of 11 days. Full data were obtained, calculated, and recorded. All runs to date have been made with Rock Springs, Wyo., bituminous coal. In these trial runs temperatures in the gasifier reached 2,300° to 2,800° F. The produced gas contained practically no tar material, and the sulfur from the coal was converted to a form, which is believed to be easily removable. A typical run yielded the following results:

Run No. 18

Coal rate	lb./hr.	1,976
Oxygen/coal ratio	cu. ft./lb. coal	9.48
Steam/coal ratio	lb./lb. coal	0.92
Total gas production	std. cu. ft./hr.	63,800
Gas analysis:		
H_2	percent	37.8
CO	do.	42.9
CO_2	do.	15.6
CH_4	do.	0.1
N_2	do.	3.6
Carbon gasified	do.	84.2
Steam decomposition	do.	6.7
Operating temperature	°F.	2,300 - 2,600
Material used per 1,000 cu. ft. CO + H_2:		
Coal	pounds	58.4
Oxygen	cubic feet	364.0
Steam	pounds	35.0

This gasifier has demonstrated that the principle of making gas from powdered coal and oxygen is sound and that the physical operations are feasible.

To guide and supplement the gasifier operations, a comprehensive study was made of the thermodynamic principles involved in the coal-oxygen-steam reaction and its application.29/ Complete data were also taken from the operation of the circulating pebble heater used to supply steam, super-heated up to 2,300° F., to the gasifier.

Kerpely Gas Producer

The demonstration plant includes a Kerpely gas producer. Normally, these, or similar conventional producers, are operated with coke using air blast. In the interest of higher capacities and high quality of gas, this unit was operated on a continuous basis in June 1950 with oxygen, or with oxygen-enriched air. Concentrations of oxygen used were 21, 50, 75, and 98 percent. Coke was either of pea or nut size. The runs were made under a cooperative agreement between the American Gas Association and the Bureau of Mines. Much information was gained on output capacities, analysis of gas produced, and operational difficulties, limitations, and control, the results of which are being compiled and evaluated.

Engineering Studies and Cost Estimates

Many engineering investigations were made in connection with the design and construction of the Gas-Synthesis Demonstration Plant and the operation of the Hydrogenation Demonstration Plant. Other studies were initiated in accordance with Public

29/ Batchelder, H. R., and Sternberg, J. C., Thermodynamic Study of Coal Gasification - Applicable to Suspension Gasification of Pulverized Coal: Ind. Eng. Chem., vol. 42, May 1950, pp. 877-882.

Law No. 290 of the 78th Congress and at the request of other government agencies. Some of this work was completed and published.

An index of Technical Oil Mission reels was completed. Additional translations of German documents were made.30/

At the request of the Corps of Engineers, U. S. Army, a chart of synthetic fuel plant requirements was prepared. Table 17 is typical of the information shown on the chart for a 10,000-barrel-per-day plant.

TABLE 17. - Requirements for a 10,000-barrel-per-day synthetic fuel plant

	Hydrogenation	Synthine using coal	Synthine using natural gas
Over-all efficiency .... percent	50.5	46.0	52.8
B.t.u./calendar day required	95 x 10^9	114 x 10^9	100 x 10^9
Plant personnel required	1,175	1,045	795
Area required .... acres	70	77	56
Products:			
LP-gas .... bbl./day	2,367	-	-
Gasoline .... bbl./day	7,220	8,290	8,290
Gas oil .... bbl./day	-	1,325	1,325
Fuel oil .... bbl./day	-	385	385
Phenols .... bbl./day	413	-	-
Total bbl./day	10,000	10,000	10,000
Oxygenated compounds .... bbl./day	-	1,104	1,104
Total bbl./day	10,000	11,104	11,104

The water requirements for the three types of synthetic fuel plants, in barrels of water per barrel of products are:

	Hydrogenation	Synthine using coal	Synthine using natural gas
Ample water available (once through operation)	300	390	190
Insufficient water (using cooling towers).	12.7	16.3	10.4
Combination cooling (air and water)	8.75	11.2	7.94

The above figures are for an average coal of approximately subbituminous rank.

30/ Copies of translations of T.O.M. reels available from the Bureau of Mines, Louisiana, Mo.

