Producer Gas:
Another Fuel for Motor Transport

PRODUCER GAS: ANOTHER FUEL FOR MOTOR TRANSPORT

Report of an Ad Hoc Panel of the
Advisory Committee on Technology Innovation
Board on Science and Technology for
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Panel on Producer Gas as Fuel for Vehicles

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Preface

If petroleum prices remain high in the years ahead, developing countries will be the hardest hit. Basic social and economic functions, such as the production and distribution of food and the provision of vital civilian services, are likely to erode. In response to rising costs of oil, development projects are already being shelved in many Third World countries, and motor transport, on which many of these nations have come to depend, is being curtailed.

Producer gas represents a proven alternative to petroleum for fueling motor transport, although neither its practicality nor the extent of its former use is widely known. (Producer gas also has important, perhaps more important, potential use; for example, to fuel pumps, driers, and electricity generators, but in this report we focus only on its use for vehicles.)

During World War II perhaps more than a million trucks, buses, tractors, taxis, motorcycles, boats, and trains were powered by gasified wood, charcoal, peat, coke, and coal. Experience during the war demonstrated that producer gas can prevent disruption in the transportation system in a country without oil. European countries, Japan, China, Korea, India, Brazil, South Africa, New Zealand, and Australia fueled large fleets of vehicles with producer gas. In 1940 and 1941 Sweden converted 35,000 vehicles to run on wood, and by 1944, nearly 90,000 Swedish trucks, tractors, and cars were "stove" powered. Mercedes-Benz, Deutz, Faun, General Motors in Denmark (under German control), Saab, Volvo, Citroën, Panhard, Renault, Imbert, and other large European companies manufactured trucks and cars powered by producer gas generators during the 1940s. The generators are not complicated, and many people with welding experience (and a supply of pipe and other common materials) built their own. Clearly this is a technology that could be well suited to many of today's nonindustrialized countries.

At the present time, several governments are taking a renewed interest in gas producers; engineers in a number of countries are building vehicle gasifiers for fun or profit; at least one large vehicle manufacturer, Magirus Deutz, is developing a line of engines to run on natural gas and producer gas; and the use of stationary gas producers is becoming more common than at any time since the 1940s.

The purpose of this report is to introduce producer gas to researchers, agencies, and institutions engaged in assisting developing countries. The panel hopes especially that the report will show decision makers, administrators, and interested scientists that the subject is well worth investigating. By reaching this audience, the panel hopes to stimulate increased testing and use of producer gas as an automotive fuel.

The panel met in Gainesville, Florida, in April 1980, and witnessed demonstrations of vehicles powered by producer gas generated from wood. The cars ran quietly and smoothly. On the open highway, a 1978 Chevrolet station wagon (see page 47), carrying five passengers and three sacks of wood weighing about 60 kg (140 lb), easily reached 100 kph (60 mph). The vehicle performed well in city traffic, pulling away from stoplights as smoothly and quickly as gasoline-powered vehicles.

The panel's study was conducted under a contract and a grant with the Bureau for Science and Technology, U.S. Agency for International Development (AID). Travel expenses for Mr. Coward were paid by the Tropical Products Institute, London; those for Mr. Hughart were paid by the World Bank.

The staff has also compiled a comprehensive producer gas bibliography containing more than 450 citations, many of them annotated. A limited number of copies of this bibliography are available from the Board on Science and Technology for International Development (BOSTID).*

BOSTID's Advisory Committee on Technology Innovation, under whose authorization this report has been produced, investigates little-known, neglected, or overlooked resources and technologies that appear promising for use in developing countries. Other energy-related reports† prepared by panels of the committee are:

- *Leucaena: Promising Forage and Tree Crop for the Tropics*
- *Tropical Legumes: Resources for the Future*
- *Firewood Crops: Shrub and Tree Species for Energy Production*
- *Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries*
- *Supplement to Energy for Rural Development*
- *Methane Generation from Human, Animal, and Agricultural Wastes*
- *Alcohol Fuels: Options for Developing Countries.*

We would appreciate hearing from readers who have contributions to make to this report on producer gas vehicles. These might be included in subsequent editions. Comments should be sent to Noel Vietmeyer, National Research Council, 2101 Constitution Avenue N.W., Washington, D.C. 20418, USA. Photographs would be particularly welcome.

*See last page for a special mailer for this bibliography (Report 36a).

†For information on how to order these and other reports, see page 98.

Contents

Introduction and Conclusions

Petroleum shortages and high costs are helping destroy the hard-won economic gains of Third World countries. Oil price increases in 1979 wiped out half of India's $7 billion in foreign exchange, a reserve that had taken years to build up. One-third of Kenya's foreign exchange is now spent to import petroleum. The Dominican Republic's total exports barely pay its $300 million oil bill, leaving little foreign exchange for other purchases. The same is true for Turkey. In Ethiopia, oil absorbs 30 percent of the available foreign exchange, although it accounts for only 4 percent of the energy used in the country.

Fuel is essential to the economic expansion of both industrialized nations and the Third World. Petroleum products not only run factories, trains, trucks, and buses, they also provide electricity and support production of thousands of items from foods to medicines. Internal combustion engines power police, fire fighting, ambulance, mass transit, and construction fleets, whose continued mobility is critical to the public welfare.

Thus the growing dilemma over petroleum provides the incentive to investigate alternative fuels, especially those suited for use directly in existing vehicles without replacing the engines.

The only nonpetroleum fuel now used in significant quantities in motor transport is ethanol. Research on other alternatives, such as methanol,* hydrogen, liquid fuels from coal, vegetable oil, and oil from tar sands and oil shale is underway. Yet another alternative fuel, although it has received little recognition and research, is producer gas.†

Producer gas is generated from solid fuels such as wood, charcoal, coal, peat, and agricultural residues. Although it has been used to power internal combustion engines since their invention, it has been largely overlooked for the past 30 years.

*See companion report No. 33, *Alcohol Fuels: Options for Developing Countries*, National Research Council, Washington, D.C.

†Producer gas is a generic name for the gas without reference to the fuel from which it is generated. Other names are generator gas, gen gas (Sweden), tracgas (Denmark), town gas, coal gas, gazogène (France, Belgium), and gasogenios (Brazil). The term wood gas is often used because in the past wood and charcoal have been the most common fuels for gasifiers on mobile equipment.

During the early 1940s, when petroleum supplies for civilian use ran out in Europe, Asia, and Australia, producer gas was responsible for putting trucks, buses, taxis, tractors, and other vehicles back on the roads, and boats back on the rivers. In 1938 Europe operated about 9,000 gas producer buses and trucks, and there were almost none on any other continent. By 1941, however, about 450,000 vehicles were in operation in all parts of the world, and by 1942 the number had grown to approximately 920,000. Gas producers were then in use not only in land vehicles, but also in boats, barges, and stationary engines. By 1946 more than a million motorized devices around the world operated on producer gas. In Europe and Asia alone, the use of producer gas in the 1940s contributed to saving millions of people from starvation.

Basically, producer gas is made when a thin stream of air passes through a bed of glowing coals. The coals may come from the burning of wood, charcoal, coke, coal, peat, or from wastes such as corn cobs, peanut shells, sawdust, bagasse, and paper. (In some cases these materials must be pressed into bricks or pellets before they will produce adequate coals, and special generators also may be needed.)

The gas is generated in a gasifier—a metal tank with a firebox, a grate, air inlets, and an outlet for the gas produced. On the incandescent carbon surface of the glowing coals, most of the carbon dioxide and steam, initially formed by the burning solid fuel, are reduced to carbon monoxide and hydrogen. When mixed with air, these gases are combustible. In the cylinder of a spark-ignition gasoline engine they can be ignited in the usual way with the existing spark plugs. In diesel engines, producer gas by itself will not ignite. However, diesel equipment may be operated on producer gas. The gas is mixed with the combustion air and then a small amount of diesel fuel is injected into the cylinders to provide ignition.

Later chapters describe producer gas technology and its history. The general advantages and limitations of this fuel are listed below.

Advantages

1. Producer gas is a practical and proven fuel. Within 6 months of the occupation of Denmark in 1940—when the German military commandeered all petroleum supplies—Danes brought food from farm to table using hundreds of civilian tractors and trucks all fueled with "wood stoves," the local name for producer gas generators. Within 12 months there were so many gas generators that wood had to be rationed and special generator permits were required. The use of gas generators could be instituted just as easily today.

2. Producer gas generators are simple to make. They are uncomplicated devices and can be built in small machine shops equipped for welding and for sheet-metal and steel-pipe work. Common, everyday materials, such as mild

TABLE 1 Number of Gas Producer Vehicles Reported in Use in 1942

Australia	45,000	India	10,000
Belgium	15,000	Japan	100,000
Brazil	22,000	New Zealand	2,280
Britain	10,000	Norway	3,500
Canada	1	Portugal	450
Chile	1,000	Scotland	47
China	500	Slovakia	50
Denmark	20,000	Spain	2,200
France	110,000	South Africa	100
Germany	350,000	Sweden	73,650
Holland	1,000	Switzerland	15,000
Hungary	6,000	United States	6
Ireland	1,100	U.S.S.R.	100,000
Italy	35,000		

Based on Egloff and Van Arsdell, 1943.

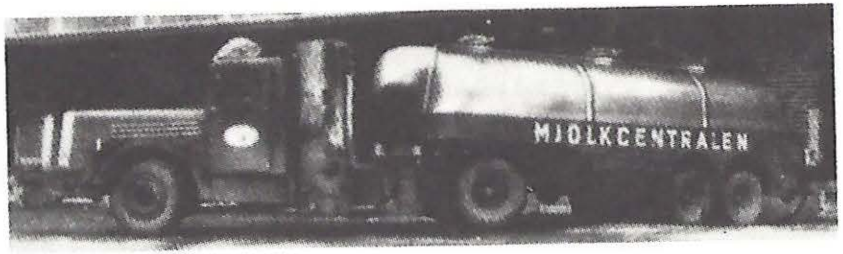
steel, standard pipe components, filters, gaskets, springs, and latches, are required for most of the construction, but it is valuable to have the throat of the generator made of stainless steel.

3. Producer gas has many applications. Discovered at the dawn of the Industrial Revolution, producer gas was originally used to power stationary engines. Between 1920 and 1949, however, it was used to fuel cars, trucks, trolleys, trains, tractors, boats, and even motorcycles. Producer gas can also be used as boiler fuel for steam and electricity generators as well as other industrial power. Some cities used to have gasworks generating "town gas," an application of producer gas that gave rise to the "Gaslight" districts of St. Louis and Chicago and that is still used in four New Zealand cities.

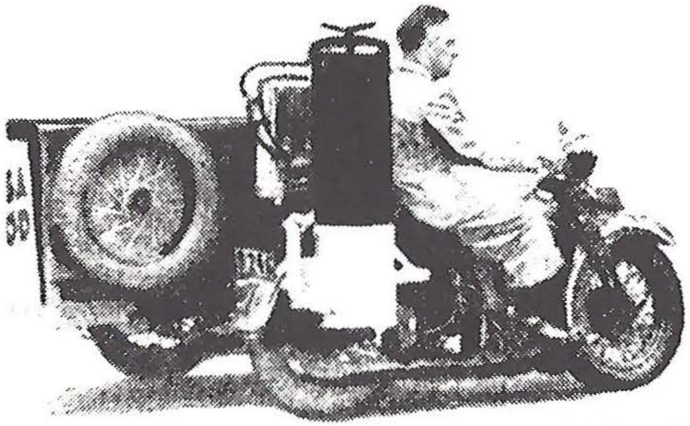
4. Producer gas requires no major modification of existing engines. To fuel existing spark-ignition engines with producer gas requires only a minor replacement of (or attachment to) the carburetion system. Producer gas requires no unconventional technology such as is required by electric-, steam-, or Stirling engine-powered motor transport. Given a set of instructions, a mechanic able to overhaul an internal combustion engine can probably install and operate a gasifier.

5. Gas producers can use renewable fuels. Rather than burning petroleum fuels, which are in finite supply, gasifiers can burn biomass that can be grown. In principle, most countries could grow their own wood, which could ensure a measure of insulation from the vagaries of international oil markets. If properly planned, the use of wood for fueling vehicles could be a spur to reforestation.*

*However, as will be noted later, this could also be a spur to *de*forestation. Under today's conditions little biomass is renewable continuously, and soil erosion is a serious global problem. Without good planning and management to match supply and demand, the widespread use of producer gas could exacerbate this problem.

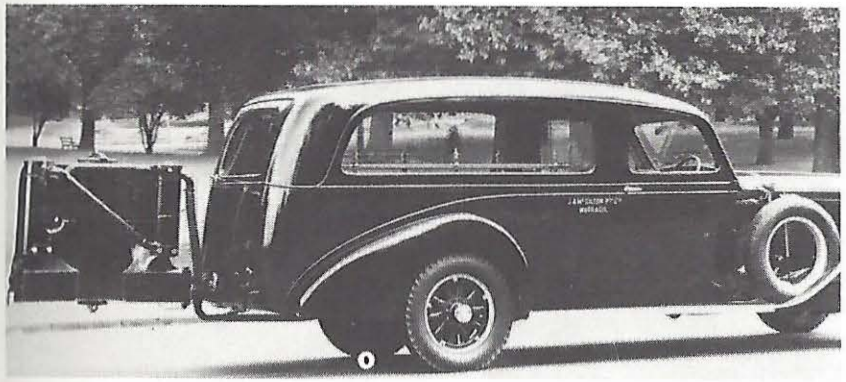


Semi-trailer, Sweden



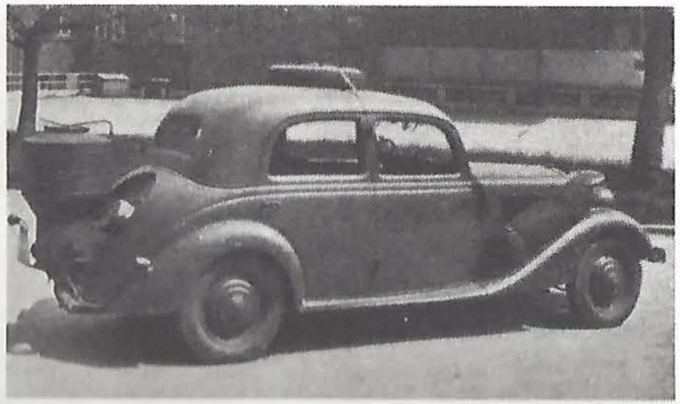
Motorcycle, Denmark

Bus, Germany

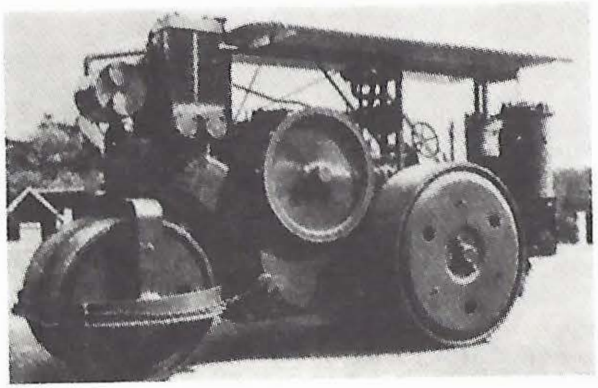


Hearse, Australia

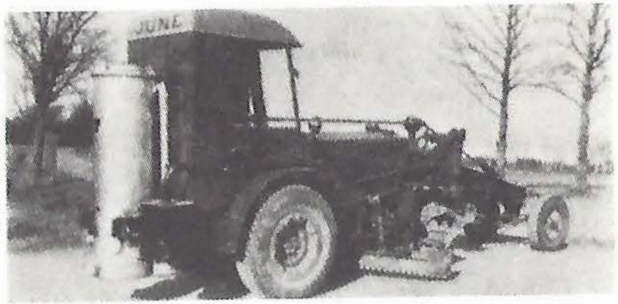
Dump truck, Sweden



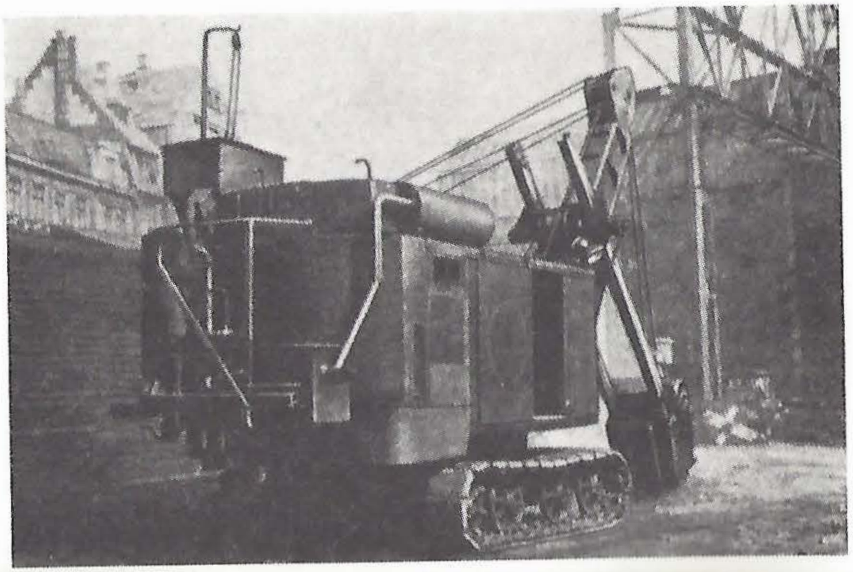
Limousine, Germany



Roller, Sweden

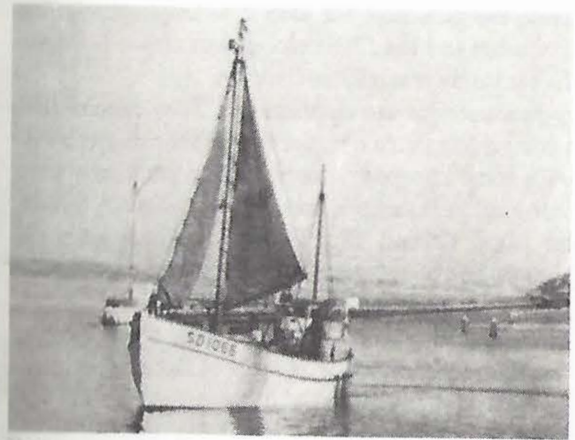


Road grader, Sweden

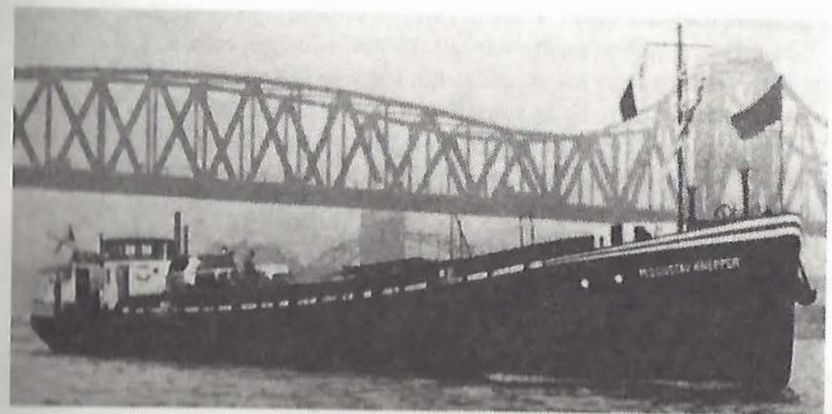


Shovel, Germany

Railbus, Sweden



Fishing boat, Sweden



River barge, Germany

Limitations

1. In any given internal combustion engine, producer gas generates less power than petroleum. Because it is made by drawing air into the generator, nitrogen gas dilutes its energy content. Engines powered by producer gas normally develop only 50–60 percent of the power generated using gasoline, although under optimal settings it is possible to obtain up to 80 percent. The added weight of the gas producer unit also contributes to loss of vehicle performance.

