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Producer Gas Engines in Villages of Less-Developed Countries

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Access to mechanical power is needed in the villages of less-developed countries (LDC's) for lift irrigation, ploughing, threshing, transportation, and other uses. Traditionally, people in LDC's have obtained a major share of their mechanical energy from draft animals, at a very low overall thermal efficiency of 3 to 5 percent (*1*). A comparison of the energy efficiency of agricultural production showed that LDC's use more energy per unit of production than do developed countries. For example, in India 20 gigajoules are needed to produce 1 metric ton of rice, compared to 6.5 GJ to produce the same crop in Japan and the United States (*1*). However, Japanese and U.S. farmers use high-quality, nonrenewable energy sources such as petroleum and natural gas, whereas virtually all the energy needed by Indian farmers is derived from crude agricultural residues and other biomass.

Summary. Producer gas engines could have an important role in the decentralized production of mechanical energy in rural areas of less-developed countries. With this technology mechanical energy is produced from solid fuels by use of internal combustion engines. A comparison with other renewable energy options, on the common basis of energy efficiency and economics, shows that producer gas engines may have significant advantages and deserve serious attention.

Until recently, some farmers could increase their energy efficiency through the use of petroleum-based machinery. As petroleum becomes more expensive and less readily available, this option becomes less attractive. Fossil fuel–poor LDC's must therefore seek to increase the energy efficiency of using renewable energy resources such as wood, crop residues, dung, and solar radiation. Given their constraints of capital, the diffuse nature of the resources, and lack of technology and know-how, this is not an easy task. For example, photovoltaic power generation is not economically feasible with current technology. Wind power and hydropower are site-specific and generally limited to stationary applications. Production of methanol and ethanol from biomass is still energy-inefficient and capital-intensive. Small steam engines have low efficiency (<10 percent). Stirling engines need a major development effort to make them cost-effective.

By contrast, the producer gas engine, which is an internal combustion (IC) engine, has several advantages. It can run on solid fuels such as wood, straw, and other crop residues; it has a moderately high engine efficiency (20 to 30 percent), a low cost, and is easily adaptable to existing IC engines. Moreover,

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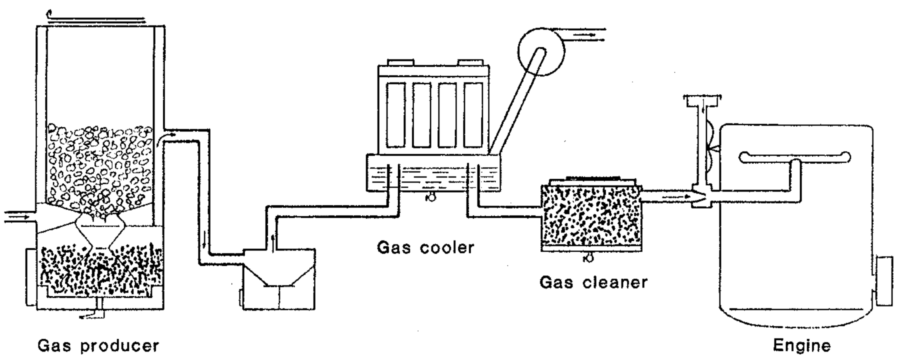

Fig. 1. Schematic of a producer gas engine.

this proven technology (pre–World War II) can provide both mobile and stationary power. Nevertheless, little effort has been made to introduce this technology into LDC's, primarily because of the convenience of running IC engines on petroleum-derived fuels. However, with the present outlook for petroleum resources and their unavailability or high cost in the rural areas of most LDC's, producer gas engines deserve a serious second look. In this article we discuss some technical and economic aspects of producer gas engines and compare them with alternative sources of mechanical energy.

