MOTOR FUELS OVER THE WORLD

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Since the world wide adoption of the automobile, the problem of procuring sufficient motor fuel of high quality has been constantly enlarging. For those countries containing sufficient supplies of crude petroleum, the problem has to do only with a constantly increasing quality demanded by the more highly efficient motor vehicles of today. The European countries with exception of Russia and Rumania are almost totally lacking in crude oil supplies, and consequently various indigenous materials are processed to form substitutes for motor fuels.

In the United States crude oil production has reached over 1,200,000,000 barrels per year. The motor fuels derived from this petroleum in the form of straight run gasoline have octane ratings as low as 15 which is much too low for use in the high compression motor of today.

High efficiency of motor fuels is dependent upon the structure of the hydrocarbons present in the gasoline. The hydrocarbons in motor fuel belong to five groups: paraffins, olefins, cycloparaffins, cycloolefins, and aromatics. Of this group, the branched chain paraffins are considered best for present day motor fuels, especially for aircraft engines. The branched chain olefins have lower octane ratings than the corresponding paraffins, while the cyclic paraffins, methyl cyclopentane and cyclohexane are still lower, ranging between 77 and 79. The aromatics, benzol, toluol, and xylols have over 100 octane rating, but due to their carbonizing tendencies have not been generally used in airplane engines.

The researches in the oil industry are tending toward the production of fewer hydrocarbons in gasoline so that the combustion conditions of the modern motor may be controlled to a nicety. Precise control is not possible with the heterogeneous mixtures of hydrocarbons now in general use. The ideal motor fuel would contain but a single hydrocarbon, or perhaps a half dozen, each to suit the climatic conditions prevailing over the country.

Cracking of gasoline and heavy oils.—Gasoline produced from the distillation of crude oil containing relatively high percentages of straight-chain paraffin hydrocarbons is subjected to temperatures of the order of 1025° F. and pressure of 750 pounds to the square inch. The gasoline of low octane rating is converted into a 68 to 78 octane product, depending upon the composition of the original gasoline. The paraffinic hydrocarbons under the high temperature and pressure conditions are converted into olefinic, cycloparaffinic, and aromatic hydrocarbons of greatly improved octane ratings. Some cracking or reforming units process over 12,000 barrels of gasoline a day. During 1938 about 240,000,000 barrels of gasoline derived from the atmospheric pressure distillation of crude oil were produced, of which 25 per cent was reformed into motor fuel of high octane rating.

When cracking crude oil or heavy oils such as kerosene, gas oil, or fuel oil, a combination distillation-cracking unit or a cracking unit alone is used. The largest combination unit, treating about 35,000 barrels of crude oil a day, produces 68 per cent of 70 octane rating gasoline. Dependent upon the type of oil processed, the conditions of temperature may range between 900 and 1025° F. and pressure to over 750 pounds per square inch. Under these conditions, the yields of motor fuel range from 50 to over 75 per cent with octane ratings from 58 to 78 depending upon the quality of the cracking stocks.

The estimated volume of cracked gasoline produced from heavy oils in the U. S. during 1938 was 270,000,000 out of a total of 510,000,000 barrels derived from the refining of crude oil.

The catalytic cracking of oil has been developed by Universal Oil Products Company so that higher octane motor fuel can be produced than from high temperature-pressure cracking. A cracking test using a Mid-Continent gas oil yielded 85 per cent of 81 octane motor fuel. When the cracked gases from this operation are polymerized selectively and then hydrogenated, a 12 per cent yield of a 96 octane rating motor fuel results. Branched-chain paraffin hydrocarbons (largely isooctanes) make up the motor fuels which are particularly suitable for airplane use. In addition to this yield of isoparaffins, 73 per cent of an 81 octane motor fuel resulted from the catalytic cracking of Mid-Continent gas oil. Such yields of high octane gasoline are not obtainable from the high temperature-pressure cracking of the same Mid-Continent gas oil. The process of catalytically cracking oil will profoundly influence automotive engine designers, as the speed and efficiencies of motor vehicles and airplanes will depend upon these types of gasoline.

The Houdry catalytic process produces an 80 octane motor fuel in 45 per cent yield on a once-through basis. A number of catalytic cracking units are now under design, construction, and operation in the United States.

Hydrocarbon gases from cracking.—In addition to the volume of cracked gasoline derived by the reforming and the cracking of oil, approximately 350,000,000,000 cubic feet of cracked gas is produced yearly. For a number of years the gas from the cracking reaction was utilized only as fuel under boilers and stills. The cracked gases contain olefinic hydrocarbons such as ethylene, propene, and butenes in addition to methane, ethane, propane, and butanes. The commercial value of the hydrocarbon gases from the cracking process and natural gas has been greatly increased by the ever growing demand for high octane motor fuel. There are three polymerization processes in commercial use, two of which are thermal and use high pressure and the other is catalytic and operates at low temperature and pressure. The type hydrocarbons present in the motor fuels produced by the thermal process are olefins, paraffins, cycloparaffins and aromatics. The catalytic polymerization process produces a branched chain olefin gasoline.