2. Maintenance, training, and driver discipline are required to keep gasifiers operating. Producer gas is much less convenient to use than liquid fuels. Before the vehicle will start, a fire must be lit, which requires from 2 to 20 minutes. When the vehicle stops for a few minutes, the driver has to decide whether to keep the fire lit. Even on long trips approximately 20 minutes are required to reload and service the generator for each 200 km traveled. The generators must be cleared of ashes and the filters changed or cleaned. Generators are messy to refuel; the tar inside is smelly and sticky.

3. Vehicles propelled by producer gas are cumbersome. They require that a generator be attached to the vehicle or to a trailer towed behind. Both systems are clumsy. (In the 1940s some European motor vehicles and trains were designed with a gas generator built in. Examples from Magirus-Deutz, Skoda, and Renault are shown on pages 12 and 13.) The awkwardness of a gas generator is less of a hindrance on tractors, trucks, and boats than on cars.

4. Fuel is bulky and difficult to store and handle. No solid, such as wood, coal, or charcoal, can match a liquid fuel for ease of handling. Furthermore, the solid fuel must be cut or pressed into blocks or chips of fist size or smaller. This is because the gas is generated in the bed of incandescent carbon and efficient generation requires a large surface area.

5. Producer gas can be hazardous. The generators are not normally explosive because they are under a slight vacuum created by the engine. However, they do produce carbon monoxide, a tasteless, odorless, colorless, and highly toxic gas. When engines are running, the vacuum ensures that no gas escapes, but when generators are being started or serviced, carbon monoxide levels can become hazardous. Therefore, generators must always be started or serviced outdoors or in well-ventilated, open buildings. Moreover, tars from the gasification process are like the creosote from a wood stove, and prolonged contact with skin must be avoided because of the presence of carcinogens.

6. Excessive use of wood fuel may increase the deforestation already disastrous in many areas. Some countries during World War II found that they had overestimated the quantity of wood available for fueling vehicles. Denmark, for example, had to ration gas generators and wood in the 1940s owing to the demand from tens of thousands of wood-powered vehicles. The pressing need for reforestation in developing countries must therefore be given the

priority it deserves before producer gas can be widely used. Moreover, the use of crop residues for gasification could significantly hasten the degradation of lands already suffering serious soil erosion.

7. In some developing countries producer gas for the rich could mean firewood shortages for the poor. Firewood is already in desperately short supply in many developing countries. (For a discussion of firewood shortages as well as fast-growing species suitable for fuelwood, see *Firewood Crops: Shrub and Tree Species for Energy Production*, Volumes I and II. For ordering information, see p. 98.) Excessive use of producer gas could lead to the rich buying the available wood to fuel vehicles, leaving the poor without firewood for cooking.

Although the limitations of producer gas are substantial, they are not insurmountable, as the recommendations in chapter 7 indicate. The technology can be used and has particular promise under special situations and fuel emergencies.

1

History

The first commercially successful internal combustion engine—built in 1860 by French inventor Etienne (Jean-Joseph) Lenoir—was powered with producer gas made from coal.* However, producer gas was little used in internal combustion engines until 1878, when a British engineer, J. E. Dowson, built a gas generator that used the vacuum in the engine intake manifold to suck the gas out of the gasifier. In Dowson's device gas formation was coupled to the engine's demands; the amount increased or decreased in direct proportion to the engine's changing power requirements. This fuel-on-demand concept has been the basis for nearly all subsequent gas producers designed for mobile engines.

By 1900 such "suction gas" engines were widely used in industry, directly competing with steam engines in economy and efficiency. Although normally fueled with coal or coke, they were often also fueled with wood or charcoal. These units, however, were exclusively large stationary engines (300-1,500 hp) generating electricity.

In 1905 producer gas first appeared on the highways when an open-topped bus powered by wood gas was built in Scotland. At that time, however, the convenience of gasoline fuel eclipsed any general use of producer gas in vehicles.

The need for alternative fuels only became obvious during World War I, when gasoline supplies were limited. In 1914 the portable gas producer—the "gazogène"—attracted attention as an experimental device in France. However, its first practical test occurred in Casablanca, Morocco, when the Automobile Club of Morocco sponsored a series of contests that included five trucks and tractors fueled by producer gas. Towards the end of the war, tests with heavy trucks were underway between Paris and Rouen and elsewhere. However, the trucks were fitted with updraft generators (see chapter 3), which were not very successful.

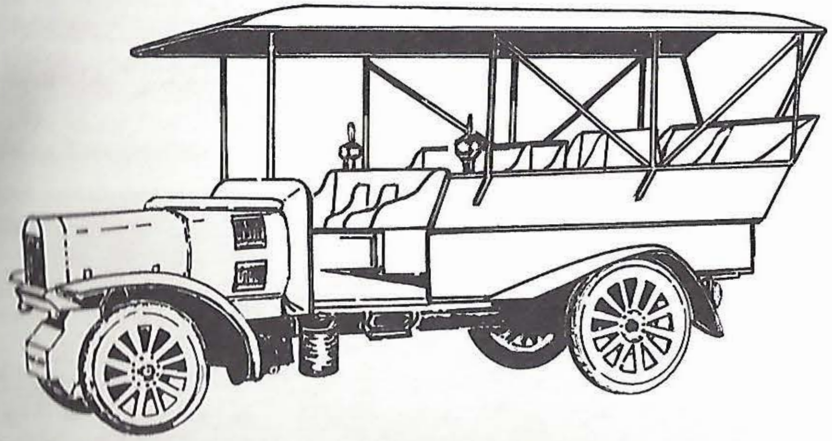
*Producer gas, however, actually predates the internal combustion engine; in the eighteenth century, blast-furnace gases (a form of producer gas) were burned to preheat furnace air in the production of iron.

Between the Wars

In 1919 Georg Imbert, perhaps the greatest name in the development of vehicle gasifiers, built a crossdraft generator for the gasification of charcoal and anthracite. In 1921 he drove a car equipped with it from Strasbourg to Paris, a distance of about 500 km (300 miles). This attracted much attention in France, and throughout the 1920s the French army sponsored gazogène rallies. In a 1927 rally, for example, trucks raced 2,812 km (1,746 miles) powered by wood, charcoal, semicoke, and peat coke.

Between 1920 and 1940, the ready availability of cheap crude oil made gasifiers unpopular, but European governments continued to encourage the development and use of producer gas. By 1930, among European countries with an ample wood supply, there was hardly one in which producer gas was not promoted by individual engineers, by industry committees, and often by government subsidies. Moreover, Great Britain, France, and Italy promoted the use of producer gas in their colonies.

By 1923, 25 different types of generators were commercially available in France. By 1929, about 1,880 vehicles powered by producer gas were running on French roads; two-thirds of them were operated by the army. In an effort to stimulate greater use of producer gas, the minister of agriculture in 1935 asked the water and forest service to hold two exhibitions a year to demonstrate wood- and charcoal-gas motors and their uses in agriculture and transportation. Meetings of a Wood Gas Congress were held under the chairmanship of the French ministers of agriculture and of public works.



The first portable gas producer was patented by an Englishman, Samuel Brown, in 1836, but such a plant was not used for motor transport until 1901. During 1901–1903, a gas producer patented by J. W. and G. J. Parker powered first a 2.5-hp and later a 25-hp car a distance of 1,000 miles. Over the next decade, J. W. Parker made further improvements to this plant.

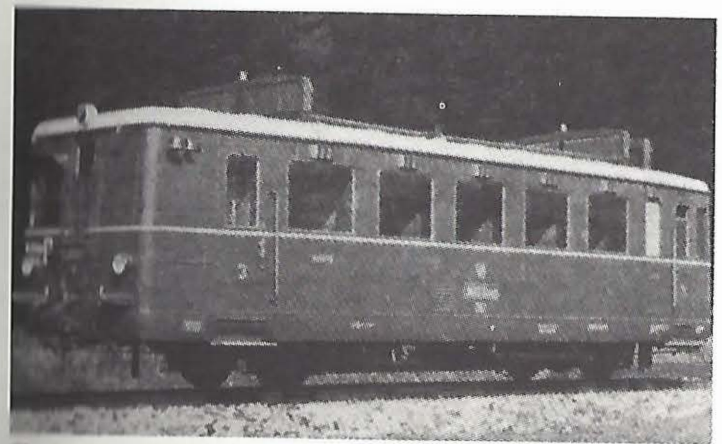
During World War II many prominent automotive companies manufactured gas producer vehicles. . .

Renault, France

Imbert, Germany

Ford, Germany

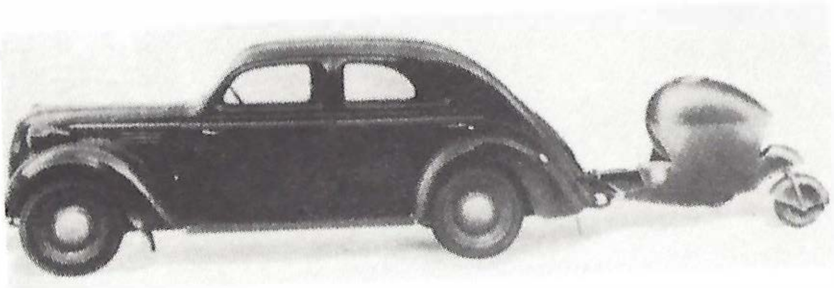
Magirus-Deutz, Germany



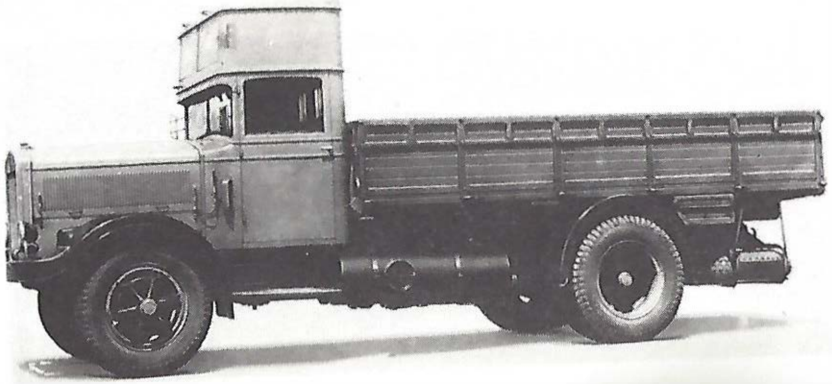
Škoda, Czechoslovakia

Daimler-Benz, Germany

Saab, Sweden.



Volvo, Sweden.



Fiat, Italy.

General Motors, Australia.

General Motors, Denmark.

Moreover, the French Automobile Club formed a wood-gas section and conducted an annual demonstration drive. Other demonstrations of wood-gas devices were held in French North Africa and, in 1937, 140 gasifier-equipped trucks took part in French army war games, each vehicle covering 3,000–5,000 km.

By 1938, France had 7,800 producer-gas-powered trucks operating—more than 1 percent of its total truck fleet. Wood or charcoal was then available from about 1,500 French service stations. Truck drivers were taught to operate gas producers at special schools; for instance, the Ecole de Gazogène at Draguignan.

In Germany, promotion of producer gas became a national policy of Hitler's Third Reich; the Reichsamt für Wirtschaftsaufbau (Department for Industrial Growth) developed generators for tractors; the National-Socialistic Driver Corps trained drivers for producer gas vehicles; the Wehrmacht developed units for tanks and other military equipment. In 1935 a rail motor coach (railcar) powered by a wood-gas generator began running between Bielstein and Waldbroel, near Cologne.* Also in 1935, the German government sponsored a "Test Drive with Domestic Fuels," in which 38 trucks (4.5–13 tons gross weight) drove from Rome to Paris with generators fueled by coal, lignite, charcoal, wood, and peat.

German government and industry developed many types of gasifiers. Most were built by hand, although two types (the Imbert and the Roth) were mass produced and distributed throughout the Axis world. (Most taxis in Paris, for example, were powered by these gasifiers, even as late as 1949.)

In Italy, Mussolini's government organized a permanent international committee on charcoal fuel that sponsored tests and rallies of gasifier-powered cars from all over Europe and from many Latin American countries. In addition, Austria sponsored international alpine test drives with producer gas and other alternative fuels in 1933 and 1934.

World War II, Europe

After Germany's invasion of Poland, the production and use of generator-powered vehicles was limited only by the shortage of metals and tires. Gasifiers came into widespread use in all European countries. Within 2 years, France had 100,000 trucks, 30,000 tractors, hundreds of river barges, and

*The 32-passenger railcar, equipped with an Imbert generator and spark ignition engine, reached speeds of 56 kph (35 mph). Its 100-hp gasoline engine gave 75 hp on wood-gas fuel after the compression ratio was increased to 8:1.

some large river boats* fueled with producer gas, and had launched a program to get 1 million generators into service.

To Europe at large, producer gas became the "civilian fuel." By March 1944 more than 80 percent of the trucks and other large vehicles and 26 percent of civilian automobiles (260,000 cars) in Europe had been converted to producer gas.† Eventually, no major European country had fewer than 10,000 producer gas vehicles.

One of the most effective uses of producer gas was not on vehicles at all. It was, in fact, the fueling of industrial installations such as sawmills, rock crushers, and pumping stations. Many fishing trawlers also converted to producer gas. The technology was often crucial to survival because it allowed the continuation of many critical civilian services that otherwise would have ceased.

France

Hailed as *le carburant national* by then French Chief of Staff Pétain, producer gas was propagandized as a key to France's survival in World War II. Conversion to generators was urged as a patriotic duty in Vichy France; their espousal became a popular political rallying call. To ride only in generator-powered cars when on official business was an unwritten law observed scrupulously by ministers of agriculture and by officials in the French forest service.‡

In 1941 France undertook the wholesale conversion of commercial and military vehicles to solid fuel; by year's end 50,000 charcoal-burning cars were in operation and 40,000 more were in production. France met about 20 percent of her normal needs for motor fuel using solid fuel and alcohol fuel. The main occupation of the youth corps (organized in lieu of military service) was producing charcoal, 36,000 tons of which were manufactured each month in 1942.

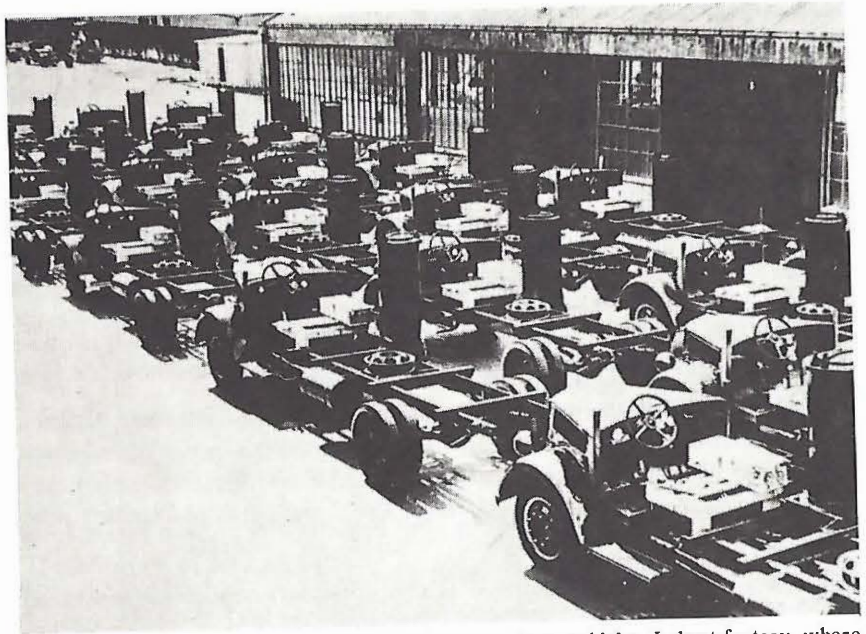
Germany

By 1943, the German government had ordered that all road and farm tractors of 25 hp and over use producer gas for motive power. In addition, all

*The vessel *Kelch*, a gasifier-powered motorboat with a 300-passenger capacity, began operation in 1937 on the Oberspree near Berlin. The output of the unaltered engine (70–80 hp) gave it a speed of about 10 mph. In 1940 a 700-hp Rhine tug was fitted with a Deutz generator.

†Enemy Branch, British Foreign Office and Ministry of Economic Warfare. 1944. Review of the Substitute Fuel Position in Continental Europe.

‡Glesinger, E. L. 1949. *The Coming Age of Wood.* Simon and Schuster, New York.



Germany, about 1943. Mass production of gas producer vehicles, Imbert factory, where some 500,000 gas producers were manufactured during World War II. (E. E. Donath)

stationary and ship engines operating on liquid fuels were converted wherever possible to the use of either producer gas or high- or low-pressure gas operation. The only types excepted from this order were certain military vehicles and those vehicles which could not, for construction reasons, be converted to the use of solid fuels. All new civil and military trucks were being built to utilize producer gas.

Because Germany was rich in coal and lignite, most of its gasifiers were designed for these fuels rather than for wood. After July 1942 the use of coal or coke rather than wood was prescribed for fueling gasifiers because wood became scarce. Filling stations were required to carry standardized sacks of wood, charcoal, or coal fuels. Also in 1942 the gas producer program was transferred to a special office (Zentralstelle für Generatoren) within the Ministry for Armaments and War Production. The Imbert Company alone reportedly produced more than half a million generators before the war ended.

Producer gas units were often used by the German army to transport vehicles and supplies to the eastern front in Russia. Some tanks were driven to the front with detachable producer gas units that were then shipped back to the railhead for use on other tanks. Much of the German army's training was conducted using vehicles and tanks fueled by producer gas.

United Kingdom

On a hilly stretch of road on the outskirts of London, between Sidcup and King, the British Fuel Research Station set up a test course for producer gas vehicles in 1939. More than 1,400 road trials were conducted on this and other courses, covering a total of 300,000 km (190,000 miles). Four round trips, each a distance of 173 km (107 miles), were required for each vehicle. The fuel consumption, speed, time in each gear, engine temperature, weight of ash, features of the various generators, and different fuels were all measured. This resulted in the selection of two gasifiers designed to be produced rapidly at low cost and to be suitable for vehicles up to 6 tons gross weight and 3–4 liters engine displacement.*

Many British buses were fueled by these gasifiers throughout the war years (see pages 20 and 61).

Denmark

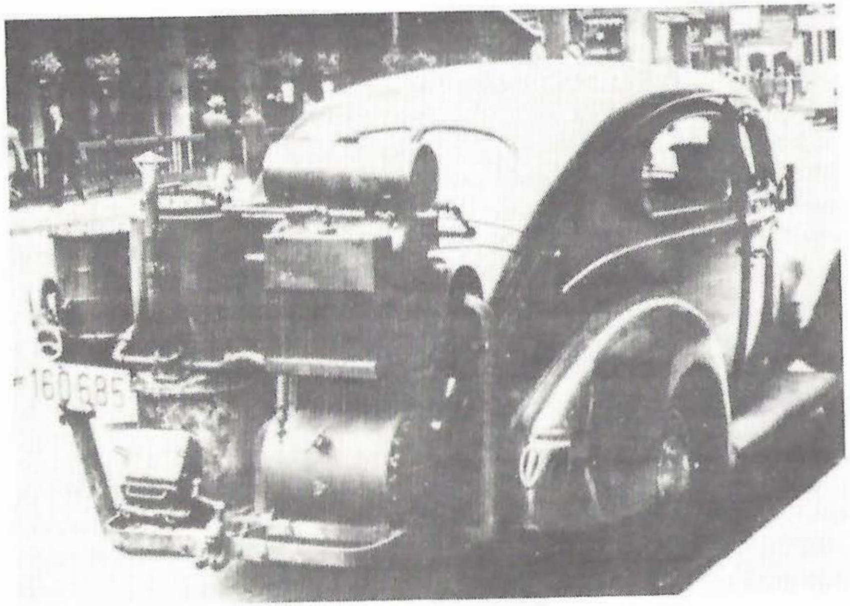
The German occupation of Denmark in April 1940 immediately left the civilian population without petroleum. Within 48 hours panic over food supplies drained warehouses containing a 2-month supply. The threat of starvation hung over the country because there was no way to transport food from the farms to the cities.

