Producing gas from crop residues

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A pilot model downdraft gasifier demonstrated the feasibility of using crop and wood residues to produce low-Btu gas.

To determine the potential for obtaining energy from timber and crop residues in California, a pilot producer-gas plant constructed at the University of California, Davis, was operated for several months on various residue fuels. (Producer gas is the result of thermochemical processes that take place in a gas producer.)

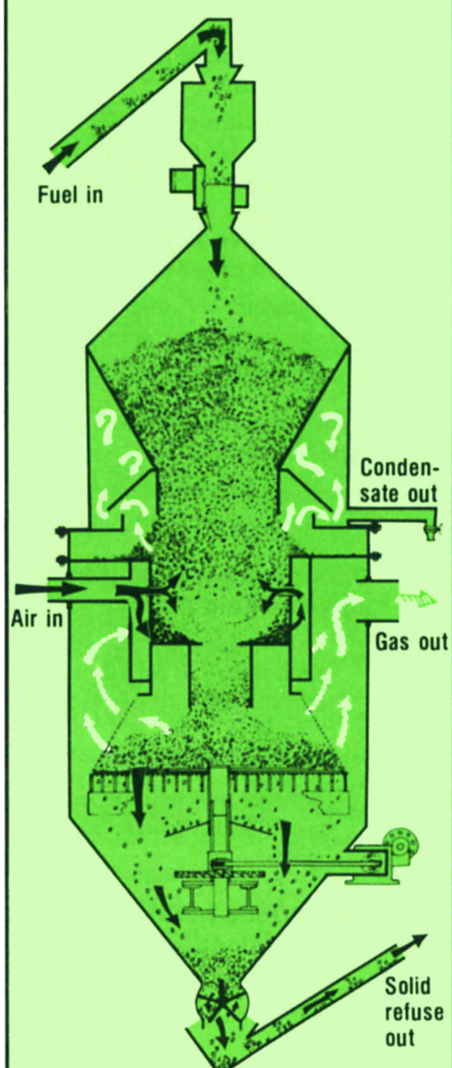
These tests and previous ones with experimental downdraft gasifiers show that there is good potential for energy recovery from crop and forest residues such as fruit pits, almond and walnut shells, corn cobs, and wood chips. However, other fuels, such as rice, barley, and bean straw, cotton stalks, and cotton gin trash, produced enough slag to interfere seriously with operation of the pilot plant.

Gas producers fueled with coal, coke, wood chips or various residues have been in use for more than a century. The earlier ones were large, stationary updraft devices, with air blown in at the bottom and producer gas discharged at the top. Because the hot gases flow against the stream of fuel, the updraft design is less efficient and also yields gas with a high tar and steam content, which cannot be used for internal combustion engines. However, both updraft and the more recent crossdraft gasifiers are less susceptible to slagging than the downdraft type.

During World War II in Europe and Japan, small, batch-fed, charcoal-burning downdraft gas producers were developed for use on tractors and trucks. More recently in Sweden, such small downdraft devices on vehicles have been highly successful when burning charcoal or uniformly sized wood chips dried to 20 percent or less moisture.

Research goals

In 1976, a grant from the California Energy Commission supported the construction and testing of a downdraft mobile producer-gas plant designed to yield 10 million Btu per hour. This pilot plant was based on a Swedish design and on extensive tests at Davis with a laboratory prototype. There were two primary purposes: first, to operate the mobile plant for various uses (fueling a steam boiler, generating electricity with a diesel engine, producing heated air) and, second, to test the gasification characteristics of a wide range of agricultural and forest residues — in particular to determine the potential of each fuel for slagging. For the second purpose, both the mobile pilot plant and the laboratory gas producer were used.



Flow of fuel, air, gas, and ash in a downdraft gasifier.

After tests at Diamond/Sunsweet, Inc., Stockton, and at the State Printing Plant, Sacramento, the pilot plant was operated for more than 530 hours over a period of about 5 months at the California Primate Research Center at Davis. It ran continuously for nearly 15 days during the last part of that period. Tests were made firing a boiler, operating an air-heating burner and, briefly, running a diesel engine on a combination of producer gas and No. 2 diesel fuel.

For the Davis tests, fuels used in the gasifier were (1) a mixture of 50 percent wood chips, 25 percent cleaned and cubed cotton gin trash, and 25 percent cubed barley straw, (2) corn cobs, and (3) wood chips. The fuel containing cotton and grain crop residues formed enough slag to block the gasification process within a few hours. The other fuels produced very satisfactory results.

One difficulty was that a 500-foot hot gas line from the gasifier to the boiler was required. This excessive distance resulted in high tar accumulation rates so that the boiler had to be shut down frequently to clean the gas feeding mechanism and burner. Tar accumulation could be reduced by preheating the insulated hot gas line or, preferably, by situating the gasifier as close as possible to the boiler.