Octane rating and pay load.—The manufacture of isooctane having 100 octane rating in large quantities has had a profound influence on the design and operation of modern airplane motors. From the former expensive method of producing isobutenes from butyl alcohol, and synthesizing isooctane ($25 a gallon), we are able to polymerize the normal and isobutenes present in the butane and butene fraction derived from the cracking process. The butenes react with one another and then, on hydrogenation, are converted into 90 to 100 octane motor fuel.

By the use of 100 octane motor fuel it has been estimated that each pay load could be increased by $2,000 on the China Clipper ships flying from California to the Orient. In engines designed to make use of the higher-quality fuels, it has been estimated that each additional octane number is worth from two to five cents per gallon in the earning power of the gasoline. A limiting factor on the value of octane increase is that the heat value must be maintained, or the octane increase must be discounted by about two numbers for each per cent lowering in heat content of the fuel compared to hydrocarbons, if fuels such as ethyl alcohol, ethers, or ketones are used. Hydrocarbon fuels contain the highest energy content on a weight basis, and therefore higher octane ratings mean increased take-off and pay-load ability and cruising range. The increase from 85 to 100 octane fuel in airplanes raises the pay load from 20 to 30 per cent, cuts the take-off distance in half, increases speed from 20 to 30 per cent, and the altitude climb 25 per cent or more.

Since significant oil resources are lacking in every European nation except Rumania and Russia, the subsidized and compulsory use of substitute motor fuels is practiced by most European powers to obtain economic and military self-sufficiency.

In 1937 Europe satisfied 18 per cent of its motor fuel requirements with substitute fuels; in 1938, an estimated 25 per cent. The estimated extra cost of the substitute fuels consumed in Europe during 1937 over what comparable quantities of imported gasoline would have cost was $235,000,000, equivalent to 32 cents for every gallon of substitute fuel consumed. The extra cost of such fuels in 1938 will probably be increased to $300,000,000.

Constituting 7 per cent of all motor fuel consumption, synthetic gasoline hydrogenated from coal and carbon monoxide moved up in 1937 to an apparently permanent position as Europe's

TABLE I—EUROPEAN PROPORTIONS OF SUBSTITUTE FUELS IN 1937*

IN METRIC TONS

Country	Alcohol	Benzene	Oil from Coal and Synthetic Gasoline	Shale Spirit	Total Substitutes	Total light Motor Fuel Consumption	Per Cent Substitutes
Germany	210,000	430,000	800,000		1,440,000	2,640,000	54.5
Estonia				7,300	7,300	14,300	51.9
Czechoslovakia	50,600	12,000			62,600	220,000	28.5
Lithuania	1,294				1,294	5,700	22.7
Hungary	10,516	3,100			13,616	69,100	19.7
Poland	7,955	10,000			17,955	98,200	18.3
Latvia	2,154			1,300	3,454	19,400	17.8
Yugoslavia	3,806				3,806	30,200	12.6
Belgium		36,700			36,700	408,800	9.0
France	153,400	80,000	13,000	1,500	247,900	2,827,000	8.8
United Kingdom	16,000	230,000	120,000	26,000	392,000	4,840,000	8.1
Italy	37,000				37,000	483,500	7.7
Austria	2,300	8,200			10,500	146,300	7.2
Sweden	15,247	500			15,747	503,200	3.1
Holland		10,800			10,800	392,600	2.8
Finland		200		2,700	2,900	112,500	2.6
Switzerland	50	3,000			3,050	203,900	1.5
Total	510,332	824,500	933,000	38,800	2,306,622	13,014,700	17.7

* Total European light motor fuel consumption, including countries not enumerated, was 14,344,000 metric tons.

primary and cheapest substitute fuel, even though costing governments and consumers an estimated $79,514,500 more than an equivalent amount of imported gasoline. Previously the main substitute fuel, benzol, dropped to second place during 1937 when it accounted for 6.3 per cent of total European motor fuel consumption and cost governments and consumers $49,463,000 more than the same amount of imported gasoline. Power alcohol which represents 4.3 per cent of European motor fuel consumption declined in use 25 per cent in 1937 from the previous year, lowering that product to third rank among substitute fuels. Its estimated cost over imported gasoline, including subsidies, was $104,060,500. Of the numerous secondary substitute fuels, compressed gases were the most important, supplanting an estimated 190,000 tons of gasoline, and showing signs of continued increase in usage.

Coal and carbon monoxide hydrogenation.—In 1937 when 7,500,000 barrels of synthetic gasoline were produced by direct hydrogenation of coal and by hydrogenation of carbon monoxide derived from coal, this gasoline became established as Europe's primary substitute fuel. Both hydrogenation processes were developed in Germany and there is an annual production of 17,000,000 barrels of synthetic gasoline from units now (March 1939) operating and building or designed. About 1,300,000 barrels a year are produced in England from direct coal hydrogenation to gasoline. One catalytic unit in France at capacity operation can convert water gas from coal into 110,000 barrels of motor fuel annually. No other countries are using these processes at present.

Direct hydrogenation of coal into gasoline is carried out at pressures of the order of 4,000 lbs. and temperatures of about 850° F. in the presence of catalysts. (See fig. 1.)

The second process, the hydrogenation of carbon monoxide (Fischer-Tropsch process), is carried out at atmospheric or super-atmospheric pressure in the presence of catalysts and temperatures of the order of 350° F. (See fig. 2.) This latter process yields a mixture called "Kogasin Oil," comprising motor fuel, kerosene, Diesel oil and paraffin wax, and motor fuel production from it in Germany will be 530,000 tons annually from units now operating and under design and construction.