A commission was quickly established under the chairmanship of Niels Bohr, the physicist. Although the commission considered many options, it determined that the producer gas generator was the only practical alternative to gasoline for motor transport. Within 6 months of the Nazi occupation Denmark had some 1,000 gasifiers in operation. As a result, farm produce was moving to market and a major civilian tragedy was narrowly avoided.†

Danish vehicles were initially fueled with wood, but other fuels included lignite, seaweed, sawdust briquettes, and various peats, which were available in large quantity. Factories were built to blend, dry, and form peat into briquette blocks. These solid fuels served Danish agriculture and industry until the Allied armies brought abundant, cheap gasoline and diesel fuel in 1945.

*Hurley and Fitton, 1948.
†The Gestapo allowed the commission to experiment with a gasifier-powered fishing boat, which the underground eventually used to smuggle Niels Bohr out of Denmark.

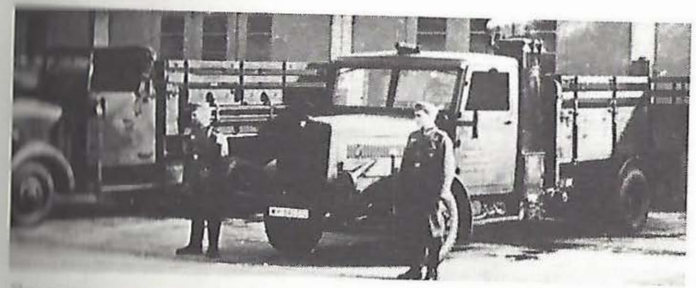
Gas producers were found throughout the world during World War II. . .



Belgium

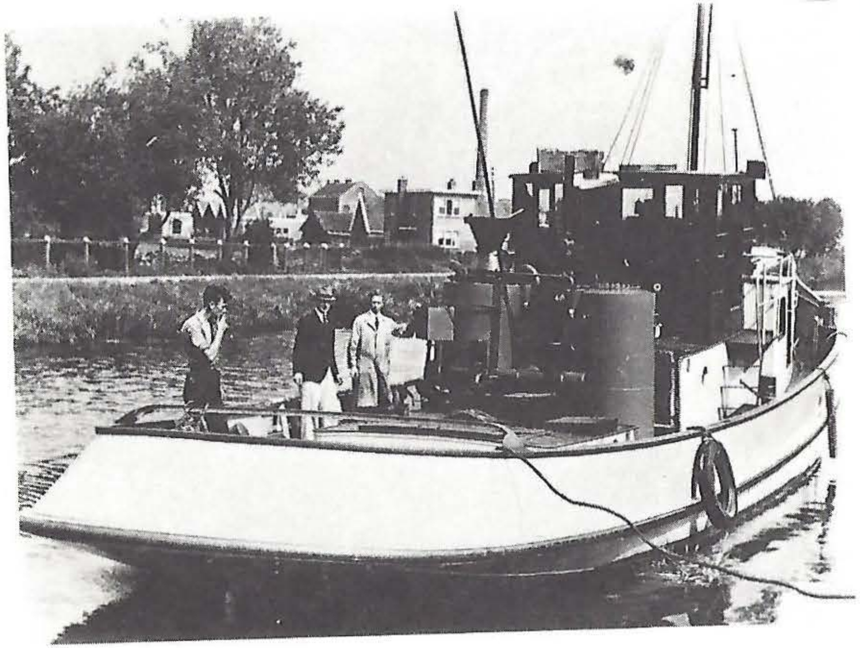
England

France

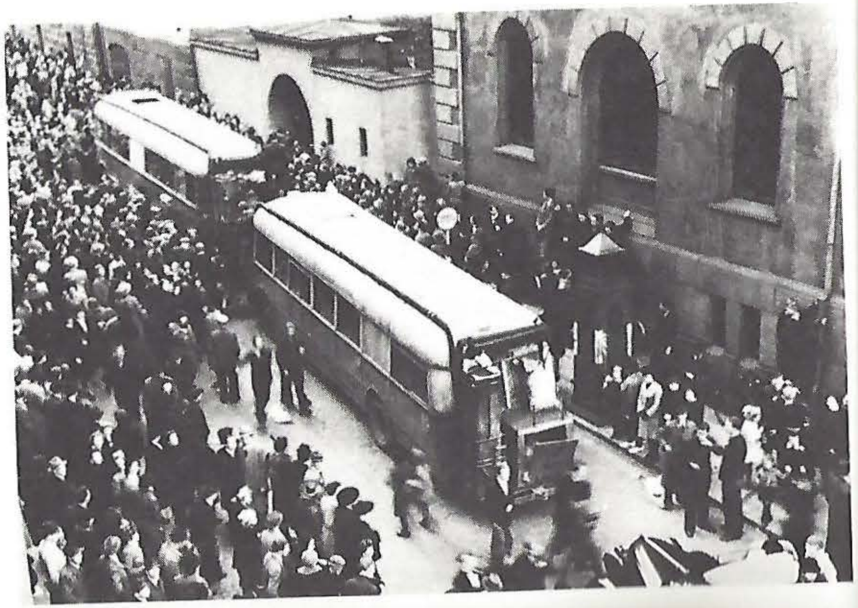


Germany

Italy

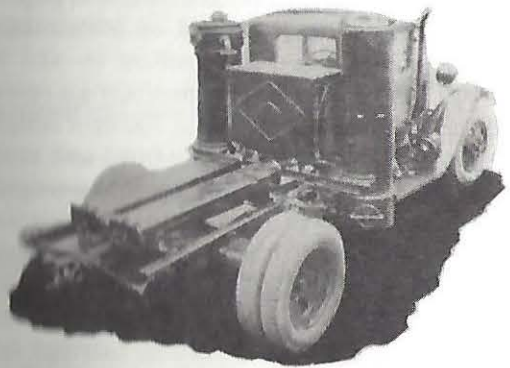


Netherlands

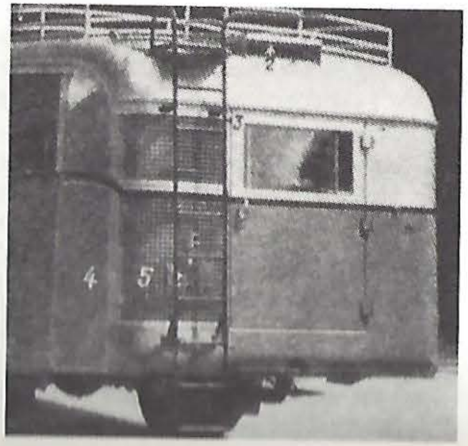


Norway

Portugal



Soviet Union



Switzerland

Sweden

The importance of wood-gas generators to wartime Europe is perhaps best illustrated by what occurred in Sweden. In September 1939 Sweden had about 1,500 motor vehicles–almost exclusively trucks and buses–driven by gas from charcoal; by March 1942 there were about 67,000 (35,000 passenger cars, 3,400 buses, 28,500 trucks). On May 1, 1943, there were 73,650 producer gas vehicles, representing 91 percent of all vehicles on the roads. (This, however, was only about 33 percent of the prewar number.) The Government Fuel Commission, organized in 1940, set up a government-owned generator corporation (Svenska Gengas Aktiebolaget) to promote the industrial development of wood gas. Under the supervision of the commission, some 500 makes of generators were approved, and manufacturing capacity was pushed to 3,000 units a month.

By the summer of 1942, when shortages of materials halted production, one-third of Sweden's motor vehicles had been equipped with gasifiers and were on the road; 15,000 tractors were back at work, and thousands of producer gas units had been installed in fishing boats and on locomotives. Beginning in 1940 about 100 Swedish railcars and auxiliary (6- and 8-cylinder) locomotives of up to 300 hp were converted to producer gas operation. Fifty Ford automobiles fitted for running on rails and 700 light railcars used for inspection and maintenance of the tracks also were fitted with small producers weighing less than 150 lb. Furthermore, stationary units were generating gas for industrial and municipal power. It was estimated that 2.5 million m^3 (90 million ft^3) of charcoal (supplied from about 3,000 furnaces) and 2 million m^3 (70 million ft^3) of wood were consumed each year by Swedish vehicles. Government officials credit wood gas and Sweden's forests with a major contribution to the nation's survival.

Soviet Union

During World War II the Soviet Union built many Stalinez tractors, with 60-hp 4-cylinder engines, specially designed for wood-gas operation with producers attached. Generators were designed by the Scientific Motor Car and Tractor Institute, the Central Academy for Forestry Engineering, and the Monnet Experiment Base. Factories at Kharkov and Stalingrad manufactured wood-gas units. From 1938 to June 1941 the Kharkov factory completed about 16,000 generators for the standard farm tractor.

Other Nations

By the end of 1940 Finland had equipped about 8,500 motor vehicles with charcoal-gas generators. Yugoslavia was also using vehicles fueled with charcoal gas. Switzerland had 15,000 wood-gas vehicles and manufactured gasifier-powered locomotives at Winterthur. In 1942 the Italian government decreed that every one of the 68,500 farm tractors in Italy had to be modified to use producer gas by 1947. In Norway 300 fishing vessels were equipped with gas generators in 1943. Also, the entire Dutch fishing fleet was ordered to use producer gas because there was no means of obtaining liquid fuels.

World War II, Outside Europe

Japan

In its war preparations Japan gave high priority to producer gas generators. The Japanese Home Office instructed police in 1939 to refuse the registration of new automobiles not equipped to run on charcoal gas or other substitute fuels. The Ford and General Motors plants in Japan suspended work on cars other than those designed to operate on producer gas.

Australia and New Zealand

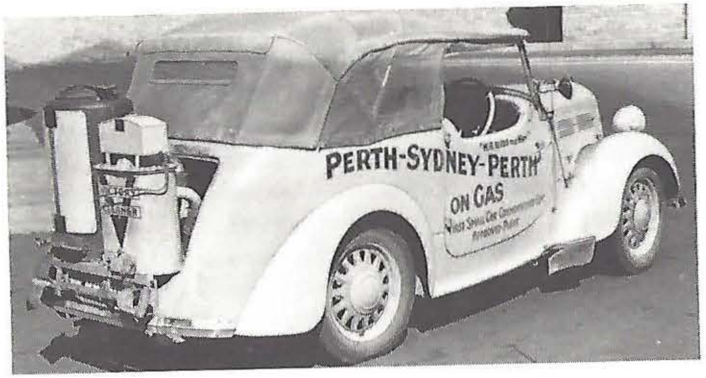
In Australia no less than 34 different types of gas producers were available commercially in 1939. To ensure that all designs were safe, efficient, easy to maintain, and reliable, the Australian government set up gas producer testing facilities. Units could not be sold until they had passed compulsory government tests. Prices (including mounting) ranged from £64-90 (U.S. $256-360) for units designed for trucks with 30-hp engines. By 1942 about 15,000 vehicles operated on charcoal gas in Australia, including more than 700 tractors in the state of Western Australia; by 1943 more than 45,000 gas producer vehicles were in use.

In New Zealand, shortly after the war began, a technical committee was set up to investigate the use of producer gas. Between September 1939 and August 1940 the committee tested existing producers and designed an improved version. By 1943 1,773 cars and 507 trucks had been fitted with gas producers.*

Brazil

To aid in overcoming the fuel problem affecting transportation, the Brazilian government in 1942 authorized the importation of material into

*Bailey, 1979.



Australia

Brazil

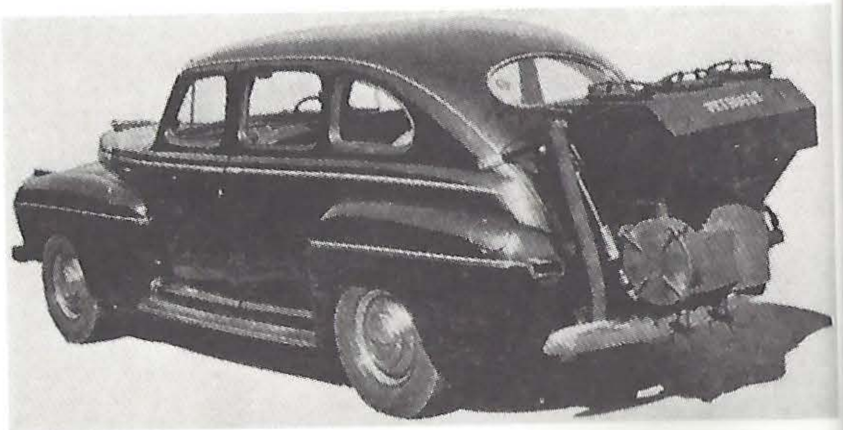
Argentina

Cuba

China

India

New Zealand



South Africa

Japan

Melbourne, Australia, 1940. Gas producer show. (E. L. Cranstone)

São Paulo to manufacture 11,000 "gasogenios" to be installed in trucks and buses. Official reports from Brazil indicated that as of April 15, 1943, more than 2,000 gasogene automobiles were in circulation in Rio de Janeiro, and about 10,000 vehicles equipped with this device were operating in São Paulo. Later it was reported that 20,000 producer vehicles were in operation. Dozens of generators built for cars were actually sent to farms to power gasoline engines that produced electricity, particularly for lighting.

Two large factories were constructed to manufacture producer gas generators; about 40 generators were built daily. Demand for charcoal for these units became so great that a large cement company turned over one of its mills for the preparation of powdered charcoal to be sold at former gasoline service stations.

Other Countries

In India and other Asian countries gas producers on cars became a familiar sight in the 1940s. U.S. missions returning from China declared that wood gas was the shortest way around that nation's transport-fuel problems. In the United States in 1943 there were only about six producer-gas-propelled motor vehicles operating experimentally on wood or charcoal, but thousands of generators were built in Michigan for export to China.

2

Modern Experience

Following World War II the use of producer gas as a fuel for motor transport was largely forgotten. But in response to rising petroleum prices in the 1970s and the further threat of shortages, a number of governments, engineers, and small companies have begun reinvestigating gas producers and their modern potential. Most are solitary efforts by individuals or small groups of engineers. However, the governments of Sweden, South Africa, and the Philippines have formally committed their nations to developing gas producers suitable for vehicles. The mounting worldwide interest in producer gas is leading to new designs that could make wood-, charcoal-, and coal-powered vehicles safe, efficient, and economical.

Sweden

Concerned by a threatened cutoff of oil during the Suez crisis, the Swedish government decided to review the technology in 1956. This resulted in development of a highly successful downdraft gas producer for use on tractors and trucks. It was fueled with sized wood chips dried to 20 percent moisture content (or less). Tractors and trucks were equipped with standard, naturally aspirated diesel engines modified to operate in the dual-fuel mode with about 10 percent fuel used to ignite the producer gas.

In cooperation with Swedish automakers Volvo and Saab-Scania, the National Swedish Testing Institute for Agricultural Machinery has developed gas producer models for cars and tractors with 2- to 4.5-liter engines, for 3.5- to 6-liter engines, and for trucks with 6- to 11-liter engines.* Plans, stampings, and toolings are fully worked out for each of the three models. In the event of a fuel-supply emergency, Sweden hopes to be able to begin production within 6 months and subsequently manufacture 10,000 units a month. The capacity of the nation's paper mills to produce large amounts of chipped wood (the first step in papermaking) is sufficient to provide the basic fuel.

*The three units are shown in operation on pages 45 and 46.

South Africa

The South African government is making a major drive for use of wood-fueled gasifiers for small engines. A national working group has been formed composed of gasifier manufacturers, financiers, and researchers. The objective is to gasify 1 million tons of timber products per year by the end of 1985. The gasifiers are expected to be used mainly for stationary purposes, such as for pumping water, generating electricity, and drying crops in remote farm areas, but they will be simple, compact, and light enough for use on vehicles.

The South African Council for Scientific and Industrial Research (CSIR) plans to ask a few companies to manufacture and market about 12 wood-gas systems (to CSIR design) for a series of closely monitored field trials, after which CSIR will complete its design concepts. It will then set guidelines for design and manufacture, for minimum performance standards, and for operating manuals. In addition, CSIR will design four standard sizes of stainless steel hearths and arrange for their mass production at lowest possible cost for general use by any company interested in manufacturing gas producers. Subsequently, CSIR plans to develop sophisticated features such as improved methods of fuel preparation and handling, ash removal, afterburning, and performance monitoring and control.*

Philippines

In 1980 President and Mrs. Marcos directed government agencies to investigate the applicability of gasifiers to Philippine vehicles. As a result, 25 gasoline and 3 diesel vehicles were fitted with charcoal-fueled gasifiers.

In 1981 a caravan of gas producer buses and cars spent a month delivering goods and services to people in rural areas on the islands of Luzon, Visayas, and Mindanao. Then a grueling 6-day rally covering some 2,500 km was set up to test the reliability and endurance of the gasifiers and vehicles. The experienced rally drivers reportedly confirmed the practicality of gasification as a petroleum substitute.

Since then, government initiatives have led to the building of prototypes of producer-gas-powered fishing boats, irrigation pumps, and electricity generators for rural areas. Two charcoal-fueled "jeepney" buses are running routes in Metro Manila to popularize the use of producer gas and to determine the durability of gasifiers and the economics of their use.

*Information from F. R. Hose, Division Head, Engineering Systems, National Timber Research Institute, Council for Scientific and Industrial Research, P.O. Box 395, Pretoria 0001, South Africa.

United States

In the United States there is a resurgence of interest in producer gas vehicles. It is manifested largely by new university research and development programs and by some enthusiasts among the public. Moreover, at least three wood-powered cars have been driven across the country in recent years and a Vehicle Gasifier Association has been formed. There is also growing interest in small stationary gasifiers, particularly for use on farms and in small industry. A number of small companies now manufacture commercial units.

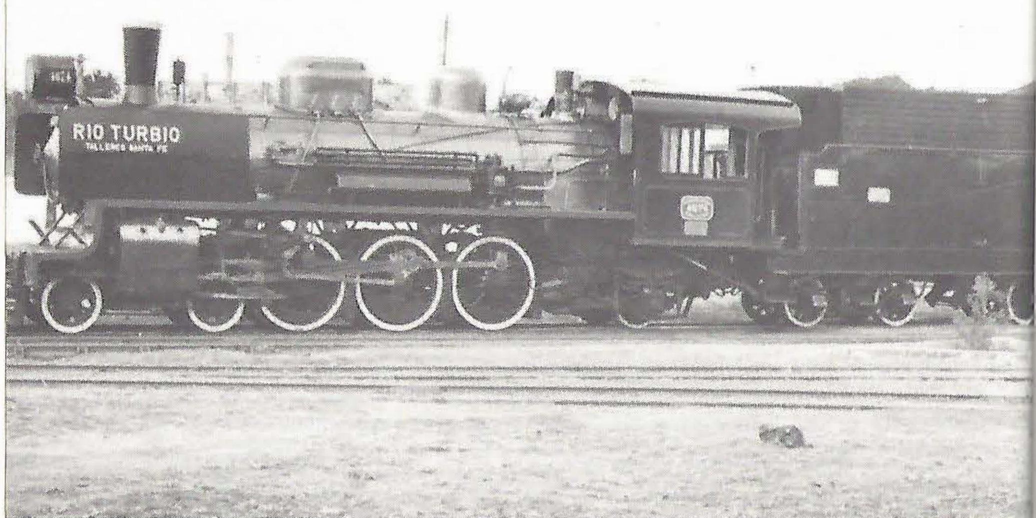
Locomotives

In Argentina and South Africa engineers have successfully retrofitted steam locomotives with gasifiers. This may prove to be an innovative mobile use of producer gas, perhaps one that gives new life to the steam locomotive technology, now considered obsolete. It may have application to steamships and other devices traditionally fueled by steam.

Firing a steam boiler with producer gas avoids the complexities of gas cleaning needed by an internal combustion engine. The gasifiers can be updraft and, at least in principle, tars or other combustible by-products are of little concern, as they burn away in the boiler.

