ASSESSING THE BENEFITS OF BIOGAS

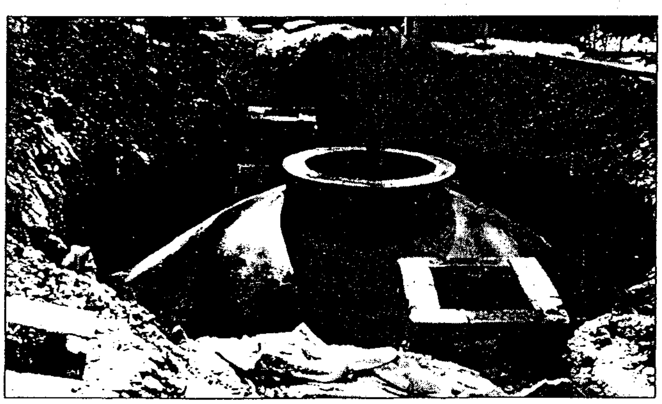
Many impediments may deter families from progressing from highly polluting, cheap, biomass fuels toward cleaner, expensive, commercial fuels, as depicted by the energy ladder shown in Figure 4 on page 30. Biogas systems allow families to turn cheap biomass into relatively clean fuel with a household "digester." During the 1970s, more than six million family-sized biogas digesters were constructed in China. Biogas promoters emphasized the sanitary and nutrient conservation benefits of these systems. Early failure of many systems and increased interest in their energy potential resulted in a re-evaluation of the program at the end of the decade. The program has shifted away from locally available materials and traditional constructions, which were quite inexpensive but lasted only three to four years; instead, it currently emphasizes high-quality, concrete construction and systematic operation. Labor and material costs for a household system are now more than 200 yuan (about $60 U.S.), but reliability is greatly improved and systems are lasting longer than 10 years. During the 1980s, about 500,000 of these improved systems have been constructed each year throughout China.[1]

While the financial and economic viability of biogas systems still may be arguable, these installations undeniably benefit users by providing renewable household fuel supplies, plant nutrient and organic material conservation, and better sanitation. Another benefit of biogas lies in its cleanliness relative to direct combustion biomass or coal, which otherwise prevails in China. Pots are not blackened with soot during cooking with biogas, but of greater significance is the general reduction in pollutant emissions from cooking fires and the reduced exposure of cooks and children to these emissions.

Biogas, produced by the anaerobic microbial decomposition of organic materials, is a mixture of gases. The exact composition depends on factors such as the materials digested, impurities in the dilution water, length of the digestion period, integrity of the digester tank, general state of digester health, and various other parameters of digestion (temperature, moisture content, acidity, digestible carbon/nitrogen ratio, etc.). With a healthy digester, methane is the chief component, generally varying from 50 to 70 percent, but occasionally higher. Biogas is useful for combustion with common burners when the methane content exceeds 50 percent. The other primary component, carbon dioxide, generally constitutes from 30 to 40 percent.

The environment within a digester generally causes biogas to be saturated with water vapor. Small amounts of carbon monoxide, hydrogen, oxygen, nitrogen, ammonia, a few larger hydrocarbons, and hydrogen sulfide may also be present. Hydrogen is a normal product of the first phase of the digestion process and, in some systems, may comprise more than 5 percent of the total gas produced.[2] Nitrogen or oxygen in the gas usually indicates a leakage of air into the digestion tank, while nitrogen and ammonia can also result from an excessively low carbon/nitrogen ratio in the biomass. Hydrogen sulfide, with its characteristic smell of rotten eggs, is usually present at levels less than 10 parts per million (ppm), but tends to increase with any upset in the digestion process,[3] and with high levels of natural sulfates in the biomass or dilution water.

The flame temperature of biogas composed of 60 percent methane and 35 percent carbon dioxide is about 1,200°C. With reasonably complete combustion at this temperature, carbon dioxide and water vapor are unchanged; methane and other hydrocarbons form water vapor and carbon dioxide; any carbon monoxide, hydrogen, or oxygen produces more water vapor and carbon dioxide; some nitrogen is unchanged, while some is likely to form nitrogen oxides (although less than is formed when natural gas burns); and hydrogen sulfide is converted to sulfur dioxide and perhaps a small amount of sulfur trioxide. Thus, air pollutant emissions from biogas combustion are similar to those from natural gas, although in different proportions: suspended particulates, hydrocarbons, and nitrogen oxides are usually lower; carbon monoxide is likely to be about the same; and only sulfur oxides are likely to be higher.