Exact and official figures on production costs of motor fuel from hydrogenation processes are lacking, but a number of European sources privately place them at 17 and 19 cents per U. S. gallon.

Indicating far lower costs than for any other liquid substitute fuel in Europe, including benzol, oil shale spirit, and alcohol, these prices point to the main reason why synthetic gasoline hydrogenated from coal has emerged as Europe's primary gasoline substitute. Costly however obtained, self-sufficiency in motor fuel naturally is desired at the lowest price. Another important factor is that all other significant liquid substitutes are only partial substitutes and must be blended with larger amounts of gasoline for satisfactory operation in present day automobiles, whereas synthetic gasoline from coal so closely approximates the qualities and characteristics of gasoline from oil that its use alone is practicable. Production of synthetic gasoline from coal offers nations like Germany, with ample coal resources and technological facilities, the only promising route to motor fuel self-sufficiency which has appeared throughout Europe. Largely by this means Germany became 54.5 per cent self-sufficient in light fuel requirements in 1937, and its self-sufficiency during 1938 will probably be further increased.

Prevailing costs of gasoline from coal in Europe must not be considered conclusive. Private data from American sources closely in touch with foreign coal hydrogenation operations indicate that these costs translated to U. S. conditions today would range from 14 to 16 cents per gallon. In any remote future when the United States might need to process coal into motor fuel, materially lower prices would result from the thorough application of American petroleum refining technology, effecting substantial reductions in capital and operating costs which in European units, the first constructed, have been high.

Benzol motor fuel.—The prime source of benzol motor fuel is the high-temperature carbonization of coal, which yields gas, coal tar, and metallurgical coke. The gas is scrubbed with oil or activated carbon and the coal tar is distilled, giving a maximum yield of 3 gallons of benzene of 90 octane rating per ton of coal. It is blended with lower grade fuels to raise their antiknock value.

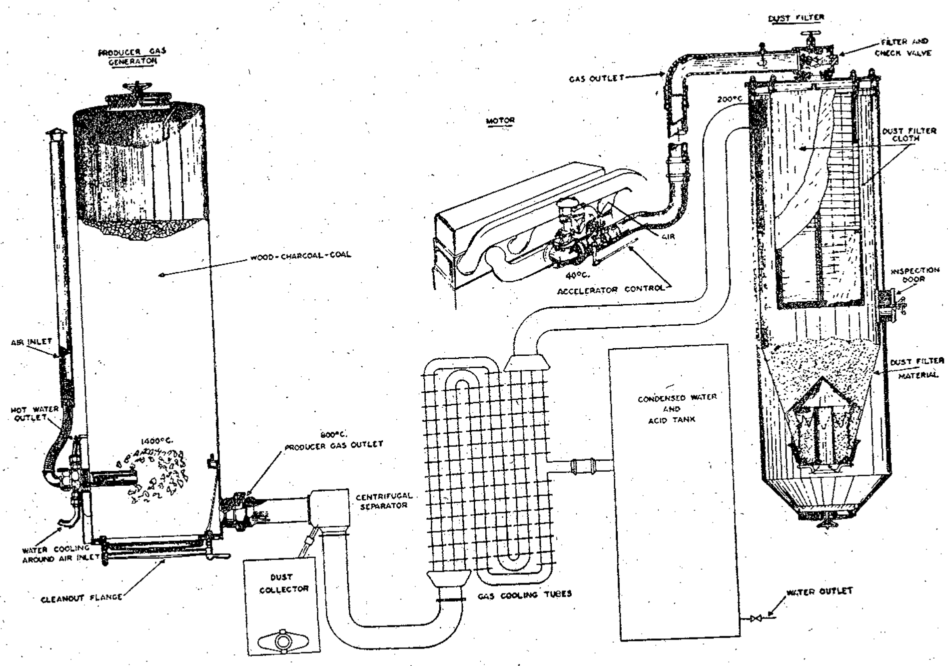

Fig. 1.—Motor fuel from coal hydrogenation.