All these and other modern examples of gas producer development are depicted briefly in the following pages. These are gasifiers for which we were able to obtain photographs; no endorsement of these products over others is intended.

Argentina



Buenos Aires, 1979. The Argentine locomotive, engine number 4674, was manufactured in 1919 by Baldwin and Co., an American firm. In 1979 an updraft generator was fitted into the cab so that the locomotive could be fueled by charcoal, coal, wood, or a mixture. The generator contains a thick fuel bed, which reportedly yields an abundance of combustible gases. The locomotive's boiler is unmodified, except for replacing the stationary grate with a rocking one.

According to the researchers involved, burning producer gas rather than coal means that the boiler tubes remain free of soot and largely free of fly ash. And with no soot to insulate the boiler tubes, steam production is considerably increased.

Because gas producers operate on a restricted air flow, the fierce draft and highly intensive combustion of a regular steam boiler are much reduced. This means that the firebed is far less disturbed and, consequently, no sparks, cinders, or smoke are emitted by gasifier-powered locomotives, even with the most offending coal. Thus, one of the main limitations of steam locomotives– their dirtiness–is removed.

To increase the heat content of the gas, some of the used steam from the cylinders is injected with the primary air into the ashpan of the generator. This causes water gas to form, and by rapidly cooling the ashes it reduces clinker formation. (Information from L. D. Porta, Azara 1557, Banfield 1828, Argentina.)

Australia

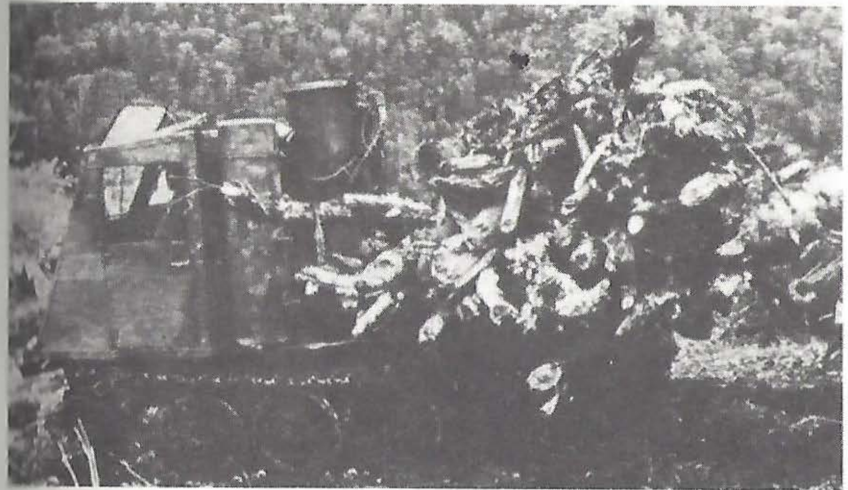
Perth, Western Australia, 1981. A Toyota diesel Land Cruiser fitted with dual firebox gas producer being tested. The unit has both an updraft generator for charcoal fuel and a downdraft generator for wood chips. The two are coupled so that gas from the wood chips passes through the burning charcoal and is purified of tars before entering the engine. For short runs, only the charcoal generator is lit. It is efficient, quick starting, and handles variable loads with little change in gas quality. For long runs, both fireboxes are lit. The gas formed by the downdraft generator supplements that from the updraft generator. The downdraft generator has three rows of air inlets (tuyères). By unplugging the different rows a wide array of fuels and horsepowers can be accommodated. The unit shown was sized for use on an 8-ton truck. (C. V. Pederick, P.Y. Box 11, Wagin, Western Australia.)

Belgium

Brussels, 1979. This Mercedes Unimog recently did 100 km in 1 hour, running at full power. It used 20 kg of charcoal, with a gas producer unit weighing 450 kg, with a range of 3 hours at 60 kph. (Lambiotte, S. A., Brussels)

Andenne, 1981. "Dual fuel" diesel truck with gasifier fueled with wood, charcoal, peat, densified wood waste, or coconut waste. (S. A. Willy)

China



Manchuria, 1964. A Chinese-built 5-ton logging tractor patterned on a Russian model (TDT-40) but modified to operate on wood fuel. It is shown here with the deck apron raised and fully loaded. The gas generator is mounted directly behind the cab. The load of wood will be used for mining timbers and pulpwood and for craft work and tractor fuel. (S. D. Richardson. 1966. *Forestry in Communist China*. The Johns Hopkins Press, Baltimore, Maryland)

The fuel store of the logging tractor, containing small hardwood blocks (mainly birch, oak, and ash). (S. D. Richardson. 1966. *Forestry in Communist China*. The Johns Hopkins Press, Baltimore, Maryland)

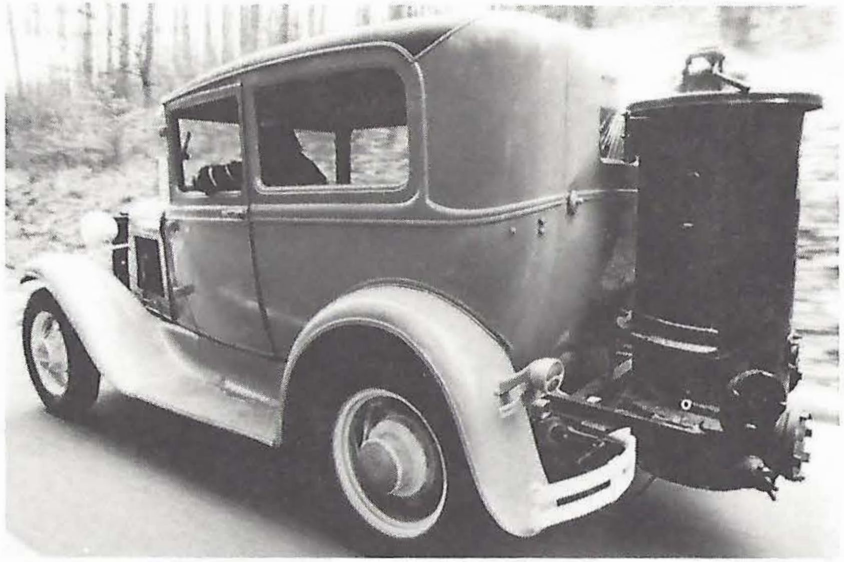
Finland

Olkkala, 1980. Wood-powered diesel tractor. (VAKOLA, Valtion Maatalouskoneiden Tutkimuslaitos)

France

Paris, 1981. Truck powered by wood. (Génétrans, Paris)

Germany



Bonn, 1981. A 1930 Ford Model A powered by a World War II Imbert generator, fueled by a mixture of birch wood, wood shavings, and sawdust. (W. Drehsen)

Eschborn, 1980. Wood-powered tractor designed for developing country use. (GTZ)

Laos

Vientiane, 1981. Swedish Svedlund charcoal-fueled generator on a jeep. (B. Sandberg)

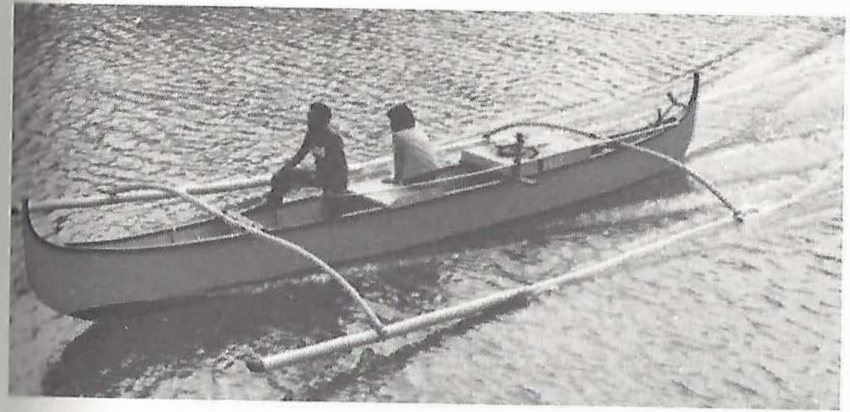
Philippines

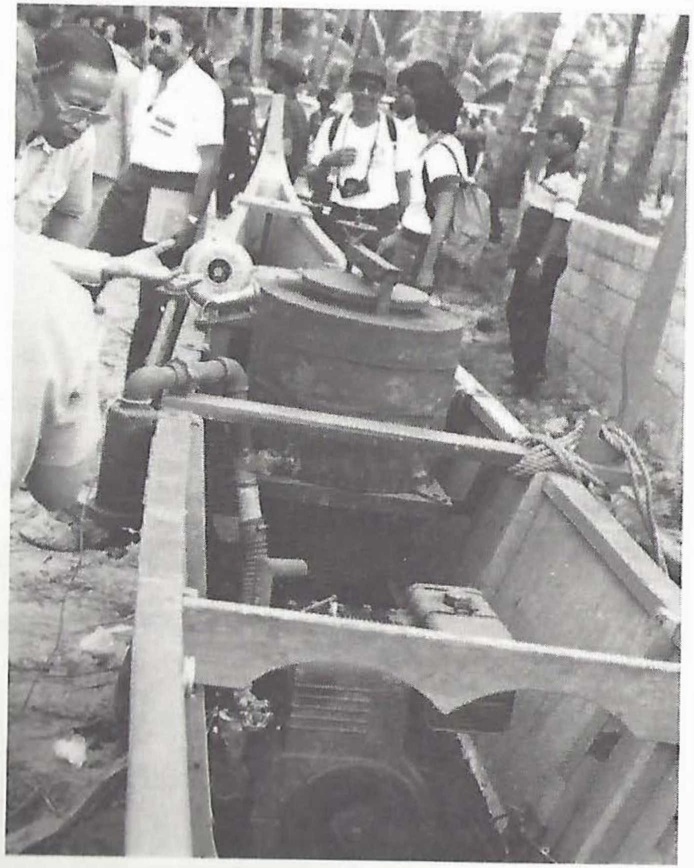
Manila, 1981. This jeepney recently completed a 160-km test journey consuming 20 kg charcoal. At current prices of diesel and charcoal in Manila, the charcoal fuel is estimated to be one-fourth to one-fifth of the price of diesel, and based on daily travel of 100–150 km, the jeepney owner could repay the additional cost of the generator from savings in the cost of fuel in 5-6 months of operation.

The experimental vehicle is fitted with an extra water tank, from which water is added to the gas generator to produce water gas when additional power is needed, climbing hills, for example. (Commander A. Protacio, Director, Project Sta. Barbara, Manila)

Twenty-five gasoline-engine vehicles are being tested at present for operation on charcoal and steam, while three diesel vehicles are operating on charcoal and air. Seven producer-powered jeepneys are operating in Metro Manila, charging reduced fares for commuters.

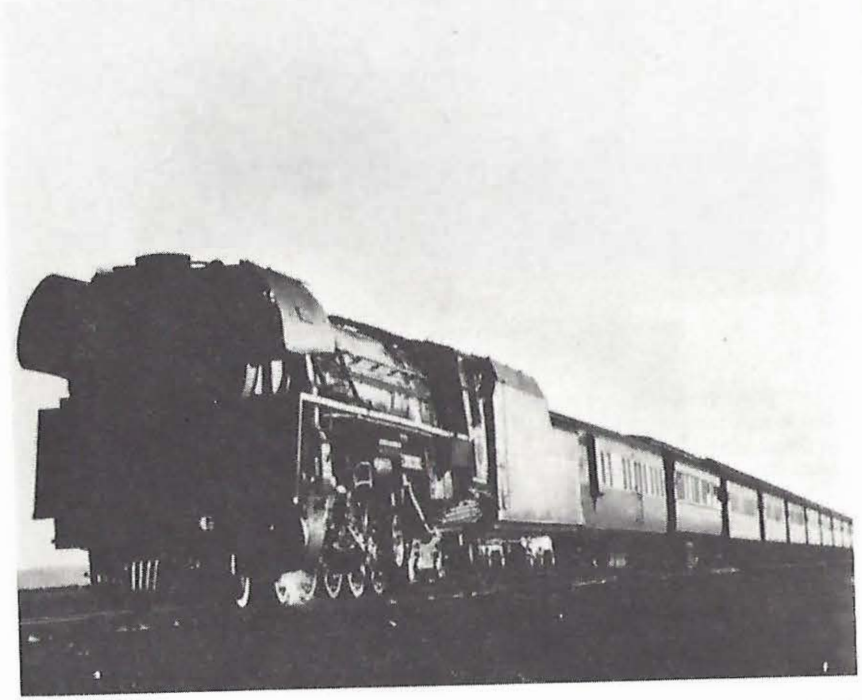
Tacloban City. In 1979 the Philippines Auto Rally Club was forced to forego activities due to petroleum shortages. But auto rallying returned to the sporting scene in a 7-day, 2,500-km rally of 14 gas producer vehicles in June 1981. (Philippine News Agency)





Bolinao, Philippines. Experimental wood-powered fishing boat. The 16-hp engine uses 6 kg of wood chips per hour. (Formerly it consumed 2 liters of gasoline per hour.) The conversion to producer gas is calculated to pay for itself in fuel savings in less than a year. ([illegible] Shay)

South Africa



Pretoria, 1982. An application of producer gas has been made on engine number 3450, a steam locomotive of the South African Railways. The locomotive has now finished its tests, reportedly with good results. In one test, it successfully replaced electric locomotives in heavy, uphill, stop-and-start passenger service.

Because the generator operates on restricted air flow, only 30-40 percent of the combustion air passes through the firebed. (The rest is added in the boiler chamber.) The fierce draft and highly intensive combustion of a regular steam locomotive are much reduced. Therefore, the firebed is far less disturbed and no sparks, cinder, or smoke are emitted by the gasifier-powered engine. This is an important advantage in trackside safety and cleanlines. The picture shows engine number 3450 on official test pulling an express train, which includes a dynanometer car. The train was traveling at 113 kph (70 mph).

Sweden

As already noted, the Swedish government has designed three gas producers for nationwide use in emergencies. The three units are shown in operation below. The fuel economy figures quoted represent averages over several years and thousands of hours and miles. The operators are farmers and truckers who use the vehicles in their daily work. (Pictures and information supplied by E. Johansson, National Swedish Testing Institute for Agricultural Machinery)

Uppsala, 1980. Model F-300 gas producer. This 2.1 Volvo sedan operating on Swedish country roads at an average speed of 65 kph (40 mph) with a 100-kg (250-lb) load required 1.5 liters (0.4 kg) of chipped wood per km (1.4 lb per mile).

Uppsala, 1979. Model F-500 gas producer. When harrowing heavy soil, this diesel-powered 6.1 tractor burned 150 liters (36–48 kg, 32 gal, 0.9 bushels, or 79–109 lb) of chipped wood and 2 liters (0.4 gal) of diesel fuel per hour. Without producer gas the tractor required 10–12 liters (2–2.6 gal) of diesel fuel per hour. Use of producer gas, therefore, saved 8–10 liters (1.8–2.2 gal) of diesel fuel per hour.

Uppsala, 1979. Model F-700 gas producer. This Saab-Scania diesel truck has been operating for 2,300 hours. The truck has covered 185,000 km (115,000 miles) transporting farm equipment between farms and dealer stores. This involved much stop-and-go driving (the hardest test for a vehicle fueled with producer gas) and has not as yet required engine overhaul. A 6-ton load traveling at 50 kph (30 mph) was found to consume 12-16 kg (50 liters, 26-35 lb, or 11 gal) of chipped soft woods such as spruce and pine (12 percent moisture, wet basis) to travel 10 km (6.25 miles) together with 0.8 liters (0.2 gal) of diesel fuel used to ignite the producer gas in the cylinders. Without producer gas the truck would have used 4-5 liters of diesel fuel per 10 km (0.9-1.0 gal per 6.25 miles) for the same duty.

United States

1979. This wood-burning 1978 Chevrolet Malibu station wagon (from which the fuel tank has been removed) drove 4,320 km (2,700 miles) from Jacksonville, Florida, to Los Angeles, California, fueled entirely by scrap wood. The generator holds enough wood for about 160 km (100 miles) of travel. On the open highway the vehicle easily cruised at 91 kph (55 mph) and reached a top speed of 108 kph (65 mph). Fuel economy averaged about 3.5 km per kg of wood (1 mile per lb), a considerable savings in fuel cost over gasoline. Body-mounted 1981 versions of the wood-powered generator are shown below. (Ben Russell, President, ECON, P.O. Box 828, Alexander City, Alabama 35010, USA)

Gainesville, Florida, 1981. The tiny generator that powers this wood-burning motorcycle was constructed at the University of Florida out of a fire-extinguisher casing. The vehicle gets 70 km per kg of wood (20 miles per lb). (*Sun* Photo by Barbara Hansen)

Miami, Florida, 1981. A charge of 110 lb of wood in the generator of this wood-powered 8,000-lb Lincoln Continental limousine takes it 85 miles or so on flat Florida terrain. In 1981, under a contract from the Department of Energy, its owner toured many southern universities demonstrating producer gas technology, especially to engineering students. (H. La Fontaine, 1995 Keystone Boulevard, Miami, Florida 33181, USA)

La Crosse, Florida, 1981. Wood-burning farm tractor used for plowing, mowing, and other farm chores. (R. Hargrave, photo courtesy *Florida Times-Union*/Ed Stansel)

North Carolina, 1981. Wood-powered pickup truck sponsored by a popular U.S. magazine. Top: refueling at the scrap heap of a North Carolina bed manufacturer. (*Mother Earth News*, Hendersonville, North Carolina)

3

Technology

Chemistry

When a thin stream of air passes through a densely packed bed of charcoal burning at temperatures above 1,000° C (1,832° F) the carbon is transformed into carbon monoxide gas:

$$2C + \underbrace{O_2 + 4\,N_2}_{\text{air}} \rightarrow 2CO + 4N_2$$

The resulting mixture of one-third carbon monoxide and two-thirds nitrogen is producer gas.

The carbon monoxide is formed by way of two separate reactions. First, the oxygen in the air stream combines with the carbon in the burning fuel (for example, wood or charcoal) to form carbon dioxide:

$$C + O_2 \rightarrow CO_2$$

Second, carbon dioxide contacts the red-hot burning charcoal and is reduced to carbon monoxide:

$$CO_2 + C \rightarrow 2CO$$

Although carbon monoxide is the main fuel gas in producer gas, methane and hydrogen accompany it. Methane forms by the catalytic "cracking" of volatile hydrocarbons and other organic compounds. Hydrogen forms when water vapor, from damp fuel or damp air, passes through the bed of hot charcoal:

$$H_2O + C \rightarrow CO + H_2$$

Typical compositions (by volume) of producer gas made from wood are:

carbon monoxide (CO)	18-25%
hydrogen (H_2)	13-15%
methane (CH_4)	3-5%
heavy hydrocarbons	0.2-0.4%
carbon dioxide (CO_2)	5-10%
nitrogen (N_2)	45-54%
water vapor (H_2O)	10-15%

Carbon dioxide results mostly from incomplete reduction in the generator; nitrogen comes from the air used to burn the fuel. Both gases are noncombustible and so decrease the energy content of producer gas to about 5,200 kJ per m^3 (140 Btu per ft^3).

Producer Gas Generation

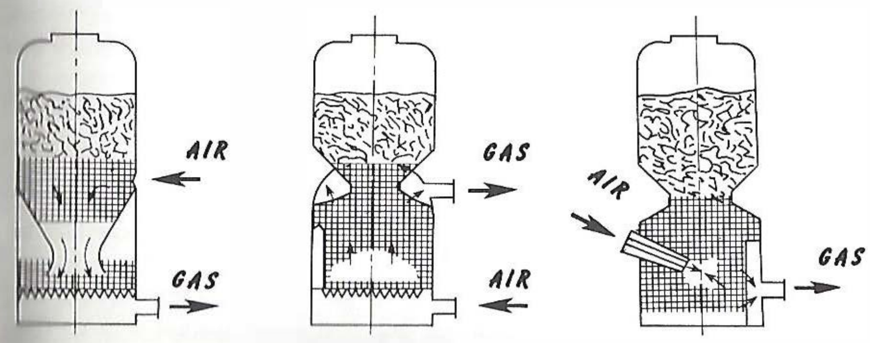
The system that makes producer gas has four main components:

- a generator to make the gas from the solid fuel;
- a cleaner to filter soot and ash from the hot gas;
- a cooler to condense tars and other liquid impurities; and
- a valve to mix the producer gas with air, as well as a throttle valve to meter the mixture into the engine intake manifold.

