STATE OF ILLINOIS
DWIGHT H. GREEN, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
FRANK G. THOMPSON, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

CIRCULAR NO. 128

TRENDS IN COAL UTILIZATION

BY

FRANK H. REED, G. R. YOHE, O. W. REES,
AND HAROLD W. JACKMAN

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TRENDS IN COAL UTILIZATION*

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In an article entitled "Today's Efficiencies, Tomorrow's Wastes" in the November, 1946, issue of Chemical Industries (1),** Charles M. A. Stine said:

"Coal was but a fuel to our grandfathers. To us, it is a storehouse of raw materials essential in the making of countless things. From coal today we derive all of the colors of the rainbow, the scents of flowers, healing drugs, plastics, brush bristles, fine hosiery, fabrics, explosives, and an endless list of products.

"Since our grandfathers' time, great industries have declined and greater industries have risen because of the simple realization that coal is not only a fuel but a veritable storehouse of chemicals--basic building materials of Nature. Once we saw coal in that light, and industrial techniques were developed for its more efficient utilization as a chemical raw material, coal's influence was felt in such diverse fields as the growing of indigo in India, of roses in Persia, of hogs in Mongolia, of silkworms in Japan, and of rubber in Malaya.

"Whereas, a few generations ago, the most efficient utilization of coal might have been considered to be achieved by the invention of a better coal-burning furnace, it is now not beyond probability that, a few generations hence, the use of coal as fuel alone may be prohibited by law as criminally wasteful."

The coal reserves which are estimated to be sufficient to last well over 1,000 years at present rates make up 98.8 percent of the mineral fuel reserves of this country. The remaining 1.2 percent consists of 0.8 percent oil shale and 0.2 percent each petroleum and natural gas (2).

The use of coal as a fuel had a long history before petroleum and natural gas came into the picture; shale oil is not yet of commercial significance, but must not be overlooked as a future source of premium fuels. Petroleum and natural gas have appeared in the fuels markets to an appreciable extent only since the beginning of the

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* Presented before Coal Technology Division, Pittsburgh Section of the American Chemical Society, March 24, 1947.

** Numbers in parentheses refer to Bibliography at end.

present century, and then almost entirely as fuels specifically refined and modified to suit definite uses. It is within the last decade that they have become seriously competitive with coal in certain markets. Coal has been burned principally as mined, with a minimum of cleaning, sizing, and preparation necessary to meet the competition of other coals and the demands of the equipment in which it is to be used. Burning equipment which provides an insufficient supply of air or oxygen under conditions otherwise proper for complete combustion is the chief cause of the smoke nuisance which has brought about the smoke abatement campaigns in many of our large cities. An insufficient supply of air or oxygen in the burning of oil or gas would result in an even greater smoke nuisance. Carbon black is produced by limiting the air supply in the burning of natural gas, and smoke screens and smudge fires are readily produced by burning oil with a limited supply of air. When oil and gas were introduced as fuels in the domestic and industrial markets, the necessity for complete combustion was recognized, not only in order to prevent smoke and dirt, but also in order to utilize as completely as possible the entire fuel value of a high-priced source of heat and energy. Consequently, the vendors of gas and oil developed suitable burning equipment and permitted the burning of these fuels in approved installations only. Coal, on the other hand, has been priced so low that the domestic consumer has never paid serious attention to the poor efficiencies obtained through losses by incomplete combustion and the use of poorly designed equipment.

DOMESTIC HEATING

The development and use of household insulation reduced the cost of home heating proportionately just as much for the user of coal as it did for the user of oil and gas. However, it played into the hands of the gas and oil producers to the disadvantage of coal because it enabled the householder in many localities to heat an average-sized insulated house cleanly and automatically with oil or gas approximately as cheaply as he had formerly heated an uninsulated house of the same size with coal. Even though the total fuel cost of automatic home heat by oil or gas may be appreciably more than that of heating the same space by coal, the greater cleanliness and ease of maintenance has caused these premium fuels to be favored over coal to such an extent that many coal producers are greatly disturbed over the inroads which are being made into the market for domestic coals.

If we consider the quantities of coal involved in domestic utilization, we will see that in general the tonnages demanded for this market have increased in the past few years. Table 1 shows re-

Table 1.--Retail Deliveries of Domestic Fuel

Year	Coal Thousands of tons Deliveries	Coal Index	Oil Thousands of bbls. Sales	Oil Index	Gas Millions of cu. ft. Consumption	Gas Index
1936	84,200	100	99,257	100	345,000	100
1937	80,076	95	116,617	117	371,844	108
1938	68,520	81	118,323	119	367,772	106
1939	71,570	85	136,232	137	391,153	113
1940	87,700	104	160,379	162	443,646	128
1941	97,460	115	167,514	169	447,000	130
1942	104,750	124	168,989	171	498,537	144
1943	122,764	146	155,251	156	529,444	153
1944	124,906	148			582,000	169
1945	121,805	145				

tail deliveries from 1936 to 1945. It includes coal supplied through retailers for heating homes and small businesses, and for more ready comparison, index values are shown in which 1936 has been used as the base year. It will be noted that tonnages delivered to retailers were below the base year in 1937, 1938, and 1939, increased in 1940 through 1944, and dropped slightly in 1945.

Data for domestic utilization of oil and gas are also shown in table 1 for comparison. It will be seen that oil made a steady and more rapid increase through 1942 than did coal. A drop is shown for 1943 which may have been due in part to scarcity of materials for manufacturing new oil burning equipment, to a lower supply of fuel oil due to demands for huge supplies of motor fuels in the war years, and to transportation difficulties, particularly to the eastern seaboard.