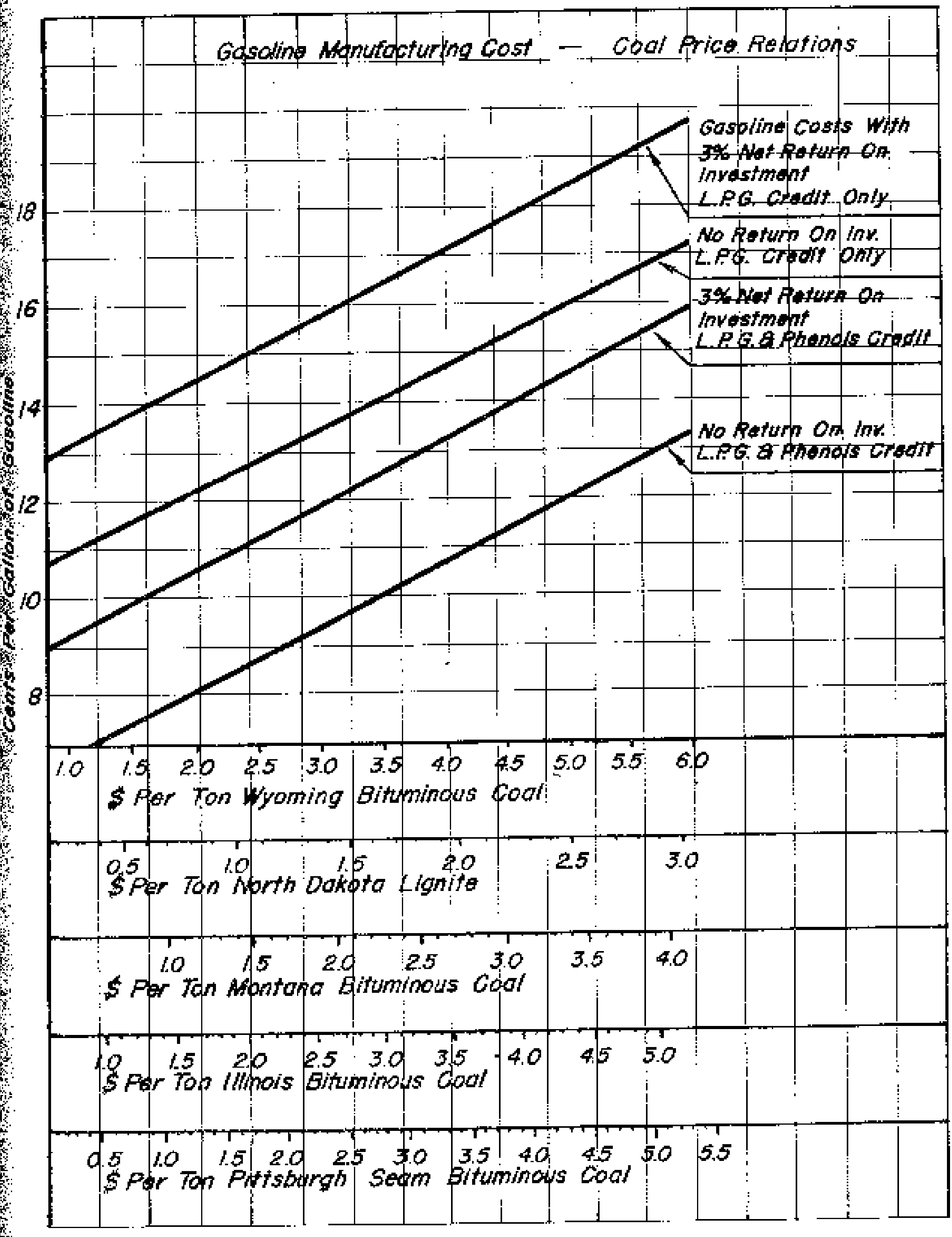

Figure 32. - Relation of gasoline manufacturing cost to coal prices for 30,000 bbl./day coal-hydrogenation plants.

The subject of coal hydrogenation and the special equipment used in the Coal-Hydrogenation Demonstration Plant at Louisiana, Mo., are described in a number of published reports.[31][32][33][34][35][36][37]

A review was made of the possibilities of making hydrogen from retort gas and coker tail gas produced in shale-oil refining. It was found that both of these gases could serve as feed to the hydrocarbon-steam cracking operation, whereupon 98-percent hydrogen could be produced by shifting and CO_2 scrubbing of the effluent gases. From 21 million standard cubic feet of retort gas, 34.2 million cubic feet of hydrogen gas can be produced. Similarly, 3.25 million cubic feet of coker tail gas will produce 8.7 million cubic feet of hydrogen. Of the two gases, coker tail gas is preferred because it has a lower total sulfur content and a lower content of inerts, which makes for smaller equipment sizes.