Generator

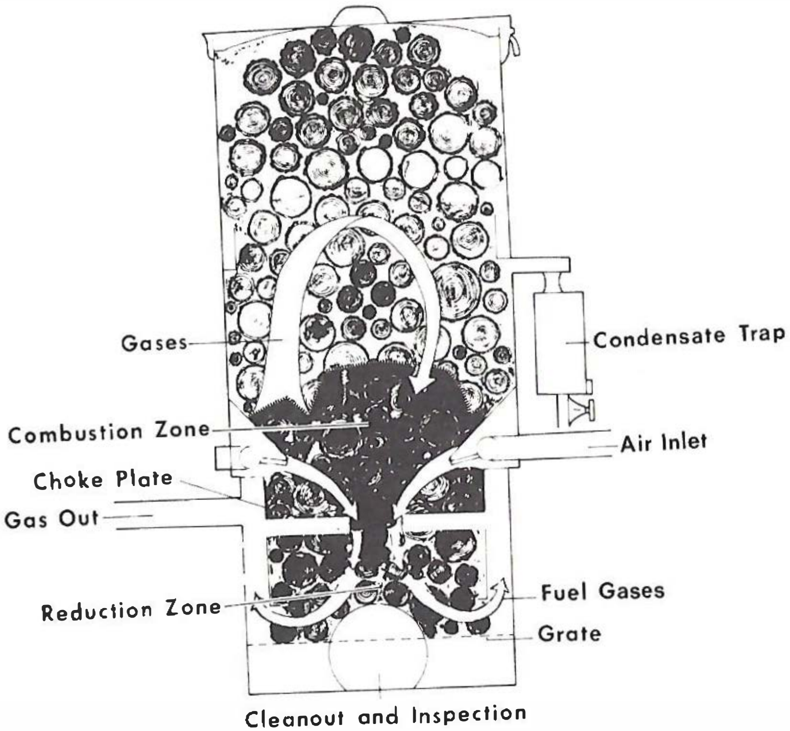
The heart of the system is the generator. It is typically a cylindrical or rectangular metal tank containing space for fuel, a firebox, and an ash pit. The upper part holds the fuel—normally a 30-minute to 2-hour supply. Its lid can be opened for refueling and is often spring-loaded to relieve any pressure that might build up inside.

The fuel falls into the combustion chamber. Air drawn through this firebox section keeps the fuel burning and produces a bed of red-hot charcoal



Downdraft Updraft Crossdraft

The three basic types of generator. (E. E. Donath)



that is at least 15 cm (6 in.) deep and is sufficiently compact that the gas streams flowing through must contact the glowing carbon surfaces. Vibration of the moving vehicle usuall yshakes the charcoal down and prevents "bridging."

Three types of combustion chambers, differing in the relative positions of the air inlet and the gas outlet, are used.

In updraft generators, air enters below the firebox, passes upward through the incandescent charcoal, through the raw fuel in the upper section, and exits near the top of the generator. This is the simplest type of generator to build and operate. The emerging gas has practically no ash in it, but it contains tars and water vapor picked up as the gas passes upwards through the unburned fuel. Updraft generators are thus best suited for use with tar-free fuels (for example, charcoal), especially in stationary engines. They are also suitable for devices that burn gas directly to produce heat. Most town-gas generators, for example, are the updraft type.

In downdraft generators, air enters the firebox above the fire zone. Combustion gases then pass downward through the hot charcoal and exit near the bottom of the generator. This is a good type for vehicle use and for wood fuels because impurities are carried into the fire zone where tars are degraded (cracked to methane) and steam reacts to produce water gas. A constriction in the hearth (the "throat") helps ensure that all the gaseous products pass through the hottest zone. Downdraft generators produce much less tar, but more ash, in the gas than updraft generators. They are also more complicated to build and maintain.

In crossdraft generators, air enters through a nozzle projecting into the side of the firebox. The gases travel horizontally through the hot coals, exiting through the opposite side of the generator. This type of generator is suitable for motor vehicles using dry, low-tar fuels.*

Many arrangements for introducing air to the generator have been designed. All have a one-way valve to prevent gas from exiting through the air port. Some designs cool the generator jacket with the incoming air, which also heats the air and boosts production of carbon monoxide.

The narrow air stream entering the generator causes a small zone of the fuel pile to burn very quickly and very hot (between 1,600° and 1,800° C). This generates producer gas rapidly. Air normally enters the generator through nozzles (tuyères) that discharge it into the heart of the fuel pile. The surrounding fuel then insulates the generator walls, which can be made of mild steel rather than fire brick.

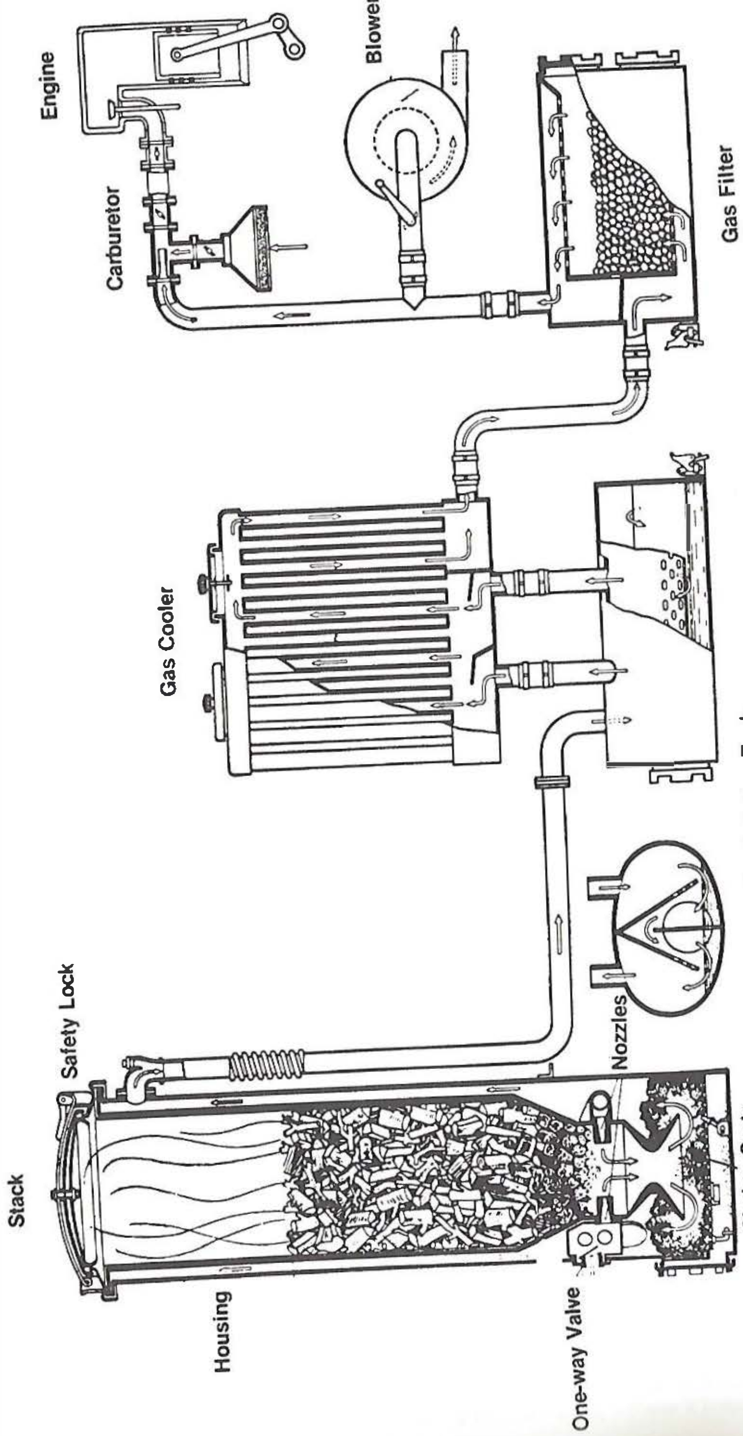
Below the throat the grate supports the burning fuel and passes the falling ash into a chamber at the bottom of the generator.

Filters

Before entering an engine, producer gas must be filtered to remove entrained ash and soot. Failure to remove these impurities may result in excessive wear, carbon deposits, pitting of the valve seats, sludging of the oil, and in extreme cases, seizing of the engine.

Most early filters were cumbersome, requiring felt, horsehair, sawdust, cork, or steel wool. Today, the filtration process can be simplified by using

*Many variations on the updraft, downdraft, and crossdraft generators have been designed. A British unit manufactured during the 1940s by the Brush Electrical Engineering Company, the Brush-Koela (*koela* is the Hindi word for charcoal) "Duo-Draught," employed crossdraft for starting (claimed to be quicker), with updraft for regular operation (claimed to be more economical). The unit was designed to operate with charcoal as a fuel and found a market particularly in India.



Basic layout of gas producer system. (Svedlund Design)

fiberglass. Often a cyclone separator is included in the system to whirl ash and soot out of the hot gas stream and into a small sump. A well-designed cyclone separator can remove more than 80 percent of fly ash particles greater than 10 microns in size.

Because the whole generating system is operated by the engine's weak suction, the cleaning system must be simple so as not to impede the gas flow.

Although many filters used in the past were not efficient and led to excessive engine wear and poor performance, the gas can, with simple designs, actually be made cleaner than commercial-grade gasoline. A rule of thumb during World War II was that 10 mg of dust per m^3 of producer gas gave about the same engine wear as gasoline. An outstanding filter was devised by British Coal using slag wood. It resulted in gas with only 2 mg dust per m^3 and could go 1,000 km between cleanings.* French researchers showed that a gas producer with an oil-foam filter could provide longer engine service life than gasoline could.†

The dust in producer gas is carbonaceous flyash (sodium and potassium carbonate, for example), which is not as abrasive as airborne silica dust, a well-known cause of engine wear.

Scrubbers

As already noted, downdraft gasifiers yield a gas that is notably free of tar. Nevertheless, when engines are idling, the fire can die down so much that the generator's throat gets "cold" spots and a fine mist of tar can pass through without contacting incandescent coals. Then, when air is added to such producer gas, just before it enters the engine, the resultant pressure drop can cause the tar mist to separate. This, in turn, causes sticky valves and rings, slow starting, and heat buildup in the engine. A recent innovative approach to this problem is the development of a generator throat that can be closed like a camera shutter, so that tar cannot leak around the central zone of burning carbon.‡

The more traditional approach is to use a scrubber or "wet" filter to capture the droplets of tar in the mist. This can be a scrubber in which the gas comes into intimate contact with water or an oil-impregnated filter. Government researchers in South Africa have designed a gas producer system that involves no filters at all. It uses a cyclone separator to remove large particles of

*Hurley, 1940.
†French, 1944.
‡Information from S. Nunnikhoven, Oakville, Iowa.

fly ash and a water scrubber to catch tar and small fly ash particles. They report high performance from this simple system.*

A scrubber newly designed in the United States is made so that water is pulled up the sides of the scrubber cylinder by the gas stream itself. The water then tumbles back in sheets and droplets, so that there is intimate contact between gas and water without creation of excessive back pressure.†

Disposing of the clearing water from a scrubber is a potential problem because it contains carcinogenic tars. Perhaps the best answer is to feed it back into the generator. It contains sodium and potassium carbonates from dissolved fly ash, and these catalyze production of water gas and hence improve the gasification process.

Cooler

At temperatures between 280° and 380° C, acetic acid, methyl alcohol, hydrocarbons, and light tar form in the generator; between 380° and 500° C, some viscous tar and hydrocarbons are produced. All these impurities, as well as water vapor, sometimes contaminate the gas. To remove them, an air cooler is usually placed after the cleaners. (In producer gas units made to power motor boats, water was used.) It condenses the liquid contaminants and cools the gas before it is piped to the engine.‡ The cooler the gas the more power it gives because the amount of combustible material in a given volume is increased. Coolers can be surprisingly small and simple because the vehicle's motion generally makes for efficient heat exchange. They usually contain a bank of light-gauge tubes (sometimes finned with sheet metal) that have few sharp bends, which could impede gas flow. Normally they are placed vertically, to allow dust and tar to fall out.

Carburetion

About 70 percent of the total heat of combustion of the fuel remains in the producer gas available to be liberated through complete combustion in the engine. For producer gas to burn, air must be added:

*Information from F. R. Hose (see footnote, p. 32). In tests, this stationary unit ran 250 hours at 3,000 rpm (roughly equivalent to 12,500 miles of open-country driving, and the spark plugs and valves were not discolored and the engine oil was certified as safe for further use by the manufacturer.

†Information from B.V. Alvarez.

‡With wood fuels, gas leaving a downdraft or crossdraft generator has a temperature of about 450° C. With charcoal and coal fuels, gas temperature can be as high as 700°–800° C. Cooling devices typically reduce the gas temperature to 140°–200° C.

$$\underbrace{2CO + 4N_2}_{\text{producer gas}} + \underbrace{O_2 + 4N_2}_{\text{air}} \rightarrow 2CO_2 + 8N_2 + 257{,}000 \text{ kJ}$$

The pipe that brings the gas from the cleaning system to the engine is attached directly to the engine intake manifold, bypassing the carburetor. (The carburetor is often retained, however, to allow gasoline to be used when wanted.) Attached to the pipe is a short arm fitted with a butterfly valve that allows air to enter and mix with the producer gas. The combustible mixture obtained is very sensitive to variation in the air content, which the driver adjusts, usually by a lever on the dashboard.* (In a gasoline-powered engine the carburetor automatically provides a predetermined amount of air.) The ideal ratio is about 1 volume of air to 1.2 volumes of gas.

A second butterfly valve, this one in the pipe just before it enters the engine, controls the amount of the gas-air mixture entering the cylinder. This valve acts as a throttle and is controlled in the normal way by the accelerator pedal.

The pipe is often fitted with a simple spring-loaded valve to release any pressure that might build up. Wire wool is sometimes inserted to prevent flashback along the pipe towards the generator.

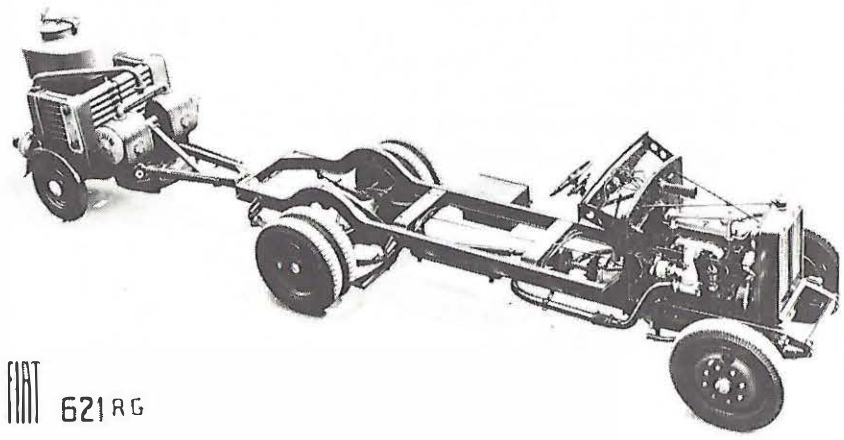
Location of the Generator

Gas generators have been mounted on trailers, roofs, hoods (bonnets), running boards, and in trunks (boots). They have been fastened to the sides of tractors and motorcycles. Some cars, trains, buses, and streetcars (trams) had generators enclosed within the body.

An advantage of placing a generator at the back of the vehicle is that the gas reaches the engine well cooled after passing through the long pipe. Some rear- or trailer-mounted generators can dispense with the cooler entirely. On trucks the gas producer, filters, and coolers often can be fitted conveniently into the space between the cab and the body.

Mounting the producer on a trailer obviates modification of the vehicle's bodywork, allows easy access for servicing and repairs, allows more flexibility in designing the unit, and does not require strengthening the springs on the vehicle.

*In some vehicles the accelerator pedal controlled the ratio of air to fuel. By pressing down hard on the accelerator, the driver could use gasoline for extra power on hills.



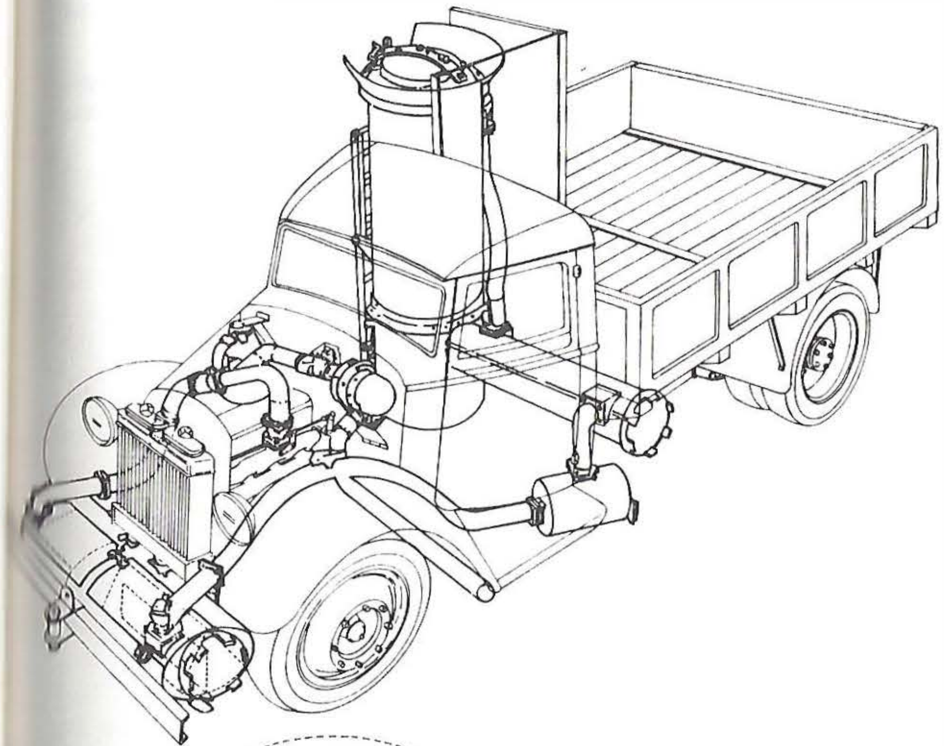
Many ingenious ways have been found to fit the gas-producing system onto vehicles. Some of the main layouts are diagrammed on these pages.

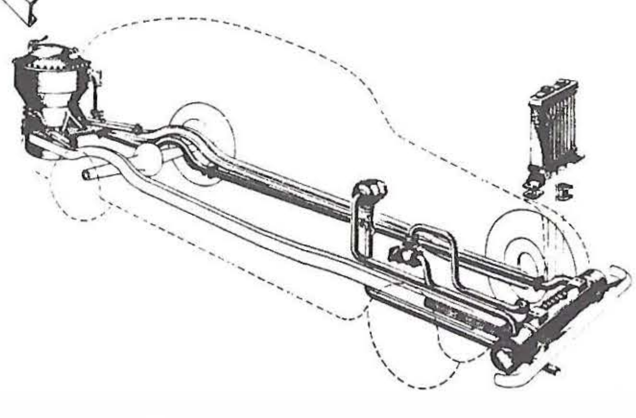
Operating Producer Gas Vehicles

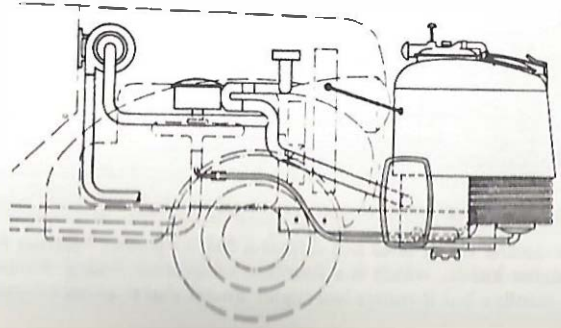
In using producer gas a driver controls not only the operation of the vehicle but also the production of the fuel. To start the vehicle the driver first fills the generator with wood or charcoal, ignites it through a capped port at the bottom of the generator, opens the cap on a small chimney, and turns a handle to suck air through the generator and get the solid fuel burning. Some generators include a small fan, powered by the vehicle's battery. Initially smoke belches out of the chimney, but after about 5 minutes the fire is well lit and a clear vapor—producer gas—emerges. (The fuel value of this gas can be demonstrated by igniting it at the chimney. A shaft of blue and gold flame shoots out, looking like the flare of a tiny natural gas well.) The chimney is closed to shut off the escaping vapor, the driver climbs into the vehicle, adjusts the air-mixing valve, and turns the starter. This sucks the mixture of producer gas and air into the intake manifold to start the engine in the usual manner.

