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Wallace E. Tyner, John Adams

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RURAL ELECTRIFICATION IN INDIA: BIOGAS VERSUS LARGE SCALE POWER*

by

Wally Tyner
Cornell University

John Adams
University of Maryland

One possible means of providing electricity to India's 550,000 villages is by using animal, human, and possibly some forms of vegetable waste to make methane, a fuel that can be employed in small generators located in or near the communities to be served. This method is often called the gobar gas process in India since "gobar"--cattle dung--is the main ingredient. The principal alternative, and the one that has been pushed in recent drives for rural electrification, is large-scale power works, using coal, hydroelectric potential, atomic energy, or now possibly oil or gas. Reliance upon the large-scale system mandates an extensive power grid, which the local system does not. The Indian government is considering a commitment to a sizeable small-scale power program, possibly assisted by multilateral foreign aid. The economic basis of this decision and its ramifications for rural society have not, however, been systematically assessed.

In this paper we will undertake a cost analysis of the two major rural power options: central power facilities and biogas units. We will contrast our findings with the estimates of the major previous studies of biogas electrification. In our judgement,

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their cost estimates have been substantially biased towards local units. Our conclusion is that, on average, centralized power production and distribution have an appreciable cost advantage over local units. Where villages are remote from transmission lines, however, small scale units may provide a cost savings. There are thus numerous locations in rural India where gobar gas facilities may serve at least as a transitional source of power. We will comment upon the administrative problems associated with providing and servicing these decentralized generators and mention some of the implications of implanting this new technology in the Indian village setting.

That biological materials can be used to generate combustible gases has been known for some time. In northern Italy in 1776, Alessandra Volta recognized the correspondence between the volume of combustible gas generated by lake sediments and the amount of plant material in the sediment. During the second world war a number of vehicles in Germany were converted to methane operation. Research in India began at the Indian Agricultural Research Institute in 1939. Although a number of experimental plants were developed, it was not until the early 1960s that a practical design was available for field use.

The principal energy ingredient in biogas is methane, CH_4, or natural gas. Biogas is formed in one of two ways: (1) When organic material is left exposed to the air, the gaseous byproducts of decay escape into the atmosphere, and the residue is compost. This decay process is termed aerobic because it is enabled by bacteria that work in the presence of oxygen. (2) The process of forming useful biogas is known as anaerobic digestion since it occurs in the absence of oxygen. During the first phase, sludge materials are broken down into smaller molecules. Organic compounds are oxidized to acids or alcohols, the oxygen in the material fed to the digestor is used up, and large amounts of carbon dioxide are formed. In the second phase, bacteria convert the acids and alcohols into methane and carbon dioxide. Generally, 60 to 70 percent of the gas formed is methane. A delicately balanced environment is required. Changes in acidity, temperature, input mix, and other factors affect the pace and yield of the reactions. For example, the amount of gas generated is a function of temperature. About twice the amount of gas per ton of manure is produced at 75° C (167°F) as at 25° C (77°F). Methane generation stops completely below 10° C (50°F). Temperatures in North India in the winter frequently fall beneath this threshold and under such conditions some biogas may have to be used to provide heat for the plant, thereby reducing its net yield.

Cost of Centralized Power Generation

In order to calculate an estimated cost of electricity per kilowatt hour, it is necessary first to estimate the initial capital costs. Capital costs of either biogas or central power facilities include three components: the cost of the power plant, transmission costs, and the cost of village electrification. The ultimate calculation of capital costs per kilowatt hour depends not only upon these cost estimates but upon utilization factors--that is, the degree to which installed capacity is utilized. Unreasonable assumptions regarding any of the capital cost components or the utilization factors will substantially bias the final cost per kilowatt hour estimate.

A number of studies have attempted to compute the costs of installing and operating gobar gas units. Among these, only a few have compared rural electrification using biogas with centralized generation alternatives.[1] Makhijani and Poole estimated the total capital cost for coal-fired generating plants in India at $500 per kilowatt. This cost estimate included $250 per kilowatt for the generating station, $50 per kilowatt for transmission, and $200 per kilowatt for rural electrification. Capital cost for thermal generating plants in 1970 was about $200 per kilowatt.[2] The generating station and transmission costs reported by Makhijani and Poole for 1974 appear somewhat high but reasonable, allowing for inflation. At a 12 percent discount rate the annual amortization per kilowatt is $60.[3]

Their rural distribution cost estimate assumes that the average transmission distance from the main line to each village is 8 kilometers. Joint distribution to several villages would reduce these costs. It is clear, too, that costs for a given village will be lower the nearer it is situated to major power lines and that with the growth of India's national power system more and more villages will be closer to such lines. Without knowing the exact distribution costs for a particular village, it is impossible to determine whether central or biogas costs per kilowatt hour would be lower. Estimates that use average distribution costs can thus only provide a basis for a general comparison of the two systems.

