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and ETW, which shows that the water lifted from DBW for irrigation is cheaper than ETW and among DBW, EDBW is cheaper than DDBW. Therefore, it is suggested that before investing heavy amount on ETW in the area, the other feasible alternatives such as EDBW and DDBW need to be carefully examined and investment in an unplanned manner should be checked.

BIO-GAS FOR FUEL AND FERTILIZERS IN RURAL INDIA—A SOCIAL BENEFIT-COST ANALYSIS

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With the ever increasing population the three major and inter-connected problems facing India are food, fuel and fertilizers. Out of over 5 lakh villages, only 1,05,440 villages were electrified and 16,20,522 pumpsets and tube-wells set up by the end of the Fourth Plan. The targets for the Fifth Plan are even higher and in the context of high oil prices, bio-gas plants are expected to play an important role in meeting the fertilizer and fuel requirements of rural India. As a rough estimate, if the entire quantum of cow-dung available for India's 237 million cattle were processed through bio-gas plants, it would provide 28 million tons of fertilizer nutrients (N P K) for Indian agriculture. In addition, these will also produce 22,425 million cu.m. of gas (29.152 million tons of soft coke) to meet the energy needs of the village for irrigation, lighting, agro-based industries and cooking.

I

The objectives of this paper are (*i*) to present a social cost-benefit analysis of a bio-gas plant; (*ii*) to study the economics of a household bio-gas plant vis-a-vis a community plant; and (*iii*) the role of bio-gas plants in meeting the rural energy needs.

It is well-known that, from time immemorial, cow dung has been used in India either for preparing farmyard manure or as a traditional fuel for cooking purposes in village homes. In this connection, it has been estimated that nearly one-third of the cattle dung available in the country is burnt away as fuel owing to the scarcity of alternative sources of energy. This wasteful practice of burning cow dung for fuel in the countryside not only deprives the soil of an important source of organic matter for improving fertility, but also acts as a great hindrance in fully exploiting the energy potential present in the dung.

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In this context, the possibility of using biological process of anaerobic fermentation to reconcile the conflicting needs of both fuel and manure from the same dung has stimulated renewed world wide interest in bio-gas plants. The gas plant generates a combustible gas known as methane for use as a fuel, through the digestion of cellulosic organic waste and refuse materials without impairing their manurial value.

A cost-benefit analysis of bio-gas plants in conventional rupee terms is difficult because there are no well organized and stable markets for the inputs to and the outputs of anaerobic digesters in rural India. Consequently, the value of net benefits or losses accrued from a bio-gas plant are difficult to measure.

However, attempts have been made by the Khadi and Village Industries Commission (KVIC) and the Indian Institute of Management. But there are some drawbacks in their analysis. The KVIC has taken the price of bio-gas manure as Rs. 50 per ton and that of farmyard manure as Rs. 40 per ton. But they have not given any basis for using this price. For evaluating bio-gas, the market price of the kerosene equivalent of gas, has been used. But farmers, in the absence of cow dung cakes or bio-gas, do not use kerosene. So that will not give a correct measure of opportunity cost(2).*

The Indian Institute of Management(10) has considered both the financial and economic analysis. Their results show that bio-gas plants are viable. They have also shown that the internal rate of return, the net present value and benefit-cost ratio are higher in financial analysis as compared to economic analysis.

The reason for getting a higher investment worth in the financial analysis lies in the methodology chosen to calculate the investment worth. The only difference that they have assumed between economic and financial analysis is the difference of subsidy. Benefits remaining the same, the cost in the financial analysis has been reduced to the extent of subsidy given.

In the economic analysis, following KVIC, cow dung has been evaluated in terms of the price of kerosene. The same has been done in financial analysis. But farmers do not perceive the advantage in terms of saving in kerosene.

II

SOCIAL COST-BENEFIT ANALYSIS OF BIO-GAS PRODUCTION

Methodology and Assumptions

On the benefit side, we have the output of fuel and manure, and on the cost side we have the capital cost of plant, and the operating cost which includes

*Figures in brackets relate to references cited at the end.

the opportunity cost of cow dung. In order to evaluate bio-gas, we have to take its opportunity cost, *i.e.*, the cost of the fuel which would have been utilized in the absence of bio-gas. The KVIC has used the price of kerosene. We consider that soft coke would be a natural choice for cooking before a farmer goes in for more expensive kerosene. Actually, soft coke would invariably be used as an alternative to fire wood. Hence in this analysis coal prices have been used.

