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PRODUCTION OF OIL FROM PLANT MATERIAL

By Professor E. BERL
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INTERESTING information is given about the oil situation in this country in the excellent article by Dr. P. K. Frolich,[1] past president of the American Chemical Society. Dr. Frolich states that the time is not far off when oil products should be obtained from sources other than natural oil, for example, by the hydrogenation of coal or carbon monoxide produced from coal or from natural gas or from oil shales. Not all experts in this field agree with statements about the coming scarcity of oil within the boundaries of the United States.[2]

In previous communications to SCIENCE,[3] I have stated that carbohydrates which are contained in farm products, wood, algae, etc., and which are formed by nature in enormous amounts and with greatest ease (see Table 1) can be converted into liquid fuel.[4] According to such statistics, at the present rate of oil extraction, the cheap oil in this country would be gone in about fourteen years; therefore, it is imperative that ways and means should be used in order to allow a continuous production of liquid fuel after the exhaustion of that oil under ground which can be recovered at relatively small cost.

TABLE 1

Plants	2.7×10^{11}	metric tons of C content
Annual production of cellulose and other carbohydrates	3×10^{9}	" " " "
Crude oil reserves in U. S. A.	2.64×10^{9}	" " " "
Crude oil reserves in world	4.4×10^{9}	" " " "
Annual oil production U. S. A.	1.93×10^{8}	" " " "
Annual world oil production	2.94×10^{8}	" " " "

One can get from cornstalks, corn cobs, sugar-cane, bagasse, seaweed, algae, sawdust, Irish moss, molasses, sorghum, grass or any other carbohydrate-containing

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[1] P. K. Frolich, SCIENCE, 98: 457, 484, 1943.
[2] W. Pratt, *Oil and Gas Jour.*, January 30, 1944, p. 78.
[3] E. Berl, SCIENCE, September, 1934, and January, 1935.
[4] J. G. Lippmann, *Ind. Eng. Chem.*, 27: 105, 1935.

material by a controlled internal combustion a material called "protoproduct." This protoproduct contains about 30 per cent. of phenol carbonic acids, 4.5 per cent. phenols and 63.5 per cent. neutral material. It is semi-liquid at room temperature and liquid at somewhat higher temperatures. It contains about 60 per cent. of the carbon content of the original plant material. This "carbon" yield is practically identical with the yield which one gets when water-soluble carbohydrates are converted into alcohol by fermentation. The yield in K cal (BTU)—thermal efficiency—for the conversion of plant material into liquid fuel is rather high. One long ton of dry sugar-cane (4.33×10^6 K cal "upper" heating value and 3.97×10^6 "lower" heating value)[5] contains .5 tons C. With a 60 per cent. carbon conversion, .375 tons of protoproduct (with 80 per cent. C) result which produce 3.28×10^6 K cal "upper" or 3.09×10^6 K cal "lower" heating value. The thermal efficiency is therefore 75.6 and 77.7 per cent., respectively.[6] A thermal efficiency of 76 per cent. based on oxygen-free material results if the protoproduct is hydrogenated and the asphaltic material discarded. The aforementioned "protoproduct" as a hydrophobic substance separates easily from the watery medium. No further concentration is necessary. Fermentation alcohol results as a diluted (5–8 per cent.) material which afterwards has to be concentrated to get industrial alcohol.

TABLE 2

Material	Sp. wt.	K cal/kg.		BTU/lb.		K cal/liter		BTU/gal.	
		upper	lower	upper	lower	upper	lower	upper	lower
Protoproduct	1.14	8,736	8,250	15,725	14,850	9,960	9,405	119,580	141,263
100 per cent. ethanol.	.794	7,092	6,370	12,765	11,465	5,630	5,058	84,578	75,970
95 per cent. ethanol.	.809	6,737	5,984	12,127	10,771	5,450	4,841	81,860	72,712
Gasoline	.70	11,000	10,000	19,800	18,000	7,700	7,000	115,655	105,140

Upper heating values: Liquid water in the combustion gas.
Lower heating values: Water vapor in the combustion gas.