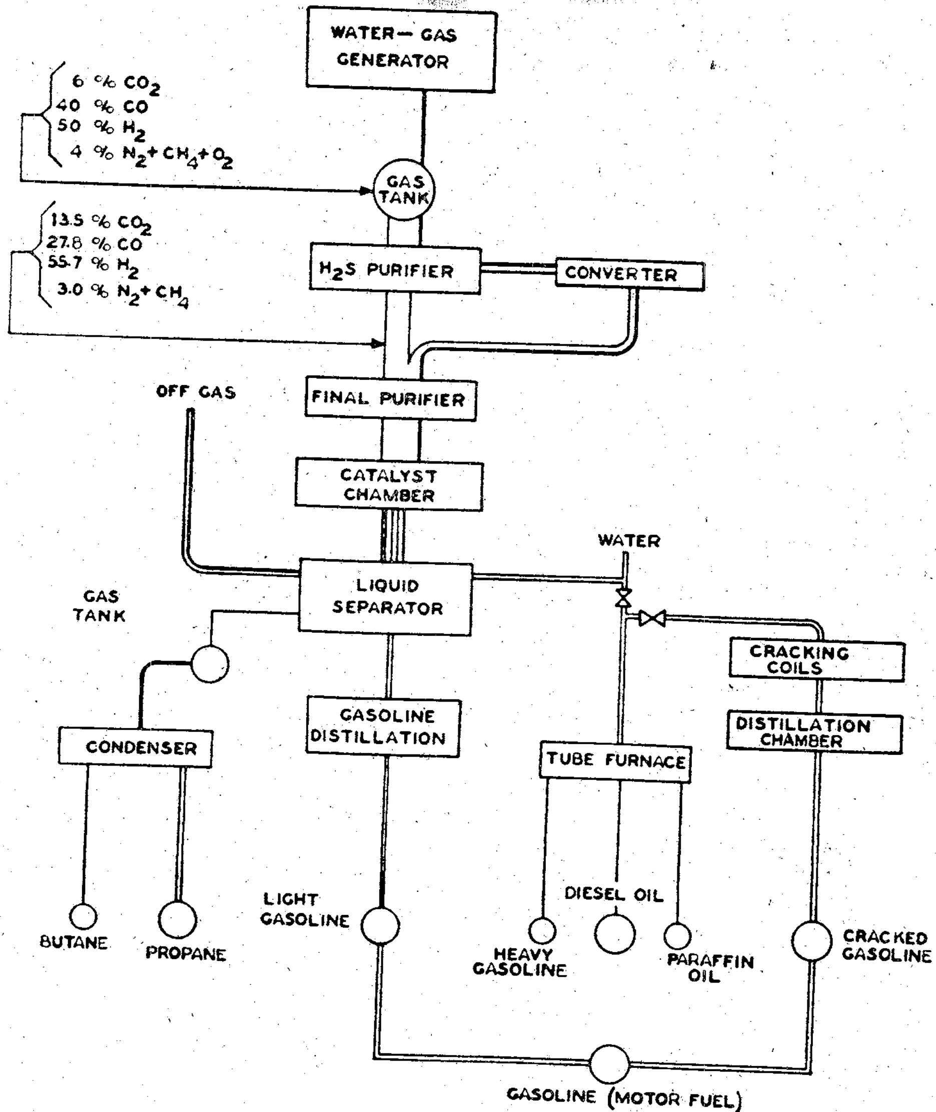

Fig. 2.—Motor fuel from water-gas reaction, Fischer-Tropsch process.

The benzene and toluene in this type fuel are diverted in wartime to munitions manufacture. The Mining and Power Commission of the French Chamber of Deputies recently reported: "Benzene would also have to be reserved in time of war for the manufacture of explosives. Its production, moreover, is limited by the activity of coke ovens and gasworks and is therefore capable only of slight expansion. . . ."

The cost to European consumers was $49,463,000 more for benzene motor fuel than it would have been for gasoline, as a result of loss of taxes, governmental subsidies, and benzene production costs. Expressed another way, it was 20 cents more for each gallon of benzene fuel consumed.

Compressed gas.—Natural gas and combustible gases rank fourth among substitute fuels; they are derived from hydrogenation of coal and carbon monoxide to hydrocarbons, and from the cracking process. The replacement of 250,000 tons of gasoline throughout Europe in 1938 is estimated.

Motor vehicles are converted into the compressed gas consuming type at costs ranging from $150 to $300. Primary changes are: a) installation of racks to hold the steel cylinder weighing 115 lbs. and more empty; b) addition of regulating valves to control the flow of gas into the motor; c) substitution of a special gas-air mixer in place of a carburetor. Cruising ranges on 2 cylinders of city gas, methane, or propane-butane are respectively 25, 85 and 225 miles. Service stations refill or replace the empty cylinders. The methane, ethane, propane and butane are stored up to 4,000 lbs. per square inch pressure in the steel alloy cylinders attached to the automotive vehicle.

Motors burning compressed gases are subsidized and granted tax reductions by the German and Italian governments. The fuel for an estimated 25,000 of such vehicles in Germany will replace 150,000 tons of gasoline in 1938. On a gallon of gasoline basis, city gas in Germany costs 43 cents, motor methane 41 cents, and propane-butane 61 cents. Natural gas used in Italian vehicles supplants about 40,000 tons (350,000 bbls.) of gasoline annually, and it is expected that within two years the use of methane from natural gas and coal carbonization will be four-fold greater than it is at present.

Alcohol motor fuels.—The increased use of power alcohol was demanded in Central Europe from 1930 to 1937 by heavy governmental subsidies. Alcohol motor fuel consumption increased in Europe during 1930 to 1936 from 59,000 to 648,000 tons. However, a sharp decline took place in 1937 with the use of only 510,000 tons, a drop of 25 per cent. A more drastic drop is indicated for 1938. Alcohol may be eliminated as a source of power as a result of the staggering economic losses involved, its diversion to other uses, and its encroachment upon food supplies.

A loss of European income of about $105,000,000 was incurred during 1937 alone, based upon subsidizing the producers, tax losses, and higher fuel costs. These losses resulted from the marketing of 510,300 tons of alcohol out of a total 11,882,600 tons or 4.3 per cent of the motor fuel used in Europe.