In order to convert bio-gas and cow dung cake into coal, the conversion factors as given in KVIC's publication(2) has been used. The calculations show that one kg. of cow dung cake is equivalent to .1959 kg. of coal (see Annexure).

The fuel value of bio-gas is directly proportional to the amount of methane it contains. J. Patel gives the following calorific values for the various compositions of digestion gas:

Sr. No.	Proportion			Net calorific value
	CH_4	H_2	CO_2	(B. Th. U. in one cu. ft.)
1.	60	10	30	579·2
2.	50	10	40	497·2
3.	45	10	45	441·2
4.	40	10	50	359·2
5.	35	10	55	349·2

Taking the median value, *i.e.*, 441.2 B. Th. U. in one cubic foot, we get the convertion first in terms of kilo calories. 441.2 B.Th.U. is equal to 114.62376 kilo calories. Converting in terms of coal replacement ratio, we get one cu. m. of bio-gas equivalent to 1.95 kg. of raw coal.

The price of coal can be estimated by taking the production cost and the transportation cost. Production cost is Rs. 70 per tonne (7). Transport cost of coal, upto rail-head, for a distance of 750 kms. is Rs. 53.60 (8). 750 kms. is roughly the distance from Surat to Kamptee and Umrer coal mines in Maharashtra. Surat has been chosen because maximum number of bio-gas plants in Gujarat is found in Surat district and Gujarat stands first in India, having 28.14 per cent of bio-gas plants (as on March 31, 1975) (10). We should also take into account the transport cost from rail-head to the ultimate consumer. It is assumed that this cost is Rs. 56.40. Thus the price of coal amounts to Rs. 180 per tonne which is also the retail price prevailing in Delhi and suburban areas. If the price of coal is Rs. 180 per tonne, the cost of one tonne of dung cakes (= 195.9 kg. of coal) will be equal to Rs. 35.26. The cost of bio-gas per cu.m. (= 1.95 kg. of coal) will be Re. 0.351.

Some research studies have shown that when cow dung is passed through the digester of a bio-gas plant, the quantityof manure increases and the quality also improves. A.K.N. Reddy, C.R. Prasad and Krishna Prasad of the Indian Institute of Science have shown that one tonne of dung cakes passed through a bio-gas plant can produce 1.2 tonnes of manure (5). Dry dung to manure ratio of farmyard manure is not available. So it is assumed here that they are in the ratio of 1:1. Next, we have to consider the N, P_2O_5 and K_2O content in bio-gas manure and farmyard manure.

In bio-gas manure, N ranges from 1.4 to 1.8, P_2O_5 from 1.1 to 2.0 and K_2O from 0.8 to 1.2 (1). In farmyard manure, N ranges from 0.5 to 1.5, P_2O_5 from 0.4 to 0.8 and K_2O from 0.5 to 1.9 (6). Taking the arithmetic mean, NPK content in bio-gas has been taken as 1.6, 1.45 and 1.0 respectively and in farmyard manure as 1.0, 0.6 and 1.2 respectively.

For estimating the value of manure, import (c.i.f.) prices of urea, diammonium phosphate and muriate of potash have been used. These prices have been adjusted by taking a premium of 30 per cent on foreign exchange. Rs. 120 have been added per tonne of urea, diammonium phosphate and muriate of potash to account for the transport cost from rail-head to the consumer and the distribution margin. In this way, the price of nitrogen has been found to be Rs. 4,065.22 per tonne, the price of P_2O_5 Rs. 4,550.65 per tonne and the price of K_2O Rs. 1,983.33 per tonne.

The smallest bio-gas plant in India can produce 2 cu. m. per day. With one kg. of wet dung we can produce .039 cu.m. (or 1.3 cu. ft.) of bio-gas. To produce 2 cu. m. of gas, 51.28 kg. of wet cow dung will be required. The requirement of cow dung per annum will be 18,717.2 kg. This is equivalent to 3,743.44 kg. of dry dung.