Producer Gas Engines

Principles. The operating principles of producer gas engines are relatively well understood, even though the complex chemical reactions of partial combustion of biomass solid fuels are not. These fuels are mixtures of carbon, hydrogen, and oxygen compounds which undergo various exothermic and endothermic reactions during partial combustion in air, as shown by Eqs. 1 to 7 in Table 1. Incoming air reacts with hot carbon exothermally to form CO_2 (Eq. 1), which is immediately reduced to CO (Eq. 2) endothermally; CO_2 also dissociates to CO and O_2 (Eq. 4), the equilibrium constant depending on the temperature. Steam, which is introduced separately for carbonaceous fuels such as coal or is inherently produced by water-containing biomass fuels, undergoes several reactions (Eqs. 5 to 7) with C and CO, producing hydrogen. Usually an equilibrium temperature of 900° to 1200°C (fuel-dependent) is maintained in the gasification zone and a gas mixture containing CO, CO_2, H_2, and light hydrocarbons is produced. Nitrogen in combustion air goes through as an inert diluent. Pyrolysis products such as organic acids and tars are also produced, especially with biomass fuels. This mixture of gases is called producer gas, and its heating values are typically low, varying from 4 to 8 megajoules per cubic meter, because of the high concentration of nitrogen.

This gas is cooled, filtered, and fed to the carburetor of an IC engine, where it is mixed with combustion air and charged to the cylinders. Cooling is essential to increase the volumetric efficiency during carburetion, and gas cleaning is essential to remove acidic, tarry, and particulate material, which would ruin the engine. During steady-state operation of a producer gas engine the suction of the engine draws inlet air into the gas producer, controlling the rate of fuel consumption and providing very simple operational control. Thus the total system of a producer gas engine consists of the following components: gasifier, cooler, cleaner, and engine (Fig. 1). The role of the gasifier is to produce, from a heterogeneous solid fuel, a clean combustible gas that can be used directly in the IC engine.

Equipment. Numerous gasifiers have been designed, patented, and operated (*2, 3*). Gasifiers can be broadly classified as updraft, downdraft, or cross-draft types. Of the three types, updraft gasifiers are generally considered the most efficient and stable (*4, 5*). With biomass feedstocks, however, downdraft gasifiers must be used, because these fuels produce tars, acids, and other pyrolysis products, which are destroyed in passing through the hot reaction zone of downdraft gasifiers (*2, 5*). The Imbert, Svelund, Panhard, Sabatier, and Brandt gasifiers (all named after their designers) have been operated with biomass fuels (*2*). Most of the designs are simple and utilize mild steel and fire clay (around the reaction zone) as the principal materials of construction.

Gas from the gasifier is cooled and cleaned by filtering before it is injected into the carburetor. Filters made with simple materials such as oil, charcoal, water, cloth, porcelain chips, sisal fibers, and so on have been used. Recently, some aluminosilicate catalysts prepared from clay were found to be good for cracking the tarry components of wood gas, and these may be used as gas cleaners (*6*). Most gas filters are simple in design and made with simple materials.

Past experience with producer gas engines has generally been with gasoline engines having a low compression ratio. It was noted, however, that the engine efficiency and operational characteristics could be vastly improved by increasing the compression ratio, modifying the carburetors, and supercharging (*2, 7*). For producer gas engines the maximum power was obtained at a stoichiometric air-to-fuel ratio, whereas a richer mixture (120 percent of the stoichiometric ratio) is necessary for maximum power in gasoline engines (*8*). The overall engine efficiency does not significantly decline when a gasoline engine is run on producer gas, but the power output is reduced (*2, 7*). Between 1939 and 1945, when producer gas was widely used, no engines were manufactured to run exclusively on this fuel. Existing engines were modified.

Today, high-compression-ratio gasoline engines and small diesel engines are common, and these would be better suited to run on producer gas than the engines of the past. Dual-fuel (spark-fired) diesel engines appear especially attractive for use with producer gas. They have high compression ratios and are designed to run on both gaseous and liquid fuels (*9, 10*); thus they could be started up with diesel fuel and then switched over to producer gas for steady-state operation. A large number of engines used for agriculture in LDC's today (for pumps, threshers, and so on) are diesel engines, which could be retrofitted to run on producer gas (*9*).