A family-sized biogas digester is being installed. (Photo: Robert Hamburg)

Sulfur Emissions

Hydrogen sulfide is a highly toxic gas with a threshold limit value for prolonged exposure of 10 ppm.[4] Its distinctive odor can be noticed by some people at concentrations of less than 1 ppm, but it quickly fatigues the sense of smell. While the greatest danger is from acute exposure, clinical experience has shown undesirable and cumulative health effects from repeated low-level exposure.[5]

Biogas almost always contains a noticeable amount of hydrogen sulfide, and the concentration may be very high. Digesters on many eastern U.S. dairy farms produce gas with concentrations as high as 6,000 ppm.[6] Methods for scrubbing hydrogen sulfide from biogas are too expensive for small systems, and even when biogas is used in internal combustion engines, scrubbing does not appear to be considered necessary.[7] Thus, biogas users may experience a chronic exposure to some level of hydrogen sulfide.

To investigate this possibility, a small study was undertaken in Henan Province of China in the spring of 1987. To measure hydrogen sulfide content, testers used color-change hydrogen sulfide detector ampules, which are designed for immersion in the gas for ten minutes and can detect levels up to 20 ppm.[8] In one village, at a distillery, and in one research digester, concentrations measured less than 10 ppm. Gas from a large research digester fed only with chicken manure was measured at a concentration of

(continued on following page)

(continued from previous page)
about 17 ppm. In another village, gas from four digesters immediately blackened the ampules, indicating a hydrogen sulfide level much greater than 20 ppm. The reason for the high levels was not determined, but one good possibility is high levels of sulfur compounds in the local water supply.

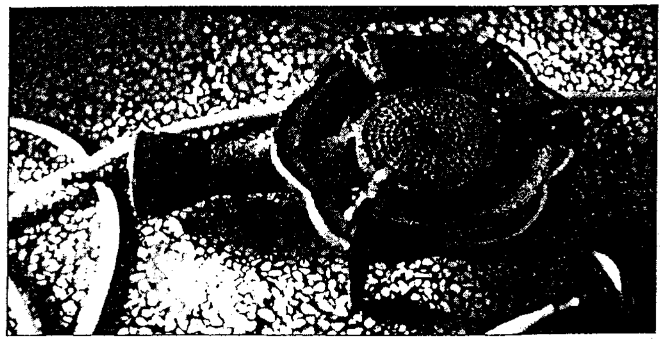
To determine whether any hydrogen sulfide remained after combustion of the biogas, 8-hour diffusion dosimeter tubes with a range of 0 to 50 ppm were hung above biogas burners during peak cooking periods. Although the odor of hydrogen sulfide was almost always noticeable during ignition of the gas, there was no indication of hydrogen sulfide during combustion. Similar sulfur dioxide dosimeter tubes with an 8-hour range of 0 to 25 ppm were hung next to the hydrogen sulfide tubes. The recorded 8-hour average concentrations in 16 biogas-burning kitchens varied from 0 to 3.9 ppm with an average of 0.86 ppm.

While this figure compares rather unfavorably with the U.S. Environmental Protection Agency's national primary 24-hour air quality standard for sulfur dioxide of 0.14 ppm,[9] it compares quite favorably with the local alternatives—coal and crop stalks. Sulfur dioxide dosimeter tubes were placed at comparable spots in 5 rural kitchens burning crop stalks for fuel and 15 urban kitchens burning coal. The stalk-burning kitchens had levels varying widely from 0 to 13 ppm, with an average of 3.2 ppm. Levels in the coal-burning kitchens varied from 1.7 to 9 ppm, with an average of 3.5 ppm. Both averages are about four times higher than the average concentration of sulfur dioxide in kitchens burning biogas.

While these sample populations are admittedly small and not random, the results are at least suggestive.