The protoproduct can be used as fuel oil or, with or without a simple treatment, in Diesel engines. Table 2 shows the superiority of the protoproduct (sp. wt. 1.14) over alcohol in its BTU (K cal) content per weight or volume unit.

About 50 per cent. of oxygen are contained in plant material, for example, in dry, ash-free sugar-cane. Protoproduct made from sugar-cane contains 20–10 per cent. of bound oxygen which can be removed by hydrogenation or by cracking. Hydrogenation of the liquid protoproduct can be carried out much more simply than that of pulverized older lignites or younger bituminous coals. After hydrogenation about 45 per cent. of the original carbon content of, for instance, sugar-cane results as gasoline, kerosene and lubrication oil. Gasoline (boiling up to 200° C. or 392° F) contains 20 per cent. of aromatics. 17.4 per cent. of the original carbon content in sugar-cane are found in this gasoline. The kerosene fraction contains 19.7 per cent. of the sugar-cane carbon. It can be cracked to lower boiling hydrocarbons. The lubrication fraction with 7.6 per cent. of the carbon content in sugar-cane shows properties identical with that of lubrication oil obtained from natural oil. The remaining asphalt-like material with 15 per cent. of the sugar-cane carbon retains after hydrogenation a few per cent. of bound oxygen. It derives mostly from the lignin content of the plant. The asphaltic material can be used for purposes where natural asphalts are used, or it can be burned as is done with pitch.

Table 3 shows conversion results for sugar-cane of which in continental U. S. (Louisiana) 18.55 long tons and in Hawaii 33.2 long tons are produced per acre a year.[7]

Our generation is rather careless with those savings which nature put under ground many millions of years ago. We recover oil from underground often with low yields.[8] We use up this oil rather imperfectly in a very short time. Then it is gone forever. It would be wise and practical to use more and more agricultural

TABLE 3

a. From 100 long tons dry sugar-cane result
    2,980 gal. gasoline
    3,430 " middle oil
    1,210 " lubrication oil, or
    8.45 long tons raw cane sugar (Louisiana)
    10.0 " " " " " (Hawaii)
b. From 100 long tons dry bagasse
    (resulting from 110 tons dry sugar-cane)
    2,550 gal. gasoline
    2,950 " middle oil
    1,020 " lubrication oil

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[5] The "upper" heating value is related to liquid water, the "lower" heating value to water vapor in the combustion products.

[6] The remaining 24.4 per cent. thermal efficiency are found in the compounds contained in the watery liquid and in the gas. This high thermal efficiency of 75.6 (77.7) per cent., which does not include the relatively small amount of heat necessary for the conversion, may be compared with the 30 per cent. thermal efficiency in the coal hydrogenation plant in Billingham (see later).

[7] U. S. Department of Commerce, Statistical Abstract of United States, 1941.

[8] Improved yields can be obtained with the use of the writer's U. S. Patent No. 2,267,548.

products for the production of liquid and semi-liquid fuel, and if necessary, of solid fuels. Nature produces per annum 3×10^9 tons carbon content in carbohydrate-containing material. The world consumption of oil at present is estimated to be 2.94×10^8 tons carbon content per year. The annually produced cellulosic plant material[4] (see also Table 1) would allow the production of about six times the actual oil consumption with an overall carbon conversion of 60 per cent. and a thermal efficiency of 75.6 and 77.7 per cent., respectively.

Thirty million (3×10^7) cars on the U. S. highways in 1941, the last "normal" year in this country, consumed 5.56×10^7 long tons of liquid fuel. If this amount of liquid fuel were to be produced from sugar-cane, due to the lower yield per acre a year in the continental United States, 9.7×10^6 acres would be needed, and with a sugar-cane production per acre a year as in Hawaii, Puerto Rico, Philippine Islands and Cuba, 5,420,000 acres would have to be planted with sugar-cane. These figures are based on the conversion to protoproduct only. If this protoproduct were converted into oxygen-free gasoline, then for continental U. S. 1.32×10^7 and in countries with a climate similar to that of Hawaii, 7.37×10^6 acres would be needed. In the last figures, the amount of raw material necessary for the deoxidation of the protoproduct is not included. The cropland harvested in the U. S. amounts to 3.2×10^8 acres. The 9.7×10^6 and 1.32×10^7 acres in continental U. S. would correspond to 3.4 per cent. and 4.13 per cent. respectively of harvested land and 1.7 per cent. and 2.3 per cent., respectively, of the land available for crops (5.3×10^8 acres).