Fuel. The source of fuel to run producer gas engines is an important issue, especially in LDC's, where biomass fuels are becoming scarcer due to population expansion and inefficient fuel use. Two possible sources of fuel are (i) residues that are not currently well utilized such as husks, nutshells, fruit seeds, and wood wastes and (ii) residues and wood that are currently used with low efficiency compared to that of producer gas technology.

In principle, any carbonaceous solid fuel could be used in gas producers. Wood, charcoal, charcoal briquettes, bagasse, corncobs, nutshells, straw, peat, and anthracite have all been used successfully (*2, 4, 11*). The characteristics of the fuel that influence the performance of the gas producer are reactivity, size, volatile matter, moisture and ash content, and volumetric energy density (VED). The reactivity of a fuel indicates its ease of gasification, and high reactivity is desirable. Fuel size determines the velocity and the course of chemical reactions in the gas producer; it also determines the pressure drop across the fuel bed, which should be small because gas producers work by engine suction. Fuels with a high volatile matter content tend to produce pyrolysis tars, which are detrimental to IC engine operation. The moisture content of the fuel should be low for high gasification efficiency, because the sensible heat required to vaporize water reduces the thermal efficiency. Fuels with a low ash content are preferred because they require less ash removal and disposal. Finally, VED determines the overall size and weight of the fuel hopper and the gas producer; this is particularly important for portable or mobile producer gas engines.

Fuel processing. The low sulfur and ash contents of wood, bagasse, straw, and other residues are major advantages of these biomass fuels. However, these fuels are high in volatile matter and moisture and have nonuniform sizes and low VED's. The operational problems created by a high volatile matter content can be reduced by using a downdraft gasifier, as mentioned earlier. The problems created by moisture content, size, and low VED can only be solved by fuel processing. Processing of biomass fuels can vary in complexity from simple size reduction (chipping, chopping, and so on) and air drying to fluid bed drying, carbonization, and densification. The degree of processing required depends on the type of biomass, initial moisture content, initial VED, and end use of the producer gas engine (whether it is stationary or mobile). Only two options—(i) simple size reduction and air drying and (ii) mechanical densification—will be discussed here.

Raw wood and freshly harvested straw contain 50 to 60 percent moisture by weight and are nonuniform in size. Air drying wood for 6 to 8 months can reduce the moisture content to around 20 percent. Straws, if stored properly, can also be dried to the point where they contain less than 20 percent moisture (*12*). Other residues such as coconut shells, walnut shells, and peanut hulls contain less moisture (~20 percent) to begin with (*4, 11*). The size requirement of the fuel depends on the type of gas producer, but wood chips ranging in size from 2 to 10 centimeters have been found adequate in most cases (*2*). Raw walnut shells (~1 cm) (*11*) and broken coconut shells (4 to 8 cm) (*4*) are satisfactory fuels for gas producers. Thus, simple drying, storage, and size reduction techniques can produce adequate gasifier fuels. However, the VED's of these fuels are low (6000 to 8500 GJ/m^3), so that large fuel hoppers and gasifiers are required. Thus if gasifiers are needed for sustained periods of mobile operation, these bulky fuels may not be usable. However, if gasifiers are stationary, used for short periods of time, or refueled at frequent intervals, then those bulky fuels may be used.

Table 1. Gasification reactions of biomass fuels.

Reaction*	Enthalpy change (kJ)
1. $C(s) + O_2(g) = CO_2(g)$	−400
2. $CO_2(g) + C(s) = 2\,CO(g)$	+160
3. $2\,C(s) + O_2(g) = 2\,CO(g)$	−240
4. $2\,CO(g) + O_2(g) = 2\,CO_2(g)$	−560
5. $H_2O(g) + C(s) = CO(g) + H_2(g)$	+120
6. $H_2O(g) + CO(g) = H_2(g) + CO_2(g)$	−40
7. $C(s) + H_2O(g) = CO_2(g) + 2\,H_2(g)$	+80

*Abbreviations: s, solid; g, gas.

