Final Report on Technical Study of Biogas Plants Installed in Pakistan

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EXECUTIVE SUMMARY

- Dissemination of biogas technology in Pakistan started in 1974 with a comprehensive government programme and till the end of 2006 some 6000 plants have been installed across the country. Keeping in view the estimated potential of fine million plants, the achievement till date is negligible.
- Realization of the fact that the success of the proposed National Domestic Biogas Programme in Pakistan depends heavily upon the workable and effective implementation plan that is based upon the grassroots reality of the sector, a study was proposed by SNV to collect and analyze information on present status of biogas plants and various biogas related issues from the users' level.
- The overall objective of the proposed study was to conduct a technical review of existing biogas plants constructed across Pakistan over the past years to facilitate the preparation of implementation plan for the proposed National Domestic Biogas Programme. The field study was carried out during the period November 04 to 19, 2007 in 38 randomly sampled biogas households from eight different districts as well as Capital Islamabad representing two provinces out of four in Pakistan. These plants were installed by PCRET (26 nos.), PRSP (5 nos.), FIDA (5 nos.) and GCO (2 nos.) during the period 1998 to 2006. Among the sampled plants were floating drum model (27 nos.), fixed dome Nepalese GGC model (10 nos.) and Plastic Tunnel model (1 no.).
- The average family size in studied households was 10.4, with a maximum of 18 and minimum of 5. The average land holding size of 13.4 acre, average cattle holding of 8.28, average annual income of Rs.341176.50, average annual expenditure of Rs.200802.40, average net saving of Rs.140294.10 and literacy rate of 71.34% (female-59.36% and male-82.08%) indicated that biogas plants have been installed by relatively well-off peoples in the society. The corresponding national figures are …………………….respectively
- Difficulty in collecting conventional energy sources as well as their high costs, economic benefits including saving of time and money, fertilizer of higher nutrient value, availability of subsidy, fast, easy and comfortable cooking, health benefits including the reduction in smoke-borne diseases and environmental benefits such as saving of forest, clear surrounding, were the main motivational factors for the users to install biogas plants. The average size of biogas plants was found to be 4.7 cum gas production per day, which is rather oversized if viewed from domestic purpose. The average cost of installation of 5 cum floating drum plant was Rs.29425 and that of 6 cum (2 cum gas production) fixed dome plant was Rs.22000.
- The outcome of the study indicated that the whole quantity of dung produced in the stable was not fed into the plant. It showed that out of the theoretical quantity of available dung (calculated based upon the number of cattle) of 3435 (101 kg/household on an average), 1445 (42%) is fed into the plant. However, the prescribed quantity of dung based upon the hydraulic retention time of 45-50 days to produce required for the Pakistan context is 3995 kg (based upon 40 litres of gas production per kg of dung per day). The total available quantity of dung is less than (86%) the total required quantity (25 kg). The average feeding rate thus was 9 kg per 1 cum gas production capacity per day, which is 36% of the required quantity. Only 40% of the households produced required quantity of feeding materials; 43% households produced less than 60% of the required quantity. 63.33% of the total plants received less than 40% of the prescribed quantity; and 86.67% plants were under-fed. Water-dung ratio was correct in majority of the cases (65%). There were no latrine-attached plants as latrine attachment was not accepted in majority of the communities because of social taboos. Lack of O&M training and after-sale-services was observed to be a major issue. Gas leakage from MS drum and breakages of biogas stoves were reported to be the main problems.

- The outcome of the study indicated that the general physical condition of 18% of the plants were good, that of 61% is was fair and 21% poor. Despite numbers of defects and weaknesses, majority of the plants were functioning. Out of the 38 plants under analysis, 13 (34%) plants were functioning satisfactorily, 17 (45%) plants were functioning partly and the remaining 8 (21%) plants were not functioning at all during the time of field investigation. The reasons for non-functioning were migration of users abandoning the plant, leakages in MS drum, poor workmanship during construction, sub-standard quality of construction materials and appliances, and non-availability of repair and maintenance services.
- The theoretical amount of gas production from all the biogas plants under study based upon the daily feeding is 57.8 cum of biogas per day. Total biogas production based upon the gas being used is 40.8 cum per day. The calculated performance efficiency of biogas plants collectively is, therefore, 70%. All the 10 fixed dome plants had efficiency more than 95%. The average efficiency of floating drum plants was 58%. However, when viewed form the overall size of biogas plant (an average of 4.7 cum gas production/day), the efficiency of biogas plant is only 26%. The lower efficiency is the result of technical and operational defects in various components of biogas plants.
- The average burning hours of stove in the sampled households was calculated to be 3.6 hours/household/day. The gas demand in these households was reported to be an average of 4.7 hours/day/household. Gas was reported to be sufficient only in 45.1% of the households. The total demand of biogas can be fulfilled if the average efficiency of biogas plants is increased from the existing 70% to 79%. The decrease in gas production during winter season was reported to be more than 50%.
- 47% of the users were satisfied with the functioning of their plants while 24% were partly satisfied and the remaining 29% were not satisfied at all. The main reason of not satisfying was the non-functioning of plants, less gas during winter seasons, non availability of O&M services and technical failures.
- The respondents rated easy and comfortable cooking, liberation from difficult task of firewood collection and making dung cakes, time saving and workload reduction, nutrient rich fertilizer, health improvement and nutrient rich bio-fertilizer as main merits, while non-suitability of biogas stoves to cook chapati, and accommodate bigger cooking pots, significant reduction of biogas during winter, tension due to problematic components of biogas plants, foul smelling in kitchen when gas leaks, cumbersome and unhygienic process of mixing dung and water to be the main demerits of biogas technology.
- Biogas plants in general were reported to have positive impacts on the users. The findings of the study revealed that a family saved an average of 1 hour 35 minutes per day as a result of biogas plant. The average annual saving of conventional fuel sources accounted to be: firewood- 3.08 kg/hh/day, LPG – 0.11 kg/hh/day, dried dug cake - 3 kg/hh/day and agricultural residues – 1.82 kg/hh/day, the monetary value of which was calculated to be Rs.7976 per year/household, which a significant amount.
- 63.33% of the users were using bio-slurry in one or other ways where as the remaining 36.67% were not using it. Majority of the users (82%) who did not use the slurry drain it directly to open spaces or watercourses. Among those who did not use slurry, 70% of them reported that they do not have arable land to use it. Slurry was not coming out of the plant in the case of the remaining 30% of the users. Users who used slurry on farm reported that it is of high nutrient value than the farmyard manure. The use according to them were: use as organic manure without composting (65%), convey slurry directly to irrigation channel (15%), both of the above (10%), use as manure without composting as well as use to make dung cake for selling (10%). Though the users expressed their views that the production of crop has increased after the use of bio-slurry, they could not exactly quantify the increment.