Germany and France have been the heaviest consumers of power alcohol, and their supply was derived primarily from sugar beets and potatoes. Germany required a 10 per cent blend of alcohol with gasoline, but four years after the legal requirement, it was found that there was insufficient alcohol produced in the country to fulfill the law. In order to meet government specifications, it was necessary to import alcohol to cover the deficiency. During 1937, synthetic methanol was used in Germany to the extent of 70,000 tons to make up the 10 per cent alcohol quota, but it was not sufficient to stop the drain on basic foodstuffs entailed by so drastic a requirement in motor fuel. The percentage of alcohol required in motor fuel was reduced from 10 to 8.5 per cent in October, 1937, and to 6.9 per cent in April, 1938.

In France the sugar beet is grown primarily for the purpose of furnishing power alcohol, so that there is no excessive drain on foodstuffs. The laws requiring from 10 to 35 per cent alcohol in motor fuels were for the purpose of absorbing the products of the vineyards and beet farms; but as a result of drought neither group was able to produce the legal amount of alcohol required for blending.

The Germany subsidy to the potato alcohol producers is about $130 per ton of power alcohol or about 39 cents per gallon. In order to increase alcohol production 100,000 tons a year from farm products, France legislated in June, 1938, to the effect of paying $12,500,000 for this amount of alcohol, which figures a subsidy of about 36 cents per gallon.

Power alcohol consumption reached a peak of 321,300 tons in France, in 1935, dropping to 153,400 during 1937, a shrinkage of over 52 per cent. During 1935 France used over 55 per cent of the total power alcohol of Europe and about 33 per cent during 1937; an estimate is given for 1938 of less than 25 per cent of the total. The power alcohol goal set by law has not been reached (the percentage alcohol blend during 1937 was 5.4 per cent) as a result of natural causes and to diversion of alcohol to other uses such as munitions manufacture.

In Germany the use of alcohol from agricultural products has fallen off sharply—i. e., 20,000 tons during 1937 compared to 1936. Of the 210,000 tons of alcohol used during 1937, methanol represented 70,000 tons, leaving 140,000 tons of ethanol derived from potatoes, etc. This alcohol tonnage of 140,000 is about the same quantity as was used in Germany five years ago.

Power alcohol consumption for Germany and France is shown in table II.

The data showing the alcohol consumption and percentages of the total motor fuel consumed during 1937 in European countries are shown in table III, the alcohol used in motor fuel ranging from 0.3 per cent for the United Kingdom to 23.0 per cent for Czechoslovakia.

Great Britain has never compelled the use of power alcohol for blending purposes in order to subsidize the agricultural industries. This is probably due largely to the fact that the raw material, molasses, must be imported.

The British Government further encourages alcohol motor fuel blends by exempting both their alcohol and benzene content from the import duty on motor fuel, which was 8d. per Imperial gallon (about 16 cents per U. S. gallon).

Increased gasoline taxes have formed only a part of the encouragement given to power alcohol. In most European countries alcohol is heavily subsidized—i. e., Germany 39 cents per gallon and France 36 cents per gallon; the government monopolies pay higher prices to distilleries than to distributing companies. The monetary losses entailed due to power alcohol use in the countries of Europe during 1937 was $104,060,500.

The following table shows alcohol tax losses, subsidies, and extra cost to consumer above tax-paid gasoline:

Germany	$53,738,000
France	36,634,000
United Kingdom	1,538,000
Italy	4,145,500
Czechoslovakia	3,032,500
Hungary	1,677,500
Yugoslavia	930,000
Sweden	849,000
Poland	584,000
Latvia	367,000
Austria	383,500
Lithuania	181,500
Total	$104,060,500

Europe's power alcohol policies have made difficulties for motorists which have been little recognized in the United States. The instability of alcohol supplies has caused repeated changes in the octane ratings of fuel sold the public. No sooner do car operators and automobile manufacturers adjust engines to run on fuels of a given antiknock value than an increase or decrease in the supply of power alcohol results in the raising or lowering of the antiknock value of fuels and in making readjustments necessary.

On June 17, 1938, the French Government was confronted with a surplus of wheat and imposed an additional tax of 20 centimes per liter (2.1 cents per U. S. gallon) on gasoline to subsidize the manufacture of power alcohol primarily from wheat to the amount of 1,250,000 hectoliters (32,875,000 U. S. gallons) annually, with the result that alcohol again must be blended in essence tourisme and a further change in octane rating is made necessary.

Armaments and alcohol policies.—Recent events have confirmed previous analyses showing that the primary reason for compulsory use of alcohol in motor fuel in Europe is the desire of the countries to develop and maintain their alcohol industries for the purpose of national defense; this is done not merely as a protection against failure of petroleum supplies in wartime due to blockades but to assure adequate capacity for manufacture of a prime raw material in making munitions—namely, alcohol. Significantly, the war scare which gripped all Europe during 1937 was accompanied by a sharp decline of alcohol used in motor fuel. This decrease was far too great to be explainable solely by crop shortages in sugar beets, the main source of alcohol in France and Italy, and must be attributed to the large quantities of alcohol consumed for armament purposes. Classified as confidential military information, diversion of alcohol from motor fuel channels to use in making munitions has seldom been publicly mentioned. In at least one instance, however, it has been reported as a cause for the decline in France of alcohol for motor fuel purposes during 1937. Numerous informed sources abroad privately acknowledge that similar diversion of alcohol is also an important factor for the decline of alcohol for use in motor fuel in Italy and probably in Germany.