Densification can produce fuels with a lower moisture content, more uniform size, and higher VED than raw biomass. The capital and energy requirements depend on the degree of densification. Some straw densification processes such as rolling and compressing are relatively simple and produce rolls and briquettes with bulk densities of 0.3 to 0.8 gram per cubic centimeter, VED's of 6000 to 15,000 GJ/m^3, and moisture contents around 20 percent (*12, 13*). Wood wastes, bagasse, peanut hulls, and so on can also be densified by several processes (*13–16*). Usually these processes have three steps: size reduction, drying, and densification. The temperatures developed during densification (~150°C) help to soften the lignin, which acts as a binding agent and imparts satisfactory strength to the pellets or briquettes when they are cooled. The products are uniform in size, have a low moisture content (< 20 percent), and are usually resistant to wetting. The VED's of such materials range from 12,500 to 17,000 GJ/m^3 (*13*). These materials have been termed ideal gasifier fuels (*17*).

Fuel processing by any of these sophisticated densification methods involves capital and operating costs. The capital costs for densification for optimally sized plants (100 to 300 tons of product per day) range from \$2 to \$3 per gigajoule of product per year (*13–16*). The overall energy efficiencies of such processes are high and will be discussed later. Because the amount of fuel processing required depends on the properties of the biomass feedstock and the end use of the producer gas engines, the overall cost of fuel processing also depends on these factors and it is not possible to make a generalized economic analysis. For rural applications in LDC's, where capital is scarce, simple fuel processing methods such as chipping, air drying, bundling, rolling, and compressing may be the more appropriate option. However, some fuel processing and dry storage appears to be essential for satisfactory operation of producer gas engines.

Energy efficiency. The overall energy efficiency is the product of the efficiencies of the individual steps—fuel processing, gas production, and engine performance. If air-dired biomass fuels are to be used directly, their moisture content should be less than 20 percent. Drying and densification require capital investment, but the energy efficiency of these steps can be fairly high (80 to 90 percent) (*13*). Charcoal and charcoal briquettes are excellent fuels for gas producers, but the thermal efficiencies of carbonization processes are low (40 to 50 percent) (*5, 18*).

The thermal efficiency of gas production also depends on the type of fuel. When air-dried biomass (< 20 percent moisture) is used, the thermal efficiency is around 60 to 70 percent (*4, 11*). Charcoal and charcoal briquettes can be gasified with 75 to 80 percent thermal efficiency (*2, 5*). Densified biomass can also be gasified with 75 to 80 percent thermal efficiency (*17*). Hence part of the efficiency loss during fuel processing is offset by the higher gasification efficiency of processed fuels such as charcoal and densified biomass.

The thermal efficiency of an IC engine depends on the engine type. The dual-fuel diesel engine can be operated at efficiencies exceeding 30 percent. Retrofitting existing gasoline or diesel engines does not reduce the energy efficiency; only the rated power may be slightly lower (*7, 8*). Thus the efficiency of an IC engine running on producer gas will not be very different from its efficiency with liquid fuels—that is, in the range of 20 to 30 percent.

The range of thermal efficiencies for individual steps as well as the overall efficiency of shaft power production is shown in Table 2. Three fuel processing options have been chosen. Options 1 and 2 can provide an overall efficiency of

Table 2. Energy efficiency for producer gas technology.

Option	Fuel processing	Thermal efficiency for fuel processing (%)	Gasifier efficiency (%)	Engine efficiency (%)	Overall efficiency to shaft power (%)
1	Air drying, simple size reduction, simple densification	100	60–70	20–30	12–21
2	Drying, complex densification	80–90	75–80	20–30	12–22
3	Carbonization, charcoal briquetting	40–50	75–80	20–30	6–12

shaft power production of 12 to 22 percent, starting from biomass raw materials such as wood, agricultural residues, seeds, and shells.