To convert the annual capital charge of $60 per kilowatt to a cost per kilowatt hour, utilization factors must be employed. For centralized power generation, a proper approach is to separate rural distribution costs from generation and transmission costs and apply an appropriate utilization factor to each portion. The average generating plant utilization factor for India as a whole has been in the range of 48 to 55 percent, which is comparable to the average plant utilization factor for the United States.[4] The plant utilization factor should be applied to the generation and transmission portion of total capital cost ($300 or $36 per year at a 12 percent discount rate). The appropriate factor for rural distribution cost ($200 or $24 per year at a 12 percent discount rate) is derived from the rate of power consumption per kilowatt of connected load in rural areas. From 1966 to 1971, agricultural sector consumption in India ranged from 657 to 842 kilowatt hours per kilowatt of connected load representing distribution network utilization of 8 to 10 percent.[5] Total rural sector consumption rates would be somewhat higher.

In their analysis, Makhijani and Poole used the same utilization factor for both generation and transmission and rural distribution. They used two different factors: 1150 and 800 kilowatt hours per kilowatt per year which represent 13 and 10 percent utilization factors respectively.[6] These factors are appropriate for the rural distribution component but not for the generation and transmission components of total capital cost. Makhijani and Poole evidently believe that a power plant would serve only rural areas, that no urban or industrial consumption would be serviced from the plant.

Table 1 displays a range of unit costs of centralized power supply; it includes our estimates as well as those of Makhijani and Poole and others. Items one and two are actual unit cost calculations by Henderson (2.2 cents per kilowatt hour) and Venkataraman (1.5 cents). The two Makhijani and Poole estimates for their assumed 10 percent and 13 percent capacity utilization factors are 8.5 cents and 6.2 cents per kilowatt hour, respectively. Item five is our estimate. We assume a plant utilization factor of 45 percent which yields a capital amortization cost for generation and transmission of .9 cents per kilowatt hour. We assume rural consumption of 1100 kilowatt hours per kilowatt of connected load (12.6 percent utilization) which yields a capital amortization cost for rural distribution of 2.2 cents per kilowatt hour. Hence, our total value for amortized capital cost is 3.1 cents per kilowatt hour (using a 12 percent discount rate). If Henderson's operating cost per kilowatt hour of 1.3 cents is raised to 1.5 cents to allow for inflation, the total unit cost of centralized fossil fuel power generation for rural areas becomes 4.6 cents per kilowatt hour. Because this cost estimate was calculated using conservative utilization factors, it should be considered the upper limit for centralized power costs

Table 1

Unit Cost of Centralized Electricity Supply in India

	Capital cost-amortization (cents per kwh)	Operating cost (cents per kwh)	Total unit cost (cents per kwh)
1. actual 1971-1972 costs	.9	1.3	2.2
2. actual 1967-1968 costs	.8	.7	1.5
3. capacity utilization = 10 percent 800 kwh/kw/yr	7.5	1.0	8.5
4. capacity utilization = 13 percent 1150 kwh/kw/yr	5.2	1.0	6.2
5. plant capacity utilization = 45 percent rural distribution utilization = 13 percent 3942 and 1100 kwh/kw/yr	3.1	1.5	4.6

SOURCES: (1) Henderson, p. 87; (2) Venkataraman, pp. 84-88; (3) and (4) Makhijani and Poole, pp. 97-98; (5) authors' calculations.

for villages an "average" distance from power lines. This cost estimate will be compared with the biogas generation cost estimates discussed below.

Biogas Based Power Generation

The physical parameters controlling the generation of electricity using a decentralized biogas system are summarized in Table 2. Column one contains our estimates; columns two and three show comparable data from other sources. In an average village there are in the neighborhood of 250 to 300 cattle. Assuming that each animal will provide about three kilograms of dry dung each day and that three-quarters of that amount is collected for use, the total amount available will be 675 kilograms. Our estimate is thus higher than those of Prasad et al. (596 kilograms) and of Makhijani and Poole (622 kilograms). Multiplication of usable dry dung by the biogas yield per kilogram (11 cubic feet) and by the BTU content of a cubic foot of gas, yields the total BTU content. When this total is divided by the energy conversion factor and multiplied by the efficiency of the power generator, a maximum power generation estimate is derived. This is 337 kilowatt hours per day, and is lower than those calculated by Prasad et al. and Makhijani-Poole. We believe, however, that this is an optimistic value and an upper limit with current technology.