- Bio-slurry has been found to be beneficial in decreasing the use of chemical fertilizers. As responded by the user, saving of chemical fertilizer because of the use of bio-slurry varied from 25 kg to 450 kg per year; the average being 52 kg per household/year. The average saving per household, thus, was Rs. 780 per year.
- The FIRRs of floating drum plants of 5 cum size calculated based upon the cost of installation as responded by the users were 19% and 39% with and without subsidy respectively. FIRRs of fixed dome plant of 6 cum capacity were 29% and 42% respectively. This indicates that the return on investment made for the installation of biogas plant was above the opportunity cost in the capital market, which is about 12% in Pakistan. Likewise, when future anticipated quality improvement options were incorporated in the cost, the FIRRs with and without subsidy for 5 cum floating drum plant were 14% and 19% respectively. The NPV and B/C ration are also indicated the financial viability of all the biogas plants in the given conditions. The EIRR of biogas plants ranged from 23% to 46% for a 6 cum capacity fixed dome biogas plant depending upon various variables.
- Four potential models of biogas plants were evaluated to assess the best model for Pakistan. The outcome of the ranking exercise revealed that there is not a wide difference on ratings among the four models under study. The GGC model being disseminated under the Biogas Programme in Nepal and recently piloted in Sialkot and DI Khan districts in Pakistan has been ranked to be the most suitable plant for mass dissemination in Pakistan. The suitability of this design for both brick and stone masonry works; simplicity in construction; higher resistance of gas holder against ground tremors, easy access for cleaning and maintenance of digester and gas holder; higher level of user's satisfaction; and proven track record of successful functioning in different countries under SNV's biogas programme make this model more suitable than others. Labour intensive construction of gas holder, relatively less suitability of the model in areas with high water table (because of flat bottom), and more time and efforts needed in quality control are the main shortcomings of this design. The Indian Deenbandhu and floating drum design stood second and third.
- In conclusion, the outcome of this study suggested that the existing biogas plants are functioning at a satisfactory level though there are lots of rooms for further improvement. Installation of about 6000 biogas digester across the country till the end of 2006 has been instrumental in popularization of the technology at the grassroots level. Moreover, the functional plants have been found to be effective tools for the promotion and extension of the technology. However, the higher rate of failure of these biogas plants has demotivated the neighbouring households to adopt biogas technology fearing waste of investment.
- Based upon the major finding of the study, the following recommendations are made to effectively implement the proposed Domestic Biogas Program in Pakistan:
    - Though Pakistan has proven record of successful installation of floating drum design biogas plants, this technology has gradually become obsolete, in other parts of the world with the development of new models, especially the fixed dome models. For, wide-scale dissemination of biogas technology under the framework of the proposed biogas programme, it is recommended to adopt fixed dome models that has been in use in other SNV programme countries with necessary modification to suit the Pakistani context.
    - There is urgent need for the modification of the existing design of floating drum model biogas plants to suit the gas use patterns in Pakistan. This will help in optimization of the plant and there by reduction in cost of installation.
    - Apparently, there are lot of technical defects in the existing floating dome model – the main being the quality of MS drum (gas holder). The drum should be fabricated with thicker sheet-metal and care should be provided to avoid unnecessary joints in it.

- There is utmost need of formulation of quality standards on construction, operation and maintenance of biogas plant giving special attention to the local conditions.
- To overcome the existing problem of repair and maintenance services, an of effective repair and maintenance mechanisms should be formulated and enforced to safeguard the interest of farmers and get demonstration effects from the older plants.
- Private sector development is fundamental for the wide scale dissemination of biogas technology. The proposed biogas programme should institutionalise and strengthen the existing private sector operating in biogas sector.
- Biogas program should be integrated with other rural development and poverty alleviation programs. To penetrate more into poorer section of the society, a massive awareness campaign, a stable subsidy policy as well as group loans without collateral should be one of the strategies for implementation of the program.
- Institutionalization and capacity building of the partner agencies should be one of the prime objectives of the biogas program. Effective partnership modality has to be developed and operationalised.
- Proper orientation is needed to the users on effective use of slurry.
- Future dissemination initiatives should be focused on context-specific motivational factors. Local plant owners, local governmental and non-governmental bodies, civil society organizations, functional groups, key community leaders and educational institutions could be mobilized effectively to promote and extend the technology.
- ‘Quality’ should be the prime concern and focus of any biogas programme. Quality control mechanisms should be an integral part of the programme implementation from the very onset.

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I cordially extend my thanks and gratitude to all the respondent plant users who provided their valuable time to answer the long questionnaires. I hope that the study truthfully reflects the views, problems and perceptions of these people.

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ABBREVIATIONS

ASS	After Sales Service
BPT	Biogas Practice Team
BRE	Biogas/Renewable Energy
BSP	Biogas Sector Partnership (Nepal)
Cum	Cubic Meter
EIRR	Economic Internal Rate of Return
FIDA	Foundation for Integrated Development Action
FIRR	Financial Internal Rate of Return
GCO	Green Circle Organisation
GGC	Gobar Gas (Biogas) Company
hh	Households
HRT	Hydraulic Retention Time
IRSD	Initiative for Rural and Sustainable Development
MFI	Micro-finance Institutions
MS	Mild Steel
NGO	Non Governmental Organization
O&M	Operation and Maintenance
PCRET	Pakistan Centre for Renewable Energy Technologies
PRSP	Punjab Rural Support Programme
RCC	Reinforced Cement Concrete
R&D	Research and Development
SNV	Netherlands Development Organization
Rs.	Pakistan Rupees
WB	World Bank

Exchange Rate (October 2005)

1 USD = Rs. 60
1 Euro = Rs. 85

1. INTRODUCTION

1.1 History of biogas in Pakistan

The history of biogas technology in Pakistan is about 35 years old. Around six thousand digesters have reportedly been installed across the country till the end of 2006 as against the technical potential of about five million digesters based on its suitable climate and availability of feedstock, the cattle dung.

The Government of Pakistan started a comprehensive biogas scheme in 1974 and commissioned 4,137 biogas units by 1987 throughout the country. These were large floating drum biogas plants with capacity varying from 5-15 cubic meters gas production per day. This programme was implemented in three phases. During the first phase, 100 demonstration units were installed under grant by the government. During the second phase, the cost of the biogas was shared between the beneficiaries and the government. In a subsequent third phase, the government withdrew financial support for the biogas plants, although technical support continued to be provided free of cost. Unfortunately, after the withdrawal of the government financial support, the project did not progress any further (World Energy Council).

The Pakistan Centre for Renewable Energy Technologies (PCRET) is the leader in the country to disseminate biogas technology and has supported installation of around 1600 biogas plants till the end of 2006. In addition to these 1600 household biogas plants it has installed, PCRET has plans to install another 2,500 plants by 2008 for which Government of Pakistan has approved financial support.

The Initiative for Rural and Sustainable Development (IRSD), an NGO, has installed around 150 biogas plants with support from the UNDP Small Grants Program. Some Regional Support Programmes and NGOs have also included biogas among the projects they support. The NGO ‘Koshis’ in Sialkot, Punjab has reportedly helped villagers to build over 200 biogas plants. Another NGO Green Circle Organization is building community based plants with funding from the Pakistan Poverty Alleviation Fund. Most NGOs received technical assistance from PCRET in the design of their plants. With some exceptions most plants are still installed on a pilot basis and have not been promoted commercially to any large scale.

Most of the biogas plants installed in recent years have been smaller household designs (3 to 5 cum gas production per day) compared to the larger plants in the 1970s and 1980s. The biogas technology most commonly used in Pakistan is the floating drum design. Another design, Chinese fixed-dome design, was reported to be installed on a pilot basis but was reportedly not successful. The Chinese design pilot biogas plants apparently showed persistent leakage and seepage problems and moreover the gas pressure was reported to be low.

Twelve fixed-dome ‘Nepalese design’ biogas plants of Model GGC 2047 of $6m^3$ were installed in tehsil Pasrur of Sialkot District in partnership with the Punjab Rural Support Program (PRSP) and four plants of the same design were installed in sizes 8 (2 nos.), 20 and 35 m^3 in Dera Ismail Khan in partnership with the Foundation for Integrated Development Action (FIDA) by the Rural Support Programme-Network (RSPN) in June of 2007. FIDA was reported to have plans to continue supports to install biogas plants in its working areas.

1.2 Study Background

Realization of the importance of biogas technology to supplement the conventional energy sources in the rural areas of Pakistan, Netherlands Development Organization (SNV) joined with Winrock International and UNDP to carry out a study on feasibility of a household biogas programme in the country in early

2007. The outcome of the study revealed that Pakistan has one of the largest unexploited biogas resources in the region and based on the availability of livestock and suitable climatic conditions, the technical potential was estimated to be over 5 million household biogas digesters in the country. The study recommended to proceed ahead to prepare an Implementation Document for the execution of a large scale household biogas program in Pakistan. The study also pointed out the need of following preparatory works to prepare a realistic Implementation Plan.

- Technology assessment of both the floating drum design currently being used in Pakistan and the fixed dome design biogas digester which is just piloted in Pakistan and has proven track records of success in China, Nepal, Laos, Rwanda and other Asian countries; before deciding on the appropriate technology for the pilot phase;
- Survey of existing biogas plants based on representative sample, including functional and dysfunctional units.