TABLE II—POWER ALCOHOL CONSUMPTION IN GERMANY AND FRANCE, 1930-37

Year	Germany	France	European total
	(Metric tons)		
1930	?	28,000	59,000
1931	50,000	52,100	121,000
1932	95,000	69,100	182,000
1933	135,000	180,000	362,000
1934	170,000	203,000	445,000
1935	170,000	321,300	576,000
1936	207,000*	303,900	646,000
1937	210,000*	153,400	510,000

* Includes methanol: 47,000 tons in 1936, 70,000 tons in 1937.

TABLE III—POWER ALCOHOL CONSUMPTION IN EUROPEAN COUNTRIES, 1937

Country	Power alcohol consumption	Total light motor fuel consumption	Alcohol
	(Metric tons)		(Per cent)
Germany	210,000	2,640,000	8.0
France	153,400	2,827,000	5.4
Czechoslovakia	50,600	220,000	23.0
Italy	37,000	483,500	7.6
United Kingdom	16,000	4,840,000	0.3
Sweden	15,200	503,200	3.0
Hungary	10,500	69,100	15.2
Poland	8,000	98,200	8.1
Yugoslavia	3,800	30,200	12.6
Austria	2,300	146,300	1.6
Latvia	2,200	19,400	11.1
Lithuania	1,300	5,700	22.7
Total	510,300	11,882,600	4.3

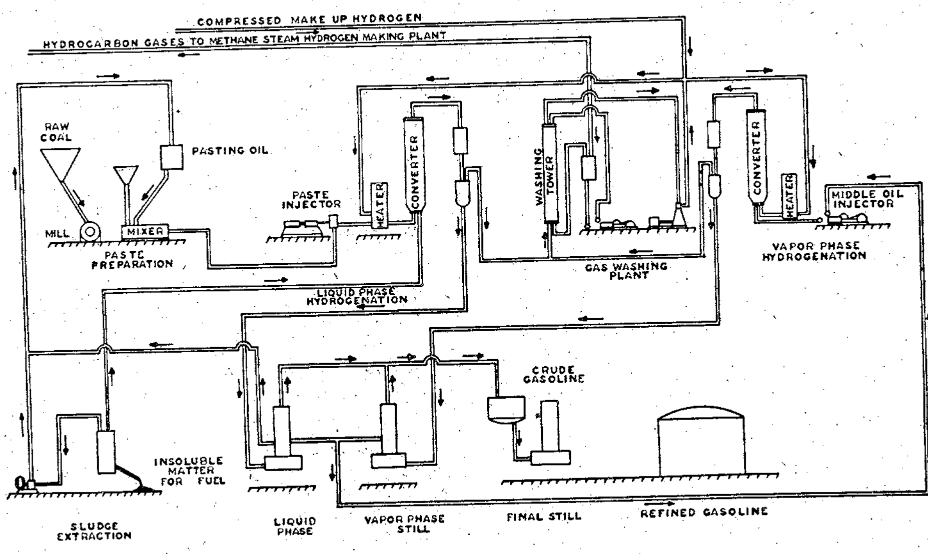

Fig. 3.—Producer gas motor fuel system.

Because of the natural inclination of foreign nations to avoid this sensitive topic, it is likely that the desire to maintain a vital wartime industry in a continuous condition which permits operations at peak capacity has been greatly understressed as a cause of Europe's compulsory use of alcohol in motor fuel. A realistic appraisal of the situation compels the conclusion that this consideration has been a basic incentive for Europe's power alcohol policies, possibly outweighing even the desire to overcome vulnerability to wartime failure of petroleum supplies due to blockade. At times incapable of meeting all peacetime requirements as in 1937, most European nations clearly do not have alcohol industries of sufficient capacities to meet motor fuel needs and wartime scale of munitions manufacture simultaneously. Indications are that at least one major European nation does not contemplate the use of any alcohol in motor fuel in the event of war. The pleas of automobile manufacturers and others have been rejected to advance the octane ratings of various fuels on the grounds that in wartime no alcohol would be available for that purpose, that the country's limited supply of tetraethyl lead would be used up in military fuels, and that commercial vehicles consequently should not be adapted to fuels of high antiknock value in face of the probability that they would have to run on straight gasoline of relatively low antiknock value in time of war.

The Mining and Power Commission of the French Chamber of Deputies recently reported: "So far as alcohol is concerned, wartime requirements for the explosives industry, for solvents, and for medicinal purposes would be so great that they would far exceed domestic production. This is borne out by the experience of the Great War, when French consumption amounted to between 5 and 6 million hectoliters, of which domestic output was able to supply 1 million hectoliters only. In time of national emergency alcohol would be far too valuable to be used as a motor fuel.

Producer gas from wood.—Wood and coal as producers of gas upon which automotive engines can run are not primary sources of motor fuel. The estimated total of wood-burning vehicles in Europe is about 9,000, with 4,500 in France, and 2,200 in both Germany and Italy, with Russia planning to put 56,000 wood-burning vehicles into use during the next two years. The 450,000,000 pounds of wood which they consume replace about 53,000 tons of gasoline annually.