A detailed estimate[38] was completed for the commercial production of gasoline by the hydrogenation of coal. Five coals typical of large deposits in widely separated areas of the country were selected, and the cost of commercial plants was determined (fig. 32). Each plant is to produce 30,000 barrels of liquid products per calendar day.

A short summary of coal consumption, products distribution, plant and manufacturing costs, byproduct credit, and net cost figures is given in table 18.

After the 30,000-barrel-per-day coal-hydrogenation plant estimate was completed, a comparative estimate was prepared investigating motor gasoline, aviation grade, and jet-fuel production based on Illinois No. 6 bituminous coal as raw material at $3.12 per ton. The results of this estimate are summarized in table 19.

31/ Markovits, J. A., Coal Hydrogenation - Summary of Process and Brief Description of Special Equipment Used in Demonstration Plant at Louisiana, Mo.: Mech. Eng., vol. 71, July 1949, pp. 553-560.

32/ Markovits, J. A., Braun, K. C., Donovan, J. T., and Sandaker, J. H., Special Equipment in the Coal-Hydrogenation Demonstration Plant: Bureau of Mines Rept. of Investigations 4584, 1950, 40 pp.

33/ Donovan, J. T., Josenhans, M., and Markovits, J. A., High-Pressure Vessels in Coal-Hydrogenation Service: Trans. Am. Soc. Mech. Eng., vol. 72, May 1950, pp. 357-363 (Paper 49 - PET-6).

34/ Sandaker, J. H., Markovits, J. A., and Breitschreider, K. B., High-Pressure (10,300 p.s.i.) Piping, Flanged Joints, Fittings, and Valves for Coal-Hydrogenation Service: Trans. Am. Soc. Mech. Eng., vol. 72, May 1950, pp. 365-372 (Paper 49 - PET-2).

35/ Laughrey, P. W., Gwillim, W. I., Schappert, H., and Markovits, J. A., Design of Preheaters and Heat Exchangers for Coal-Hydrogenation Plants: Trans. Am. Soc. Mech. Eng., vol. 72, May 1950, pp. 385-391 (Paper 49 - PET-1).

36/ Bruno, C. L., Coyer, F. W., and Markovits, J. A., Instrumentation for Coal-Hydrogenation Service: Trans. Am. Soc. Mech. Eng., vol. 72, May 1950, pp. 373-378 (Paper 49 - PET-4).

37/ Leonard, B. H., Jr., Gardner, G. D., and Markovits, J. A., Metallurgical and Fabrication Considerations in the Coal-Hydrogenation Demonstration-Plant Construction: Trans. Am. Soc. Mech. Eng., vol. 72, May 1950, pp. 379-383 (Paper 49 - PET-5).

38/ 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.

TABLE 18. - Estimate for commercial production of gasoline and byproducts by the hydrogenation of coal

Coal consumption and final products

	Bituminous coal			Subbituminous coal, Montana	Lignite, North Dakota
	Wyoming	Illinois	Pittsburgh seam		
Consumption:					
Run-of-mine coal ...... tons/day	11,830	13,120	10,760	16,550	22,200
Production:					
Gasoline .... bbl./day	21,660	21,630	20,250	22,360	22,500
LP-gas .... bbl./day	7,100	7,130	8,510	6,400	6,260
Phenols .... bbl./day	1,240	1,240	1,240	1,240	1,240
Total, bbl./day	30,000	30,000	30,000	30,000	30,000
Plant-cost estimate[1]					
Hydrogenation section.. M dollars	$ 97,292	$ 99,625	$106,805	$ 98,635	$ 96,865
Gas-production section. do.	54,749	53,204	54,750	57,710	60,074
General and auxiliary plants .... do.	90,879	93,974	96,265	97,678	98,303
Total M dollars	$242,920	$246,803	$257,820	$254,023	$255,242
$1 bbl./day	8,097	8,227	8,594	8,467	8,508
Field labor .... M man-hours	21,736	22,013	22,803	22,733	22,968
Steel .... tons	158,000	159,000	167,000	164,000	165,000
Manufacturing costs					
Coal as mined .... $ /ton	$3.56	$3.12	$4.02	$1.10	$1.85
Personnel:					
Labor (operation)	2,400	2,440	2,540	2,510	2,520
Supervision and clerical	620	630	655	645	650
Total personnel	3,020	3,070	3,195	3,155	3,170
Costs, $ /day for 30,000 bbl./day of liquid products:					
Coal	$ 42,111	$ 40,925	$ 43,243	$ 18,162	$ 41,066
Other materials	17,156	17,443	19,286	18,212	18,103
Other direct costs	28,177	28,636	29,913	29,462	29,591
Indirect costs	17,847	18,136	18,945	18,662	18,746
Fixed costs (15 years amortization	55,212	56,072	58,591	57,386	57,967
Total	$160,503	$161,212	$169,978	$141,884	$165,473
Byproduct credit:					
Phenols at $0.10/lb.	$ 45,000	$ 45,000	$ 45,000	$ 45,000	$ 45,000
LP-gas at $0.08/gal.	23,856	23,957	28,594	21,504	21,034
Total credits	$ 68,856	$ 68,957	$ 73,594	$ 66,504	$ 66,034
Total net costs .... $ /day	$ 91,647	$ 92,255	$ 96,384	$ 75,380	$ 99,439
Unit costs ..... $ /gal. gasoline	$ 0.101	$ 0.102	$ 0.113	$ 0.080	$ 0.105