Alternative Renewable Energy Sources

There are several alternative renewable energy sources for the production of mechanical power: biomass, direct solar radiation, wind, and water. Biomass can be utilized through draft animals as well as through internal and external combustion engines. Other forms of solar energy can be converted in solar thermal engines, motors powered by photovoltaic cells, windmills, and water mills. In this section we compare these alternatives on the basis of capital costs, overall efficiency, scalability, end use, and current status of the technology (Table 3).

Biomass-based energy sources fall into several broad categories: draft animals, IC engines utilizing biogas, producer gas or liquid fuels such as ethanol or methanol (derived from crops or crop residues), and external combustion engines such as the Stirling engine running on any combustible material. They have associated with them two capital costs, for fuel processing and for energy conversion devices. The only capital cost for direct solar options is that of the conversion device.

Draft animals continue to provide the bulk of the energy input to agriculture in many LDC's (*1*, *19*). They feed on cellulosic materials such as straw and hay as well as starches and proteins from grains, leaves, and legumes. These materials need little preparation before being fed to the animals and thus capital costs for fuel processing are low. Draft animals are inefficient converters of biomass to mechanical energy. They can utilize only 40 to 50 percent of the energy content of the feed, the rest being rejected as dung (*1*). Of the feed energy retained only a small portion is available for mechanical work, and the overall efficiency of conversion of feed to work is typically only 3 to 5 percent. Energy can be recovered from the dung as discussed below. Indian bullocks, commonly used for draft, cost \$60 to \$175 (*20*) and provide a mechanical output of around 0.5 kilowatt (*21*)—a cost of \$120 to \$350 per kilowatt (*22*). Draft animals are versatile; they can provide stationary power for water pumping and threshing as well as mobile power for ploughing and transportation. Their relatively small initial cost and versatility (see Table 3) presumably account for their widespread use.

Animal dung can be digested anaerobically to produce biogas, which is a good fuel for IC engines. Utilizing the biogas energy in this way increases the energy efficiency over using animals for draft only. Anaerobic digestion, however, has a low thermal conversion efficiency (35 to 40 percent) because not all components of manure are easily digestible (*23*). Moreover, the capital costs associated with digester construction are around \$11.50 per gigajoule of product per year for a digester producing 2200 m^3 of biogas per year (Indian Agricultural Research Institute design) (*24*). This is much higher than the unit capital costs for a biomass densification plant. Assuming a biogas engine efficiency of 20 to 30 percent, the overall efficiency of conversion from feed to mechanical power

Table 3. Comparison of renewable energy options.

Technology	Input raw material	Capital cost: Fuel processing (\$/GJ-year)	Capital cost: Energy conversion device (\$/kW)	Overall efficiency (raw material to shaft power) (%)	Scale (minimum size) (kW)	End use*	Technology status
Draft animal	Cattle feed	Small	120–350	3–5	0.1–0.5	S,M	In use
Producer gas engine							
Simple fuel processing	Any dry biomass	Small	150–250†	12–21	2	S,M	Available
Complex densification	Biomass	2–3	150–250†	12–22	2	S,M	Available
Biogas	Animal manure	11.5	100–200	7–12‡	0.1–0.5	S	Current
Liquid fuels							
Ethanol	Starch, sugar	12.5–25	100–200	Very small	0.3–0.5	S,M	Current
Ethanol	Lignocellulose	35	100–200	Very small	0.1–0.5	S,M	Under development
Methanol	Lignocellulose	26–33	100–200	Uncertain	0.1–0.5	S,M	Under development
Stirling engines	Any dry biomass	Same as producer gas engine	300–400	3–4	0.1–0.5	S,M	Under development
Solar							
Thermal	Direct	N.A.§	7,500–30,000		0.3	S	Under development
Wind	Indirect	N.A.§	4,000–10,000		0.2	S	Current
Photovoltaic	Direct	N.A.§	7,000–50,000		0.1	S	Under development

*S, stationary; M, mobile. †The gasifier cost is included in the engine and not as a fuel processing cost. ‡This includes the power output of the draft animal. §Not applicable.

by the biogas route is low—4 to 7 percent (*25*). If we add the draft output power of the animals derived from the same feed input, the combined overall efficiency is still only 7 to 12 percent. Biogas engines, unlike draft animals, are generally limited to stationary power applications (see Table 3).