TABLE 4

ANNUAL PRODUCTION FIGURES FOR CONTINENTAL U. S. AND FOR HAWAII FOR 1937–1940[7] AND CONVERSION FIGURES INTO OIL

	Total acreage harvested for sugar cane and seed	Total product. of sugar-cane and seed long ton	Long ton sugar-cane/acre	Raw sugar long ton	Raw sugar long ton/acre	Long ton raw sugar/long ton cane	Long ton proto-product per acre	Barrels proto-product per acre	Long ton proto-product by total conversion of sugar-cane	Barrels proto-product by total conversion of sugar-cane
Continental U. S.	2.92×10^5	5.01×10^6	18.55	4.24×10^5	1.45	.085	5.565	30.7	1.625×10^6	8.96×10^7
Hawaii	2.36×10^5	7.83×10^6	33.20	7.83×10^5	3.32	.10	9.96	55.0	2.35×10^6	12.98×10^7

6.6×10^7 tons of liquid fuel—in other words, more than the 30,000,000 cars consumed in 1941—could be produced in the U. S. A. if the 2.6×10^8 tons of plant waste produced annually would be converted into liquid fuel.

In this country and more advantageously in countries with tropical climate, very large amounts of carbohydrate-containing material can be produced. Table 4 shows the yields per acre a year for sugar-cane crops (which allows the maximum carbohydrate production per acre a year) in the continental United States and in Hawaii.[7] From dry sugar-cane, bagasse (Table 3) or other crops, interesting amounts of protoproduct and oxygen-free liquid fuel can be obtained. In using these, one would not use up the present oil reserves with dangerous speed. One would not consume coal of which about five tons are necessary to produce one ton of liquid fuel (this corresponds to 30 per cent. thermal efficiency) and one would not run into difficult transportation problems which are connected with the use of oil shale and disposal of distilled material. Oil shale allows the production of 30–70 gallons of oil with .90–.77 tons of valueless residue per ton of shale.

The total production of sugar-cane in Hawaii, Puerto Rico, Philippine Islands and Cuba which have practically the same climate and, therefore, the same production of sugar-cane in long tons per acre a year can be seen from Table 5.

TABLE 5

Hawaii	7.83×10^6
Puerto Rico	7.83×10^6
Philippine Isl.	9.4×10^6
Cuba	35.2×10^6
	60.26×10^6

From these four countries one could produce 1.8×10^7 tons of liquid fuel, which is nearly one third of the consumption in 1941 for the 30,000,000 cars. The planting of sugar-cane in these and other tropical countries, for instance, Brazil, certainly could be multiplied provided there would be a use for the increased sugar-cane output.

9.7×10^7 acres planted with sugar-cane would be needed in the continental United States to produce the alcohol equivalent to 5.56×10^7 long tons of liquid hydrocarbon fuel. This compares with the above-mentioned 9.7×10^6 acres planted in continental U. S. necessary to furnish the fuel for 3×10^7 cars. Less than 10 per cent. of the sugar-cane content present as saccharose are converted into alcohol. With the process of the writer, altogether 70 per cent., which represents the total carbohydrate content of the sugar-cane, including cellulose, can be converted into liquid fuel.

The synthetic fuel production in Fortress Europe dominated by Germany is estimated to be 1×10^7 tons, to which 4–5 × 10^6 tons of natural crude produced in Roumania, occupied Poland, Austria and Germany have to be added. In other words, the 1.8 × 10^7 tons of liquid fuel which could be produced from the present sugar-cane production in Hawaii, Puerto Rico, Philippine Islands and Cuba are 80 per cent. higher than Germany produces in her synthetic oil plants, in which certainly more than $2,000,000,000 have been invested. Continental U.S.A. produces now 2.2 × 10^8 tons of crude oil.