Build upon the outcome of the feasibility study, SNV proposed an assignment to prepare an Implementation Documents. More specifically, the assignment was aimed at the following activities:

- Assessment of the most appropriate biogas technology to be disseminated in the proposed programme, among others, based on a survey of existing biogas plants, including both functional and dysfunctional units;
- Additional organisational and institutional assessment, among others, based on interviews with representatives of key-stakeholders to understand and agree on the most effective institutional set-up for the initiative, including the location and mode of operation of the national biogas programme office;
- Further discussion and agreement about strategies to overcome the barriers for large-scale dissemination of domestic biogas through interviews with the major stakeholders, especially with regard to construction and after sales by private sector organisations and to financing by banks and MFIs;
- Detailed planning of activities and (national and international) human resources, budgeting and proposed financing, with clear output targets. To the extent possible, local capacity building organisations to be considered for the provision of technical assistance during the implementation of the programme;
- Initial discussion with the Government of Pakistan and other potential donors to solicit support for the programme.

A technical study was therefore proposed as an integral part of the assignment aiming at collecting various technical data and information on functioning of existing biogas plants in the country to facilitate the formulation of effective implementation documents.

1.3 Study Rationale

It is well understood that the success of biogas programme depends heavily upon the workable and effective implementation plan that is based upon the grassroots reality of the sector. These include, among others, information on physical status and functioning of existing biogas plants, users' perception on the technology, impact of biogas plants on the users, and capacity of the grassroots communities to adopt and internalize the technology. Information on these issues would help in deciding best suitable implementation modality for the program. This technical study has been considered to be instrumental in colleting first hand primary data and information on these issues from the users' level so that the findings are reflected in the plan.

1.4 Objective and Scope

The overall objective of the proposed study was to conduct a technical review of existing biogas plants constructed across Pakistan over the past years to facilitate the preparation of implementation plan for the proposed National Domestic Biogas Programme. Information on the following aspects were collected and analyzed:

a. Socio-economic characteristics of sampled biogas households (population pattern, family size, occupations, land holdings, agricultural production, livestock ownership, educational status etc.)
b. Construction, Operation and maintenance of biogas plant
c. General perception of users on the use of biogas
d. Physical status and functioning of biogas plant
e. Impacts of biogas on users
f. Assessment of best suitable model(s) to be disseminated under the framework of proposed biogas programme
g. General recommendations for the proposed biogas program

1.5 Approach and Methodology

1.5.1 Study Tools

Both primary as well as secondary data and information were collected during the course of the study. The study was conducted in close accordance with the objectives. Particular attention was paid to objectively verifiable indicators depending on the level of factual, quantitative and statistical information available, and the degree to which it was possible to quantify and extrapolate conclusions from field investigation and observation.

The main instrument of the study was the structured questionnaires and open-ended unstructured interviews with the respective plant user. Additional investigation tools included observations, especially of different components of biogas plants, cattle-sheds, household kitchen and slurry pits in the sampled households, and informal discussions with people in the survey clusters. The structured questionnaires were discussed among experts from various organizations involved in biogas promotion and extension in Pakistan prior to the field-testing.

During the field survey process, the study team adopted an interactive approach rather than a ‘question and answer session’ with the respondents to enhance the quality of data and information collected.

Photo 1.1: Data Collection in one of the HHs

1.5.2 Sampling

The sampling exercise was governed by the available time for the study (10-12 days for the field study), proximity of the biogas-households from Islamabad and information provided by PCRET on location of biogas plants. Two-stage random sampling method was used to select biogas households for the field investigation. At first, districts which had considerable numbers of biogas plants were selected from two accessible provinces among the four in Pakistan (Sindh was not included due to its remoteness from Islamabad and Baluchistan because of the security reasons) and Islamabad. From a list of biogas households in these provinces, 6 districts in Punjab and 2 in North-West Frontier Province were selected. A purposive random sampling method was used to select required number of biogas households from each district. The following table shows the districts and number of plants selected from each of them.

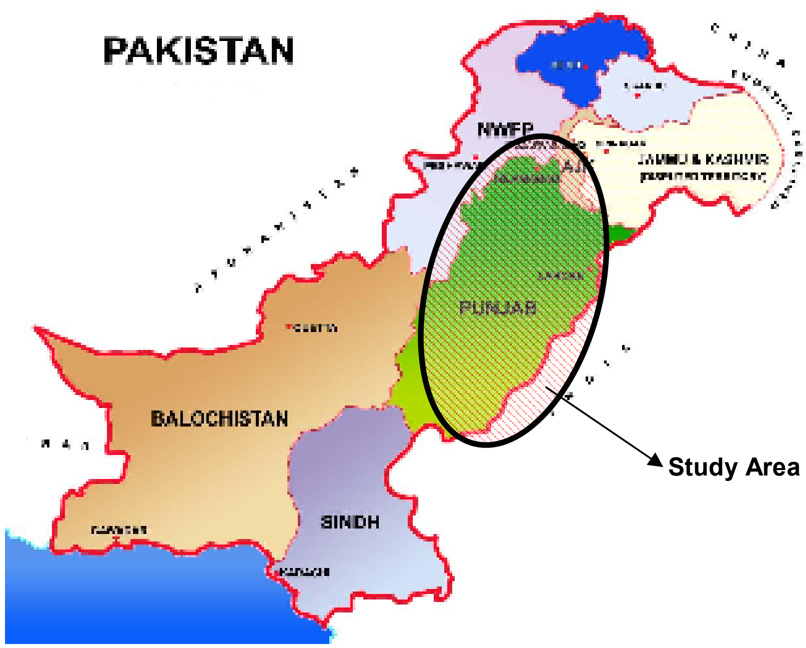
Table-1.1: Biogas Plants Sampled for the Study

Province	**District**	**No. of Plant sampled**	**Installed by**			
			PCRET	PRSP	FIDA	GCO
Islamabad		4	4			
Punjab	Bahawalpur	4	4			
	Okara	5	3			2
	Shekhupura	3	3			
	Narowal	2	2			
	Sialkot	8	3	5		
	Gujralwala	4	4			
North West Frontier	DI Khan	5			5	
	Appattabad	3	3			
Total		**38**	**26**	**5**	**5**	**2**

As shown in the table 38 plants (26 PCRET, 5 PRSP, 5 FIDA and 2 GCO) from Islamabad and 8 districts across Pakistan were sampled for the study. Among the sampled plants were floating drum model (27 nos.), fixed dome Nepalese GGC model (10 nos.) and Plastic Tunnel model (1 no.).

The locations of sampled districts are shown in Figure-1.1.

Figure-1.1: Location of Sampled Districts



Given the total number of plants installed in Pakistan (about 6000, till the end of September 2007), the sample size is not enough to be representative of the entire picture of biogas program in Pakistan. Hence the finding of the study should be considered as indicative rather than representative.

1.5.3 Methodology

The whole study was divided into three major phases based upon the activities carried out:

a. Inception Phase: Desk Study and Mobilization

The collection of secondary data and information, formulation of field investigation methodologies, preparation of questionnaires, checklists and formats, logistic arrangements for field visits were the main activities carried out during this phase. The field visit itinerary was also prepared.

b. Investigation and Data Collection Phase: Field Study

Field investigation works (which consumed 11 days) using appropriate tools and techniques as described above was the main activities during this phase. Biogas plant owners, family members, some key persons in the communities were consulted and their opinion collected. The average time spent in one biogas household to collect data and information was 50 minutes with a maximum of 1 hour and 30 minutes and a minimum of 35 minutes.

c. Concluding Phase: Data Analysis, Interpretation and Report Preparation

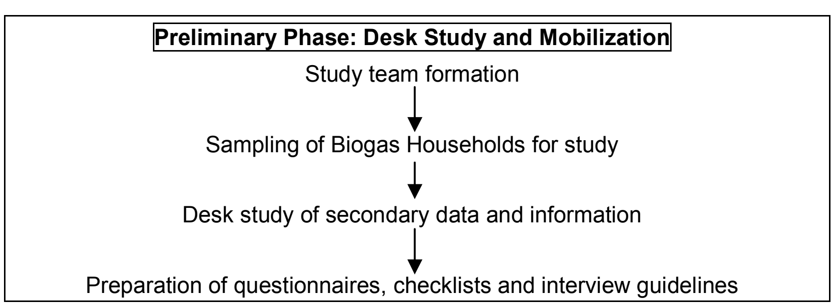
Once the field activities were completed, all the data collected from the field and from secondary sources were crosschecked, verified, cleaned and analyzed using appropriate computer software programmes (EPI Info, MS Excel and MS Word). These primary data and information were triangulated with available secondary data and information. The outcome of the analysis has been incorporated in a concise report.