At Holten, Germany, (May, 1938), the cost of dried wood was 51 cents per sack of 82 pounds, and about 16 cents' worth (25 lbs.) gives about the same distance performance as a gallon of gasoline. At first glance this seems cheap, since the retail price of motor fuel in Berlin was 59 cents per gallon in June, 1938. However, 36 cents of that price was tax, while wood is not taxed and wood-burning vehicles pay only one-half the regular vehicle tax. The government subsidizes conversion of vehicles to wood-burners, costs of which run from $300 to $500, depending on the size and work required. Labor, repair and depreciation costs are high, due to frequent cleanings necessary of fouled generating equipment and its relatively short life. The 30 per cent lower heat value of wood gas compared to gasoline reduces the power output. The cumbersome generating equipment, weighing 1,850 pounds in cases of 90-horsepower 5-ton trucks, cuts down payloads an average of 20 per cent. Except when specially equipped to start on gasoline, excessive warm-up periods are necessary, ranging from 10 to 20 minutes.

In fig. 3 is shown a typical generator for producing gas from wood. In Europe these devices for generating producer gas are termed "gasogenes."

A few gas producer motor vehicles, the exact number of which is undetermined, operate on brown coal, lignite, anthracite coal, and peat coal alone or mixed with wood or wood charcoal. Belgium favors an 80 to 20 mixture of anthracite and charcoal. Lower fuel costs are claimed than when city gas is used, but high ash formations, discharge of high percentages of sulfur dioxide in the exhaust gases, and slag formations which attack the ceramic lining of generators, have halted the progress of these producer gas fuels.

Oil shale motor fuels.—Production of motor fuel from oil shale in Europe during 1937 is shown in the following table, in metric tons. Unworked deposits of oil shale also lie in Sweden, Spain and Czechoslovakia.

	Metric tons
United Kingdom	26,000
Estonia	7,300
Finland	2,700
France	1,500
Latvia	1,300
Total	38,800

The extra cost of the above quantities of shale gasoline compared to imported gasoline and from losses in taxes, government subsidies, and production costs was $1,848,500. Of this amount the major share, $1,309,000 was borne by the motorists of Great Britain. The estimated extra cost of motor fuel from oil shale per ton produced was as follows in 1937: $50 in the United Kingdom; $37 in Estonia; $36.30 in Finland; $70 in France; $41 in Latvia. Estonia has worked its oil shale deposits commercially since 1922, and has never used any other type of substitute fuel. Except for 2,700 tons of oil shale spirit and 200 tons of benzol annually (1937), Finland consumes only gasoline derived from crude oil.

Assuming 22 gallons of oil yielded per ton of shale, estimated reserves of oil in Scotland are 280,000,000 tons or a potential 6,160,000,000 gallons of oil. Approximately 1,400,000 tons are worked annually (1937) from which 100,000 tons of marketable products are extracted, consisting of motor fuel, kerosene, Diesel oil, wax and ammonium sulfate. Shale motor spirits in Great Britain are exempt from the tax of 15 cents per U. S. gallon on imported gasoline, and their estimated cost of production is 15 cents per U. S. gallon. Because of their low octane rating, shale spirits give satisfactory performance in modern engines only if cracked or blended with higher octane fuels.

Estimated reserves of shale are as follows in four other countries: 3,500,000,000 tons with an oil potential of 675,000,000 tons in Estonia; 1,800,000 tons with a motor fuel potential of 100,000 tons in Italy; 5,000,000,000 tons in Sweden, 630,000,000 tons of which can be cheaply mined and converted into 32,000,000 tons of oil; 21,000,000 tons in France. Small scale tests with oil shale have been carried out in Italy, but there has been no commercial production to date. An experimental unit in Sweden processes 75 tons of oil shale daily, from which a yield of 3 tons of oil is obtained.

Ammonia, hydrogen, acetylene, and coal dust as motor fuels.—The desperate desire of nations to make themselves self-sufficient in substitute motor fuels is reflected in the experimental work going on with such substances as ammonia, hydrogen, and acetylene.

Synthetic ammonia has been used in Italy as a motor fuel substitute. The ammonia is dissociated to hydrogen and nitrogen by means of a so-called catalytic disintegrator, maintained at a temperature of 850-1100° F. by the exhaust gases from the motor. Vaporization of the liquefied ammonia is accomplished by releasing the pressure in the storage tank and counteracting the refrigerating effect thus encountered by means of a disintegrator which utilizes the heat from the motor exhaust. In Cherso, Italy, a test using a Fiat passenger car developed 31 miles per hour in a road test. As a motor fuel the low heating value of ammonia (4.450 kcal. per kg.) does not lend itself to wide use. The high cost involved in the use of ammonia is another factor retarding its use.

Experiments on acetylene as a fuel indicated that acetylene cannot do the full work of a gasoline engine and that thermal efficiency is highest with dilute air-gas mixtures.

Hydrogen as motor fuel in the form of compressed gas has also been tried. The results so far certainly do not look very promising.

The methods of using coal dust as a motor fuel are slowly being worked out in Germany as a result of the further desire for self-sufficiency. The first coal-dust engine for "practical purposes" was ordered for a German power station in April, 1938. It has been suggested that a "great future" awaits the new engine since the fuel may be purchased at low cost, and also the coal used is indigenous to the country.