Efficiency levels

The tests showed that the gasifier system, when using nonslagging fuels (wood chips), delivered 83 out of every 100 Btu in the fuel to the boiler fire box.

The gasification yield from nonslagging fuels (percentage of the weight of wet fuel converted to hot raw gas) ranged from 86 percent for street tree chips, which contained some soil, to 97 percent for wood blocks of Douglas fir.

The heating value of producer gas yielded by wood chips in the mobile pilot plant was about 200 Btu per cubic foot of gas. Corn cobs produced 160 to 170 Btu per cubic foot. Various nonslagging fuels tested in the laboratory unit yielded gas with a heating value of 150 to 200 Btu per cubic foot.

The gasification rate affected both gas quality and gas conversion efficiency. At low rates (10 to 20 pounds per hour per square foot of effective firebox area), quality was poor and less gas was produced from a pound of fuel. The same was true of high rates (190 to 200 pounds per hour per square foot of firebox). Good gasification occurred when the rate was 140 to 160 pounds of fuel per square foot of firebox area.

Thermal efficiency of the boiler was only slightly reduced by the substitution of producer gas for natural gas. Using natural gas with a steady load, boiler efficiency was 84 percent. With producer gas and a highly varying load, minimum efficiency was 78 percent.

When the diesel engine was operated on dual fuels (producer gas with diesel fuel for ignition), the gas had a high water content, and engine operation was only fair. Of the rated 60 kilowatts, maximum output was 55 kilowatts, of which 32.5 percent was supplied by the diesel fuel. Drier gas probably would reduce the proportion of diesel fuel required and result in satisfactory engine operation.

When the air-heating burner was operated with producer gas from corn cobs, both the gasifier and the burner functioned very well. Automatic controls to mix ambient and recycled heated air to maintain burner combustion air at about 225° F functioned well and eliminated condensation at the burner jets. The average burner output rate was 1.672 million Btu per hour (enough to furnish one-third of the heat required for a large, 15-bale-per-hour cotton gin or to heat 15 five-room homes).

Environmental impact

Tests in cooperation with the California Air Resources Board showed that producer gas efficiently generated from clean fuels results in boiler stack effluents with no more impact on air quality than if the fuel were natural gas. In fact, nitrogen oxides were only about one-third of the normal for natural-gas-fired boilers because of the lower combustion temperature of the low-Btu gas. Hydrocarbon emissions could be lowered substantially in future installations by regulating boiler air intake automatically according to stack gas analysis. Particulate emissions also could be lowered by gas cleanup equipment.

Solid and liquid wastes from the gas producer include char from the spent fuel, fine carbon dust collected in the hot-gas cyclone, and condensate collected during intermittent operation. None of these created substantial disposal problems. From 6.4 to 8.4 percent of the fuel was removed as ash. Carbon dust separated by the cyclone was 0.1 to 0.2 percent of the fuel. During 531 hours of operation at the Primate Center, when the pilot plant was stopped and started about 30 times, approximately 100 gallons of water and tar condensate were collected.

Variation in fuels

The feasibility of using agricultural and forest residues to generate low-Btu gas from the downdraft type of gasifier was clearly

TABLE 1. Ash Content (Dry Basis) of Nonslagging and Slagging Raw Fuels Gasified in Downdraft Laboratory Gas Producer

Nonslagging fuel	Percent ash	Slagging fuel	Percent ash
Alfalfa, cubed straw from seed crop	6.0	Bean (dry) straw, cubed	10.2
Almond shell, hard shell variety, fines removed	4.8	Bark, white fir (from skidded saw log, screened over 3/8" hardware cloth)	39.9
Corn cobs, broken	1.5	Barley straw, 75%; corn fodder, 25%; binder, 6%, cubed. Both normal and low-combustion air rates	10.3
Olive pits, air dried	2.2	Corn fodder, cubed	6.4
Peach pits, air dried	0.9	Cotton gin trash, screened for 20-mesh fines and cubed	17.6
Prune pits, air dried	0.5	Cotton stalks, cubed	17.2
Tree chippings, city trees, air dried	3.0	Rice hulls, pelleted	14.9
Walnut shell, cracked	1.1	Safflower straw, cubed (very small amount of slagging)	6.0
Walnut shell, mulled and pelleted	1.0	Wastepaper pellets	10.4
Wood blocks (approximately 2" x 2") Douglas fir	0.2	Walnut shell, mulled, 75%; rice straw, 15%; sawdust, 10%	5.8
Wood chips, kiln-dried wood mfg. waste, hogged	0.2	Wheat straw, 50%; corn fodder, 50%, cubed	7.4
Wood chips, manzanita	0.4		
Wood chips, whole log	0.1		

TABLE 2. Producer-gas Energy Available as Hot Raw Gas and Cool Clean Gas from Two Agricultural Residues

	Million Btu/ton dry residue	
Residues	Hot raw gas*	Cool clean gas†
Cotton stalks (6,800 Btu/lb dry)	11.56	10.20
Corn fodder (7,800 Btu/lb dry)	13.26	11.70

*Hot raw gas (for firing steam boilers or producing hot air) at 85 percent efficiency.
†Cool clean gas (for operating gasoline and dual-fueled diesel engines) at 75 percent efficiency.