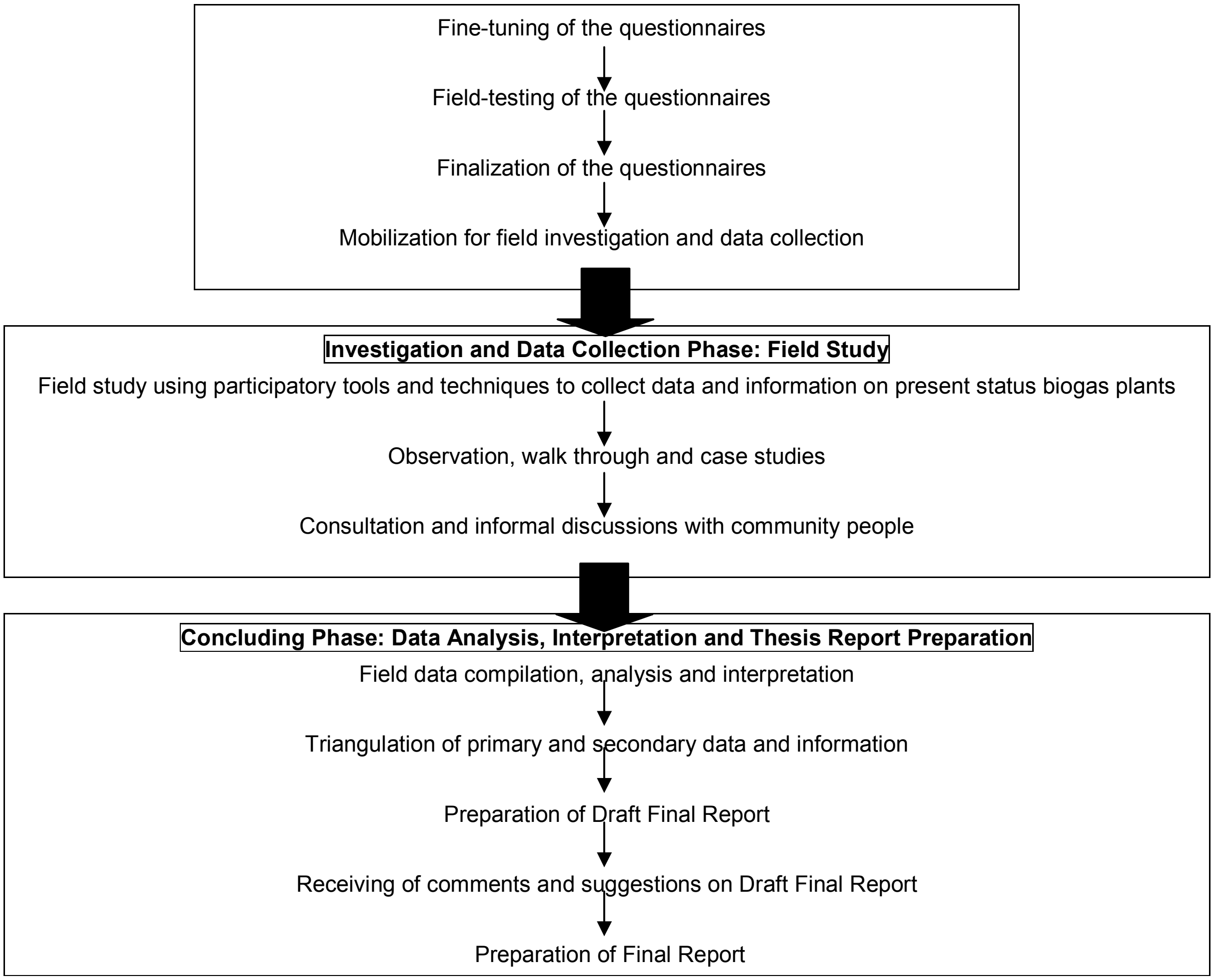
Out of the 8 biogas households studied, only 34 have been included in the socio-economic analysis due to two main reasons:

- Two plants installed by GCO were totally abandoned. Moreover, these were community plants.
- Two of the plants installed under the framework of FIDA biogas program were too big in size (35 and 20 cum) to be compared with other plants studied during the survey. These plants were taken as outlier, which may significantly misrepresent the study findings on various issues such as average plant size.

The general methodology followed during the study has been illustrated in the following diagramme.

Figure-1.2: Methodology Adopted during the Study





1.6 Limitations

The study team has attempted to be as participatory and consultative as possible during field investigation. However, as like in every studies/surveys of this type, this study has its limitations as described hereafter:

a. In absence of a structured, organized and authentic list of existing biogas households, biogas plants for this survey were selected with the help of either personnel from PCRET offices or a mason or plant owners. These informants were found to have tendency to select biogas plants that are fully operational. This has increased the sampling error to a great extent. The percentage of non-functional biogas plants, therefore, could substantially be greater than that revealed by the outcome of this survey.
b. Given the limited sample size and confined coverage, the findings of the study may not represent the whole country. However, the outcome will be significantly same in areas with similar socio-economic, cultural and geographical settings. The outcome of the study therefore, is more indicative than representative.
c. The source of primary data and information was mainly the household survey. It should be noted that views and findings contained in this report are those derived from the responses of the respective respondents.

d. Among many others, the study had intended to explore some basic family/household level information on land holding, income and expenditure. It is possible that there were some shortcomings in dragging actual information on these aspects. It was felt that some of the respondents had general tendency of hiding exact information due to various reasons while some others were hesitant to talk about it, some claimed ignorance and some mentioned an amount that proved to be very low or high later on. The same was the case on time spent on different biogas related activities and total burning hours of biogas stoves. Since it was a survey of the users, there was no actual measurement and as far as quantifiable data and information were concerned, recall method was used, which may not be very exact.

e. Despite genuine efforts, this study having been conducted within a short period of timeframe and with many other constraints might possess some errors methodologically and in the findings presented here in.

2. SOCIO-ECONOMIC CHARECTERISTCS

The outcome of the study indicated that most of the individual biogas households were well off by rural Pakistani standards, as characterized by higher income level, large and medium land holdings, plenty of livestock, and many educated family members. The findings on socio-economic characteristics of the plant owners under study are described below:

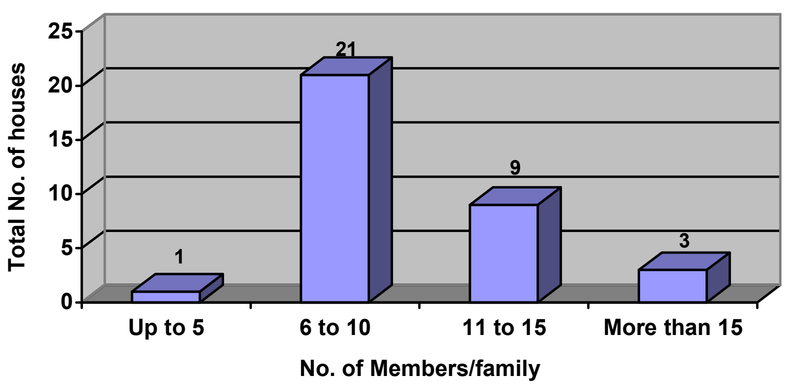
2.1 Demography

The total population of the 34 households under study was found to be 354 among which 171 (48%) were female members and 182 (52%) were male members. The average family size was 10.4, which is higher than the national average size of ?????. Household with maximum and minimum numbers of family members had 18 and 5 members respectively. The oldest person was of 85 years of age, a female member in Bahawalpur district. Table-2.1 and the Figure-2.1 show the population composition and distribution of family members respectively in the studied households.