The domestic use of gas showed a steady and more rapid increase than coal from 1936 to 1944, but a slower increase than oil during comparable years.

K. C. Richmond, Editor of Coal-Heat, provided the figures shown in table 2 for estimates of stoker coal required from 1933 to 1947 (3). In general, these requirements have increased throughout the period. The increase of 3,482,000 tons in 1946 is exceeded only by 4,140,000 tons for 1941.

Table 2.--Annual Rate of Stoker Coal Consumption

Date	Tons
January 1, 1933	3,880,000
January 1, 1934	4,858,000
January 1, 1935	6,141,000
January 1, 1936	7,837,000
January 1, 1937	10,487,000
January 1, 1938	13,731,000
January 1, 1939	16,450,000
January 1, 1940	19,680,000
January 1, 1941	23,400,000
January 1, 1942	27,540,000
January 1, 1943	30,170,000
January 1, 1944	33,920,000
January 1, 1945	37,098,000
January 1, 1946	40,548,000
January 1, 1947	44,030,000

Table 3.--Geographical Distribution of Fuel Choices, Released by National Housing Agency (In percent)

Fuel	Total U. S.	New England	Middle Atlantic	East, North Central	West, North Central
Coal	27	30	32	51	26
Oil	21	55	22	11	15
Gas	52	15	46	38	59

Fuel	South Atlantic	East, South Central	West, South Central	Mountain	Pacific
Coal	30	51	1	20	5
Oil	48	17	3	19	17
Gas	22	32	96	61	78

Thus, the trend of domestic utilization of coal, as well as oil and gas, has been up during the past several years. But what of the future? Some surveys of types of heat planned for new homes have been made. A report of one of these surveys, recently published by the National Mineral Wool Association (1946), is given in table 3. This indicates that coal heat, on a national basis, definitely is not uppermost in the plans of new home builders (27 percent for coal against 73 percent for oil and gas). Another of these surveys, the Institute of Boiler and Radiator Manufacturers Heating Trends Survey (4), represents a cross-section of the thinking of more than 750 builders and architects in the territory east of the Mississippi and north of the Ohio rivers. The results of this survey, in regard to planned types of heat in new homes, are summarized as follows:

1. Oil firing - 53 percent (a reduction from 59 percent in use in 1940).
2. Gas firing - 38 percent (an increase from 17 percent in 1940).
3. Coal, hand firing - 7 percent (a drop from 23 percent in 1940).
4. Coal, stoker firing - 1 percent (a drop from 1.6 percent in 1940).
5. Unknown - 1 percent.

While figures arrived at in different surveys vary, the trends shown are definitely away from coal.

These trends away from coal as the future domestic fuel offer a challenge to producers of domestic coal. What is to be done

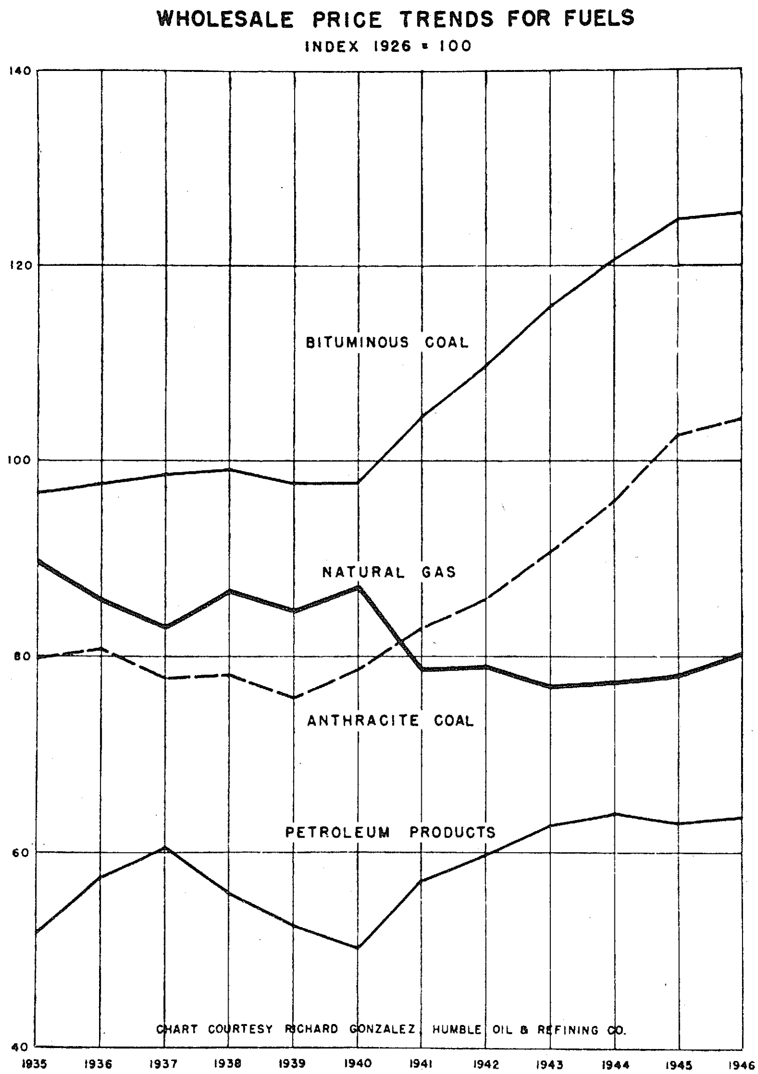

Fig. 1

about it? Future choice of fuel for the home will be based on two factors; first, cost, and second, convenience and cleanliness. At the present time coal has lost much of its cost advantage due to the fact that coal prices have risen steadily since 1940, while petroleum products have risen less steeply, and natural gas has actually shown a drop up to 1943 and only a slight rise since then (5) (fig. 1). The price differential in favor of coal has become so small that many consumers are willing to pay the additional cost in order to obtain the added convenience and cleanliness of oil or gas. This convenience is greatly desired, and coal heating plants have not yet provided it to the degree demanded by the home owner and his wife.