If the production of bio-gas remained the same, throughout the year, one would expect the production of bio-gas to be (2 $\times$ 365) 730 cu. m. per annum. But the production of bio-gas goes down when the temperature goes down. So some adjustments will have to be made. For calculating the seasonal variation in production of gas, 122, 120 and 123 days were taken for summer, winter and the monsoon respectively. During summer, the production is 2 cu.m. per day. During monsoon, the production goes down by 10 per cent. This has been found out in a sample study conducted in Gujarat by the Indian Institute of Management (10). In order to estimate the fall in gas production during winter months in different regions as a percentage of normal, the Indian Council of Agricultural Research (ICAR) conducted a study (1) and they have come out with the following results :

	Frequency			
Per cent fall	North	West	South	Overall
No change	1	5	11	17
20—30%	10	7	5	22
30—40%	19	5	2	26
50%	17	9	1	27
Above 50%	3	—	—	3
	64	39	27	130

If we consider the fall, in average, in India, *i.e.*, the last column, we can estimate the average production in winter months.

Production of gas (x)	Frequency (f)	(x × f)
1	17	17·00
·75	22	16·50
·65	26	16·90
·50	27	13·50
·25	3	0·75
	95	64·65

$$\text{Arithmetic mean} = \frac{\Sigma fx}{\Sigma x} = \frac{64\cdot 65}{95} = .68$$

Thus we find that the production of gas in winter is only about two-thirds of actual production.

So, gas obtained in summer in a 2 cu. m. plant is 244 cu.m (2 × 122). In winter the production is 160 cu. m. ($\frac{4}{3}\times$ 120) and in monsoon it is 221.4 cu. m. ($\frac{9}{5}\times$ 123). It amounts to 625.4 cu. m. per annum. The cost of one cu.m. of bio-gas is Re. 0.351. So the value of 625.4 cu. m. will be Rs. 219.52. It means that a 2 cu.m. bio-gas plant can produce fuel worth Rs. 219.52 per annum.

Fertilizers :—3,743.44 kg. of cow dung cakes used per annum in a bio-gas plant can produce 4,492.128 kg. of manure per annum. N, P_2O_5 and K_2O content in this manure will be 71.87 kg., 66.33 kg. and 44.92 kg. respectively. The value of N, P_2O_5 and K_2O will be Rs. 291.72, Rs. 301.80 and Rs. 288.94 respectively. This adds up to Rs. 682.53 which is the value of manure produced by a bio-gas plant having a capacity of 2 cu.m. per day. The total value of output produced by this plant will be Rs. 902.05.

Next, we consider the cost involved in the production of bio-gas. In the sample survey conducted by the Indian Institute of Management (10), the sample respondents were asked to give information on their initial installation cost and frequency of breakdown of various components. The reported cost of installation of plants of different sizes in various years was higher than the KVIC estimates for the corresponding year in all cases. Of the technical problems experienced by 65 per cent of the plants, corrosion of the gas holder and breakage of the central guide pipe were the most common. The average life of the gas holder before it got corroded was 8 years and not 10, as assumed by the KVIC experts. The hose pipe burst every 2 years on an average.

Since the initial costs incurred by the farmers in the sample were not applicable (due to an increase in prices), the KVIC estimates were used in the social benefit-cost analysis. The cost of paint was also taken from the KVIC estimates for the same reason mentioned above. However, the sample information regarding the corrosion of gas holders and breakdown of hose pipe has been used. The economic life has been taken to be 30 years instead of the KVIC estimate of 40 years(11). The cost of the hose pipe was taken as Rs. 18 irrespective of the plant size as reported by the sample farms.

The total initial cost of a 2 cu.m. bio-gas plant has been taken as Rs. 2,332. It includes cost of the gas holder, civil construction, pipeline and appliances which are Rs. 933, Rs. 1,143 and Rs. 256 respectively.