Table-2.1: Population Pattern

Age Group	No of People		
	Male	**Female**	**Total**
Less than 6	10	16	26
6 to 16	32	31	63
17 to 45	97	88	185
46 to 60	28	21	49
61 to 75	11	9	20
Above 75	5	6	11
Total	**183**	**171**	**354**

Fig-2.1: Distribution of Family Members



As can be seen from Table-2.1, economically active population (age group 17 to 60) has share of 66% in the total population size. Interestingly, 9% of the populations are above 61 years of age. Another fact as seen from the Figure 2.1 is the predominance of 6-10 member-sized families among the biogas users, which comprises of 62% of the total households under study. The finding indicated that biogas plants have been installed in households with comparatively higher number of family members. The family size in 44% of the households remained same before the installation of biogas plants and during the time of survey, whereas it was decreased in 27% households and increased in 27% households. The change was reported mainly due to marriages and permanent migration of some of the family members.

2.2 Economic Status

2.2.1 Occupation

The survey indicated that the primary source of income for the majority of the households (85%) was agriculture and agro-based small and medium entrepreneurship. The major occupations of the family members have been given in the following table.

Table-2.2: Occupation of Household Members

Primary Occupation	No of People		Total	Percentage
	Male	Female		
Less than 6 years	10	16	26	7.3
Agriculture/Agro-based business	47	46	93	26.3
Small Business/Self Employed	26	2	28	7.9
Teaching	6	4	10	2.8
Government Services	9	2	11	3.1
Other services	16	5	21	5.9
Students	42	32	74	20.9
House-wife/household works	0	49	49	13.8
Contractor	2	0	2	0.6
Overseas Employment	5	0	5	1.4
No job/Old People	16	15	31	8.8
Retired Service Holders	4	0	4	1.1
Total	**183**	**171**	**354**	**100**

As shown in Table -2.2, 26.3% of the household members are fully involved in agriculture and agro-based occupations.

2.2.2 Land Holdings

The average land holding size of the households under study was 25 acre (13.4 acre – own land and 11.6 acre – rented-in land) per households, with a minimum of 0.1 and maximum of 242 acres. The average size was much higher than the national average of ????, which indicated that the biogas plants were installed in comparatively bigger holding households. The standard deviation of 46.8 indicates that the gap of smaller and bigger land holdings is very large. The outcome of the study indicated that 41% of the sampled households rented-in land from others for cultivation and pay lump sum cash to the landlords per year. Table 2.3 shows the land holding patterns in the households under study.

Table-2.3: Land Holding Pattern

Land Holdings in acres	No. of HHs possessing		Rented in+own
	Own	Rented-in	
0 to 1	5	20	4
1.01 to 5	10	3	6
5.01 to 10	6	3	7
10.01 to 20	9	4	8
20.01 to 50	2	3	6
More than 50	2	1	3
Total	**34**	**34**	**34**

- Own Land: Average 13.4 acre (min-0.1 acre, max-100 acre)
- Rented in Land: Average 11.6 acre (min-0, max-180 acre)
- Total land holding: Average: 25 acre (min-0.1 acre, max-242 acre)

2.2.3 Agricultural Production

The major crops (cereal and cash crops) cultivated were reported to be paddy, wheat, cotton, sugarcane, vegetables and fruits. Maize, *bajra*, oilseeds, and lentils were also reported to be cultivated. Paddy was stated to be surplus in 15 hhs, wheat in 11 hh, oilseed in 2 hhs, vegetables in 8 hhs, fruits in 5 hh, cotton in 8 hh, sugarcane in 5 hh and lentils in 3 hh. The gross average amount earned from selling of agricultural crops and agricultural product such as milk, milk-products and meat was reported to be Rs. 245446 per household per year.

2.2.4 Livestock Farming

The biogas households owned cattle (cow, ox and buffalo), during the time of survey, at and average of 8.28 cattle per household which was much higher than the national average of ????. The maximum number of cattle was 37 and the minimum was zero. The following table shows information on cattle holding.

Table-2.4: Number of Cattle Owned

Type of Cattle	Average/household	Maximum	Minimum	Standard Deviation
Cow/oxen	3.53	19	0	4.42
Buffalo	4.75	30	0	5.8
Cattle (Cow/oxen and buffalo)	8.28	37	0	7.6
Goat	3.71	35	0	6.6
Chicken	6.75	70	0	13.8
Donkey	11 households had donkey @ 1 donkey each.			

One household did not keep any cattle. 76% of the cow/oxen and 96% of the buffalo were reported to be stall-fed and the remaining were open-grazed for about 6 hours outside the cattle-shed. The number of cattle was reported to be increased in 84% of the households. The decline in number of cattle was very insignificant. The higher standard deviations suggested that the distribution of animals is not homogenous.

2.2.5 Income-Expenditure Pattern

The annual income and expenditure in the biogas households were calculated to be Rs. 341176.5 (maximum - Rs.25,00,000; minimum - Rs.25,000; standard deviation - 5.05) and Rs. 200882.40 (maximum - Rs.10,00,000; minimum - Rs. 25,000; Standard deviation – 2.27) per household respectively. These amounts are significantly higher than the national average of Rs.. ………… and Rs. ……… respectively. The annual average saving therefore was Rs. 140294.10 (maximum - Rs.15,00,000; minimum - Rs. 0; standard deviation – 3.06) per household. Expenditure was higher than income (deficit) in 1 household in which deficit was Rs.50,000 last year. Six households have balance of income and expenses. The higher standard deviation of income-range suggested the extremities in annual income pattern. Interestingly, the value of standard deviation was less in expense range than that of income suggesting that the extremity was less in expenditure patterns.

The biogas owners had pucca houses in 26% cases, semi-pucca houses in 62% cases and kuchha houses in 12% of the cases.

2.3 Educational Status

The overall literacy rate in the sampled households (excluding children below 6 years of age) was 71.34%, which was higher than the national average of ?????%. The female and male literacy rates were calculated to be 59.36% and 82.08% respectively as against the national figures of ???? and ???% respectively. The educational status of the members in the studied biogas families has been given in Table-2.5.

Table-2.5: Educational Status of Household Members

Education	No. of People		Total
	Male	Female	
Illiterate/Not attending Schools	31	63	94
Grade 1	9	6	15
Grade 2	2	4	6
Grade 3	6	2	8
Grade 4	4	3	7
Grade 5	8	6	14
Grade 6	3	4	7
Grade 7	7	9	16
Grade 8	26	21	47
Grade 9	7	4	11
Grade 10	22	11	33
Grade 11	6	4	10
Grade 12	22	9	31
Bachelors Degree	13	7	20
Masters Degree	7	2	9
Children below 6 years	10	16	26
Total	**183**	**171**	**354**

More female members (63) were illiterate than male members (31). Out of the 29 persons who had education higher than graduation (bachelor degree), 20 (69%) were male members. Interestingly, the drop-out rate of both the male and female members is high after grade 8. The data on educational status of the biogas family members indicated that though the numbers are much higher than the national average, the pattern is similar to that of the nation as a whole, where the figure are better for male than female.

3. CONSTRUCTION, OPERATION AND MAINTENANCE OF BIOGAS PLANT

3.1 Construction

3.1.1 Plant Location

The biogas households sampled for the study represented eight districts from two provinces in Pakistan as well as capital Islamabad. Majority of the plants were located in easily accessible areas, where basic infrastructure services existed. Easily accessible roads and electricity grid connections in most of the sampled households (35 out of 38) indicated that these plants were installed in accessible areas.

3.1.2 Reason and Year of Installation

The respondents were asked to give most important reasons/motivating factors for the installation of biogas plants. As per them, the most popular motivating factors to install biogas plant were the difficulty in collecting conventional energy sources as well as their high costs (22hhs), economic benefits including saving of time and money (19hhs), fertilizer of higher nutrient value (18hhs), availability of subsidy (17hhs), fast, easy and comfortable cooking (15hhs), health benefits including the reduction in smoke-borne diseases (12hhs) and environmental benefits such as saving of forest, clear surrounding (11hhs). The following table shows the responses of the respondents on the reasons for the installation of biogas plants.