1/ Construction costs are based on the first quarter of 1948.

TABLE 19. - Total liquid-products estimate for 30,000-Barrel-per-day coal-hydrogenation plants

	Motor gasoline		Aviation gasoline		Jet fuel, JP-3	
	78 Octane No.	82 Octane No.	91 Octane No.	100 Octane No.	Motor-gasoline plant	Jet-fuel plant
Production of major product, bbl./day	21,630	21,630	20,121	11,920	24,260	24,260
Plant cost, M dollars	246,803	246,803	240,119	276,940	253,639	242,589
Cost of major product, gal., with credit for phenols	10.2	10.3	11.4	15.0	10.3	9.8
Without credit for phenols	14.2	14.3	15.7	17.9	14.0	13.5

One hundred octane-grade aviation gasoline produced by coal hydrogenation at a cost of 15 cents per gallon is competitive with that produced from crude oil. The production of this material is only 11,920 barrels per day in a 30,000-barrel-per-day plant. In addition, 12,208 barrels per day of 91 octane gasoline is made. If alkylate could be purchased, an additional 17,450 barrels per day of 100 octane aviation gasoline could be produced.

A study was made showing the effect of various percentages of return on capital investment for coal-hydrogenation plants producing various grades of gasoline. The results of this study are shown in table 20.

An estimate was made for converting the existing Morgantown Ordnance Works (600-ton-per-day synthetic ammonia plant) to a coal-hydrogenation plant, using Pittsburgh seam coal as feed. Based on the capacity of the existing hyper compressors of 70 million cubic feet of hydrogen per day, it was calculated that 7,600 barrels per calendar day of liquid-oil products could be produced at this plant. Coal requirement is 2,640 tons per day. Capital cost for additional new facilities is 47 million dollars. With coal at $4.50 a ton, the production cost of gasoline, after credit for LP-gas and phenols, is 17.3 cents per gallon. It is estimated that a personnel of 900 would be required to run the plant. If a hydroforming unit were installed, 8,216 barrels per calendar day of marketable aromatic chemicals could be produced.

An engineering and economic study was made to determine the cost of manufacture of a 900-B.t.u.-per-cubic-foot gas, using silt washings from anthracite coal-cleaning operations. The process selected was the gas-synthesis or Fischer-Tropsch process, using two fluidized-bed reactors. Two alternates for the gasification of the silt were selected: (a) Pressure dust gasification and (b) Lurgi gasification of pellets made from the silt. In each alternate the basic process units consist of a coal-preparation plant, gasification and oxygen plants, a dust-removal system, a water-gas shift for adjustment of hydrogen and carbon monoxide ratio, a water-washing step for removal of CO_2 and H_2S, a final sulfur-removal plant, and the synthesis step wherein hydrogen and carbon monoxide react over a suitable catalyst, producing water, which condenses out, and the finished city gas.

The cost of production, including no profit, but amortizing the total investment cost over a period of 15 years, is 54.5 cents per thousand cubic feet of 900-B.t.u.-per-cubic-foot gas, using the pressure dust gasification, and 63.5 cents, using the Lurgi gasification.

Capital investment cost for the two alternates is $57,955,000 and $59,950,000, respectively, for 65,650,000 standard cubic feet per calendar day of 900-B.t.u. city gas.

An engineering and cost comparison is shown in table 21.