Mechanical power derived from biomass by producer gas engines has already been discussed. Of the two fuel processing options, simple fuel processing (air drying, chopping, and so on) has small capital costs. The capital costs for densification with optimally sized plants (100 to 300 tons of product per day) range from $2 to $3 per gigajoule of product per year (*13–16*). Capital costs for IC engines are based on the cost of small engines (2 to 5 kW) produced in India (*26*) plus an estimated cost for the gas producer (*27*). Larger IC engines have lower unit capital costs.

Biomass can also be converted to liquid fuels, such as ethanol or methanol, which can then be used in IC engines. Ethanol can be produced from sugars or starches by existing fermentation and separation technology. The capital costs of such distilleries range from $1 to $2 per gallon of ethanol per year (*28, 29*). This translates to a capital cost of $12.50 to $25 per gigajoule of product per year. In LDC's where food shortages are chronic, using starches or sugars for production of ethanol will rarely be possible. Ethanol production from lignocellulosic biomass has yet to become a viable technology; for instance, acid hydrolysis of lignocellulose is a low-yielding, inefficient, and expensive process. A plant producing 95,000 m^3 of ethanol per year from wood by acid hydrolysis would cost about $35 per gigajoule of product per year (*30*). The thermal energy efficiency of ethanol production is low because large amounts of energy are needed for distillation and wood pretreatment, and hydrolysis yields are low. We have not cited any figures because we do not know any with certainty.

Methanol can be produced by biomass gasification followed by catalytic conversion of synthesis gas. So far, only large methanol plants have been proposed for biomass utilization. For instance, a plant proposed for Brazil that would produce 4 million kilograms of methanol per day (from 8.4 million kilograms of dry wood per day) is expected to cost $350 million (*31*). This translates to a capital cost of about $26 per gigajoule of product per year. Smaller plants (40 million gallons per year) would cost about $33 per gigajoule of product per year (*32*). Locating such large plants and transporting such quantities of biomass to a central plant might also involve significant energy penalties.

A Stirling cycle engine operated directly on solid biomass fuel is another converison device for mechanical power. Such external combustion engines are currently under development. A major developer expects that when they reach production, their 950-watt, low-pressure, hot-air Stirling engine will cost $300 to $400 per kilowatt (*33*). This engine has a lower power output than most IC engines in use today. Even smaller Stirling engines may be practicable for water pumping and electricity generation. Beale *et al.* (*33, 34*) anticipate a 100-W, "free piston" Stirling engine pump to be sold for less than $100 when it is in large-scale production. At an assumed pumping efficiency of 50 percent, the shaft output of this engine would be 200 W, so that the capital cost including the pump would amount to $500 per kilowatt. Thus Stirling engines would cost about twice as much as present IC engines but would be available on a much smaller scale. The thermal efficiency for shaft power production of the 950-W engine would be 17 percent (*33*). Direct combustion of solid biomass fuels may be only 20 percent efficient (*34*), so that the overall efficiency of conversion of biomass energy to shaft power would be 3 to 4 percent. The fuel may be processed into much smaller pieces suitable for fluidized-bed combustors to yield combustion efficiencies of 50 to 70 percent. However, this could substantially increase the capital cost, and the overall thermal efficiency would remain relatively low, 8 to 12 percent.