Table-3.1: Motivating Factors to Install Biogas Plant

Motivating Factors	No. of HHs*
Difficulty in getting conventional energy sources as well as their high costs	22
Economic benefits (saves time and energy)	19
Fertilizer of higher nutrient value	18
Subsidy	17
Fast, easy and comfortable cooking	15
Health benefits (clean kitchen, no smoke-borne diseases, proper management of dung)	12
Environmental benefits (saving of forest, clean surrounding etc.)	11
Motivation from service provider	7
Motivation from other plant owners	4
Social benefits/Prestige	3
Proper use of cattle dung	2
Adopt the new technology and make the village ideal living place	2

** more than 1 response from some respondents*

As in other countries like Nepal and India where biogas plants have been disseminated to a significant extent, the benefit of biogas to replace the conventional fuel sources was reported to be the main motivating factor to install biogas plants. Interestingly, environmental benefits of biogas plants like saving of forest, clean surrounding, and proper use of waste materials etc. were also valued in Pakistan as in Bangladesh.

Among the 38 plants inspected during the study, the oldest plants (1 number) was in operation for nine years (installed in 1998) and the youngest plants (10 numbers) were operating for slightly more than 6 months. 1 plant was installed in 2006 while 4 plants were in commission for more than two years, 5 plants in service for more than three years, 8 of them in use for more than four years, 2 plants were functional for more than five years and 5 plants were in use for more than six years. The remaining 2 plants were working for the last seven years.

3.1.3 Decision Making for the Installation

When asked the respondents on who made the final decision to install biogas plant, 62% of them told that the decision was taken by the household head – the male members in all the cases. 23% were reported to have a discussion in the family before deciding where as the younger members – son or daughters in the family decided in 12% of the cases. The remaining 3% reported that their related took decisions. The respondents told that they knew about the technology through government officials (52%), service providers (19%), friends and relatives (8%), biogas users (11%), and the publicity media (4%). The remaining 6% knew about it through more than one of the above-mentioned mediums.

3.1.4 Type and Size of Plant

Out of the 38 plants selected for the study, the majority (27 plants) were floating drum model based upon the Indian KVIC design. Among the remaining 11 plants, 10 were fixed dome plants (the Nepalese GGC model derived from Chinese design) and 1 was a plastic tunnel type.

Photo 1: Floating Drum Plant

Photo 2: Plastic Tunnel Plant

Photo 2: Nepalese GGC Plant

Among these 27 floating drum plants under study, 21 plants were of capacity of 5 cum gas production per day, followed by 5 of 8 cum and 1 of 10 cum. Likewise The 10 fixed dome plants had the capacity (digester plus gas storage) of 35 cum (1 plant), 20 cum (1 plant), 8 cum (3 plants) and 6 cum (5 plants) respectively. The plastic tunnel plant was reported to be producing 10 cum of biogas per day. The average size of biogas plants under study was 4.7 cum gas production per day, which is very much higher than those in Nepal and India where the average sizes are 1.60 cum (2006) and 2.5 cum (2004) respectively. The size of the plants was reported to be selected based upon the recommendations from the service providers. 4.5% of the respondent felt that the size of the plant was small for them to meet the fuel need. Similarly 18% of them recommended that the sizes need to be increased in the future if biogas technology is to be made popular among the rural people.

3.1.5 Construction Management

PCRET, PRSP, FIDA, ISRD and GCO are directly involved in supporting the installation of biogas plants at the farmer's households in Pakistan. PCRET through its provincial and district offices mobilises local NGOs like KOSHISH in promotion and marketing. PCRET technicians provide training to local mason on construction and local mechanical workshops on fabrication of Mild Steel (MS) drum, the gas holder. Once the demand is collected, the PCRET technicians visit the selected households to check the technical feasibility and financial viability (affordability of farmer to pay). If found feasible, a local mason is contracted to construct biogas plant and a mechanical workshop is hired to fabricate the MS drum. The farmer pays the cost of installation. Once the installation work is done, a completion report is prepared and sent to PCRET office in Islamabad through district and provincial offices. The farmer is provided with the subsidy amount when the completion report is approved by the central office.

PRSP and FIDA called for the technical support of a biogas expert from Biogas Sector Partnership (BSP) in Nepal who organised and conducted on-the-job training for technicians and masons to install Nepalese Model GGC Biogas Plant. Households for the installation of biogas plants were selected from the villages where these organisations were having poverty alleviation programmes. A flat rate subsidy of Rs 6000 and an interest free loan of Rs.16,000 from a revolving fund was provided by PRSP to the villagers to install biogas plants. PRSP has plans to use the revolving fund to support other potential farmers to install biogas plants. However, FIDA provided the entire cost of biogas plants as grant to the villagers keeping in view the poor socio-economic conditions of the villagers.

ISRD and GCO are mobilised the manpower trained by PCRET to install biogas plants. GCO provided investment grant to install community plants with the financial support from the Pakistan Poverty Alleviation Fund. Likewise, ISRD supported communities through the UNDP Small Grants Program.

The study findings revealed that biogas plants were constructed by skilled masons with good knowledge on biogas plant in 52% of the cases, followed by skilled mason without good knowledge on biogas plant in 35% cases and unskilled masons in 13% of the cases. Though 44% of the plant owners felt that some technical standards were set by the service providers as regards the quality of construction materials and construction methods, 85% of them did not know anything about those standards. The rest of the respondents believed that no such standards were set.

3.1.6 Financing for Construction

Biogas plants in Pakistan, in majority of the cases, were financed in two ways – a flat rate subsidy from the government on the investment cost and cash contribution from respective plant owners to fill gap, if any. The subsidy provided by the government was insufficient to meet the total cost of installation and a gap existed which the farmers must bridge. This gap was filled by cash of their own or by credit received from service providers on some pre-defined terms and conditions. Total investment cost of biogas plants ranged from Rs.24,000 for biogas plant of capacity 5 cum gas production to Rs.45,000 for a plant of 8 cum gas production per day. Likewise, the cost of fixed dome GGC plant were reported to be Rs.22,000 for 6 cum, Rs.28,000 for 8 cum, Rs.50,000 for 8 cum and Rs.125,000 for 35 cum plant. The average cost of 5 cum floating drum plant was Rs.29,425 and 6 cum GGC plant was Rs.22,000. Minimum, average and maximum costs of installation of biogas plants are shown in the following table:

Table3.2: Cost of Installation of Biogas Plant

Size of Plant (cum gas production per day)	**Type of Plant**	**Average Cost in Rs.**	**Maximum Cost in Rs.**	**Minimum Cost in Rs.**
5	Floating drum	29,425	35,000	24,000
8	Floating drum	34,500	45,000	32,000
2 (6 cum overall)	Fixed dome	22,000	22,000	22,000
2.5 (8 cum overall)	Fixed dome	28,000	28,000	28,000
6 (20 cum overall)	Fixed dome	50,000	50,000	50,000
10 (35 cum overall)	Fixed dome	125,000	125,000	125,000

None of the users of floating drum plant were reported to have taken loan to install their biogas plants. The outcome of the study revealed a fact that taking loan for constructing biogas plant is not a common practice in Pakistan. The reasons as mentioned not to take loan were[1]: good economic condition (57%),

[1] Some respondents had more than 1 answer

attitude against the philosophy of taking loans (38%), fear that loans may degrade social prestige (23%), non-availability of credit facility (11%), and ignorance on availability of loan facility (6%).
PCRET provided investment subsidy of Rs.15,000 and Rs.12,500 to install floating drum plant of 5 cum and 3 cum capacity respectively. PRSP rendered a subsidy of Rs.6000 and interest free credit of Rs.16,000 to install fixed dome plant of 6 cum capacity. However, FIDA supported the entire cost of plant as an investment grant. According to 27% of the respondents, the cost of installation of biogas plant was cheap where as 40% of them told that it was reasonable. The remaining 33% expressed that the cost was quite expensive. The subsidy on the investment cost has been one of the main motivating factors to install biogas for 17 out of 34 (50%) plant owners. Interestingly, 74% of the respondents told that they would not have installed biogas if subsidy was not provided.