TABLE 20. - Cost of producing various grades of liquid products by 30,000-barrel-per-day coal-hydrogenation plants

	Motor gasoline		Aviation gasoline		Jet fuel, JP-3	
	76 Octane No.	82 Octane No.	91 Octane No.	100 Octane No.	Motor gasoline plant	Jet-fuel plant
Products, bbl./day:						
Motor gasoline	23,000	23,000	-	-	-	-
Aviation gasoline, 91 O.N.	-	-	21,491	13,576	-	-
Aviation gasoline, 100 O.N. ...	-	-	-	11,920	-	-
Jet fuel, JP-3	-	-	-	-	25,670	25,680
LP-gas	7,130	7,130	8,639	2,582	4,465	4,455
Total	30,130	30,130	30,130	28,080	30,135	30,135
Plant cost, M dollars	246,803	246,803	248,119	276,940	253,639	242,589
Cost of major product, without credit for phenols:						
No return on investment1/	14.2	14.3	15.7	17.9	14.0	13.5
40 percent income tax, 6 percent return2/	21.6	21.7	23.7	33.0 3/(23.3)	20.8	20.0
3 percent return before income taxes, 40 percent income tax, 4 percent return after income tax4/	17.8	17.9	19.6	25.1 3/(20.3)	17.5	16.6

1/ Includes cost of raw materials, operating costs, linear depreciation at 6-2/3 percent per year, a credit of other products at market value, no profit on investment and no income tax.

2/ Same as above but with 6 percent return after 40 percent income tax.

3/ If alkylate is purchased at 20 cents per gallon and blended with the surplus 91 octane to make all 100 octane (31,300 barrels) then the new selling price of the 100 octane is lowered to those figures shown in parentheses. Credit for the 91 octane is eliminated, but the capital charges are distributed over this larger production of 100 octane gasoline.

4/ Based on 50 percent of plant investment at 3 percent without taxes (loan or bond issue) and 50 percent of plant investment at 4 percent after 40 percent income tax (stock issue).

TABLE 21. - Engineering and cost comparison of pressure-dust and Lurgi methods of gasification

	Pressure-dust gasification	Lurgi gasification
Process coal .... tons/calendar day	5,760	4,194
Coal for power and steam .... do.	464	2,070
Coal for gasifier preheater .... do.	711	-
Coal for steam superheater .... do.	-	270
Total coal .... do.	6,935	6,534
Oxygen required .... do.	3,690	1,485
Operators per shift	43	59
Total plant investment including working capital and interest during construction	$60,155,000	$62,200,000
Total direct costs (silt coal at $12.5 and pellets at $2.50 per ton).	$ 19,194	$ 24,424
Total indirect costs	3,900	4,285
Total fixed costs	12,590	12,930
Total daily costs	$ 35,684	$ 41,639
Gas production, cu. ft./calendar day (900 B.t.u./cu.ft).	65,650,000	
Cost .... ¢/1,000 cu. ft.	54.5	63.5