Producer gas vehicles are often designed to retain the capacity to use gasoline or diesel fuel. Liquid fuels are useful for starting the vehicle, for example, and when the generator is fully alight the driver switches over to producer gas. Gasoline or diesel fuel also can be switched in if the vehicle is laboring on a steep climb or is carrying a heavy load.

Rapid starts and high-speed hill climbing with producer gas vehicles are not possible. But power loss was perhaps more of a problem 40 years ago when, by current standards, vehicles were underpowered. The loss of power in today's vehicle fueled by producer gas is less noticeable under normal driving conditions because of the engine's unused capacity. The higher compression







ratios in modern engines greatly improve the performance of producer gas. Although they accelerate sluggishly, their acceleration is roughly comparable to that of diesel automobiles.

Producer gas has a higher octane rating than gasoline (120 compared with 90–106).* Thus the ignition timing of the engine can be advanced by 8°–10° over the setting for gasoline fuel. Each engine design has its own best setting.

Filters normally are cleaned about every 500 miles; ash is removed every 1,000 miles, and the generator is cleaned every 2,000 miles.

Engine Performance

Producer gas is a lean fuel. Even under ideal conditions it yields only 80 percent of the power obtained from the same volume of a gasoline vapor. In practice during the 1940s, the loss of power often amounted to 50 percent. However, engines at that time had average compression ratios of 5:1.

Power can be increased by increasing the compression ratio to 8 or more to 1. Engines using producer gas made from charcoal have gained 8 percent in efficiency when the compression ratio is increased from 5:1 to 6:1; 6 percent when increased from 6:1 to 7:1; and 4 percent when increased from 7:1 to 8:1. With compression ratios higher than 10:1, special cylinder heads are necessary, and above 14:1, piston and cylinder-head designs become critical. Engines that may have to use gasoline as an alternative fuel should have ratios from 6.5:1 to 9:1, and even then the 9:1 ratio is on the high side. The resonance set up by a "tuned exhaust" leaves a slight vacuum in the cylinder, which helps suck the gas through and improves producer gas performance.

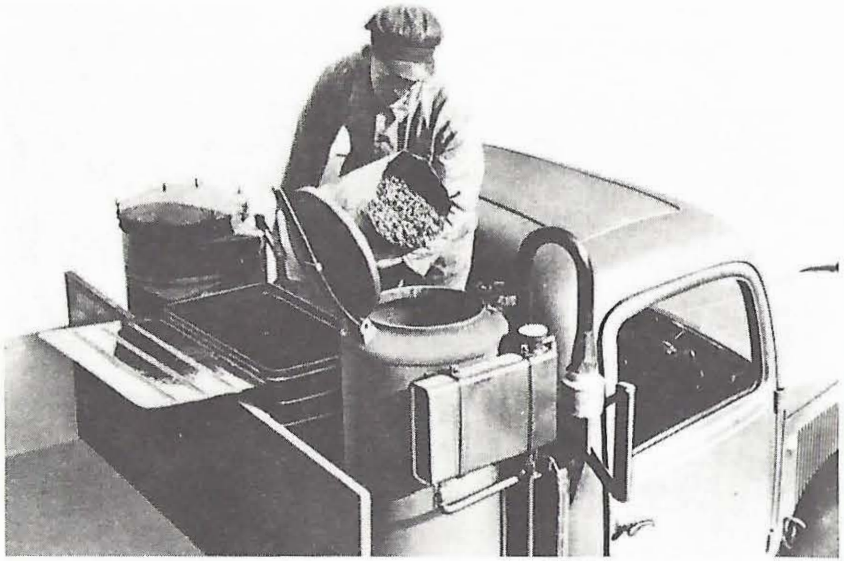
TABLE 2 Exhaust Gas Components

	Gasoline		Diesel Oil		Producer Gas	
	Combustion Complete	Combustion Incomplete	Light Load	Full Load	Anthracite	Charcoal
CO_2 (%)	12	7.8	5.8	13.2	14.6	17.3
CO (%)	0.6	10.5	–	0.6	0.6	0.5
O_3 (%)	0.2	0.2	–	1.4	0.4	0.8

Source: Donath, 1980.

*The octane rating does not reflect a fuel's "power." Rather it measures a fuel's effect on engine knock, which is a function of ignition timing. Producer gas has less "power" than gasoline but it causes less engine knock and thus has a higher octane rating.

A 1943 advertisement for a British gas producer.



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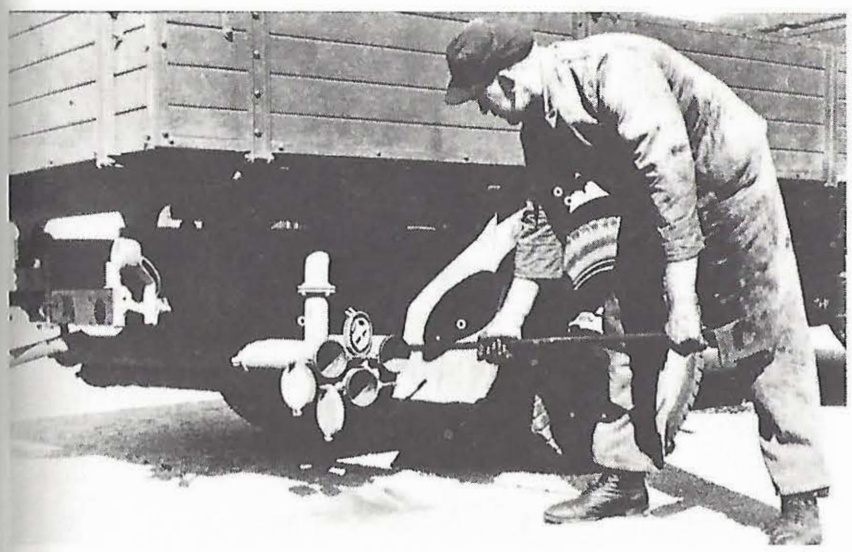
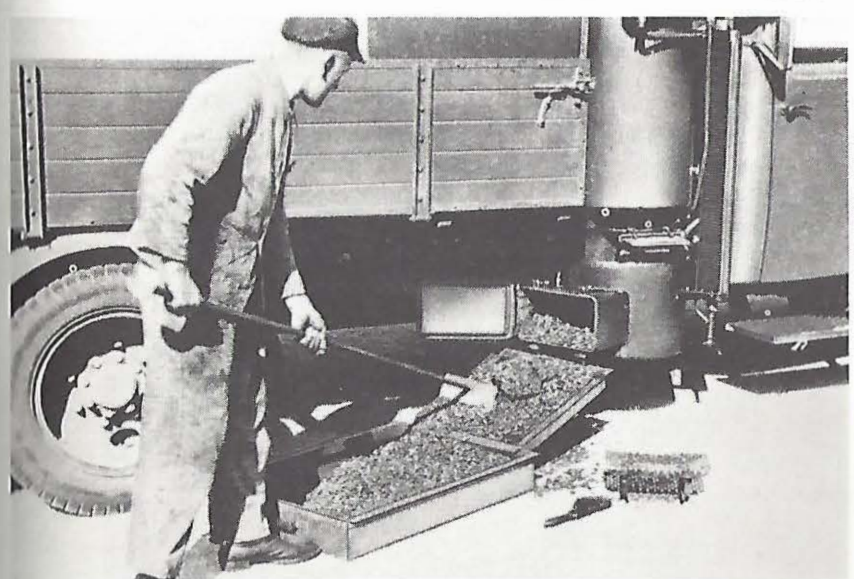




Producer gas is not as convenient a fuel as gasoline or diesel. The user must develop skills to drive his vehicle and must spend time maintaining the producer equipment. Shown here in photographs of a 1940s Mercedes-Benz are the main steps for maintaining the gas-producing system:

1. Filling the generator
2. Cleaning the filters
3. Cleaning the cooler
4. Removing ash.

(Pictures courtesy E. E. Donath)

1

2

3

4

Producer gas in Japan, 1945.

1. Lighting the generators.
2. Sorting fines from the charcoal fuel for better performance.
3. Charcoal supply for vehicles.
4. Stoking the generator.

The exhaust from producer vehicles can be expected to be free of hydrocarbons since the producer gas contains only a minor amount of methane and is free of higher hydrocarbons. During World War II the carbon monoxide content of the exhaust was similar to that of Otto and Diesel engines used at that time. For the carbon monoxide content the figures shown in Table 2 were given in 1939.*

*Donath, 1980.

4

Fuels

Gas generators require fuels that are solid particles, roughly uniform in size, that glow and burn readily and are free of dust and dirt. In principle, generators can be designed to gasify any carbonaceous fuel that produces a deep bed of red-hot coals and does not plug the producer with slag or excessive ash.

The wide array of fuels suitable for gas generators is a potential economic benefit. During World War II Denmark, Norway, and Sweden powered their vehicles mainly with wood (blocks, branches, chips, scrap wood); Australia with charcoal; Britain with coke; and Germany with anthracite and brown coal, or lignite, briquettes. Even agricultural residues, if compressed into blocks, pellets, or briquettes, can fuel vehicles. Danish experience exemplifies the benefits of being able to use different fuels. In 1940 Danes started fueling their trucks and tractors with wood, but when supplies ran short after a year or so, they switched to briquettes of peat dug from the peat bogs in Jutland. Then towards the war's end, when German forces also rationed the use of peat, some resourceful Danes turned to using pelletized seaweed.

Although generators can be designed to gasify virtually any solid fuel, the different fuels are not interchangeable: generators designed for tar-free fuels such as anthracite cannot handle tar-containing fuels such as wood.

Fuel size is important. Lumps that are too large reduce the fuel's reactivity, the gas's heating value, and the producer's efficiency. Large pieces also form fly ash excessively.

The quality of fuel increases as its carbon content increases. Thus charcoal and coke are better producer gas fuels than their parent materials.

Many fuels contain small quantities of nitrogen and sulfur in addition to carbon, hydrogen, and oxygen. In the gasification process, sulfur forms corrosive sulfuric gases as well as inert constituents that deposit in the slag.

A fuel's ash content and ash properties determine to a great extent the amount of labor required to maintain and operate the producer. After gasification, incombustible residues remain as ash or slag and must be removed to avoid plugging of the producer. Gasification of any residues that have an ash content of 5 percent or more requires a gas producer designed to handle the slag resulting from ash melting in the combustion zone. (For example, a downdraft gas producer that works well with wood fuel will be choked by the slag from nearly all fuels having 5 percent or more ash.)

In practice, solid fuels contain water. Wood, for instance, contains up to 25 percent moisture when air dry, and at least 40 percent when green. Gas generators need air-dry fuel. Excessive moisture cools the generator, thereby reducing the efficiency of the gasification. Water also impedes restarting because as the generator cools, condensing steam dampens the fuel. Excessive moisture also puts an additional load on the gas purification and cooling system.

Wood

In Scandinavia during World War II, wood was the major fuel used to power civilian motor transport. Air-dry wood produces an excellent gas, it has the advantage of ready availability, and its use bypasses the charcoal kiln and the resultant loss of energy in charcoal production. On the other hand, wood

Bonn, West Germany, 1981. Fueling the generator. (W. Drehsen)

TABLE 3 Cylinder Wear with Producer Gas and Other Fuels

Fuel	Inches per 1,000 Miles	Millimeters per 1,000 Kilometers
Wood	1.000185	0.00287
Charcoal	0.00368	1.00572
Anthracite	0.0006	0.009
Lignite coke	0.0014	0.022
Coal coke	0.00115	0.018
Peat coke	0.0012	0.019
Lignite briquettes	0.002	0.031
Methanol	0.0002	0.0031
LPG	0.0001	0.0016

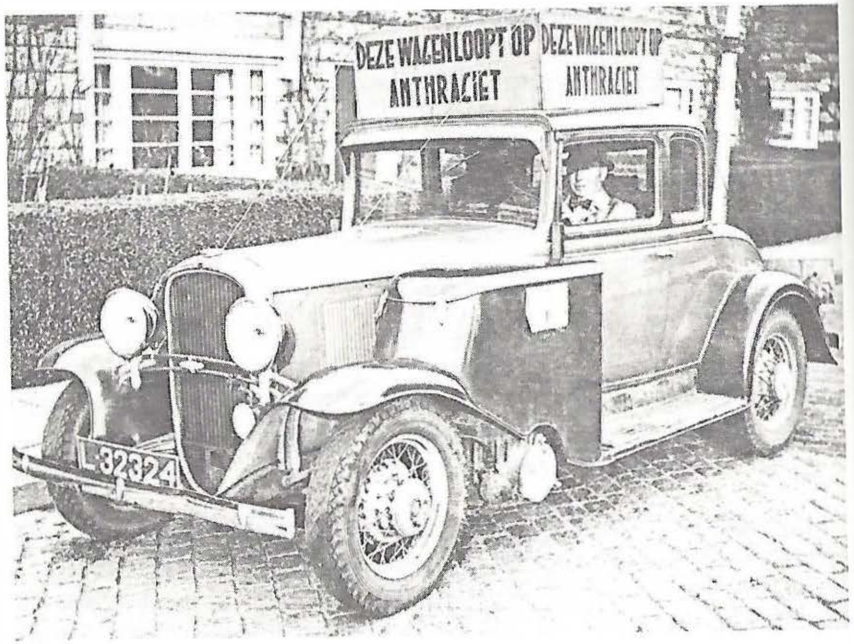
Source: Donath, 1980.

is bulky and produces tars. In using wood it is important to ensure that distillation products—in particular, tar and acid vapors—pass through, and are destroyed in, the fire zone. Therefore, use of wood requires that a downdraft or crossdraft generator be employed. Even then, any tars and moisture that escape must be condensed and trapped from the gas before it reaches the engine.

Before use in a vehicle generator, wood must be dry and chipped or cubed into fairly regular blocks.* During World War II Sweden developed ingenious machinery to saw cubed wood from logs. But cubes are expensive to produce and difficult to transport and handle. In the last 20 years Swedish experimenters have been using chipped wood. Chips are easy to make in bulk and are routinely produced as the first step in papermaking. (In a fuel emergency Sweden plans to turn paper-pulp factories over to producing chips to fuel trucks and for defense purposes.) Chipped wood is easier to handle in bulk than blocks are, and no difficulties have been experienced in using it. However, it does tend to bridge in the gas generator, and a small (windshield-wiper) motor is used to vibrate the grate and shake the chips down automatically when the gas pressure drops because of bridging.

Spruce, pine, birch, and beech are considered suitable for wood gas in Sweden. In developing nations there are many species that should also be suitable. In India during World War II, tamarind wood was considered best for vehicle gasifiers. Ideas on other species can be obtained from the companion report *Firewood Crops: Shrub and Tree Species for Energy Production* (see page 98).

*Soviet scientists have reportedly developed downdraft gas generators that use green branch wood, and even straw, rather than blocks (Koroleff, 1952).



Anthracite as fuel, Holland, circa 1941.

Under ordinary driving conditions, wood is added to the gas generator every 80-100 km (50-60 miles). Hardwood, cut into chips less than 10 cm (4 in.) in length to prevent arching or pocketing in the generator, is preferable to softwood, such as pine, because it leaves fewer tars and gummy residues. Nevertheless, the cooling tanks and filters on a vehicle fueled with hardwood must be cleaned every 1,500 km (900 miles), and the motor must be checked and tuned every 8,000-13,000 km (5,000-8,000 miles).

Coal

All forms of coal—peat, lignite, bituminous coal, anthracite, and others—can theoretically be used in gas producers. Their relative advantages and limitations depend on their content of energy, moisture, volatiles, and ash.

Brown-coal briquettes were widely used in Germany during World War II. They were reported to have a heating value of 4,800 kcal per kg.* Their advantages were high reactivity and uniform size and strength in the fire zone. It was found that they could be added (up to 25 percent by volume) to wood for use in many wood-fueled generators.

*F. Jantsch, 1949. *Kraftstoff-Handbuch*. Franck's Verlagshandlung, Stuttgart. p. 248*ff*. Cylindrical briquettes 60 mm in diameter and 40 mm long, each weighing about 150 g, were generally used.

Charcoal

Except in Scandinavia, charcoal and coal were the principal producer gas fuels used during World War II. Charcoal generates a gas containing almost no moisture or tars, even after cooling. Because these by-products are absent from charcoal gas, the generator can have a simpler and lighter construction, which helps offset the high cost of charcoal. For example, it is not necessary to use downward draft or to constrict the hearth as there is no tar to catch or crack. Thus charcoal-fed generators require no grate (except a plate that prevents fuel from falling out when ashes are being removed) and need only a minimal cleaning section.

Charcoal yields a clean gas almost free of odor. It is an energy-rich fuel that gives more kilometers per kilogram than wood or most other solid fuels.

Charcoal filling station, Tokyo, Japan, circa 1943. An attendant fuels an automobile at one of the charcoal stations that appeared in Japan as gasoline became scarce and cars were converted to burn solids. (*Asahi Shimbun*)

Moreover, charcoal ignites easily and produces a gas of fairly constant composition.

On the other hand, charcoal is bulky (unless formed into briquettes), it must be stored carefully because it absorbs moisture, and during handling it can break up into a messy black dust that clogs the producer. Moreover, much energy is lost during charcoal making; to fuel gas producers with charcoal requires much more wood (per unit of energy output) than if the producers were fueled with wood directly.

Coke

Coke is formed from coal in much the same manner that charcoal is formed from wood. It, too, is an excellent fuel for generating producer gas because its volatile matter already has been driven off. Because coke is about twice as dense as charcoal, fuel hoppers of moderate size can hold a whole day's fuel supply for a truck. The amount of tar that coke produces is negligible, so coke-fired generators, like charcoal-fired generators, need no constriction in the fire zone.

Osaka, Japan, circa 1944. Technician loads a fuel brick into a car before taking it for a successful test drive. Brick was made by blending household garbage with coal dust and heavy oil residue and then baking the mixture into a solid. As wood to make charcoal became scarce, such exotic fuels were concocted. (*Asahi Shimbun*)

Madison, Wisconsin, USA, 1943. Truck fueled by sawdust. (Forest Products Laboratory, US Forest Service)

Agricultural and Industrial Residues

Producer gas can be made from virtually any solid plant materials. Wood and agricultural residues, such as peanut hulls, coconut husks and shell, corn cobs and stalks, cereal straw, bagasse, or any other forest, farm, orchard, or urban waste capable of carbonization to charcoal, can be used as fuel. Wood derivatives such as paper might also be usable as well as the "fuel pellets" now produced experimentally from garbage. In most cases, however, these fuels must be compressed into pellets or blocks (briquettes) or be processed in some other way before they will work well in a gasifier.

It has been estimated that the wood that went to waste in Germany in 1934 could have driven each of 150,000 trucks a distance of 32,000 km (20,000 miles). In France in the late 1930s, 300,000 tons of wooden railroad ties were replaced each year—enough wood to supply about 70,000 trucks, or about one-sixth of all the trucks in France.