The differences among the three results are due to the use of different yield and conversion estimates. Makhijani and Poole assumed a 60 percent conversion efficiency which is near the

Table 2

Assumptions Used for Biogas Power Generation

	Item	Units	Authors' Values	Prasad, Prasad, and Reddy	Makhijani and Poole
1.	Dry dung/cow/day	kg.	3.0	3.18	2.96
2.	No. of cattle in village		300	250	300
3.	Dry dung/village/day	kg.	900	795	888
4.	Collection efficiency	%	75	75	70
5.	Usable dry dung/village/day	kg.	675	596	622
6.	Biogas yield/kg. dry dung	cu.ft.	11	6.6	13.5[a]
7.	Energy content/cu.ft. of biogas[b]	BTU	620	620	620
8.	Conversion factor	kwh/BTU	3413	3413	3413
9.	Power generating efficiency	%	25	83[c]	25
10.	Maximum power generation/day	kwh	337	593	381

[a]Biogas yield for the Makhijani and Poole study was calculated by multiplying the energy content of dry dung (14,000 BTU/kg.) by the assumed conversion efficiency of 60 percent, and dividing the result by 620 BTU/cu.ft. This yield is equivalent to 6 cu.ft./lb. of dry dung which is the expected biogas yield at 27°C (80°F). Clearly, a net yield of this magnitude is not currently attainable during winter months in North India.

[b]Sathianathan, p. 62.

[c]Prasad, Prasad, and Reddy make the direct conversion from cubic feet of biogas to kwh using a factor of .15 kwh/cu.ft. biogas. Assuming 620 BTU/cu.ft. of biogas, this conversion amounts to a generation efficiency of 83 percent.

highest observed in experimental plants.[7] Prasad, et al. assumed a conversion efficiency of only 30 percent and this is slightly below the year round average for India. We think that 50 percent net energy conversion may be generally attainable after additional applied research and development and have used this figure, which is comparable to 11 cubic feet of biogas per kilogram of dry dung. The next key assumption concerns power generation efficiency; that is, the efficiency of the internal combustion engine and generator in converting biogas energy into electric power. Makhijani and Poole assume a generation efficiency of 25 percent which is probably near the upper limit.[8] Although gasoline engines usually run at less than 25 percent efficiency, we selected a generation efficiency of 25 percent as the best possible case. Based on these assumptions, the maximum power that could be generated per day is 337 kilowatt hours.

The costs of generating power may be estimated on two different bases: (1) assuming a portion of the biogas is used for cooking to replace dung that was previously used for this purpose; and (2) assuming a substitute (perhaps solar energy or water hyacinths) could be found for cooking so that all biogas could be used to generate electricity. The adjusted initial capital and annual costs of these two alternatives are given in Table 3. Following Makhijani and Poole, 46 percent of the biogas generated is assumed to be adequate to serve the cooking needs of two hundred families in the village. This fraction may be low in light of the technical difficulties in maintaining a high level of production. Nonetheless, we will proceed with the analysis of capital costs based on this assumption. For the applications with and without biogas used for cooking, it is asserted that the costs of the biogasification plant, the gas plant auxiliaries, land, and gas storage and compression would be identical. This procedure is valid for the first three items but is open to question for gas storage and compression. Storage facilities adequate for 50 percent of the annual production of gas were assumed in both cases. This assumption is reasonable for the case without cooking fuel, but appears to be too high for the case with cooking fuel because daily utilization of gas for cooking would even out the consumption pattern through time relative to the case without cooking fuel. Hence, we reduced the storage and compression cost for the case with cooking fuel.

Table 3 displays the revised capital and annual costs for the two cases assuming generator capacities of 66 kilowatts and 123 kilowatts. Makhijani and Poole used generator sizes of 75 kilowatts and 140 kilowatts for the with and without cooking cases respectively. Because we arrived at a lower maximum daily generation figure, we reduced the generation capacities and recalculated the cost figures. Makhijani and Poole assumed no economies of scale for the higher capacity generators, an hypothesis we retain.