In the operational cost, we have the cost of gobar, cost of paint for new gas cylinder and maintenance cost. The cost of paint for a new gas cylinder is Rs. 100 per annum. This has to be incurred only when a new gas cylinder is used, *i.e.*, it will have to be incurred during the first year, ninth year, 17th year and 25th year. During the life of the plant, the gas cylinder is replaced thrice and whenever it is replaced this cost has to be incurred. On other years, a recurring cost of paint is incurred which amounts to Rs. 50 per annum. It is 50 per cent of the cost of painting a new cylinder because only the outer side has to be painted. The cost of hose pipe is also included in operational cost and is incurred every alternate year. Labour cost has not been included because a bio-gas plant does not require much labour. The ICAR group in their study have found out that the average amount of time spent for operating the gas plants of sizes 100-200 c.ft. per day range between 35 and 50 minutes per day.

As far as the cost of gobar is concerned, it will depend upon the use to which it was put before the bio-gas plant was set up. That will give the sacrifice that the society has to incur because of the installation of the bio-gas plant. On an average, it is said that one-third of the total production of dung in the country is being converted into cakes for use as fuel and two-thirds is used as fertilizer.

In the present analysis, three alternative cases have been taken. In the first case, we assume that before the bio-gas plant was set up, one-third of cow dung was being utilized as fuel and two-thirds was being utilized as manure.

In the second alternative, it is assumed that, before the set-up of this plant, the entire stock of cow dung was being utilized as manure.

In the third alternative, it is assumed that, prior to the insta[illegible]n of the bio-gas plant, the entire stock of cow dung was being utilized [illegible]l.

III

RESULTS

Considering the first alternative, in a 2 cu. m. plant case, which uses 3,743.44 kg. of cow dung cakes, prior to the installation of bio-gas plant, 1,247.813 kg. of cow dung must have been utilized as fuel and 2,495.63 kg. as manure. The value of 1,247.813 kg. of cow dung cakes will be (1.2478 × 35.26) Rs. 44. 2,495.63 kg. of cow dung will contain 24.96 kg. of N, 14.97 kg. of P_2O_5 and 29.94 kg. of K_2O. The values of N, P_2O_5 and K_2O are Rs. 101.34 (24.96 × 4.06), Rs. 68.11 (14.97 × 4.55) and Rs. 59.28 (29.94 × 1.98) respectively. Thus the value of manure, not available for use, is Rs. 228.73. The total loss amounts to Rs. 272.73.

If we discount the costs and benefits over 30 years, the net present value comes out to be Rs. 1,366.33 at 10 per cent rate of discount and Rs.—64.98 at 18 per cent rate of discount. The benefit-cost ratio is 1.4556 at 10 per cent rate of discount and .9751 at 18 per cent rate of discount.

In the second alternative, where it is assumed that before the installation of the bio-gas plant, the entire stock of cow dung was being used as manure, the cost of gobar will be different from the amount calculated in the first alternative. In this case, N, P_2O_5 and K_2O content in 3,743.44 kg. of cow dung cakes used in our plant is the sacrifice incurred by the society. N, P_2O_5 and K_2O content in 3,743.44 kg. of dry cow dung is 37.43 kg., 22.46 kg. and 44.92 kg. respectively. The values of N, P_2O_5 and K_2O are Rs. 151.97 (37.43 × 4.06), Rs. 102.19 (22.46 × 4.55) and Rs. 88.94 (44.9 × 1.98) respectively. In this alternative, the benefits remaining the same as in the first alternative, the operational costs will change. This will lead to a change in the net present value and benefit-cost ratio. In this case, at 10 per cent rate of discount the net present value is Rs. 702.98 and at 18 per cent rate of discount it is Rs.—453.19. The benefit-cost ratio is 1.2344 at 10 per cent rate of discount and 0.8266 at 18 per cent rate of discount.

In the third alternative, where it is assumed that the entire stock of cow dung is initially used as fuel, the sacrifice incurred by the society is 3,743.44 kg. of cow dung as fuel. The value of 3,743.44 kg. of cow dung used as fuel is 131.98 (35.26 × 3.743). Here again, we have a change in the operational cost, fixed cost and benefits remaining the same as in the first alternative. The net present value, corresponding to this alternative, at 10 per cent is Rs. 2,692.93 and at 18 per cent is Rs. 829.38. The benefit-cost ratio is 1.898 at 10 per cent and 1.3173 at 18 per cent.