5

Economics

Perhaps the most basic economic aspect of producer gas is that it uses resources that countries can generate for themselves. In the event of severe petroleum shortages, producer gas could be used, in principle, to power virtually any highway vehicle and fishing boat as well as stationary engines for driving electric generators or farm machinery. The technology therefore could be used to maintain a viable transportation and power system in emergencies.

Producer gas will seldom be selected when gasoline or diesel fuel is available. The inconvenience to the user is too great. On the other hand, the political benefit of using it to reduce dependence on imported oil may in some cases outweigh pure cost considerations or user resistance. And when no liquid fuel is available, experience shows that people readily put up with the inconvenience of producer gas.

However, because producer gas has not been widely used in vehicles in 30 years, its modern costs are uncertain. Data reflecting World War II conditions have little modern relevance because use of producer gas during the war was not commercially motivated and because today's technology is not always readily comparable. For example, most gas producers built at that time used sisal, cork, or cloth filters that today would be replaced with fiberglass because it doesn't swell or catch fire. Nonetheless, some general economic conclusions can be drawn.

Fuel Consumption

Good-quality producer gas has an energy content of about 5,200 kJ per m^3 (140 Btu per ft^3). The quantity of gas that different fuels yield varies widely both with the fuel and the gasification method used. Typical yields of producer gas , for example, are: 2.3 m^3 from 1kg of wood; 4.0 m^3 from 1 kg of lignite; 3.6 m^3 from 1 kg of hard-coal coke; and 4.5 m^3 from 1 kg of anthracite.* (In British units the corresponding yields of producer gas from 1 lb of the various fuels are: wood, 36.8 ft^3; lignite, 64 ft^3; hard-coal coke, 57.6 ft^3; and anthracite, 72 ft^3.)

*Skov and Papworth, 1974.

A gas producer requires 2.5-3 kg of wood to generate about the same energy as 1 liter of gasoline; 3.3 kg of wood to generate about the same energy as 1 liter of diesel fuel; and 1-1.3 kg of charcoal or 2.5 kg of wood to generate about the equivalent of 1 kWh of electricity.* (Correspondingly, a gas producer requires 21-25 lb of wood to generate about the same energy as 1 gal of gasoline; 25-29 lb of wood to equal 1 gal of diesel fuel; and 2-3 lb of charcoal or 5.5 lb of wood to equal 1 kWh of electricity.)

Fuel-consumption figures quoted for different vehicles vary considerably because of differences in fuel, engine design, and operating conditions. Technical studies indicate, however, that about 0.8 kg (1.76 lb) of wood is required per horsepower hour.

In September 1940 in Stockholm, Sweden, 112 vehicles took part in a test of 38 different types of gas producers. Sixteen vehicles were powered by charcoal, and their fuel consumption was between 42 and 87 g per ton per km (0.14-0.29 lb per ton per mile). Twenty-two were powered by wood, and they averaged between 87 and 189 g per ton per km (0.29-0.63 lb per ton per mile). A 16.5-ton Scania truck with a Svedlund producer was the most economical. Its fuel consumption was 42 g charcoal per ton per km (0.14 lb charcoal per ton per mile). A 4-ton Volvo truck with a 3.5-ton load and a Hesselman wood-gas producer consumed 90 g of wood per ton per km (0.3 lb per ton per mile).

TABLE 4 Fuel Consumption and Equivalence Ratios

	Wood	Peat	Brown Coal Briquets	Char from Coal Briquets	Anthracite
Fuel consumption					
lb/HP_eh	2-2.6	2.2-2.9	1.8-2.2	1.5-1.8	0.9-1.1
MBtu/HP_eh	13.2-17.5	13.7-17.6	15.2-19.2	13.2-17.6	12.4-15.6
Average equivalents					
Gasoline to 1 lb solid fuel					
Equivalence (lb) of 1 gal gasoline	22.4	25	18.3	12.5	10.8
Equivalence (lb) of 1 lb gasoline	3.5	4.0	2.9	2.1	1.7

Source: Donath, 1980.

*Information supplied by J. Ascough.

TABLE 5 1939 Comparative Cost for 5-Ton Vehicles

	Gasoline		Diesel		Producer Gas		Cost Savings ($/yr) for Producer Gas Compared with:	
	(¢/mi)	($/yr)	(¢/mi)	($/yr)	(¢/mi)	($/yr)	Diesel	Gasoline
20,000 miles per year								
Fuel	3.54	708	1.73	346	0.83	166	180	542
Tires	1.25	250	12.5	250	1.25	250		
Maintenance	2.20	420	2.25	450	2.17	434		
Depreciation	1.96	370	3.10	620	2.48	496		
Labor	4.33	866	4.33	866	4.91	982		
Miscellaneous	2.38	518	2.71	542	2.75	550		
TOTAL	15.66	3,132	15.37	3,074	14.39	2,878	196	254
40,000 miles per year								
Fuel	3.54	1,416	1.73	692	0.83	332	360	1,084
Tires	1.25	500	1.25	500	1.25	500		
Maintenance	1.79	716	1.94	776	1.85	740		
Depreciation	1.56	524	2.48	992	1.98	792		
Labor	2.17	868	2.17	868	2.32	928		
Miscellaneous	1.38	552	1.51	604	1.44	576		
TOTAL	11.69	4,676	11.08	4,432	9.67	3,868	564	808

Source: Donath, 1980.

TABLE 6 Comparison of Gasoline and Producer Gas Vehicle

Miles per year	20,000	40,000
Depreciation: 20% of $1,140 ($/yr)	228	228
Cleaning: 1/2 h/200 mi @ $8/h ($/yr)	400	800
Miscellaneous: Rough estimate for solids handling larger engine, etc. ($/yr)	700	1,000
Total additional costs, producer vehicle ($/yr)	1,328	2,028
Gasoline: 8 mi/gal at $1/gal ($/yr)	2,500	5,000
Available for solid fuel ($/yr)	1,172	2,972
Wood[a]		
at 22.4 lb/gal gasoline (tons/yr)	28	56
Corresponding "break even" price at "filling station" (£/ton)	42	53
Brown coal char		
at 12.5 lb/gal gasoline (tons/yr)	15.6	31.2
Corresponding "break even" price at "filling station" (£/ton)	75	95
Anthracite		
at 10.8 lb/gal gasoline (tons/yr)	13.5	27
Corresponding "break even" price at "filling station" (£/ton)	87	110

[a]The corresponding price of one cord of wood (128 ft^3) at 21.8 lb/ft^3 would be £58 and £73, respectively.
Source: Donath, 1980

At about the same time, a large Copenhagen newspaper, *Politiken*, sponsored a competition for efficient and economic driving on wood gas among Danish truck drivers. The winning driver used only 48 g per ton per km (0.16 lb per ton per mile). The average was about 100 g per ton per km (0.33 lb per ton per mile).

In the 1940s the Germans estimated that the amount of wood required for producer-fueled trucks would be approximately 1 kg per km (3.5 lb per mile). Accordingly, they estimated that 10,000 trucks traveling an average of 30,000 km per year would need 300,000 tons of wood per year. Such an order would provide considerable employment and economic activity for any forestry enterprise, especially if the wood were converted to charcoal.

Gas producers for an average-size car or tractor may weigh 100-200 kg (200-450 lb). Their cost varies according to size and whether or not they are factory installed. In general, however, their cost in the 1940s was 10-30 percent of the cost of the vehicle.

6

Stationary Use

Although this report focuses on the use of producer gas for motor transport, there are many nonmobile uses that could make it a valuable modern fuel, especially in developing countries.

Producer gas can replace natural gas, gasoline, or fuel oils used to:

- Make steam for generating electricity;
- Fire boilers to provide heat for industries and homes;
- Fuel internal combustion engines for a wide array of purposes; and
- Provide basic chemical feedstocks such as ammonia for fertilizer and methanol.

Electricity Generation

Early in this century many electricity generators, some up to 1,500 hp, were driven by suction engines (see chapter 1) fueled by producer gas generated from coal, coke, peat, or wood. Cheap, heavy petroleum oils—a by-product of gasoline refining—made most of them economically impractical, and eventually they became obsolete. But the concept is not technologically obsolete; the current cost of petroleum fuels gives new life to biomass gasification for generation of electricity.

Large generators that ran on wood, coconut shells, or other waste were used in tropical areas before World War II. In the Ivory Coast and Gabon four or five of these are still in operation, and there is renewed interest in this technology. Companies in Canada, France, Germany, Sweden, New Zealand, and the United States have commercially available units.

Producer gas can power small generators (one as small as 4 hp has been built at the University of Florida*) for lighting, refrigeration, pumping, emergency hospital power, communications equipment, and other operations, either on portable units or in remote village locations.

*Information supplied by K. Eoff (Department of Geography) and D. Post (School of Forest Resources and Conservation), University of Florida, Gainesville, Florida 32611, USA.

The German appropriate technology organization GTZ* has already supported the development of a small portable electricity generator for use in developing countries. It is powered by wood chips, coconut shells, and similar wastes. The Tropical Products Institute of the United Kingdom† is also working in this field.

Producer-gas-powered electricity generators can be large enough to provide power for entire towns. One French company sells units that generate up to 1,000 kW. The Swiss government plans to generate electricity for remote communities and towns with gasifiers.

Reportedly, in the 1950s the Soviet government developed producer gas extensively for fueling forestry equipment. One interesting product was an electricity generator fueled by producer gas and used to power electric saws and tree harvesters linked to it by power cords. A paper on the subject refers to its ability to use green logs as fuel.‡ This is an important design development because it eliminates the need for drying the wood and for cutting it into chips or cubes.

Mechanical Power

One of the most promising applications of producer gas for developing countries is the powering of small, stationary engines. The potential uses for these engines include their use as prime movers for:

- Irrigation and village water-supply pumps;
- Sawmills;
- Rice milling;
- Grain grinding; and
- Small manufacturing or food-processing plants, especially those with by-products that can fuel gasifiers.

Heat

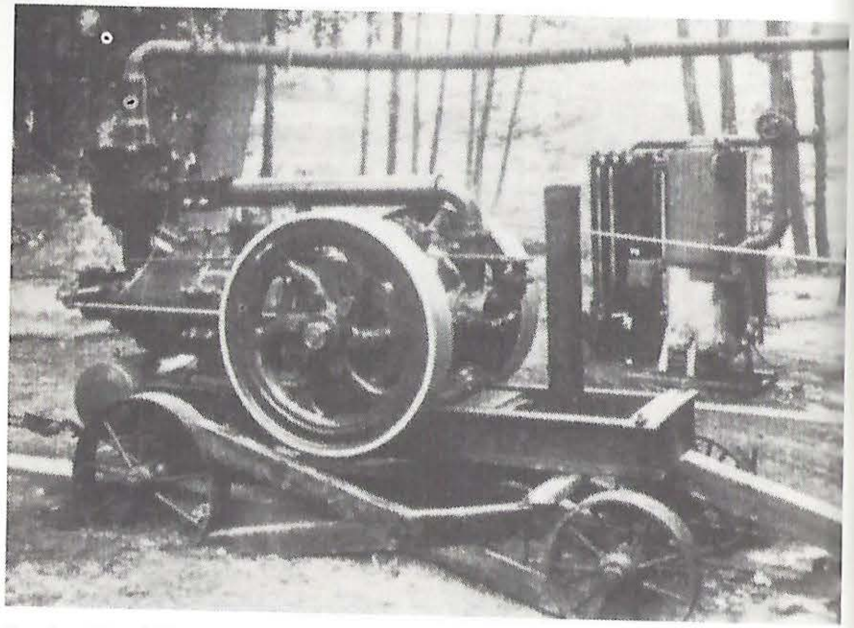
Producer gas can be used as a heat source on both a small and a large scale. Equipment designed for liquid or gaseous fossil fuels can be converted to renewable solid fuels by installing gas producers. Usually the conventional gas burner can be retained, thereby avoiding the cost of rebuilding the unit for direct burning of solid fuel.

*Gesellschaft für Technische Zusammenarbeit (GTZ) FmbH., Dag-Hammerskjöld Weg 1, Postfach 5180, D-6236, Eischborn 1, West Germany.

†The address is 56-62 Gray's Inn Road, London, WC1X 8LU, England.

‡Koroleff, 1952.

Bora Bora, French Polynesia, 1981. From 1928 to 1945 the town of Papeete, capital of Tahiti, generated the electricity needed for lighting with a gas generator fueled with coconut waste. In 1978 the island of Bora Bora (population 2,700) installed a 190-kW electricity generator fueled by gas from a stationary producer fueled by coconut shell and husks. The unit uses a small amount of diesel oil for pilot fuel. The consumption of husks is 1.5 m^3, or 150 kg, per hour. This represents the husks from about 500 nuts. It is estimated that it takes 1.3 kg of husks and 50 g (or 0.06 of a liter) of diesel oil to produce 1 kWh. This means that the average consumption of electricity for each household on Bora Bora can be paid for by collecting six husks, since the price is 20.75 francs per kWh. The only real inconvenience is that the furnace must be fed every hour with 1.5 m^3, or 150 kg, of husks. (Électricité de Tahiti, Papeete, photo courtesy *Pacific Islands Monthly*)



Sweden, World War II. Stationary gas generator (background) provides gas fuel for pulsator engine used to power a lumber mill. Such generators were also used to fuel rock crushers and other machines. In the Soviet Union foresters still use wood-powered generators for logging and milling timber in remote areas.

Manila, Philippines, 1982. A charcoal-fueled portable gas generator that can be wheeled to different sites to power small equipment such as the concrete mixer shown here. (GEMCOR, Manila)

Gasification is an efficient way to extract heat from biomass. For each 100 kcal of potential energy in the solid, gasification can extract about 80 kcal in hot, raw gas. This is more efficient than many devices that burn wood directly in a hearth or firebox. Producer gas can be piped short distances and used for industrial process heat; for example, it can be used to fuel:

- Kilns making bricks, ceramics, glass, pottery, or cement;
- Boilers in rice mills, sawmills, and sugar mills;
- Dryers for agricultural products and lumber; and
- Gas turbines and other engines for power generation.

In any use of producer gas for heat, the burner must be designed for operation on low-energy gas.

Chemical Feedstocks

In principle, producer gas can be used to synthesize methanol, a liquid fuel. At moderately high temperatures and pressures, and in the presence of a suitable catalyst, carbon monoxide and hydrogen will combine to form methanol according to the reaction $CO + 2H_2 \rightarrow CH_3OH$.

Hydrogen from producer gas has been used in the Haber process to produce ammonia. Methane and other hydrocarbons also can be obtained from producer gas.

7

Recommendations and Research Needs

To capitalize on the potential of producer gas the panel offers the following recommendations and suggestions for research.

Recommendation 1

All countries vulnerable to petroleum fuel shortages should initiate trials with producer gas vehicles.

Government research organizations, forestry schools, and engineering institutions should be encouraged to fabricate and test gas producers. This "hands-on" experience under local conditions, using local materials and local fuels, could be invaluable in case of fuel emergencies and in the probable event that fuel costs continue to rise.

Gas producers must be designed to suit fuels that will be available in reasonable quantities at all times. They must combine reliability with the utmost simplicity for service and maintenance, they must clean the gas to a very high order, and they must have high performance.

That is why research and testing is important. Gasifiers are easy to make but hard to make well. It is easy for entrepreneurs to make impossible claims and sell poor designs that lead to uneconomic performance, customer dissatisfaction, and, ultimately, to resistance to the idea of gas producers for vehicles.

Recommendation 2

Governments and international organizations should prepare for the possibility of using vehicle gasifiers in fuel emergencies.

Fuel emergencies are an ever-present threat and can be triggered by export restrictions, sabotage, or war. Sweden, recognizing this possibility, is already prepared for such an emergency. Sweden has built and tested gasifiers of three standard sizes; plans are available, machine tools and stampings are designed, and technicians are trained to manufacture them. Other countries and

interested agencies such as the United Nations Industrial Development Organization and the Food and Agriculture Organization could draw from this Swedish experience and provide technical assistance or execute programs in this field. Sets of working drawings matched to commonly used engines should be freely available to all countries vulnerable to oil cutoff.

The Australian government's policies during World War II provide a good model. As already noted, it established minimum performance standards for all gasifiers before they could be sold. Also, it provided testing facilities for researchers and inventors working on gasifier design. These policies encouraged dozens of engineers to develop gasifiers; by 1939 34 different types were available.

A useful characteristic of vehicle gasifiers is that they do not require standardization; small machine shops can make their own gasifiers from sets of drawings. However, there are advantages to having standardized, interchangeable parts. Key parts can be produced more cheaply in quantity from central locations. Proper government support and sound regulations will be needed.

The South African government's approach is a good model. It makes available, at low cost, stainless steel throats for generators of various diameter. Thus, it saves small companies the expense of fabricating small numbers of stainless steel parts and it ensures that the vital throat area will have high reliability in South African gasifiers in the 1980s.

*Governments, however, should prevent promiscuous development and proliferation of generators without first developing long-range plans to systematically replenish the wood, charcoal, or other raw materials used as fuel.**

Recommendation 3

Countries that have used producer gas in the past should compile histories and analyses of that experience.

During World War II (and earlier in some cases), the United Kingdom, Germany, Denmark, Sweden, France, Italy, Greece, the Soviet Union, Japan, Korea, China, India, New Zealand, Australia, and Brazil all used producer gas extensively. Their experience, however, has been largely lost or forgotten through disuse after the reintroduction of cheap petroleum in the 1950s and 1960s. But that experience holds important lessons for the future and should be documented while some of the major participants are still alive.

*Brazil, for example, now has a law requiring that whenever charcoal is made an equivalent number of trees must be planted to replace it.

It would be valuable for an institution somewhere in the world to take on the task of serving as a center for information on vehicle-gasifiers. There are hundreds of technical papers from the 1920s, '30s, and '40s in the literature (see companion bibliography), but they often appear in obscure journals and wartime reports that are extremely difficult to find. A single institution, funded to act as a clearinghouse for information on producer gas, would help avoid costly mistakes and needless duplication by organizing and distributing technical information.

An institution of that kind should also publish a vehicle-gasifier newsletter. When exploring the potential of producer gas as a motor transport fuel, it is vital to maintain communication among researchers. Since they are likely to be situated in remote locations, their findings may not be widely shared if technical journals remain the only source of published information on gasifier technology. A newsletter would consolidate information from around the world, provide for rapid exchange of information, and constitute a forum of informal opinions, observations, and preliminary experimental data.

Research Needs

Wartime needs forced nations to begin large-scale manufacture of producer gas generators without research and development. Today we have time to be more deliberate. We have sensitive instruments for measuring carburetion and exhaust temperatures, fuel characteristics, combustion products, and engine performance. These measurements could provide the information needed to develop more efficient operation of gasifiers and use of producer gas. Gas producers used for research purposes should be equipped so that electronic monitoring or chemical sampling can be made at several points. Then the performance of different modifications, fuels, operating conditions, and settings can be properly judged. Imprecise or false data from the past is probably clouding many design issues at the moment.

Several specific areas of research deserve attention because they could make the use of producer gas more convenient and could extend its use to new fuels and new situations. Some of these needs for research are described below.

Safety

Operational directions and design-safety features must be developed to prevent or minimize the hazards of carbon monoxide poisoning. In addition, designs that avoid prolonged exposure to the possibly carcinogenic tars formed in generators must be developed.

Gas Cleaning

Removal of ash and tar is vital to producer gas performance. Research on filters and scrubbers is needed. A first approach is to devise a set of standards so that gas quality and effectiveness of various gas cleaning systems can be compared. Modern materials such as fiberglass and lipophylic polymers (for example, the micron-rated polypropylene filters used in purifying water) may greatly improve gas producer performance over that of the past. Without regular cleaning of filters, coolers, traps, and scrubbers, high reliability cannot be achieved. It is therefore vital that these be easy to clean and have ease of access.

Stickwood as Fuel

Current gas producers require wood in the form of chips or small blocks. Generators designed to operate on stickwood are needed because stickwood can be prepared with common hand tools. If gas producers could be designed to use it, the acceptance and use of gas producers would be greatly enhanced.