Gross annual cost for a biogas plant is calculated by amortizing at a 12 percent discount rate the total initial plant

Table 3

Costs of a Decentralized Biogas Generation and Electrification Plant*

Cost Item	Gas Used For Cooking	Alternative Cooking Fuel
Capital Costs		
Biogasification plant	$ 8,000	$ 8,000
Gas plant auxiliaries	1,000	1,000
Land cost	1,000	1,000
Gas storage and compression	1,000	1,500
Cooking fuel distribution cylinders and gas stoves	8,000	---
Cost of water hyacinth or other cooking system	---	10,000
Electric generator with reciprocating gas engine and switchgear @160/kw installed	10,600	19,700
Construction supervision and training	1,000	1,000
Subtotal	$30,600	$42,200
Interest on capital during six months' construction @12 percent	1,800	2,500
Total	$32,400	$44,700
Cost per kw	491	363

Table 3 (cont'd)

Annual Costs		
Capital cost amortization	$ 4,100	$ 5,700
Residue collection at $2/ton fresh manure	2,600	2,600
Local labor and maintenance	1,300	1,300
Market town services	500	500
Labor for distributing cooking fuel	300	600
Gross annual costs	$ 8,800	$10,700
Credit for cooking fuel sales	2,000	2,000
Credit for fertilizer	2,400	2,400
Total credits	$ 4,400	$ 4,400
Net annual operating cost	4,400	6,300
Annual electricity generation at 1,000 kwh/kw	66,000 kwh	123,000 kwh
Cost per kwh	6.7¢	5.1¢

SOURCE: These cost estimates are adapted from cost values contained in Makhijani and Poole, pp. 112-116.

* All costs are rounded to the nearest $100.

investment and adding four additional costs: collection costs, labor and maintenance, market town services, and distribution costs of fuel. A twenty-five year life is assumed for the biogas plant and other equipment, which may be somewhat long given the corrosive nature of some of the materials used in biogas generation.

After figuring gross annual operating costs, it is necessary to subtract credits for cooking fuel sales and a credit for fertilizer sales to obtain a figure for net annual operating costs. Annual electricity generation was figured on the basis of 1000 kilowatt hours per kilowatt installed, the figure used by Makhijani and Poole, which represents a capacity figure of 11.4 percent.[9] Since all of the electricity generated from the biogas plant would be used in a limited rural area, this capacity utilization represents an upper limit. Using the above assumptions and cost input data, the cost per kilowatt hour of electricity with biogas used for cooking would be 6.7 cents and with no cooking provided from the biogas, 5.1 cents. Since assumptions favorable to biogas generation were used when no firm data were available, these costs represent lower limits of the costs for biogas based generation.

Comparison of Cost Estimates

Clearly, both of the biogas cost estimates are significantly greater than the 4.6 cents per kilowatt hour cost for the centralized power generation system. It should be emphasized that 4.6 cents/kwh represents the upper limit for the "average" village and that 5.1 cents/kwh represents the lower limit for power generation using the biogas system. Actual differences may be considerably greater. Based on economic considerations alone, the conclusion of this analysis is that electricity generation using centralized power facilities is on average more cost advantageous than adopting decentralized systems based on biogas generation.[10]

In some situations, however, power generation from gobar gas may be a reasonable alternative. In isolated regions, the transmission costs would be higher than those estimated. Small villages, or even caste or lineage neighborhoods, might use biogas as an interim alternative to a central source. Even if only 20 percent of India's villages fall into these categories, over 100,000 units would be installed.

It should be noted that our conclusion applies only to the use of biogas as a means of decentralized electric power generation. We have not considered the merits of gobar gas as a cleaner more healthful cooking fuel, nor have we examined the potential of the residue being a superior fertilizer, considerations which would enhance its appeal. A biogas program may be desirable solely as a means of producing both cooking fuel and fertilizer from cow dung with no associated power generation.

Potential Problems with a Biogas Power Generation Program

Before biogas is adopted in those circumstances where it is deemed desirable, there are a number of political and administrative problems that need to be resolved at the national level. In addition, if past experience with agricultural assistance, community development, and cooperative credit institutions at the village level is any guide, the villagers of India are likely to find their lives deeply affected by the program; and, in turn, they are likely to bend biogas installations to their own purposes and thereby upend the calculations of policy-makers who ignore the human factor.

The general administrative problems likely to be encountered are those typical of any new program. These include coordination of finance, production, distribution, and political activities together with assuring adequate numbers and competence of staff to carry forward the assigned tasks. Any massive diffusion of technology depends upon the dissemination of information, guidance of production and distribution by cooperation between technicians and the service population, and adequate provision for maintenance. A successful biogas program must be based on a technically sound plant which can function under a wide range of operating conditions. Much research needs to be done on plant design for improved efficiency, improved winter operating performance, use of solar energy to heat the biogas plant, proper utilization of the sludge output to conserve nutrients, and biogas plant operations in water short regions. Initial break-downs in administration, maintenance, or technical components may sour villagers on the program, and they and their neighbors may become progressively unresponsive.