Solar energy can also be converted directly through heat engines or photovoltaics and electric motors. Indirect forms of solar energy—wind and water power—can be harnessed as mechanical energy or converted to electricity. Direct solar conversion requires solar collectors or solar cells, while devices such as windmills and waterwheels are needed to extract energy from wind and water. Because of their bulk or site-specific nature (especially for water power), these devices are suited only for stationary use. Moreover, the capital costs of the conversion devices are exceedingly high, $4,000 to $50,000 per kilowatt, as shown in Table 3 (*20, 35*). Only the photovoltaic systems have a potential for significant cost reduction after the development of inexpensive solar cells, and they may cost around $700 per kilowatt (*36*).

Discussion

When discussing energy options for villages in LDC's, their shortages of capital, skilled labor, and manufacturing facilities must be considered. Of the options considered here, only draft animals, producer gas, and Stirling engines (apart from solar thermal, wind, and photovoltaic sources) involve little or no capital cost for fuel processing. Options involving liquid fuel require high capital costs for fuel processing and large centralized plants. Currently, the capital costs of conversion devices for solar technologies are exceedingly high (Table 3); if and when low-cost solar technologies (such as photovoltaics) are developed, they should be applicable to LDC villages.

Thus, for the near future, draft animals, producer gas, and Stirling engines are the most likely options for producing mechanical power from renewable resources in LDC villages. The capital cost of the energy conversion device (animal or engine) is about the same for draft animals and producer gas engines and somewhat higher for Stirling engines. Draft animals and Stirling engines have the advantage of being capable of low power output and may be suitable for applications having low power requirements. The power output of draft animals is limited to 1 to 2 kW; Stirling engines can be designed for an output of 0.1 to 100 kW or more. The upper limit on the power output of commercially available producer gas engines exceeds 100 kW (*10*); the lower limit may be about 2 kW because of practical constraints on gas producer design, but this has yet to be explored. Producer gas engines have a major advantage over both draft animals and Stirling engines in that they offer substantially higher (three- to fourfold) conversion efficiencies from biomass to output power. Stirling engines are still under development, while producer gas engines are an available technology.

Currently, the development of anaerobic digestion (biogas) technology is improving the efficiency of draft animal usage. Our analysis shows that capital costs for fuel processing (digester costs) can be substantial for this option. Anaerobic digesters are likely to limit biogas engines to stationary applications. Moreover, draft animals are net consumers of fixed nitrogen; they require vegetable proteins and other nutrients and cannot live on lignocellulose alone. Thus the apparent fertilizer value of animal manure or digester residue is only a fraction of the fixed nitrogen and other nutrients the draft animals ingest. Producer gas engines can utilize nonedible lignocellulosic raw materials. However, draft animals are versatile, can collect biomass, and deliver both stationary and mobile power.

In our comparison of various renewable energy options we have focused on capital costs for fuel processing and energy conversion, overall energy efficiency, scale, and availability of the technology. Other factors that are also important are the availability and cost of the fuel and the specific end use of the mechanical power. Fuel availability depends on biomass yield, which is determined by many factors and is apt to be location-specific. Fuel cost involves additional economic factors and is equally site-specific. We have also not considered the end-use efficiency of the device that uses the mechanical power—for instance, the efficiency of a water pump for irrigation. This efficiency will vary depending on the end use, the device, and its scale. A rigorous economic analysis would include these considerations. Nevertheless, our comparison of the alternative technologies leads to a few conclusions that should be generally applicable to LDC villages.

Given the constraints of capital, resources, and so on, the use of draft animals and development of biogas technology are sensible for LDC villages. However, producer gas engines have the potential for reducing costs and increasing the energy efficiency of utilization of biomass resources for mechanical power production. This technology deserves serious attention. Initially, producer gas technology could be developed for semistationary applications such as lift irrigation, using husks, shells, wood wastes, and other nonedible residues as fuels. Thus in the short run draft animals and producer gas need not compete for raw material resources. In the long run, if producer gas technology becomes successful, it will compete for the feed (and the land resources producing the feed) of the draft animals.

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