The development of the coal-dust engine dates back 50 years or so. Indications still show that the original difficulty of fuel feed has not been overcome since coal dust "cannot" be inducted into the motor in the same manner as liquid fuel. Special abrasive resistant cylinder walls, pistons, and rings are also necessary since the wear on ordinary steel cylinders (0.28 inches during 150 hours operation) becomes so great in a short time that the efficiency and operation of the motor are greatly impaired. Cast-iron cylinders showed 0.008 of an inch after 2 hours, 33 minutes. Chromium plated cast iron showed one-seventieth of this corrosion.

Petroleum Press Service Journal, December 30, 1938, stated that:

"It cannot yet be said with certainty whether the coal-dust engine will reach such a stage of development that it can be used for the propulsion of road vehicles; but it can be said with certainty that this will not be the case for the next ten years. The oil Diesel needed twenty-five years' development before it could be used for such purposes. The difficulties to be overcome in this respect by the coal-dust engine are considerably greater.

Summary of substitute motor fuels.—The substitutes for petroleum gasoline in Europe in 1937 composed of synthetic gasoline and benzene from coal, alcohol, and oil shale amounted to 203,306,622 tons or 15,250,000,000 barrels, or about 18 per cent of the total gasoline consumption. The tonnage of substitute fuels for each country is shown in table I.

In addition to the liquid substitutes given, two other types are produced from the gases of coal and wood. It is estimated for 1938 that compressed and producer gas from coal and wood will substitute for 243,000 tons of petroleum gasoline or 1,823,000 barrels, and about 25 per cent of the total European requirements for motor fuel will come from substitutes. The cost of European substitute fuels at average rates of exchange during 1937 is shown in table IV.

Import duty, taxes, and prices.—The highest gasoline prices in Europe are in Italy, Germany, and Lithuania and are 76, 63, and 59.6 cents per U. S. gallon, respectively. The import duty and tax per gallon of gasoline in Italy is 51 cents and for Germany 36 cents. Detailed data are shown in table V.

As a matter of contrast, the average retail price for regular grade gasoline in the United States was 19.5 cents a gallon, of which 5 cents was tax (June 1938).

TABLE IV—COST OF EUROPEAN SUBSTITUTE FUELS AT AVERAGE RATES OF EXCHANGE DURING 1937

Country	Alcohol tax, losses, subsidies, and extra cost to consumer above tax-paid gasoline	Benzene	Synthetic and L. T. C. gasoline	Shale Spirit	Total
Germany	$53,738,000	$30,238,500	$70,952,000	----	$157,928,500
France	36,634,000	6,564,500	2,523,500	$ 105,500	45,827,500
United Kingdom	1,538,000	9,660,000	6,039,000	1,309,000	18,546,000
Italy	4,145,500	----	----	----	4,145,500
Czechoslovakia	3,032,500	Not calcd.	----	----	3,032,500
Hungary	1,677,500	Not calcd.	----	----	1,677,500
Yugoslavia	930,000	----	----	----	930,000
Sweden	829,000	Not calcd.	----	----	829,000
Poland	584,000	Not calcd.	----	----	584,000
Latvia	367,000	----	----	53,500	420,500
Austria	383,500	Not calcd.	----	----	383,500
Estonia	----	----	----	282,500	282,500
Lithuania	181,500	----	----	----	181,500
Finland	----	Not calcd.	----	98,000	98,000
Total	$104,040,500	$49,463,000	$79,514,500	$1,848,500	$234,866,500

TABLE V—RETAIL PRICES, IMPORT DUTY AND TAXES ON MOTOR FUEL

Country	City	Gasoline Price	Import Duty	Import Duty and Tax
		(Cents per U. S. gallon)		
Italy	Rome	73	49	51
Germany	Berlin	59.6	31	36
Lithuania	Kaunas	63.1	23.2	23.2
Bulgaria	Sofia	50	28	39
Czechoslovakia	Prague	42.4	5	16.1
Palestine	Jerusalem	41.4	20.7	20.7
Yugoslavia	Belgrade	40.9	6.7	23.5
Switzerland	Zurich	38.2	19.2	19.2
Hungary	Budapest	38	8	26
Estonia	Tallinn	38	8.1	21.1
Latvia	Riga	37.8	14.4	21.6
Greece	Athens	37.5	19.9	21.2
United Kingdom	London	36.2	15	15
Belgium	Antwerp	36	20	20 + 9% ad valorem
France	Paris	31.8	18.5	19.5
Norway	Oslo	27.5	None	9.5
Denmark	Copenhagen	26.4	None	11

Table V—Retail Prices, Import Duty and Taxes on Motor Fuel

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Germany	Berlin	59.6	31	36
Lithuania	Kaunas	63.1	23.2	23.2
Bulgaria	Sofia	50	28	39
Czechoslovakia	Prague	42.4	5	16.1
Palestine	Jerusalem	41.4	20.7	20.7
Yugoslavia	Belgrade	40.9	6.7	23.5
Switzerland	Zurich	38.2	19.2	19.2
Hungary	Budapest	38	8	26
Estonia	Tallinn	38	8.1	21.1
Latvia	Riga	37.8	14.4	21.6
Greece	Athens	37.5	19.9	21.2
United Kingdom	London	36.2	15	15
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