Pros and Cons

Anaerobic digestion offers the opportunity to jump several rungs up the energy ladder shown in Figure 4 on page 30. In China, this jump has largely been made by single households, but much larger systems are coming on line. At the Nanyang distillery, biogas from two recently built 5,000-cubic-meter digesters will soon replace coal for cooking in 20,000 households in the city (15 to 20 percent of the population). Exhaust fans and chimneys on improved biomass stoves reduce indoor exposures and considerably dilute pollutant emissions. Unfortunately, the benefits of this dispersal have often been negated by the increasing pollution brought on by growing populations and urbanization. In addition, animals and plants sensitive to these emissions face higher pollutant levels.[10] In addition, although venting pollutants returns some sulfur and nitrogen to agricultural soils, the overall biological effects of the resultant acid rain are negative.



The Beijing model no. 4 biogas burner (Photo: Robert Hamburg)

Burning fossil fuels increases global warming through the greenhouse effect. Biogas systems, on the other hand, are totally benign in this respect, because carbon dioxide released during digestion and combustion is incorporated naturally by the biomass during its growth. Once digestion is complete, the biomass may be removed and used as fertilizer. Therefore, pound for pound, a biogas system gets more value from biomass than does direct combustion.

Thus, biogas systems are far more environmentally benign than are fossil fuels, and they offer the least polluting method for exploiting the solar energy stored in biomass. In addition, the systems may reduce human and animal intestinal diseases by destroying pathogen vectors; allow more crop residues to be used for livestock feed; and leave more manure to fertilize agricultural land.

Historically, farmers of the People's Republic of China have recognized the importance of returning organic materials to cropland. During the last two decades, thousands of researchers and technicians have conducted more than ten million experiments with small-scale biogas systems. Thus, they have gained a wealth of experience that they are willing to share.

Many problems brought on by overpopulation, which the Chinese have been facing for centuries, are now occurring worldwide, wherever populations are growing. A system that offers such significant benefits in household energy, small industry energy, soil fertility, sanitation, and possibly respiratory health, deserves consideration. Anaerobic digestion systems may offer the most environmentally and thermodynamically efficient means for exploiting biomass energy resources.

Robert Hamburg
Omega-Alpha Recycling Systems
Orma, West Virginia

1. J. D. Li, Lecture given at the Henan Academy of Sciences' Energy Research Institute, Zhengzhou, China, Summer 1987.

2. Asian-Pacific Regional Biogas Research-Training Centre, *Biogas Technology: UNDP-ESCAP-FAO-China Biogas Training Course* (Chengdu, China: Asian-Pacific Regional Biogas Research-Training Centre, 1983).

3. D. House, *The Compleat Biogas Handbook* (Aurora, Oreg.: At Home Everywhere, 1978).

4. A threshold limit value is the average concentration of toxic gas to which a normal person can be exposed for 8 hours per day, 5 days per week for an unlimited period without injury. Threshold limit values have been developed for use in occupational situations and may not indicate appropriate concentrations for the young, old, or ill. Safety and Fire Protection Committee, "Properties and Essential Information for Safe Handling and Use of Hydrogen Sulfide," *Chemical Safety Data Sheet SD-36* (Washington, D.C.: Manufacturing Chemists Association, 1968).

5. R. Tenhunen, H. Saavolainen, and P. Jappinen, "Changes in Heam Synthesis Associated with Occupational Exposure to Organic and Inorganic Sulphides," *Clinical Science* 64 (1983): 187–91.

6. J. H. Ashworth, *Mechanical, Operational and Microbiological Problems of Installed Commercial Anaerobic Digesters in the United States: Preliminary Findings from Site Visits and Recommendations for Research and Development Needs* (Burlington, Vt.: Associates in Rural Development, 1984).

7. Asian-Pacific Regional Biogas Research-Training Centre, note 2 above.

8. Mine Safety Appliances Company, "Hydrogen Sulfide Detectors," *Data Sheet 08-00-30* (Pittsburgh, Pa.: Mine Safety Appliances Company, 1986).

9. *Encyclopedia of Chemical Technology*, 3d ed., S. V. "sulfur dioxide."

10. U.S. Environmental Protection Agency, "Effects of Sulfur Oxides in the Atmosphere on Vegetation," *Air Quality Criteria for Sulfur Oxides* (Research Triangle Park, N.C.: National Environmental Research Center, 1973).