POWER GENERATION

Transportation

The Trend in Railroads

In the field of power generation we see that the trend away from coal is particularly marked in the transportation industries, and the emergence of the diesel-powered locomotive during the last decade is resulting in curtailed purchases of bituminous coal by the railroads. Robert B. McColl, President of American Locomotive Company, has stated that 95 percent of all locomotives now being ordered are diesel-electrics, and most of the other 5 percent are being ordered by roads deriving a large portion of their income from hauling coal (6).

Table 4.--Locomotives Owned (7)

Engines owned by Class I railroads	July 1, 1940		Sept. 1, 1945	
	Diesel	Steam	Diesel	Steam
Passenger	93	6,983	185	6,269
Freight	4	24,807	304	24,620
Combination pass. and freight	0	1,177	89	1,417
Switch	565	7,395	2,214	6,915
Total	662	40,362	2,792	39,221

Reference to table 4 shows that from 1940 to 1945 the Class I railroads increased their number of diesel locomotives from 662 to 2,792, while the steam locomotives decreased from 40,362 to 39,221. Diesel units appear to be especially suited to switching, where one diesel switcher is said to do the work of three steam switchers of comparable horse-power and at one-half the operating and maintenance cost.

Table 5.--Locomotives Ordered for Domestic Use (8)

Year	Diesel	Steam
1930	18	382
1935	60	30
1940	492	207
1941 (last year before war)	1,104	302
1945	691	148
1946	856	55
On order, Jan. 1, 1947	534	64

Table 5 shows how orders for the diesel units have increased over the past 16 years, while the orders for steamers have decreased. In 1941, the last year before government war buying put a stop to free industrial purchasing, there were 1, 104 diesel locomotives ordered against only 302 steamers. In 1946, the total number of locomotives ordered was less, but nearly 94 percent of those ordered were diesels.

It has been predicted by the manufacturers of diesel engines that by 1955, 40 percent of the total railroad hauling and switching tonnage will be handled by diesels, and stated that their ultimate aim is to dieselize the railroads completely. With $2,000,000,000 still invested in coal-burning locomotives this change must necessarily be gradual.

Causes for Swing to Diesel Power

This swing to diesel power by the railroads is not without cause. V. B. Fowler, Assistant to the Vice President of Electro-Motive Division of General Motors, in a recent talk gives the following advantages for diesel locomotives (9).

1. Four to five times higher thermal efficiency than reciprocating steam engines, and three times higher than the steam turbine locomotive.

2. Higher availability than steam. The national availability average on diesel switchers is 94 percent, on streamliners 93.6 percent, and diesel freights 88.1 percent. Steam locomotives average about 75 percent for the newest equipmemt.

3. Far greater ability to start loads and pull them up grades. The starting tractive effort of the 5,400 h.p. diesel freight locomotive is 225,000 pounds, as compared to 135,000 pounds on the Union Pacific's famous "Big Boy."

4. Freedom from expensive supporting services such as coal handling, ash dumping, water treatment, and extensive repair facilities.

5. Marked increase in monthly mileage per locomotive. Diesel passenger locomotives average 25,000 to 30,000 miles per month. A record for a passenger steam locomotive is 12,000 miles.

6. Ability to maintain fast schedules with increased safety and cleanliness, due to lower center of gravity and absence of smoke and steam.

7. The fact that operating and maintenance costs of diesels have, over a ten-year period, turned out to be about 50 percent of the cost of moving similar trains by steam.

Furthermore, the fuel carried by the diesel locomotive is more concentrated; a given weight contains approximately 50 percent more B.t.u. and can be carried in a somewhat smaller, more conveniently arranged space.

In speaking of relative efficiencies of steam and diesels, the following quotation from C. F. Duggan, Vice-President of the Illinois Central Railroad, is of interest (10):

"Based on output at the rail, overall thermal efficiencies will range from 20 to 25 percent for the present diesel-electric, and from 6 to 9 percent for a thoroughly modern reciprocating steam locomotive.

"This marked difference in thermal efficiency is likely to be misleading, however, unless the cost of the fuel in terms of heat units is considered. Our present coal cost runs about 13 cents per million B.t.u., and diesel fuel oil about 42 cents per million B.t.u. Placed on the basis of full-load drawbar horsepower output, this results in a cost of 0.45 cent per horsepower-hour for the diesel-electric, and 0.68 cent per horsepower-hour for the modern steam locomotive. This difference in fuel cost may be offset by the much lower first cost and resulting lower fixed charges of the steam locomotive, although its lower availability must be considered. It should also be remembered that these figures have to do with new units. Efficiencies such as these cannot be expected of the older locomotives."

Table 6.--Coal and Diesel Fuel for Locomotives (11)

Eight months Jan. - Aug.	Consumption		Unit cost (a)	
	Coal as locomotive fuel (tons)	Diesel fuel in locomotives (gallons)	Coal per ton	Diesel fuel per gallon
1940	52,424,282	37,060,028	$2.45	$0.0481
1946	66,456,408	328,416,469	3.73	0.0549
Percent increase, 1946 over 1940	26.8%	786.2%	52.2%	14.1%

(a) Including handling charges.