High-Ash Fuels

Fuels such as straw, rice hulls, cotton stalks, and trash from cotton ginning are rich in ash. Downdraft gas producers become clogged with slag when these fuels are used. Designs are needed to overcome this difficulty.

Water Injection

Water injected into a hot generator can greatly improve the quality of gas from a generator and reduce slagging of the ash. However, adding water to a wood-fueled generator can be deleterious, and this technique is now suited only to dry, high-carbon fuels such as charcoal and anthracite because they burn at such high heat that they are less easily quenched by the water. Research to overcome these practical limitations is well warranted.

Heat Reclamation

Returning the heat of exhaust to the gasifier could make vast improvements in efficiency, and research on this is needed. It might allow the use of fuels of higher moisture content, and it could reduce tar formation at low engine speeds and improve the energy content of the gas.

Catalysis

In the gasification process the presence of sodium and potassium carbonates assists the dissociation of water so that the hydrogen content—and hence the energy—of the gas is raised. Research is needed to pinpoint the effects and economic benefits of improving gas production with these or other catalysts.

Other Research Areas

Other areas requiring research include:

- The preparation, handling, and mixing of fuels;
- Removing condensates from wood gasifiers so that reduction-zone temperatures are raised and a higher quality gas results;
- Adding a second "generator" or "afterburner" to remove tars and upgrade gas quality; and
- Supercooling of the gas to increase the power obtainable from engines running on producer gas.

Appendix A

Selected Readings

This appendix contains a short list of reviews, general articles, and readily available documents whose details complement this report. Almost 500 additional references (many with annotations) are given in a companion bibliography. To order the bibliography see mailer at end of this report.

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Appendix B

Biographical Sketches of Panel Members

LES D. G. COWARD was graduated from the Institution of Mechanical Engineers, London, in 1953, became a member in 1955, and a Fellow in 1968. After war service in the Royal Navy he joined the United Kingdom Atomic Energy Authority as an engineer and was appointed to the Atomic Energy Research Establishments, first at Harwell and then at Aldermaston. He joined the Tropical Products Institute in 1967 and retired in 1982 as senior engineer and deputy head of the Industrial Development Department. He has worked on a comprehensive range of postharvest processes in a number of developing countries and on producer gas and biogas plants at the Culham Laboratories of the Tropical Products Institute. While serving at the Institute he was appointed Companion of the Imperial Service Order (1975).

RAYMOND E. DESROSIERS, a staff engineer at the Solar Energy Research Institute (SERI) in Golden, Colorado, received his Ph.D. in physical chemistry from Rensselaer Polytechnic Institute, Troy, New York, in 1975. He has experience in transport properties of polyatomic gases, combustion modeling, and ash formation in utility boilers. His activities in the Biomass Thermal Conversion Branch of SERI include construction and operation of an air gasification test facility, gasification modeling, and economic evaluation of biomass conversion options.

ERNEST E. DONATH, a consultant in fuels, especially coal and oil shale utilization, has published an article, "Vehicle Gas Producers," in *Fuel Processing Technology*, 1980. He received a Dr. Ing. Phys. Chem. from Technical University Breslau (then Germany) in 1926. He worked with the High Pressure Department, BASF Ludwigshafen/Rh on catalytic coal liquefaction where he had over one hundred patents. He has also worked for the U.S. Bureau of Mines, for the Coal Liquefaction Demonstration Plant in Louisiana and Missouri as a consultant, and as manager of the fuels research section of Koppers Company, Inc., Pittsburgh, Pennsylvania. His main research has been in synthetic liquid fuels, high pressure reactions, coal carbonization and gasification, and hydrocarbon conversion.

HAROLD E. DREGNE, Horn Professor and director of the International Center for Arid and Semi-Arid Land Studies at Texas Tech University, Lubbock, received a B.S. in chemistry and mathematics from Wisconsin

State University in 1938 and a Ph.D. in soil chemistry from Oregon State University in 1942. He was on the faculty at the University of Idaho, Washington State University, and New Mexico State University before becoming chairman of the Plant and Soil Science Department at Texas Tech in 1969. From 1970 to 1975 he was chairman of the American Association for the Advancement of Science Committee on Arid Lands. He is the editor of *Arid Lands in Transition* and author of *Soils of Arid Regions.*

KAY M. EOFF, assistant professor of physical science at the University of Florida, received his B.S. in 1953 and M.S. in 1955 from Texas College of Arts and Sciences and his Ph.D. in physics in 1963 from the University of Florida. As a geographer, he is particularly interested in the use of gasogens in the forested areas of the world. To demonstrate the simplicity of vehicular gasification technology, he and several of his colleagues at the University of Florida designed and built a gasogen-fueled pick-up truck in 1979.

JOHN W. GOODRUM, head of the Thermal Conversion Branch, Energy Research Laboratory, Engineering Experiment Station, of the Georgia Institute of Technology, received his Ph.D. from that institution. He is involved in several programs at the university for pyrolysis and gasification of biomass. This activity includes development of large-scale pilot plants for fixed-bed and entrained-flow pyrolysis. He is also involved in the development of small-scale thermal-conversion technology for the Agency for International Development.

JOHN R. GOSS, professor in the College of Agricultural and Environmental Sciences and the College of Engineering, and agricultural engineer in the Agricultural Experiment Station, University of California, Davis, received his B.S. in engineering from the University of California at Los Angeles in 1952 and his M.S. in agricultural engineering from the University of California, Davis, in 1955. He has been a member of the department since 1952. He was chairman of the department from 1968 to 1974. His research since joining the department has been concerned with the performance of the self-propelled combine, seed-cleaning plants for field crop seeds and forage-harvesting machinery, micrometeorology in agriculture, and, since 1977, gasification of lignocellulosic materials and the utilization of low Btu gas. He was on an interagency personnel appointment, U.S. Department of Agriculture, Washington, D.C., in 1975-76 and served as a consultant for FAO in Argentina in 1978. He was elected Fellow in the American Society of Agricultural Engineers in 1979.

ANDREW M. HAY, president of Calvert-Peat, Inc., obtained an M.A. in economics from St. John's College, Cambridge. In February 1968 he was made an Honorary Commander of the Order of the British Empire for his

services in furthering Anglo-American trade relations. He is the author of *A Century of Coconuts*, has lived on three continents, and traveled to 45 countries. He was a member of the Academy's Advisory Committee on Technology Innovation from 1979 to 1980.

DAVID HUGHART, an economist with the Energy Department of the World Bank, is principal author of *Prospects for Traditional and Non-Conventional Energy Sources in Developing Countries* (World Bank Staff Working Paper No. 346, July 1979). While attending the University of Michigan he worked for the Advanced Automotive Power Systems Development Division of the U.S. Environmental Protection Agency. His doctoral dissertation compared coal-based synthetic fuels and electricity as energy alternatives for automotive transportation.

ERIC JOHANSSON, managing director of the National Machinery Testing Institute of Sweden, received his B.S. from the Royal Agricultural College at Uppsala in 1955 and his M.S. from Cornell University in 1956 in agricultural and mechanical engineering. He held several positions with the International Harvester Company from 1961 to 1968 and was a national agricultural engineering specialist at the Royal Agricultural College at Uppsala from 1968 to 1974. He has also been a working member of the Royal Swedish Academy of Agriculture and Forestry since 1975.

HARRY LA FONTAINE, president of Energy Research, Miami, Florida, was born in Denmark in 1913. He received hisB.S. in 1934, M.S. in 1937, and Ph.D. in electro-mechanical engineering in Denmark and Finland. When Denmark was invaded in 1940 and all petroleum products became unavailable, he participated in a crash program to find alternate fuel for food production and transport.

He emigrated to the United States in 1950 and became affiliated with the University of Houston in Texas. In 1976 he retired from teaching, lecturing, and private business, but when the fossil fuel crisis made the reuse of biomass gasification a possibility, he and his wife, Dr. Edith La Fontaine, traveled around the world collecting data and patent descriptions and interviewing people known for their background in gasification technology.

In 1978, after visiting the Volvo factory in Sweden and observing their government-sponsored building program of wood-gas generators, he decided to disseminate the knowledge of biomass gasification technology in the United States by building and demonstrating a working unit. In 1981 he participated in 30 gasification seminars held at universities in the southeastern United States, with demonstrations of various gas generator units and his Lincoln limousine pictured on p. 48.

JOHN W. LINCOLN holds a graduate degree in architecture from Columbia

University. He first became aware of petroleum substitutes before World War II through foreign periodicals. He translated a French army officer's book on *Gazogènes Portatifs* and published parts of it in *New Steam Age* in 1942. He has restored and modified a Stanley steam car and an electric car and has also constructed and tested his own gasogen. At present, he is working on *Driving Without Gas*, a revised edition of *Methanol and Other Ways Around the Gas Pump.*

FRANÇOIS MERGEN, Pinchot Professor of Forestry, Yale University, was dean of the School of Forestry and Environmental Studies at Yale from 1965 to 1975. He received a B.A. from Luxembourg College, a B.Sc.F. from the University of New Brunswick (Canada) in 1950, an M.F. in ecology from Yale in 1951, and a Ph.D. (forest genetics) in 1954 from Yale. He is especially knowledgeable about francophone Africa and was chairman of the BOSTID Sahel program and a member of BOSTID's Advisory Committee on Technology Innovation. He was research collaborator at the Brookhaven National Laboratory, 1960-65. In 1966, he received the Award for Outstanding Achievement in Biological Research by the Society of American Foresters. He was Distinguished Professor (Fulbright-Hays Program) in Yugoslavia, 1975. Before joining the Yale faculty, he served as project leader in forest genetics for the U.S. Forest Service in Florida. Dr. Mergen has also served at various times as a consultant to FAO, foreign governments, and private forestry companies.

HUGH L. POPENOE is professor of soils, agronomy, botany, and geography and director of the Center for Tropical Agriculture and International Programs (Agriculture) at the University of Florida, Gainesville. He received his B.S. from the University of California, Davis, in 1951, and his Ph.D. in soil science from the University of Florida in 1960. From 1962 to 1965 he served as director of the Caribbean Research Program. His principal research interest has been in the area of tropical agriculture and land use. He has traveled and worked in most of the countries in the tropical areas of Latin America, Asia, and Africa and is chairman of the Board of Trustees of the Escuela Agricola Panamericana in Honduras. He is a Fellow of the American Association for the Advancement of Science, the American Society of Agronomy, the American Geographical Society, and the International Soils Science Society. He is chairman of the Advisory Committee on Technology Innovation and a member of the Board on Science and Technology for International Development.

DON POST is with the School of Forest Resources and Conservation at the University of Florida. He has helped to build a wood-fuel device for use on a pick-up truck.

BEN RUSSELL, president of Russell Lands, Inc., a timber and land development company, developed a conceptual plan, feasibility study, and a preliminary engineering report that resulted in the construction of the country's first modern, large-scale, wood-fired steam plant outside the forest products industry. This plant supplied most of the processed steam required for a large textile firm, saving some six million gallons of fuel oil annually. As a result of his work in this field and the growing market for similar types of services, he founded a company called ECON, which is devoted to the promotion of wood-residue fuel for use in industry. He is currently involved in wood energy research through a project that concerned the development of a biomass gasification system for the powering of internal combustion engines.

LAWRENCE N. SHAW is with the Agricultural Engineering Department of the University of Florida. He holds a B.S., M.S., and Ph.D. in agricultural engineering. He, Don Post, and Kay Eoff are developing a downdraft gasifier fueled by corn cobs, stickwood, bagasse, and peanut hulls.

E. GRIFFIN SHAY is a professional associate of the Board on Science and Technology for International Development.

NOEL D. VIETMEYER, staff officer for this study, is a professional associate of the Board on Science and Technology for International Development. A New Zealander by birth, with a Ph.D. in organic chemistry from the University of California, Berkeley, he now works on innovations in science that are important for developing countries.

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33. **Alcohol Fuels: Options for Developing Countries.** 1983. 128 pp. Examines the potential for the production and utilization of alcohol fuels in developing countries. Includes information on various tropical crops and their conversion to alcohols through both traditional and novel processes.

36. **Producer Gas: Another Fuel for Motor Transport.** 1983. 112 pp. During World War II Europe and Asia used wood, charcoal, and coal to fuel over a million gasoline and diesel vehicles. However, the technology has since been virtually forgotten. This report reviews producer gas and its modern potential.

38. **Supplement to Energy for Rural Development: Renewable Resources and Alternative Technologies for Developing Countries.** 1981. 240 pp. Updates the 1976 BOSTID publication and offers new material on direct and indirect uses of solar energy. Provides index to both volumes.

39. **Proceedings, International Workshop on Energy Survey Methodologies for Developing Countries.** 1980. 220 pp. Report of a 1980 workshop organized to examine past and ongoing energy survey efforts in developing countries. Includes reports from rural, urban, industry, and transportation working groups, excerpts from 12 background papers, and a directory of energy surveys for developing countries.

Technology Options for Developing Countries

8. **Ferrocement: Applications in Developing Countries.** 1973. 89 pp. Assesses state of the art and cites applications of particular interest to developing countries—boat building, construction, food and water storage facilities, etc.

14. **More Water for Arid Lands: Promising Technologies and Research Opportunities.** 1974. 153 pp. Outlines little-known but promising technologies to supply and conserve water in arid areas. (French language edition is available from BOSTID.)

21. **Making Aquatic Weeds Useful: Some Perspectives for Developing Countries.** 1976. 175 pp. Describes ways to exploit aquatic weeds for grazing, and by harvesting and processing for use as compost, animal feed, pulp, paper, and fuel. Also describes utilization for sewage and industrial wastewater treatment. Examines certain plants with potential for aquaculture.

28. **Microbial Processes: Promising Technologies for Developing Countries.** 1979. 198 pp. Discusses the potential importance of microbiology in developing countries in food and feed, plant nutrition, pest control, fuel and energy, waste treatment and utilization, and health.

31. **Food, Fuel, and Fertilizer for Organic Wastes.** 1981. 150 pp. Examines some of the opportunities for the productive utilization of organic wastes and residues commonly found in the poorer rural areas of the world.

34. **Priorities in Biotechnology Research for International Development: Proceedings of a Workshop.** 1982. 261 pp. Report of a 1982 workshop organized to examine opportunities for biotechnology research in developing countries. Includes general background papers and specific recommendations in six areas: 1) vaccines, 2) animal production, 3) monoclonal antibodies, 4) energy, 5) biological nitrogen fixation, and 6) plant cell and tissue culture.

Plants

16. **Underexploited Tropical Plants with Promising Economic Value.** 1975. 187 pp. Describes 36 little-known tropical plants that, with research, could become important cash and food crops in the future. Includes cereals, roots and tubers, vegetables, fruits, oilseeds, forage plants, and others.

22. **Guayule: An Alternative Source of Natural Rubber.** 1977. 80 pp. Describes a little-known bush that grows wild in deserts of North America and produces a rubber virtually identical with that of the rubber tree. Recommends funding for guayule development.

25. **Tropical Legumes: Resources for the Future.** 1979. 331 pp. Describes plants of the family Leguminosae, including root crops, pulses, fruits, forages, timber and wood products, ornamentals, and others.

37. **The Winged Bean: A High Protein Crop for the Tropics.** (Second Edition). 1981. 59 pp. An update of BOSTID's 1975 report of this neglected tropical legume. Describes current knowledge of winged bean and its promise.

47. **Amaranth: Modern Prospects for an Ancient Crop.** 1983. Before the time of Cortez grain amaranths were staple foods of the Aztec and Inca. Today this extremely nutritious food has a bright future. The report also discusses vegetable amaranths.

Innovations in Tropical Reforestation

26. **Leucaena: Promising Forage and Tree Crop for the Tropics.** 1977. 118 pp. Describes *Leucaena leucocephala*, a little-known Mexican plant with vigorously growing, bushy types that produce nutritious forage and organic fertilizer as well as tree types that produce timber, firewood, and pulp and paper. The plant is also useful for revegetating hillslopes, providing firebreaks, and for shade and city beautification.

27. **Firewood Crops: Shrub and Tree Species for Energy Production.** 1980. 237 pp. Examines the selection of species suitable for deliberate cultivation as firewood crops in developing countries.

35. **Sowing Forests from the Air.** 1981. 64 pp. Describes experiences with establishing forests by sowing tree seed from aircraft. Suggests testing and development of the techniques for possible use where forest destructions now outpaces reforestation.

40. **Firewood Crops: Shrub and Tree Species for Energy Production.** Volume II. 1983. A continuation of BOSTID report number 27. Describes 27 species of woody plants that seem suitable candidates for fuelwood plantations in developing countries.

41. **Mangium and Other Fast-Growing Acacias for the Humid Tropics.** 1983. 63 pp. Highlights ten acacias species that are native to the tropical rain forest of Australasia. That they could become valuable forestry resources elsewhere is suggested by the exceptional performance of *Acacia mangium* in Malaysia.

42. **Calliandra: A Versatile Small Tree for the Humid Tropics.** 1983. 56 pp. This Latin American shrub is being widely planted by villagers and government agencies in Indonesia to provide firewood, prevent erosion, yield honey, and feed livestock.

43. **Casuarinas: Nitrogen-Fixing Trees for Adverse Sites.** 1983. These robust nitrogen-fixing Australasian trees could become valuable resources for planting on harsh, eroding land to provide fuel and other products. Eighteen species for tropical lowlands and highlands, temperate zones, and semiarid regions are highlighted.

Managing Tropical Animal Resources

32. **The Water Buffalo: New Prospects for an Underutilized Animal.** 1981. 118 pp. The water buffalo is performing notably well in recent trials in such unexpected places as the United States, Australia, and Brazil. Report discusses the animal's promise, particularly emphasizing its potential for use outside Asia.

44. **Butterfly Farming in Papua New Guinea.** 1983. 36 pp. Indigenous butterflies are being reared in Papua New Guinea villages in a formal government program that both provides a cash income in remote rural areas and contributes to the conservation of wildlife and tropical forests.

45. **Crocodiles as a Resource for the Tropics.** 1983. 60 pp. In most parts of the tropics crocodilian populations are being decimated, but programs in Papua New Guinea and a few other countries demonstrate that, with care, the animals can be raised for profit while the wild populations are being protected.

46. **Little-Known Asian Animals with a Promising Economic Future.** 1983. 124 pp. Describes banteng, madura, mithan, yak, kouprey, babirusa, Javan warty pig and other obscure, but possibly globally useful wild and domesticated animals that are indigenous to Asia.

General

29. **Postharvest Food Losses in Developing Countries.** 1978. 202 pp. Assesses potential and limitations of food-loss reduction efforts; summarizes existing work and information about losses of major food crops and fish; discusses economic and social factors involved; identifies major areas of need; and suggests policy and program options for developing countries and technical assistance agencies.

30. **U.S. Science and Technology for Development: Contributions to the UN Conference.** 1978. 226 pp. Serves the U.S. Department of State as a major background document for the U.S. national paper, 1979 United Nations Conference on Science and Technology for Development.

The following topics are now under study and will be the subjects of future BOSTID reports:

- **Leucaena: Promising Forage and Tree Crop for the Tropics** (Second Edition)
- **Jojoba**

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The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the federal government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

The National Research Council

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

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The Office of International Affairs is responsible for many of the international activities of the Academy and the Research Council. Its primary objectives are to enhance U.S. scientific cooperation with other countries; to mobilize the U.S. scientific community for technical assistance to developing nations; and to coordinate international projects throughout the institution.

The Board on Science and Technology for International Development

The Board on Science and Technology for International Development (BOSTID) of the Office of International Affairs addresses a range of issues arising from the ways in which science and technology in developing countries can stimulate and complement the complex processes of social and economic development. It oversees a broad program of bilateral workshops with scientific organizations in developing countries and conducts special studies. BOSTID's Advisory Committee on Technology Innovation publishes topical reviews of unconventional technical processes and biological resources of potential importance to developing countries.

NAS NAE IOM NRC National Academy Press

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