A striking feature to note is that the net present value which is Rs. 1,366.33 at 10 per cent rate of discount in the first alternative, goes down to Rs. 702.98 in the second alternative and goes up to as high as Rs. 2,692.93 in the third alternative. It is obvious that the whole economics of bio-gas plant depends on the proportion of cow dung which is used as fertilizers before the introduction of bio-gas plants.

A study on the fertilizer value of digested cattle dung vis-a-vis fresh dung was performed by Hart in 1963 in U.S.A. His study indicates that although the quality of nitrogen undergoes a significant change, the quantity of nitrogen remains the same in a digested cattle dung as against fresh dung(4).

It will be an interesting exercise to see the economics of bio-gas plants assuming that there is no change in the value of fertilizers produced by the plant.

The benefits in this case will go down from Rs. 902.05 in the initial exercise to Rs. 565.62. In this exercise, if we consider the same three alternatives of the initial exercise, we get the net present value at 10 per cent as Rs.—1,833.34 in the first alternative, Rs.—2,496.69 in the second alternative and Rs.—506.78 in the third alternative. The benefit-cost ratios at 10 per cent are .3885 in the first alternative, .1673 in the second alternative and .831 in the third alternative. Thus we find that the economics of a bio-gas plant depends upon : (*i*) the use to which cow dung was put before the installation of the bio-gas plant, and (*ii*) the fertilizer content in digested cattle dung as against farmyard manure. But no proper information is available on these two things, especially regarding the second. Most of the studies only give the N content. P_2O_5 and K_2O are equally important and cannot be ignored. Even in the case of N, different studies give different proportions. It is also not specified whether the N content is due only to cow dung or something else is also added to the mixture. All these factors must be taken into account before large-scale adoption of bio-gas is taken up through large-scale subsidies given to the farmer.

Household vs. Community Plant

In this section, we examine the economics of a 2 cu. m. household vis-a-vis a 35 cu.m. community bio-gas plant. All the studies conducted till now on bio-gas plants have shown that it renders increasing returns to scale (10).

But a large sized bio-gas plant involves certain problems. Firstly, a large number of cattle will be required. So the plant can be run only at a community level. The second problem is regarding the distribution of bio-gas. The distribution cost is likely to be very high. The cost will, of course, depend upon the location of different houses in a village. If the houses are scattered, the distribution cost will be quite high. It is obvious that the distribution cost will increase more than proportionately with an increase in the size of a gas plant. The cost of the pipeline and appliances for a 2 cu.m. plant is Rs. 256. The cost of pipeline and appliances for a 35 cu.m. plant, as given by the KVIC (10), is Rs. 1,989. This seems to be a gross underestimate of the distribution cost. Many studies have pointed out that the distribution cost in a community bio-gas plant will be very high. But none of them has given any precise estimate within which the distribution cost should lie.

In order to find out the maximum permissible distribution cost, an exercise can be done. 35 cu.m. plant has been selected for this exercise. It has been assumed, to begin with, that the distribution cost is zero. A 35 cu.m. plant will require 897.44 kg. of wet cow dung per day and 3,27,565.6 kg. of wet cow dung per annum. This is equivalent to 65,513.12 kg. of dry dung. For this plant, Rs. 16,411 has to be incurred as initial cost (excluding distribution cost). Under operational cost, we have the cost of paint for new gas cylinder which is Rs. 687 for this plant. Maintenance cost is Rs. 100 and the recurring cost of paint incurred every year, except on ninth, seventeenth and twentyfifth year, is Rs. 343.50. We also have the cost of hose pipe which is replaced every alternate year. Its cost is Rs. 18.