Effects of Swing to Diesel Power

The Bureau of Transport Economics and Statistics on November 13, 1946, published the figures shown in table 6 on coal and diesel fuel used in locomotives during the first eight months of 1940 and of 1946. It is seen that consumption of coal increased 26.8 percent, while diesel fuel increased 786.2 percent during this period. It is also seen that the unit cost of locomotive coal, including handling charges, increased 52.2 percent over this time, while diesel fuel increased only 14.1 percent. This publication goes on to state that 14,136,625 tons of coal would have been required to produce the service performed by the diesels during the eight months of 1946. From this it can be computed that 1,000 gallons of diesel oil are equivalent to 43 tons of coal, and by applying the unit costs of coal and diesel fuel given it is computed that coal would have cost 2.9 times as much as the diesel fuel used.

Information shown in table 7, also released by the Interstate Commerce Commission (12) shows the amount of coal and diesel fuel purchased by Class I railroads from 1940 to 1945. It is noted that the coal purchased was no greater in 1945 than in 1942, but that diesel fuel increased from 4.4 million to 10.8 million barrels during that time.

Table 7.--Coal and Diesel Oil Purchased by Class I Railroads for all Purposes (12)

Year	Coal (tons)	Diesel oil (barrels)
1940	91,726,397	1,933,225
1942	124,306,358	4,419,956
1944	138,795,009	7,874,416
1945	124,219,729	10,810,868

From accounts in the daily papers it is evident that the trend toward diesels and away from coal-fired locomotives continues. Such headlines as the following are seen: "Pennsylvania Buys 25 Diesels," "Complete Dieselization of Monon Railroad Seen for This Year," "64 Diesel-Electric Engines are Ordered by Union Pacific," "746 Diesels are Ordered by 30 Roads," etc. It would appear from such headings, and from consideration of all the factors, that there is no long-term future for coal on the railroads unless through research a coal-burning locomotive can be developed having operating costs and reliability equal to or better than those of a diesel.

The possibility of developing a coal-burning locomotive to compete with the diesel, as we all know, has not been overlooked. Bituminous Coal Research expects that actual service tests on two coal-burning gas turbine locomotives will be made early in 1948. John I. Yellott has predicted that their operating costs will be of the order of 26 cents per mile in comparison with 56 cents to 60 cents per mile for diesel-electric locomotives (13).

It is of interest here to note that the Baldwin Locomotive Works is to build an oil-burning gas turbine locomotive for the Santa Fe Railroad (14). All concerned will be much interested in the performance and relative costs of operation of these coal- and oil-fired turbine locomotives as well as in the comparison with the diesel-electric.

Confidence in the coal-burning turbine locomotive has been expressed by C. F. Duggan of the Illinois Central (10):

"A coal-burning gas turbine-electric locomotive, now in the development stage, will undoubtedly prove cheaper to operate than either the steam or diesel-electric. Although its thermal efficiency (15-20 percent) will be slightly lower than that of the diesel-electric, the fact that it will use fuel which is far less costly in terms of heat units than the diesel oil will result in lower operating cost."

The trend toward oil as a mover of the world's commerce is not confined to the railroads. Eugene Holman, President of the Standard Oil Company (New Jersey) (15) states that "Over 75 percent of the world's merchant fleet tonnage burns oil today - as compared with 4 percent in 1914."

Municipal Power Plants

In addition to this shift to oil power by the carriers, there is a certain amount of replacement of coal-fired equipment in municipal power plants. Diesel engines are found in the smaller light and power plants of practically every state in the Union. Illinois was credited in July, 1945, with 23 such municipally-owned plants, Iowa with 73 and Pennsylvania with 6. Table 8 shows the growth of the installed diesel-electric horse-power in such plants since 1935. It is seen that this power more than doubled from 1935 to 1943. In November, 1946, it was reported that 900 communities owned diesel-operated power plants (16), and that the number was increasing steadily.

Table 8.--Municipal Diesel-Electric Plants (17)

Year	Diesel engine installed horse-power
1935	400,000
1937	480,000
1939	730,000
1943	850,000

The story is summed up by the experience of one small Illinois community, said to be typical. A 210 h.p. diesel engine was purchased by the municipality. Within four years it had paid for itself solely out of earnings, rates for electricity had been reduced, and power was furnished without charge to the municipality for street lighting and water pumping. Coal for the original steam plant had cost $16 per day; cost for diesel fuel was only one-third that amount (17).

However, coal still plays an important part in power generation, and will continue to do so. J. R. Mahoney of the University of Utah (18) states that 65 percent of all industrial power and 55 percent of the country's electric power are still generated by coal. In the most modern power plants coal consumption per kilowatt hour is less than one pound, and the nation's average is approximately 1.3 pounds. The increase in efficiency of electric power plants during the last 45 years is depicted in table 9.

Table 9.--Production of Electric Power from Coal (a)

Year	Pounds of coal consumed per kilowatt-hour	Efficiency (b) (In percent)
1902	6.6	4.1
1917	3.3	8.3
1927	1.86	14.7
1935	1.46	18.7
1940	1.35	20.2
1945	1.30	21.0
?	1.00	27.3

(a) Data from U. S. Bureau of Mines and Federal Power Commission.
(b) Assuming 12,500 B.t.u./pound of coal; using 3,415 B.t.u. as equivalent to 1 kilowatt-hour, e.g.,

$$\frac{3415}{12500 \times 1.46} = 18.71$$

COKE MANUFACTURE

The best of our coking coals are approaching depletion. In response to the demand for "smokeless" coal, the domestic heating market as well as coke manufacture is contributing to the exhaustion of low-volatile coals, and the natural tendency to use the best first has resulted in the exploitation of the low-sulfur high-volatile coals by the coke industry.