3.2 Operation

The key to proper operation of biogas plant is the daily feeding with mix of right proportions of dung and water, frequent draining of condensed water in the pipeline through the water outlet, cleaning of stoves and lamps, oiling of gas valves and gas taps, cleaning of overflow outlet, checking of gas leakage through pipe joints and gas valves and adding of organic materials to slurry pits. As long as these tasks are carried out reliably and carefully the plant will function properly. The subsequent sections describe the finding of the study as regards the operation of the biogas plants.

3.2.1 Plant Feeding

a. Feeding Materials

The amount of gas production in biogas digester depends upon the quantity of feeding added to it daily provided the plant is technically all right. Cattle dung was the only feeding materials used. The following tables give information on available feeding and the quantity of feeding materials received by the plants under study.

Table-3.3: Dung Production

Quantity of feeding materials produced (kg/day/hh)	Number of hhs[2]
Nil (no production)	1
25.1 to 50	4
50.1 to 75	10
75.1 to 100	4
100.1 to 150	7
More than 150	3
Total	29

The outcome of the study indicated that the whole quantity of dung produced in the stable was not fed into the plant. It showed that out of the theoretical quantity of available dung (calculated based upon the number of cattle) of 3435 (101 kg/household on an average), 1445 (42%) is fed into the plant. However, the prescribed quantity of dung based upon the hydraulic retention time of 45-50 days to produce required for the Pakistan context is 3995 kg (based upon 40 litres of gas production per kg of dung per day). The total available quantity of dung is less than (86%) the total required quantity (25 kg). The average feeding rate thus was 9 kg per 1 cum gas production capacity per day, which is 36% of the required quantity.

Table-3.4: Dung Production vs. Required Quantity of Feeding Material

Production Rate	% of plants

[2] 2 hhs with community plants are not included and 7 hhs (among 8) whose plants were not functioning did not respond.

less than 20% of the required feeding	3
20-40% of the required feeding	17
41-60% of the required feeding	23
61-90% of the required feeding	17
More than 90% of the required feeding	40

Table-3.5 shows that 43% of the total households produced feeding materials less than 60% of the required quantity. 40% households produced the required quantity of feeding materials. Ironically, the outcome of the study showed that all the produced feeding material was not fed into the digester and hence the number of underfed plants was higher. The following table illustrates the feeding patterns.

Table-3.5: Actual Quantity of Dung Fed into the Plant

Feeding Rate	% of plants
less than 20% feeding	20.00%
20-40% feeding	43.33%
41-60% feeding	6.67%
61-90% feeding	16.67%
More than 90% feeding	13.33%

It is apparent from Table-3.5 that 63.33% of the total plants under study received less than 40% of the prescribed quantity of feeding materials. There were significant numbers of under-fed plants (86.67%). One of the main reasons besides insufficient production of dung for under-feeding was the fact that users were not aware of the total quantity of dung to be fed into their plants daily though they had enough dung to feed. When asked question in this issue, 53% expressed their ignorance on the required quantity of feeding. Those who replied also were found to be misinformed. Only 3 out of the 16 respondents told the correct quantity. 10 of them replied far-less quantity, 2 replied lesser quantity and the remaining 1 told more quantity then needed. It is encouraging that one plant owner collected dung from outside who did not own cattle. This plant was found to be satisfactorily functioning for the last 4 years.

b. Water-Dung Ratio

Water dung ration plays a vital role in ensuring conducive environment for micro-organisms in biodigeters to produce biogas. Higher water-dung ratio results in settling of solid particle in the floor which creates a dead volume and reduces the effective volume of digester. Likewise, feeding with less water adds the risk of formation of scum on the top of slurry layer which in long run obstruct the flow of the produced gas. The outcome of the study revealed that the water-dung ratio was 1 in 65% of the plants. These plants received equal volume of dung and water. 29% of the total biogas plants received more water than required. The remaining 6% of the plants received less water than dung.

c. Night-soil Feeding

The concept of connecting household latrines to biogas digester is unacceptable in much of Pakistan for a variety of socio-cultural and religious reasons. The thought of using gas from such a source for cooking purpose remains very much a taboo. Majority of the respondents said their relatives or neighbours would never come for a cup of tea if they knew it has been cooked with gas produced from night-soil.

Some of the responses of plant users as regards the latrine connection to biogas plants were (respondents had more than one answers):

- Gas from latrine attached plants are considered to be un-sacred (75%)
- People are hesitant to handle bio-slurry from latrine-attached plants (88%)
- Though we know that the gas received from night-soil and that received from cattle dung is same, it is still not possible to attach latrine with biogas plant as the elderly members object the ides (15%)

- There are no social and religious taboos in attaching latrines to biogas plants; however, we do not think this is necessary (24%)

3.2.2 Frequency of Operational Activities

Besides feeding of plants, other operational activities were reported to be carried out on as and when needed basis. As regards the frequency of operation of different activities, the responses were as given in Table-3.6.

Table-3.6: Frequency of Operation of Biogas Plant Components

Operation Activities	**Frequency of Operation (hhs)**									
	Daily	Once in two days	Once in 3 days	Once in 4 days	Once in a week	15 days	Monthly	Never	As and when needed	Not applicable
Plant Feeding	28	1	1	-	-	-	-	-	-	8*
Use of Main valve	6	-	-	-	-	-	-	24	-	8*
Checking leakages	-	-	-	-	-	-	-	30	-	8*
Use of Water drain	-	-	-	-	2	4	4	-	-	28 (Not installed)
Cleaning of outlet/ overflow opening	-	-	-	-	-	-	-	23	7	8*
Maintaining compost pits	-	-	-	-	-	-	-	8	39	8*
Oiling of gas tap	-	-	-	-	-	-	-	18	-	20 (Not installed)
Cleaning of gas stove	-	-	-	-	-	-	-	-	30	8*
Cleaning of gas lamp	-	-	-	-	-	-	-	-	1	37 (not installed)

** 8 plants that were not functional reported that they do not carry out any of these activities*

It is clear form Table-3.6 that majority of the plant owners lack knowledge on different operational activities needed to be carried out regularly for the trouble-free functioning of biogas plant and its components. This was due to ignorance and negligence of the users, as they have not been provided with training on operation of biogas plants. The outcome of the study also suggested that the operation and maintenance cost of biogas digester was virtually nil. The zero operational cost was due to the dung obtained from livestock they owned and labour for feeding and other operation and maintenance activities incurred no expenditure as these were not carried out. However, if the labours spent to collect water and feeding the plant are considered operation and maintenance cost in average was Rs.140.00 per plant per month (@ 15 minutes time/day) assuming the wage of labour to be Rs.150 and 8 hours working day.

3.3 After-sale-services

Lack of regular after-sale-services (ASS) provisions was reported by all the users to be the major hurdles for them to have trouble-free functional plants. Upon being asked how the required repair works were managed, 63% of the respondents replied that they have never faced the need. However, 20% told that they called the service provider to fix the problems. The remaining 17% reported that they never received the service even after requesting the service provider resulting in failure of the plants. 9% of the total respondents told that they have received the after-sales services from the service providers regularly, though there are no mandatory provisions of such services.

3.4 Training and Orientation to Users

In fact, the functioning of biogas plant is basically determined not only by the quality of construction and workmanship involved but also by the quality of operation and maintenance efforts from the users. The users should be provided with basic orientation on various aspects of operation and maintenance such as proper feeding of the plant, optimal use of biogas, effective application of slurry, timely maintenance of plant components and improving cooking environment. The following table illustrates the responses of the users when being asked if they have received any training on operation and maintenance of biogas plants from the service providers.

Table-3.7: Training on O&M of Biogas Plant

Type of training received	No. of households	% of households
No training received	19	50
Training not provided but leaflet/booklet/manual provided	1	3
Short orientation training provided by service provider (on the spot instructions from mason/company supervisors etc)	14	37
Short term O & M training (7days or less)	0	0
Long term O & M training (more than 7 days)	0	0
Short Training provided by other NGOs (not the service provider)	4	10
Total	**38**	**100**

It is evident form Table-3.7 that there is high need of training to educate the users on basic operation and maintenance of the installed plants. Existing physical status and functioning of majority of the plants under study also suggested that the users were not fully aware of the importance of effective operational activities and timely repair works for trouble-free performance of biogas plants.