In this, we assume that before the bio-gas plant was set up, two-thirds of the cow dung was being used as manure and one-third as fuel. Of 65,513.12 kg. of cow dung used 21,837.766 kg. was used as fuel. Its value is Rs. 770 approx. (21.8378 × 35.26). The remaining two-thirds, *i.e.*, 43,675.532 kg. was used as manure, which contains 436.76 kg., 262.05 kg. and 524.1 kg. respectively of N, P_2O_5 and K_2O. The values of N, P_2O_5 and K_2O are Rs. 1,773.25 (436.76 × 4.06), Rs. 1,192.33 (262.05 × 4.55) and Rs. 1,037.72 (524.1 × 1.98). The total sacrifice incurred by the society due to the installation of this plant is Rs. 4,773.30 (Rs. 4,003.30+770.00).

On the benefit side, we have the production of bio-gas and manure. In finding out the production of bio-gas, due adjustments have again to be made for seasonal variations. The normal production goes down by 14 per cent during monsoon (10) and 33 per cent during winter(1). After making these adjustments the value of bio-gas at the rate of Re. 0.351 per cu.m. is Rs. 3,780.94.

65,513.12 kg. of dry dung used can produce 78,615.744 kg. of manure. N, P_2O_5 and K_2O content will be 1,257.85 kg., 1,139.93 kg. and 786.16 kg.

respectively. The values of N, P_2O_5 and K_2O are Rs. 5,106.87, Rs. 5,186.68 and Rs. 1,556.60 respectively. Thus the total benefit amounts to Rs. 15,631.09 which comprises Rs. 3,780.94 worth of gas and Rs. 11,850.15 worth of manure.

The net present value of this plant at 10 per cent is Rs. 75,491.77 and at 20 per cent it is Rs. 33,193.92. It means that if 10 per cent is the internal rate of return, the distribution cost can go up to Rs. 75,491.77. At 20 per cent internal rate of return the distribution cost can go upto Rs. 33,193.92. The distribution cost in a community bio-gas plant, even though is likely to be high, may not be as high as this. This additional benefit, which is accruing purely due to returns to scale can be used for subsidising the price of bio-gas for the poor people who will be consuming it. This is a must because the government has to provide an alternative source of fuel to the people who were previously using it at negligible cost and which they cannot get now because this plant has blocked a large part of fuel previously used by them. One of the criticisms against the bio-gas plant is that it only serves the rural rich. This can be avoided if the gas is provided at subsidised price to the rural poor. But the amount of subsidy will depend upon the actual distribution cost.

Any cost-benefit analysis of bio-gas plants will be incomplete, if the intangible benefits accruing, are not taken into account. The utilization of bio-gas is almost pollution free. Its use can play an important part in reducing the detrimental health costs involved with continuous use of firewood and other vegetable materials. Cooking with bio-gas rather than with soot producing fuels is a significant move towards improving the quality of life in rural India.

Another benefit of bio-gas may be found in the fact that reliance on it as a fuel involves neither dependence on foreign energy resources nor dependence on a diminishing supply of domestic energy resources. Firewood, charcoal, kerosene, petroleum and coal reserves may not last forever, Bio-gas is available as long as cattle play a major role in agriculture.

Unlike electricity production, the production of bio-gas does not involve large-scale technology. The decentralised technology of bio-gas production would be under the control of the farmer. If all of the benefits associated with bio-gas production could be properly qualified, the benefits might outweigh costs substantially.

Finally, we have to see the role of bio-gas plants in meeting the rural energy needs. The Indian Institute of Management, in their sample survey in Gujarat, found that the sample gas plant owner-households were the richer sections of the rural population. In fact, those households which were in the lowest socio-economic rung categories in the sample were far better off than the conventionally known marginal farmers and landless labourers. The smallest bio-gas plant, *i.e.*, a 2 cu.m. plant requires 3 to 5 animals. Bio-gas required for cooking per person per day is 12 cu.ft (5). If there are 5 members in a family, the bio-gas produced will be just sufficient for cooking. If bio-gas is to be used for lighting, irrigation and running industries, a bigger plant will have to be installed. A bigger plant will require more animals, which many of the households in the rural areas may not possess. The alternative is to consider a community bio-gas plant. A community plant can be taken up provided the distribution cost is not very high. So we cannot say to what extent the bio-gas plants will provide a solution to the farm energy requirements.