During the war years when the demand for steel was high and transportation facilities were overloaded, certain plants demonstrated that it was possible to make acceptable coke from coals of lower rank, and that cokes of higher ash and sulfur content and of weaker structure could be used with acceptable blast furnace efficiencies if the operation of these furnaces was adjusted suitably. In certain instances, char made by partial devolatilization of high-volatile coal has been substituted for low-volatile coal.

The approaching exhaustion of the better coals, along with that of the high-grade ore, marks out the trend for the steel industry. Processes must be developed (they are, in fact, being studied now) for the use of lower rank coals, weaker cokes, and up-graded ores. Blast furnace operation will have to be modified to suit these materials.

The solution of this problem must be found in the immediate future. Our present civilization is based upon the wide use of iron and steel. No substitute for coke and the blast furnace in the reduction of iron ores has so far gained sufficient prominence to be given serious consideration.

While speaking of the carbonization industry, it may be well to point out that the wide variety of chemicals, much publicized as stemming from coal, actually come largely from by-products of coking, not directly from raw coal. No cheaper source has yet been found for most of these crudes, yet only a little over half of the coal tar is currently distilled. Competition from petroleum products is being felt in this field, and the experiences of the war taught us that if the urgency is sufficiently great, many of these "coal tar" intermediates can be made from petroleum.

SUMMARY OF COAL UTILIZATION

A summary of the consumption of coal by industries in 1945 shows the following:

	Percent
Coke Industry	17
Electric Utilities	13
Heavy Industry	26
Railroads	22
Retail Market	22
	100

In the light of trends described above it is evident that railroads and the retail market face a serious loss of trade to competitive fuels; utilities and heavy industry may be in a better position to continue with solid fuel, but here too, competition is being felt. Coke manufacture alone is not immediately threatened by fluid fuels, but who can say that this immunity will continue indefinitely?

TRENDS IN COAL RESEARCH

We have seen that there are many unsolved problems confronting the coal technologists. It is also well known, but in the past at least has been less well appreciated, that the solving of problems requires much investigation and experiment - the type of work which we call research.

It is gratifying to those of us who are interested in coal problems to note that there is a definite upward trend in the amount of coal research being carried on. Depicting this trend, but not by any means giving complete data on investments in coal research, is figure 2, which shows the rapid rise in expenditures for general research by Bituminous Coal Research in recent years (19). The budget figure for 1947 has been announced by Dr. Rose as $447,200 (20). The expenditures by the Bureau of Mines for "Fuel Testing" show a rising trend that is less steep.

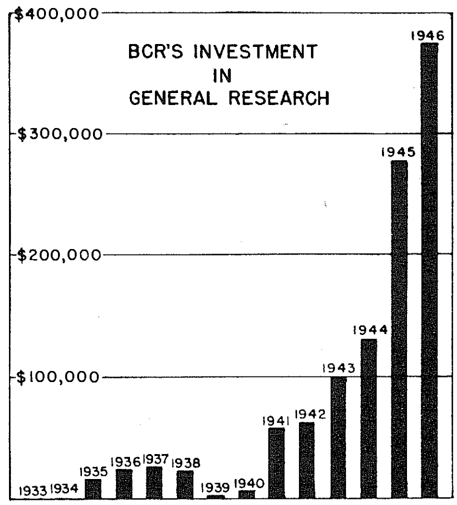

Fig. 2.--BCR's Expenditures Grow. Amounts are exclusive of projects of Locomotive Development Committee.
(From Bituminous Coal Research, Vol. 6, No. 1, 1946)

However, before we congratulate ourselves that all is well, and that research will shortly restore coal to an advantageous position among its competitors, let us examine the trend, past as well as present, more critically. In about 1911, Mellon Institute for Industrial Research began operating on a fellowship system, and in that year a fellowship on petroleum refining was initiated. It has been continued ever since. But what of other fuel industries, and in particular bituminous coal? Figure 3* shows the number of persons engaged in research at Mellon Institute by years since 1925 on (1) petroleum refining, (2) gas by-products, gas purification and natural gas, (3) anthracite, and (4) smoke abatement and coal products research, exclusive of the work on tar and its products. The last are excluded because research on them does not reveal the nature of coal nor contribute directly to its utilization. This picture may be subject to some distortion due to turnover within certain years, as total numbers of persons were counted, regardless of rank or length of employment, but it does show that over the years, other fuel research has far outstripped coal at this Institute.

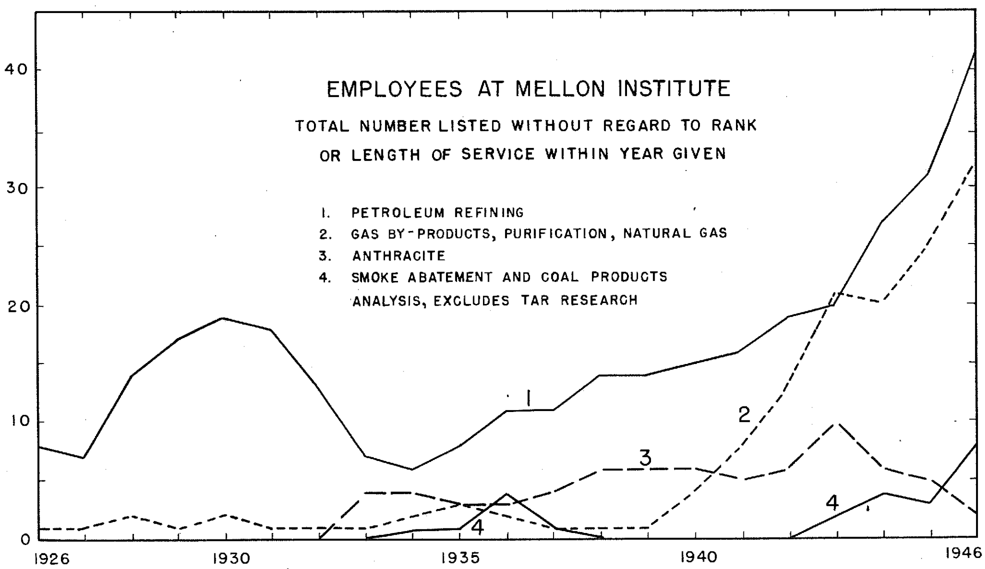

Fig. 3

* Data for figures 3 to 5 taken from the News Edition of Ind. Eng. Chem. and Chem. and Eng. News for the years represented.