There is also the danger that new biogas units will be emplaced in villages which are close to existing roads, towns, and power lines. This pattern may tend to result from ease of access for construction, maintenance, and monitoring. Yet these are the sites where biogas power generation offers little or no cost advantage. Officials will have to take special steps to ensure that decentralized rural electrification reaches into the more remote areas where it will do the most good and does not end up as merely another facility provided to the already built-up regions.

Major obstacles to the successful dissemination and utilization of biogas plants in Indian villages are found at the village level. Currently, cow dung is used directly for fuel and compost in many Indian villages, and there is an existing social-cum-economic structure that provides for the collection, drying, and distribution of the dung fuel. The institutional structure is so arranged that, generally, fuel is available for the cooking needs of villagers in all castes or economic classes, and without regard to the distribution of cattle ownership.

If a biogas plant is established, then cow dung would not be used directly as a fuel but would be "transformed" into another type of fuel and fertilizer. One could anticipate that many of the types of tensions associated with commercialization of the village economic system and with the adoption of new farm technologies would recur. As in these previous cases, the new development provides novel opportunities for gain for some in the village and threatens to deprive others of existing income rights. In turn, these economic changes will interact with caste and status relationships and with the village political system. At present, dung is a nonmarketed commodity subject to rules and rights that govern its sharing. As with crops, labor, land, and water, dung will become a marketed and priced item subject to distribution through the market system. It is reasonable to suppose that the village cattle owners, who are likely in the main to be the wealthier peasant farmers, will attempt to assert latent property rights to their beasts' dung. Their power and status are likely to enable them to get their way. The losers will be the poorer families whose women and children collect dung for cooking. They will have to seek alternative sources of fuel. Some may even lose small incomes from the sale of dried dung.

On the distribution side, some equitable and enforceable method must be devised for governing the flow of gas, electricity, and fertilizer. Even if initial efforts to ensure even-handed community control and to design an equitable pattern are successful (which is not likely), it would be surprising if the big men of the village were not able to abort these, place themselves astride power and gas lines, and appropriate more than their share of energy and fertilizer.

One may with some confidence predict a worsening of the internal distribution of resources and incomes inside the village. A prerequisite to taking the biogas system into village India must be the design of a set of locally intelligible property rights and payments that do not do excessive violence to existing economic relationships--it is too much to expect a change for the better. At a minimum, some serious thought must be given to determining what effects the new technology will have on village institutions and how the villagers will respond.

Footnotes

1. See Arjun Makhijani and Alan Poole, Energy and Agriculture in the Third World (Cambridge: Ballinger Publishing Co., 1975); C. R. Prasad, K. Krishna Prasad, and A. K. N. Reddy, "Biogas Plants: Prospects, Problems, and Tasks," Economic and Political Weekly, Special Number, August 1974, pp. 1347-1364; M. A. Sathianathan, Biogas: Achievements and Challenges (New Delhi: Association of Voluntary Agencies for Rural Development, 1975); a more general survey is found in Roger Revelle, "Energy Use in Rural India," Science 192 (4 June 1976), pp. 969-975.

2. Government of India, Report of the Fuel Policy Committee (New Delhi: Government of India Press, 1975), p. 84.

3. Makhijani and Poole used a 15 percent discount rate, but to achieve consistency with their analysis of a typical decentralized unit it is necessary to use a 12 percent rate.

4. Statistical Yearbook of the Electrical Utility Industry for 1974 (New York: Edison Electric Institute, 1975), pp. 6-15; G.O.I., Report of the Fuel Policy Committee, p. 80.

5. G.O.I., Report of the Fuel Policy Committee, p. 87.

6. Makhijani and Poole, p. 97.

7. Makhijani and Poole, p. 149; also see, Sathianathan, pp. 31-34; Prasad et al., p. 134-39.

Footnotes (cont'd)

8. Sathianathan, pp. 68-69.

9. This capacity fraction is somewhat lower than that used for the centralized system because greater capacity is required in the decentralized system for the same load due to the heavy demand of motor starting requirements (Makhijani and Poole, p. 116).

10. Venkataraman reports that average cost of electrifying a village in India is about $9000, much less than the cost of a biogas electrification unit (p. 94). K. Venkataraman, Power Development in India, The Financial Aspects (New Delhi: Wiley Eastern Pvt. Ltd., 1972).