TABLE 3. Costs of Obtaining Producer Gas from Agricultural Residues

	Residue preparation ($/ton)*					
Residues	Baling	Cubing	50-mile haul	Total	Hot-raw gasification ($/ton dry residue)†	Total costs ($/ton dry residue)
Cotton stalks	$22	$12	$ 5	$39	$15	$54
Corn fodder	22	10	5	37	13	50

*Storage of prepared fuel (about $0.60 per ton) not included.
†Costs of cool clean gas for use in gasoline and dual-fueled diesel engines are about $1 higher.

TABLE 4. Costs of Producer Gas Compared with Those of Fossil Fuels

	Values of replaced fuel/ton dry residue			Difference between replaced fuel values and costs of obtaining producer gas/ton dry residues§		
Residue	Natural gas*	Gasoline†	Diesel‡	Natural gas	Gasoline	Diesel
Cotton stalks	$52	$110	$87	-($2)	$55	$32
Corn fodder	59	127	100	9	76	49

*Natural gas @ $4.47/million Btu.
†Gasoline @ $1.30/gallon. (120,000 Btu/gallon)
‡Diesel fuel @ $1.20/gallon. (140,000 Btu/gallon)
§Costs are for hot raw gas to replace natural gas in burners and cool clean gas for engines.

demonstrated. Wood wastes (excluding bark), fruit pits, nut shells, and corn cobs are good to excellent fuels for gasification. Other fuels tested—rice hulls and straw; cotton gin trash; corn fodder; straw from cereal grains, oil crops and dry beans—produce more ash (table 1), and slag formation becomes a problem when the ash content is above 5 or 6 percent.

Considering all aspects of the downdraft gasification process, it appears that the two most desirable fuels tested were dried prune pits and wood blocks (2 by 2 inches, Douglas fir). The next most desirable group of fuels included corn cobs, peach and olive pits, unprocessed nut shells, and wood chips of a shape and size comparable to whole-log chips for paper pulp.

Because of the physical relationship between the partial-combustion zone and the reduction zone in the firebox, it appears that small amounts of silicon in a fuel—as little as 2 percent—make it unacceptable for downdraft gasification. This is certainly true for rice straw and rice hulls. Wastepaper pellets also proved unsatisfactory, because they contain approximately 4 percent silicon from glass not removed when the paper is separated from raw solid waste.

Alternative designs

For fuels with substantial slagging problems, it appears that another approach to gasification is needed. It is known that improved crossdraft and updraft gasifiers can handle coal fuels that produce slag, although more testing is needed to determine how well they operate with cellulosic fuels such as agricultural and forest residues. Plans for such testing are under way.

Assuming that the problem of slagging can be overcome, another question remains: What are the costs and savings? Tables 2, 3, and 4 show the producer-gas energy available in two common agricultural residues, estimated costs of preparing and gasifying those fuels, and the resulting values compared with those of fossil fuels.

Only in the case of cotton stalks as a substitute for natural gas does an efficient gasification process appear unprofitable at these cost levels. It should be noted that the cost of energy per million Btu is about 2½ times higher for gasoline and diesel fuel than it is for natural gas. For that reason, gasification may hold more economic promise as a substitute for gasoline and diesel fuel than for natural gas.

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Rural rebound: newcomers revitalize small towns

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Small rural towns, long characterized as depressed, isolated, and socially backward, have undergone a remarkable transformation since about 1970, experiencing either population stabilization or growth, and in the United States, Europe, and Japan their economies have rebounded.

Rural areas, once thought of as pastoral and agricultural or based on extractive industry, are rapidly moving toward more balanced and robust economies. Newcomers seeking attractive rural settings and simpler lifestyles are largely contributing to this greater economic viability.

Only a small percentage of rural populations continue to make their living from farming. New technology and knowledge-intensive industry, tourism and service organizations are forming a large part of what is coming to be termed post-industrial or advanced industrial rural society.

Butte Community College offers educational and employment opportunities to residents in the Oroville area. Photo by Tracy Borland