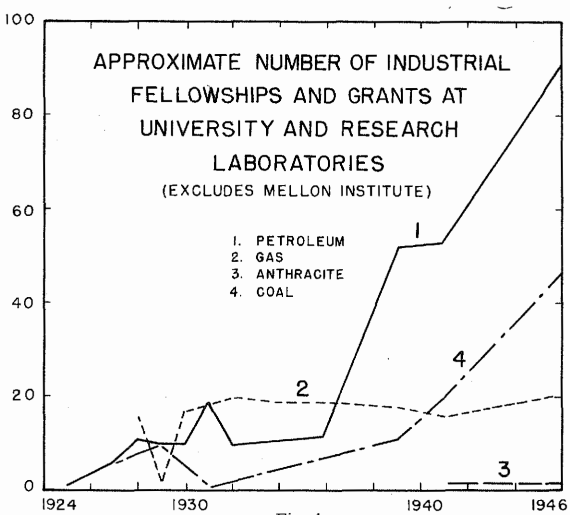

Fig. 4

To pursue the question further, let us examine the trend in sponsorship of fellowships elsewhere. Figure 4 shows the number of fellowships and grants supported by companies in several lines of fuel research. This does not include fellowships at Mellon, nor does it include those sponsored by such associations as the A. G. A., A. P. I., B. C. R., Michigan Gas Association, etc. It will be seen that oil companies have for years sponsored more research in our universities and comparable laboratories than has the coal industry. Figure 5 shows approximately the total fellowships and grants sponsored by companies and trade associations over the same years, and reveals a similar trend. No claim is made for strict accuracy in these figures, because all the reports have not been made on a sufficiently detailed basis, but the comparison between the fuels represented is significant.

These data do not complete the picture, for they reveal nothing of the work carried on in each industry's own laboratories. It is no secret that numerous petroleum companies have their own well-staffed research laboratories which have been investigating the problems of the industry and devoting time and effort to fundamental studies for many years, but where is the coal company that has done a comparable job on its product? And the trend in the petroleum field is still upward. Gustav Egloff has stated (21): "As an indication of trends in industrial research, an authority estimates that by 1950 as high as ten percent of petroleum refinery personnel will be engaged in research projects." In the same paper he says: "Among the larger corporations those

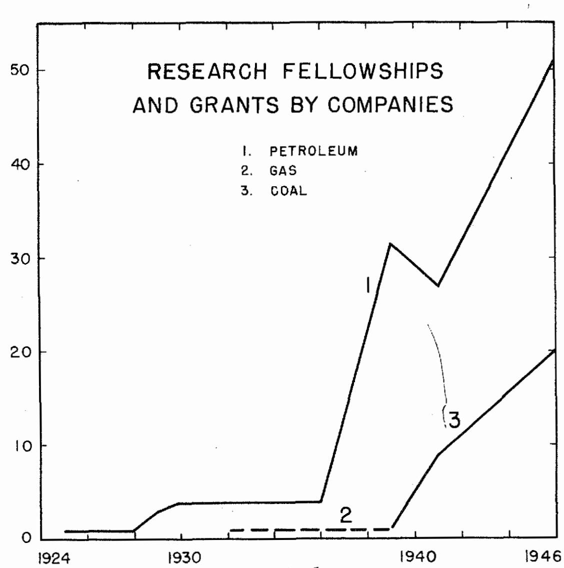

Fig. 5

of steel, coal, railroad, milling and textile industries lag far behind in research ...."

There is a difference between the positions of the coal and oil companies which may well be pointed out. There are comparatively few oil companies, and in general they are large and prosperous, while in the ranks of the coal producers there are many small mining companies that cannot afford, and should not attempt, to build research laboratories. Research is expensive; it takes time as well as money to reach the stage where realization on the investment becomes profit. This is particularly true of fundamental research which has no immediate dollars-and-cents goal in view. Cooperation is undoubtedly the solution here; support of associations, such as Bituminous Coal Research, which can organize and carry on research, sponsoring of fellowships which will result in additions to our store of knowledge about coal and at the same time train men for further service to the industry, and the support of investigations at established research laboratories such as the Fuel Research Laboratory at Carnegie Institute of Technology and at our universities. It is good to see the present trend in this direction, yet it would seem that an industry as important as the coal industry should be able to bear more research, and that a resource as rich as our coal should be the subject of more extensive investigation.

Now let us consider briefly some of the recent trends in new developments which are probably indicative of the factors to be considered in directing research projects on the utilization of coal.

Looking forward to the dwindling of our petroleum reserves, the Bureau of Mines has been investigating for some years the preparation of liquid fuels by the Bergius process. In 1944 money was appropriated for a pilot plant which is now under construction at Louisiana, Missouri. It is reported that gas-synthesis processes of the Fischer-Tropsch type will be tried out in this plant also. A gas-synthesis research laboratory is also under way at Morgantown, West Virginia. Here the use of oxygen in gasifying coals will be tried by the Bureau of Mines, and, no doubt, much important fundamental and practical information will be gained.