That hydrogenation of coal with the Bergius-I. G. process and of carbon monoxide with the Fischer-Tropsch process is carried out on a large scale in Germany (10,000,000 tons per year) is not perfect proof that these processes under the present conditions is the only way to end the oil shortage for this and other countries. Great Britain has not enlarged her Billingham coal hydrogenation plant, with about 150,000 tons of oil products per year.[9] Hydrogenation of coal and carbon monoxide can not be carried out without large government subsidies (6.65 cents per gallon on home-produced petrol in Great Britain).

Any synthetic method whatsoever must produce liquid and solid fuels at prices higher than the very low present prices of natural oil and bituminous coals in this country. Farish[10] and Williams[11] gave data from which the high price of coal hydrogenation products can be seen (22.6 cents per gallon for gasoline with coal hydrogenation,[10] 24.4 cents per gallon with carbon monoxide hydrogenation from coke,[11] 19.2 cents from bituminous coal,[10] 18.2 cents from subbituminus coal,[11] 18.2 cents[11] and 8.8 cents[10] respectively from natural gas). Direct costs per gallon of gasoline are 15.9 cents for coal hydrogenation[10] and 14.7 cents for carbon monoxide hydrogenation.[10] 6.7 and 4.5 cents per gallon, respectively, have to be spent for 10 per cent. depreciation. The production of liquid and semi-liquid fuels from plant material, especially in tropical and subtropical countries, or where practically valueless wastes result, can be made at rather low prices provided the transportation problem does not offer special difficulties.

This plant conversion process has the great advantage that it does not touch the materials underground. In this and other countries the farmer must produce more raw materials for industrial purposes. In smaller installations, plant material could be converted into the fuel which is necessary for his tractors and for heating his home. This can not be done by the coal hydrogenation which, according to our present knowledge, must be carried out in large and very costly installations.

The plant conversion process puts liquid fuel at the disposition of practically all civilized nations. Any country which is not blessed with natural oil and which has or can develop an adequate agricultural or forest production can now produce an important part of its liquid fuel needs.

The author expresses his thanks to A. Schmidt, H. Biebesheimer, W. Dienst, A. B. Cramer, H. Heinemann and D. Myers for their valuable collaboration.

OBITUARY

MEMORIAL TO FRANK LEVERETT

On November 15, 1943, after an illness of only a few weeks, Frank Leverett passed away at his home, 1724 South University Avenue in Ann Arbor, Michigan, at the age of 84 years. Until the time of his last illness he was active in researches dealing with glacial geology, a field in which he had gained a most enviable and world-wide reputation.

Frank Leverett was born at Denmark, Iowa, on March 10, 1859, the son of Ebenezer Turner Leverett and Rowena (Houston) Leverett. He was descended from a line of ancestors that emigrated from Boston, England, to Boston, Massachusetts, in 1663.

Upon completion of his academic training in Denmark Academy, Leverett taught in the public schools during 1878–1879. For three years following, until 1883, he served as instructor in natural sciences at Denmark Academy. It was in this position, while conducting field excursions with his classes, that he first became interested in the study of geology. In the fall of 1883 he entered Colorado College, where he took courses in mineralogy and assaying. In 1884 he enrolled in Iowa State College of Agriculture and Mechanic Arts and was graduated from that institution with a degree of bachelor of science in 1885.

Following his graduation from Iowa State College, Leverett journeyed on foot to Madison, Wisconsin, to confer with T. C. Chamberlain, then president of the university, concerning the possibility of obtaining a job on the U. S. Geological Survey. Being director of the Division of Glacial Geology in the Federal Survey, Chamberlin made an opening for young Leverett and assigned him to a temporary job as field assistant in glacial geology. Inspired by this opportunity to engage in a field of work which seemed to satisfy completely his cravings for scientific adventure, Leverett

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[9] W. A. Bone and G. W. Himus, Coal, Its Constitution and Uses, 1936, p. 556.

[10] W. S. Farish, Committee on Mines and Mining, House of Representatives, July 15, 1942.

[11] J. P. Williams, Subcommittee on War Minerals of the Committee on Public Lands and Surveys, U. S. Senate, August 6, 1943 (Pittsburgh).