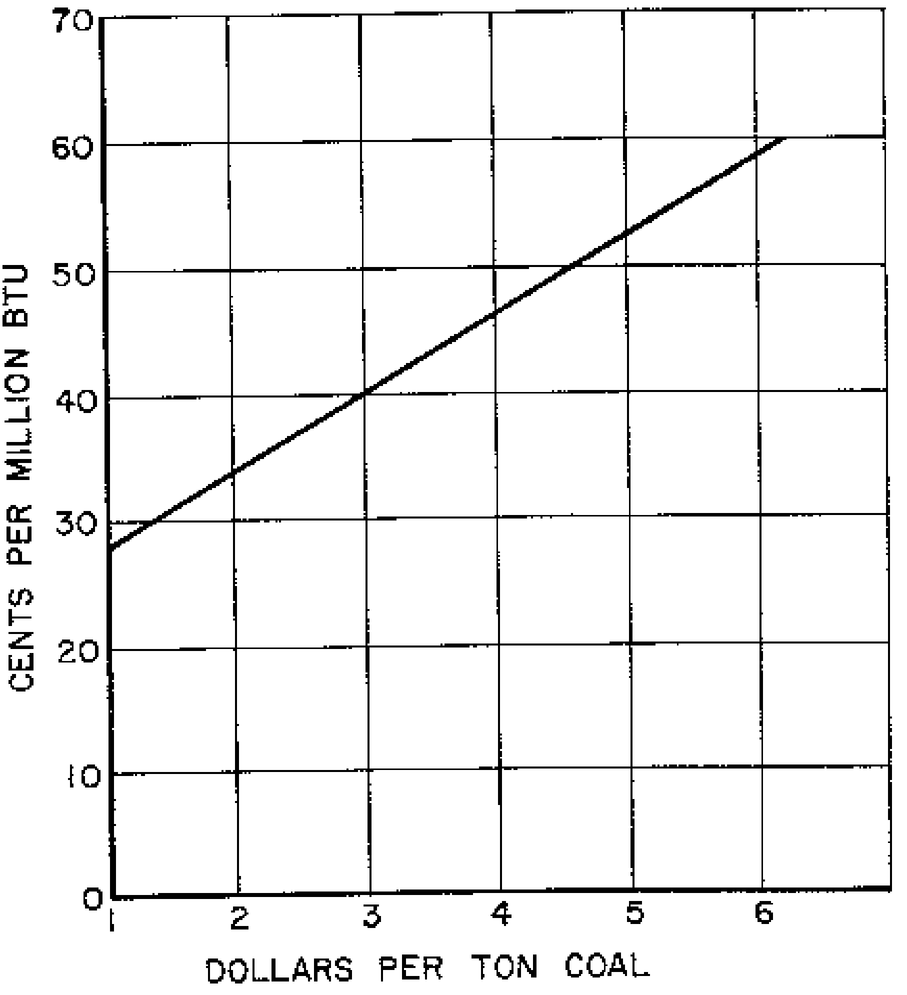

Figure 33. - Cost of byproduct city gas from synthetic liquid fuels plants vs. cost of coal at the plant site.

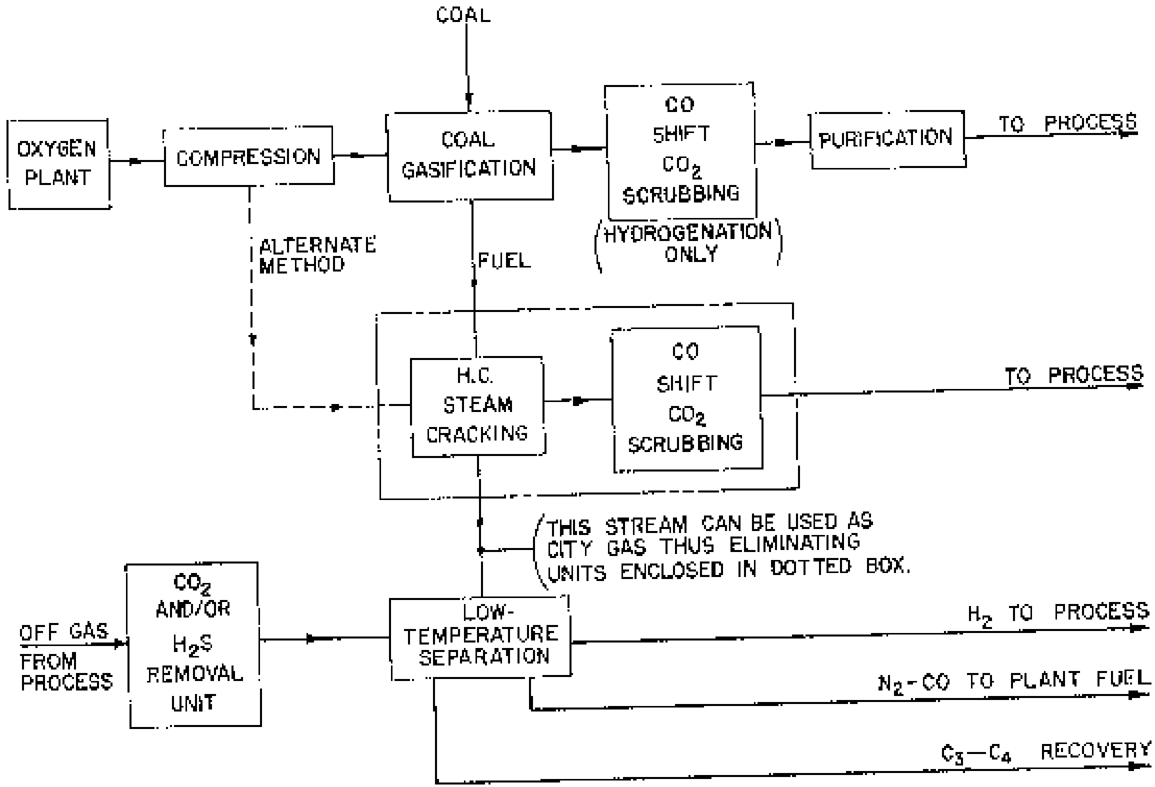

Figure 34. - Process units in synthetic liquid fuels plants making byproduct city gas.