In January of this year the Bureau of Mines set fire to one section of a $2\frac{1}{2}$-foot coal seam near Jasper, Alabama (22). If gasification of coal seams in place underground becomes successful and widely applicable, it will provide not only a method of reclaiming coal which would not be used otherwise, but also, a new source of raw materials for the manufacture of gas and synthetic liquid fuels.

An economic process for the synthesis of gasoline from natural gas is reported by Hydrocarbon Research Incorporated (23) of New York City. A plant is to be built at Brownsville, Texas, for the daily production of 5800 barrels of motor fuel, 1200 barrels of diesel fuel and 150,000 pounds of crude alcohols. Allowing 3½ cents per gallon for the diesel fuel and ½ cent per pound for the alcohols, it is estimated that the gasoline will have an overall cost of 5 1/4 cents per gallon which would put it in the competitive field with gasoline from petroleum. The process is dependent upon cheap oxygen. The company estimates that this can be produced by the Linde-Frankl low pressure process at a cost of 4.8 cents per thousand cubic feet. The plant is designed to produce 40 million cubic feet of oxygen per day.

As soon as the Brownsville plant has demonstrated that it can operate successfully and continuously over a period of time on the above basis, our natural gas reserves of 175 trillion cubic feet will be equal potentially to our oil reserves as a source of liquid fuels. The company estimates that gas at 17 cents per thousand cubic feet just balances crude oil at the refinery at $1.35 per barrel.

Another plant for which very similar claims are made is being planned by the Stanolind Oil and Gas Company for operation at Hugoton in the southwestern Kansas gas field (24).

Hydrocarbon Research is projecting another use for cheap oxygen - the production of city gas from coal and oxygen. It reports the successful construction and operation of a pilot plant for city gas, the heating value of which varied from 580 to 900 B.t.u. per cubic foot (23). Their estimates indicate that by applying advanced oil refinery techniques city gas can be made in such localities as New York City from bituminous coal and oxygen at a cost below the cost of natural gas purchased at 5 cents per thousand cubic feet in Texas and sent to the east coast by pipe line. The company reports plans for a pilot plant to produce "city gas" or "pipe line" gas of 1000 B.t.u. heating value directly and continuously from coal and oxygen. Their present calculations indicate that 6 cent gasoline from $2.00 per ton coal is not more than two or three years away.

A news item in the March 10 issue of Chemical and Engineering News is of definite interest and importance in this connection (25). The Pittsburgh Consolidation Coal Company is to undertake an accelerated modernization research and development program concentrated on commercial processes for converting coal into gasoline, other liquid fuels, and gas of high heating value.

The present trend in development of synthetic liquid fuels has been nicely summarized very recently in Petroleum Processing (26):

"There is little question that the Bureau's work constitutes one of the largest present research programs in the field of synthetic liquid fuels. It is highly significant to note, however, that Robert P. Russell of the Standard Oil Development Company recently stated that one-third of his company's present annual research budget is devoted to studies in this field. Moreover, many other petroleum companies (Texas, Gulf, Standard of Indiana, Phillips, etc.) and others (Koppers, Kellogg, Pittsburgh Consolidation Coal, etc.) are also busily engaged in research on the Synthine and other liquid fuel processes."

The present upward trend in coal research is preponderantly along the lines of "practical," or applied research. It is unfortunate that fundamental research on coal has not, over the years, been considered an attractive field of endeavor by scientists generally, nor been deemed worth the cost by the industry, for now we find ourselves face to face with many baffling practical problems, but deficient in fundamental knowledge upon which to base their solutions. The value of this fundamental information about our resources has been demonstrated many times in other fields; as an example that it may benefit coal, consider the early work on oxidation methods of studying coal constitution. This "academic" work showed that aromatic carboxylic acids were derivable from coal (27); recent work on the preparation of aromatic acids on a pilot plant scale at the Coal Research Laboratory of Carnegie Institute of Technology (28) indicates the possibility of practical importance and value of such findings. It is a hope more than it is a present trend that the pace of fundamental research shall be stepped up.

It is understandable that applied research should predominate in the present trend, for coal literally has been forced into it. It is competition from oil and gas, which are easier to burn smokelessly, that is pushing the study of smokeless solid fuels and smokeless coal burning equipment in the domestic field. It is strong, hard competition from the convenient, ashless oil and gas that is forcing the work on automatic ash removal coal burners and on gasification of coal itself. It is the cleanliness of other fuels that has brought us cleaner coal. It is relentless economic rivalry of diesel locomotives that is making necessary the investigations of better, more efficient coal burning power units. The investigation of coals heretofore not considered as raw materials for metallurgical coke has been prompted by industrial necessity growing out of cost of transportation and approaching depletion of certain coals which have long been used for this purpose. It is the spectre of approaching exhaustion of petroleum resources that has made it wise to explore the difficult path of coal liquefaction by hydrogenation.

This is not an attempt to belittle applied research. Such work is needed, and desperately needed, yet we must face the facts that we know far too little about what coal really is, and that we have far too few scientists at work unraveling its tangled constitution.

A paragraph on "Research Profits" appeared in a recent issue of our news journal. It is of such significance that quotation is justified here.

"Speaking recently on the savings that have resulted from his company's research effort over a period of ten years, Robert P. Russell, president of the Standard Oil Development Company, asserted that a total of $15,400 of added profit to the stockholders was realized for each thousand dollars spent by the research and development groups. Savings in royalties which otherwise would have been paid to outside groups amounted to $3,700 for each thousand dollars spent on research and development; profits realized through process and product improvement were $9,600; profits from new products were $2,100 (29)."

