	tons	177,000
	tons per bbl.-day	6.55

^{1/} Based on National Petroleum Council Committee Report (10).
^{2/} Boiler-plant makeup only.
^{3/} Includes 2,720 miners.

TABLE 26. - N.P.C. 1952 estimate for Fischer-Tropsch gasoline cost^{1/}

Plant size, bbl./stream-day	12,174	30,000
Stream year..... days	330	330
Total investment..... dollars	184,600,000	379,700,000
Operating cost..... annual dollars (including depreciation)	33,809,000	68,483,000
Production, annual:		
L.P.G..... bbl.	210,240	516,110
Gasoline..... do.	3,178,420	7,801,510
Fuel oil..... do.	626,300	1,537,380
Sulfur..... tons	69,350	170,090
Value of L.P.G. and sulfur..... annual dollars	1,775,000	4,354,100
Cost above byproduct returns..... do.	32,034,000	64,128,900
Gasoline equivalent of fuel oil at 70 percent.....bbl.	438,410	1,076,170
Total equivalent gasoline.....gal.	151,906,860	372,862,560
Cost of equivalent gasoline, cents/gal.:		
Before profit and income tax.....	21.1	17.2
At 6% return after 50% income tax.....	35.7	29.2

^{1/} Based on National Petroleum Council Committee Report (10).

Literature Cited

1. BUREAU OF MINES. Cost Estimate for Coal Hydrogenation. Ms. rept., Jan. 11, 1952, 44 pp.
2. CHAFFEE, C. G., AND HIRST, L. L. Liquid Fuel From Coal; Progress Report on Hydrogenation Demonstration Plant. Ind. Eng. Chem., vol. 45, No. 4, April 1953, pp. 822-838.
3. EBASCO SERVICES, INC. Coal Hydrogenation Plants - A Review of Certain Elements of the Bureau of Mines Cost Estimates For Synthetic Liquid Fuels. New York, March 1952, 158 pp.
4. FIELD, J. H., BENSON, H. E., AND ANDERSON, R. B. Current Status of Synthetic Liquid Fuels by the Fischer-Tropsch Process. Presented before AICE, Salt Lake City, Utah, September 1958.
5. FORD, BACON & DAVIS, INC. Summary Report for Bureau of Mines, Department of the Interior. The Synthetic Liquid Fuel Potential of the United States. Mar. 3, 1952, 32 pp.
6. HIRST, L. L., MARKOVITS, J. A.; SKINNER, L. C., DOUGHERTY, R. W., AND DONATH, E. E. Estimated Plant and Operating Costs for Producing Gasoline by Coal Hydrogenation. Bureau of Mines Rept. of Investigations 4564, 1949, 83 pp.
7. HUBMANN, O. Advances in the Technique of Gasifying Fine, High-Ash Coal Under Pressure. Internat. Conf. on Complete Gasification of Mined Coal, Liège, Belgium, 1954, pp. 169-177.
8. LINTON, JOHN A., AND TISDALL, GORDON C. Commercial Production of Synthesis Gas From Low Grade Coal. Part 2: Plant Operation and Byproduct Recovery. Coke and Gas, vol. 19, No. 222, November 1957, pp. 442-447.
9. MORGAN, R. E., ECKERD, J. W., RATWAY, J., AND BAKER, A. F. Lurgi-Gasifier Tests of Pennsylvania Anthracite. Bureau of Mines Rept. of Investigations 5420, 1958, 22 pp.
10. NATIONAL PETROLEUM COUNCIL COMMITTEE ON SYNTHETIC LIQUID FUELS PRODUCTION COST. Supplementary Report of the Subcommittee to the National Petroleum Council Committee on Synthetic Liquid Fuels Production Cost. Feb. 1, 1953.
11. OSTHAUS, K. H. The Development and Application of the Gasification of Pulverized Coal by the Koppers-Totzek Process. Internat. Conf. on Complete Gasification of Mined Coal, Liège, Belgium, 1954, pp. 255-264.
12. STRIMBECK, G. R., HOLDEN, J. H., MCGEE, J. P., AND HIRST, L. L. Recent Work by the Bureau of Mines on the Gasification of Pulverized Coal. Proc. Am. Gas Assoc., 1955, pp. 1006-1037.