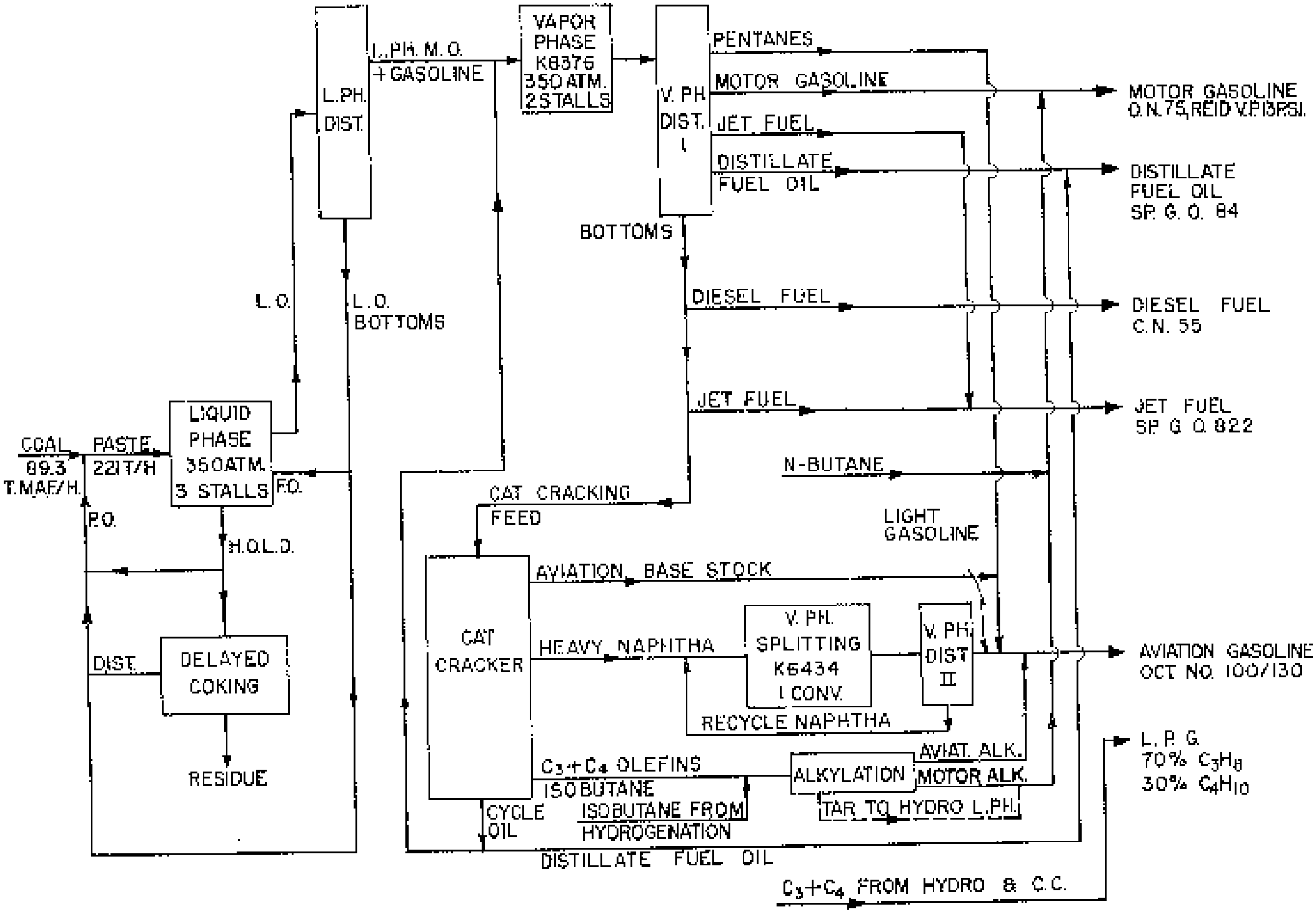

Figure 35. - Flow sheet for 10,000 bbl./day coal-to-oil plant using Alaskan subbituminous coal.

Data showing the possibilities of producing public-utility gas in a synthetic liquid fuel plant were discussed.39/40/

Hydrocarbons recovered from the off gas of synthetic fuels plants have been suggested as a source of city gas. The value of this gas to the synthetic fuels process is obtained by determining the cost of additional coal-gasification facilities required to replace the hydrogen or synthesis gas normally made from the off gas. Its value has been calculated as 44 cents per million B.t.u., using a bituminous coal costing $3.56 per ton.