There are some hidden factors in this computation. The research workers at the Standard Oil Development Company have access to the technical literature that records the results of years of experimental work, applied and fundamental, by thousands of scientists throughout the world. Insofar as their results have been of use to Standard Oil, these thousands have worked free for that organization. Yet all of our research is on this type of cooperative basis; chemists investigating coal have access to the same literature. Applied research everywhere makes use of whatever fundamental results it can, and it is part of the responsibility of those sponsoring and doing coal research now to see to it that the applied researches of the future shall have a firmer foundation of fundamental knowledge than do such investigations today.

And of the future? Today the trend in fuel utilization is definitely away from solid fuels with their attending problems and nuisances, and toward fluid fuels which are clean, convenient, and readily adaptable to automatic equipment. The trend is away from gloves, shovel and broom, and toward the easy-turning or automatic valve.

Meeting of insistent customer demands is characteristic of American industry. Will not the demand for fluid fuels be met sooner or later; more or less completely? And is it not likely to be shown that present research on improved coal burners is, after all, a "stop-gap" type of research which is now necessary to help tide the coal industry along until the more inevitable developments are perfected?

Would it not be to the ultimate advantage of the coal industry to learn more of the inner and intimate nature of our coal; to study more exhaustively the processes whereby its complex molecules may be converted into simpler ones which then may be reformed into "tailor-made" fuels, chemical intermediates, and the like? For then, far from competing with our friends in petroleum technology, we would be cooperating with them. Fortunately, this trend is already discernible; it is the trend which coal men should encourage and support.

BIBLIOGRAPHY

1. Stine, Charles M. A., Today's efficiencies, tomorrow's wastes: Chemical Industries, vol. 59, No. 5, pp. 824-5, 1946.

2. Fieldner, Arno C., The application of various types of solid fuel to synthetic gas and oil production: Coal-Heat, vol. 50, No. 5, p. 30, November 1946.

3. Richmond, K. C., Stoker coal demands show steady increase through war years: Coal-Heat, vol. 51, No. 3, p. 16, March 1947.

4. Ferry, R. E., Heating trends survey: p. 102, May 1946, The Institute of Boiler and Radiator Manufacturers, 60 E. 42nd St., New York 17, N.Y.

5. Symonds, Gardiner, Natural gas for mixing, reforming and enriching manufactured gas: Gas Age, vol. 98, No. 10, p. 38, November 14, 1946.

6. Anon., Diesels 95 percent of new R.R. orders: Coal Age, vol. 52, No. 2, p. 138, February 1947.

7. Anon., Growth of diesel power on principal coal-carrying railroads: National Coal Association, November 1945.

8. Miles, Fred C., Locomotives ordered and built in 1946: Railway Age, vol. 122, No. 1, p. 110, January 4, 1947; Anon., Equipment installed in 1946: Railway Age, vol. 122, No. 4, pp. 241-2, January 25, 1947.

9. Fowler, V. B., Address before the Investment Analysts' Club, Chicago, November 21, 1945.

10. Duggan, C. F., Private communication, March 11, 1947.

11. Monthly comment on transportation statistics: Bureau of Transport Economics and Statistics, Interstate Commerce Commission, November 13, 1946.

12. Interstate Commerce Commission, Statement M-230, 1940-1945.

13. Yellott, J. I., Address before Philadelphia Section, A. S. M. E., November 1946.

14. Anon., Will use oil in new gas turbine engine for locomotive: National Petroleum News, vol. 39, No. 6, p. 24, February 5, 1947.

15. Holman, Eugene, Address before the 51st Annual Congress of American Industry, New York, December 4, 1946.

16. Chicago Journal of Commerce, November 21, 1946.

17. Diesel Facts: Diesel Engine Manufacturers' Association, Chicago 2, Illinois. Book One, pp. 2-3, July 1945.

18. Mahoney, J. R., Coal's place in a mature Western economy: Coal, vol. 8, No. 10, January 1947. (Utah Fuel Co. and Calumet Fuel Co.)

19. Rose, H. J., $401,000 budget for research approved: Bituminous Coal Research Bull., vol. 6, No. 1, January-March 1946.

20. Rose, H. J., Many millions now being spent on coal research here and abroad: Mining and Metallurgy, vol. 28, No. 482, pp. 110-111, February 1947.

21. Egloff, Gustav, Research and management: The Chemist, vol. 24, No. 3, March 1947.

22. O'Rear, N. B., U. S. Dept. of the Interior Information Service, Bureau of Mines Release No. 3529, February 18, 1947.

23. Keith, P. C., Synthetic gasoline from natural gas: Chemical Industries, vol. 59, No. 1, pp. 58-63, July 1946.

24. Anon., Stanolind Oil and Gas Co. designing commercial-scale plant to synthesize oil from natural gas in southwestern Kansas: Chemical and Engineering News, vol. 25, No. 4, p. 240, January 27, 1947.

25. Anon., Coal company expands research: Chemical and Engineering News, vol. 25, No. 10, p. 700, March 10, 1947.

26. Anon., Government research on synthine process: Petroleum Processing, vol. 2, No. 3, p. 172, March 1947.

27. Bone, W. A. and Himus, G. W., Coal, its constitution and uses: Chapter XI, Longmans, Green and Co., 1936.

28. Franke, N. W. and Kiebler, M. W., Organic acids by direct oxidation of coal: Chemical Industries, vol. 58, No. 4, pp. 580-1, April 1946.

29. Anon., Research profits: Chemical and Engineering News, vol. 25, No. 8, p. 576, February 24, 1947.

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