If bio-gas plants are viable, as pointed out by the KVIC, a question might arise as to why the farmers have not taken up this plant on a mass scale. On an average, the plants grew at the rate of 2.2 per cent between 1961-62 and 1974-75(10). One of the reasons is that the farmers do not perceive the advantage in terms of saving in kerosene or saving in coal. They use firewood, (non-commercial) agricultural wastes, *karathi*, etc., whose cost is almost negligible to them. There is a lack of a felt need for gas plants among the villagers because of the availability of an alternative source of energy for cooking. So as far as an individual farmer is concerned, the benefit accrues only in terms of fertilizers. Against this benefit, he has to set the capital cost that has to be incurred. The low price of fertilizers in the past may be one reason for the slow rate of growth of the bio-gas plants.

Secondly, there are institutional constraints imposed by the distribution of income among the rural population. Approximately 30 per cent are landless and have little or no access to capital markets (4).

Another problem is that the banks do not provide for long-term financing. This requires the farmers to make large expenditures in the initial years. Sometimes, when the loans can be obtained, a rather extensive delay in the arrival of materials is a common occurrence.

Finally, there may be physical constraints. For example, water is required for anaerobic digestion in equal proportion to the amount of dung required. In some areas of India, the scarcity of water may be the limiting input for bio-gas production which places it in competition with other alternative uses of water such as farming and household use (4).

ANNEXURE

(*i*)	One kg. of dung cake contains	2,092 kilo calories
	Thermal efficiency	11%
	Mode of burning	Open chulah
	Effective heat kilo calories	$2{,}092 \times \frac{11}{100}$
		$= 230 \cdot 12$ kilo calories

One kg. of soft coke contains	6,292 kilo calories
Thermal efficiency	28%
Mode of burning	Open chulah
Effective heat kilo calories	$6292 \times \frac{28}{100}$
	= 1761·76 kilo calories

If the effective heat available from one kg. of cow dung cakes is to be obtained through the use of soft coke, the amount of soft coke needed will be $\frac{1}{1761 \cdot 76} \times 230 \cdot 12 = 0 \cdot 1306$ kg.

As per normal yield rate of soft coke, the amount of raw coal that will be needed for the above is $1.5 \times .1306 = .1959$ kg.

(ii) Thermal efficiency of bio-gas	60%
Mode of burning	Standard burner

Effective heat utilization of 1 cu. ft. of bio-gas..$114 \cdot 624 \times \frac{60}{100} = 68 \cdot 7744$ kilo calories.

Effective heat utilization of 1 kg. of soft coke..1,761·76 kilo calories

$\therefore$ the amount of soft coke that will be needed to get 68·7744 kilo calories$= \frac{68 \cdot 7744}{1761.76} = \cdot 039$ kg. of soft coke per cu. ft. of bio-gas.

The amount of raw coal that will be needed $= \cdot 039 \times 1 \cdot 5 = .0585$ kg. cu. ft.

One cu. ft. = ·03 cu. m.

For ·03 cu. m., ·0585 kg. of raw coal is needed.

$\therefore$ for one cu. m. $= \cdot 0585 \times \frac{100}{3} = 1 \cdot 95$.

For one cu. m. of bio-gas 1·95 kg. of raw coal is needed.

Production cost of coal	Rs. 70·00
Transport cost of coal (upto rail-head—750 km.)	Rs. 53·60
	Rs. 123·60
Transport cost from rail-head to the consumer	Rs. 56·40
Cost for the consumer	Rs. 180·00

·1959 kg. of raw coal	1 kg. of cow dung
or 195·9 kg. of raw coal	1 tonne of cow dung
1000 kg. of raw coal costs	Rs. 180
$\therefore$ 195·9 kg. of raw coal will be	$\frac{180}{1000} \times 195 \cdot 9 = 35 \cdot 262$

∴ one tonne of dung cakes will cost .. .. Rs. 35·26·

1000 kg. of raw coal costs .. .. Rs. 180·00

1·95 kg. of raw coal will cost .. .. Rs. $\frac{100}{1000} \times 1{\cdot}95$ = Re. 0·351·

Cost of one cu. m. of bio-gas .. .. .. = Re. 0·351·

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