The use of this gas as a source of city gas will have an important and far-reaching effect upon the gas industry. Assuming 1 million barrels per day of synthetic liquid fuel (about 18 percent of present petroleum production) and only 75-percent utilization of byproduct hydrocarbons from synthetic liquid fuels plants, about 710 billion cubic feet per day, or, roughly, 7-1/2 million therms per day will be available. This volume of gas is about 1-1/2 times the 1946 combined consumption of the cities of New York, Chicago, Philadelphia, and Detroit and about 90 percent of the total manufactured-gas production of the entire United States in 1944. Cost chart and flow diagram for this study are shown in figures 33 and 34.

Process flow sheet, material and heat balances, and cost studies were prepared for a 10,000-barrel-per-day synthetic fuels plant using Alaskan coal. It was proposed to use coal of the following analysis as the raw material:

	As mined	Moisture- and ash-free basis
H_2O	23.9	
Ash	5.1	
Volatile matter .... percent		51.8
Fixed carbon .... do.		48.2
H .... do.		5.4
C .... do.		71.5
N .... do.		.9
O .... do.		21.9
S .... do.		.3
B.t.u./lb.		12,217

The proposed plant would yield the following products needed in Alaska:

	General specifications
Aviation gasoline	100/130 grade
Motor gasoline	75 A.S.T.M. O.N.
Diesel oil	Grade "C"
Distillate fuel oil and LP-gas	No. 2
Jet fuel	JP-3

The diversification of the liquid fuels produced shows the versatility of the coal-hydrogenation process when combined with a catalytic cracking unit, such as was contemplated for this plant. The flow diagram of the proposed plant is shown in figure 35.

39/ Symonds, F. L., Laughrey, P. W., Skinner, L. C., Batchelder, H. R., and Donath, E. E., Potential New Source of Utility Gas Supply Offered by Synthesis Program - Impact of Synthetic Fuels: Am. Gas Assoc. Monthly, vol. 31, July-August 1949, pp. 18-20, 24.

40/ Symonds, F. L., Laughrey, P. W., Skinner, L. C., Batchelder, H. R., and Donath, E. E., Public Utility Gas as a Byproduct of Synthetic Liquid Fuels Production: Proc. Am. Gas Assoc., 1949, pp. 789-795.

A summary of a cost study on the coal-to-oil plant in Alaska compared to a similar plant in the United States is given below:

		Costs, plant located in U. S.	Costs, plant located in Alaska
Coal at plant site	$ /ton	1.85	6.50
Labor	$/hour	1.75	2.75
Power	¢/kw.-hr.	0.5	0.5
Period of amortization	years	15	15
Total product cost	¢/gallon	15.0	35.0
Total capital cost		$93,700,000.00	$243,800,000.00

Technical Reports and Foreign Document Work

Abstracts and Bibliographies

Compilation of synthetic liquid fuels abstracts has been continued in the bi-monthly form, and approximately 1,000 copies of each issue are supplied to a mailing list. A comprehensive coverage of current literature and patents is being maintained.

A bibliography of pressure hydrogenation was completed, which contains three sections: 2,503 annotated literature references; 3,569 annotated patent references; and a subject literature index, a subject patent index, and a numerical patent index. Preparation of a bibliography of the Fischer-Tropsch process, was begun. Completion of this compilation has been delayed somewhat beyond the time originally planned in order that several hundred German patent applications could be searched and those of interest incorporated in the bibliography. A bibliography of Bureau of Mines investigations on the production of synthetic liquid fuels was completed.41/

A general review of the research activities currently under way in the Bruceton laboratories was published.42/

Foreign Documents

Indexing of foreign documents was continued. About 1,000 additional documents were reviewed and indexed during the fiscal year. These include the separate documents in 25 FIAT reels which were later transposed to TOM reels 281-305. All documents in these files, except those in TOM reels 1-279, of special interest to the synthetic liquid fuels program are now subject indexed.

41/ Golumbic, Norma, Anderson, Hazel C., and Grass, Robert C., Revised Bibliography of Bureau of Mines Investigations on the Production of Liquid Fuels from Oil Shale, Coal, Lignite, and Natural Gas (to 1949): Bureau of Mines Inf. Circ. 7534, 1949, 53 pp. (Revision of Inf. Circ. 7304 by Arno C. Fieldner and Paul L. Fisher.)

42/ Grass, R. C., and Storch, H. H., Coal-to-Oil Research at Bruceton, Pa.: Chem. Eng. News, vol. 28, Feb. 27, 1950, pp. 646-648.