3.5 Maintenance

During the field study, when respondent were asked if they could carry out repair and maintenance works by their own, only three respondents replied in positive. All the respondents expressed urgent need of training on minor repair and maintenance works to effectively manage their biogas plants. The responses of the users on being asked on the problems that they are facing are summarised in the Table-3.8.

Table-3.8: Common Problems in Biogas Plants

Common Problems Reported	**% of plants**
Leakage in Gas Storage tank	50.00%
Problems with gas stoves	38.2%
Problems with main gas valves	29.4%
Problems with low gas during winter	29.4%
Problems with pipelines	26.4%
Problems with cracks in digester wall	17.6%
Problems with clogging of inlet pipe	5.88%
Problems with foul scent in kitchen/food	5.88%

As reported, leakage of biogas from MS drum is the main problem. The outcome of the study suggested that the users do not carry out routine repair works (painting of drum) to minimise the risk of gas leakage. The reason for not doing such repair works was reported to be the difficulty in unloading and reloading of the steel drum by their own. However, some minor repair works were carried out by the users. Out of the 34 biogas plants, 14 plants (41%) have received some sorts of maintenance works. Likewise, 17 (50%) plants are still in need of urgent repair works. The following were the major repair works carried out as responded by the users:

Table-3.9: Major Repairs Works Carried Out

Repair works carried out	**Positive responses (No. of Plants)**
Main gas valve repaired/replaced	11
Gas stove repaired/replaced	8
Structures repaired/renovated	5
Pipeline repaired	2

Gas storage tank (steel drum)	2

The following table shows amount spent on repair works.

Table-3.10: Amount Spent on Repair Works

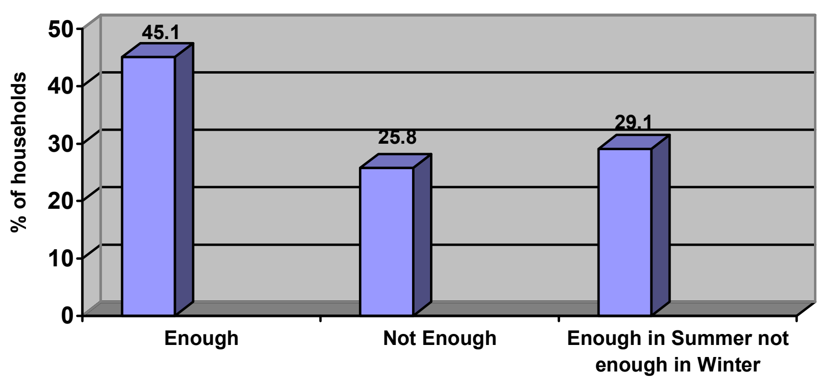
Total amount spent in the last 12 months	No. of Plants	Total Amount Spent (Rs.)
None (no expenditure)	20	0
Less than Rs 200	2	375
Rs. 201 to 500	2	825
Rs. 501 to 1000	9	7565
More than 1000	1	1650
Total	**34**	**10415**

As shown in Table-3.10 a total of Rs. 10415 was spent by the plant owners to repair their plants. Major share of this maintenance cost was reported to be taken by the gas stove followed by main gas valves and structural components. The average maintenance cost per plant was, therefore, found to be Rs. 306.32 per year.

3.6 Gas Production and Use

The outcome of the study indicated that the main application of biogas was on cooking. Biogas was used only for cooking purpose in all the households where plants are under operation. Biogas stoves with single burner have been installed in 15 out of 29 households. The remaining households have stoves with double burners. 25 households have installed only one stove and the remaining 4 have two stoves. Biogas lamp was installed in one of the users whose plant has been out of order during the time of survey. While calculating the gas production, therefore, use of gas for cooking has only been considered. The following chart illustrates the sufficiency of biogas for cooking purpose.

Figure-3.1 : Sufficiency of Biogas



The average burning hours of stove in the sampled households was calculated to be 3.6 hours/household per day. The gas demand in these households was reported to be an average of 4.7 hours per day per household. Gas was reported to be sufficient in 45.1% of the households whose plants were functioning. Another 29.1% households reported that biogas is not sufficient during winter season when the production drops to less than half, though it is sufficient in summer. The remaining 25.8% told that they are running shortage of biogas throughout the year. When asked on the reasons for shortage of biogas, the respondents felt that it was due to less gas production during cold season (10 hhs), defective construction and technical failures (5hhs), lack of timely repair and maintenance work (2hhs), under-fed plants (1 hhs), and combination of any of the above (1 hh). Interestingly, the amount of dung feed into the digester in totality is enough to meet the demand. The theoretical gas production from the dung fed into the digester per day (1445 kg/day) is 57.8 cum (165 burning hours) which was slightly more than the total anticipated stove burning hours of 160 per day. The theoretical burning hours of stove based upon the average size of plants (4.7 cum) under study has been 456.5, which is far more than the actual amount of gas being received. The following table illustrates some facts on feeding and gas production.

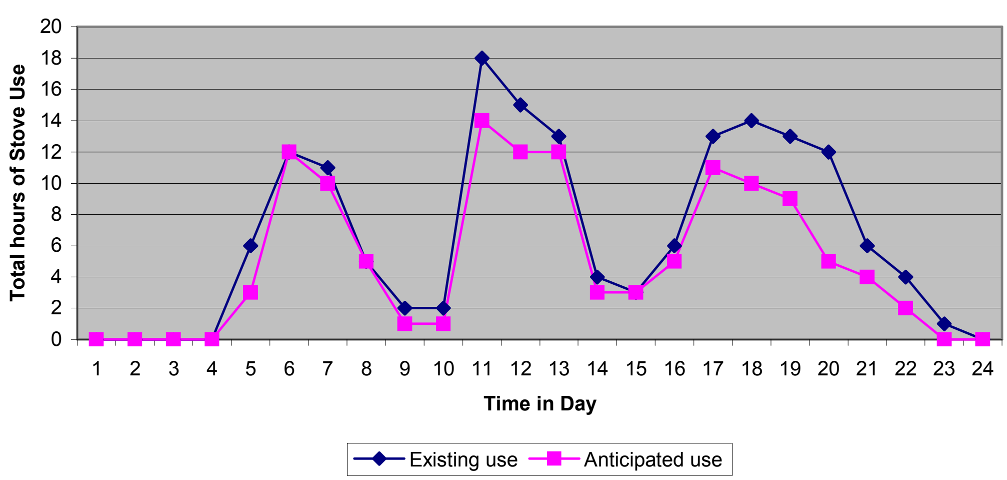
Table-3.11: Some Facts on Feeding and Gas Production

- Theoretical quantity of gas production based upon plant size: **4.7 gas cum gas production/day**
- Required quantity of dung to be feed: **117.5 kg/day**
- Available quantity of feeding: **101 kg of dung/day**
- Actual quantity feed into the digester**: 42.5 kg of dung/day/plant**
- Required to Actual feeding ratio**: 0.42**
- Theoretical quantity of gas production based upon actual feeding: **1.7 cum biogas/day/plant**
- Actual quantity of gas being produced based upon stove burning hour: **1.20 cum biogas/day/plant**
- Efficiency of biogas plants based upon their storage capacity and biogas use: **26%**
- Efficiency of biogas plants based upon feeding and burning hour: **70%**
- Average burning hours of stove: **3.6 hour/day/plant**
- Anticipated burning hour as per family requirements**: 4.7 hours/day/plant**

The outcome of the study as given Table-11.3 illustrates that the biogas plants are under-fed (42.5 kg fed as against the need of 117.5 kg) as well as oversized. Based upon the available quantity of dung which is 101 kg, the suitable average size would have been 4 cum gas production per day.

Figure 3.1 shows the biogas use pattern in an average biogas household (actual and anticipated) calculated based upon the use of biogas stoves as reported by the users. The distribution of average stove burning hours of 4.7 (anticipated) and 3.6 (actual) have been shown in the figure.

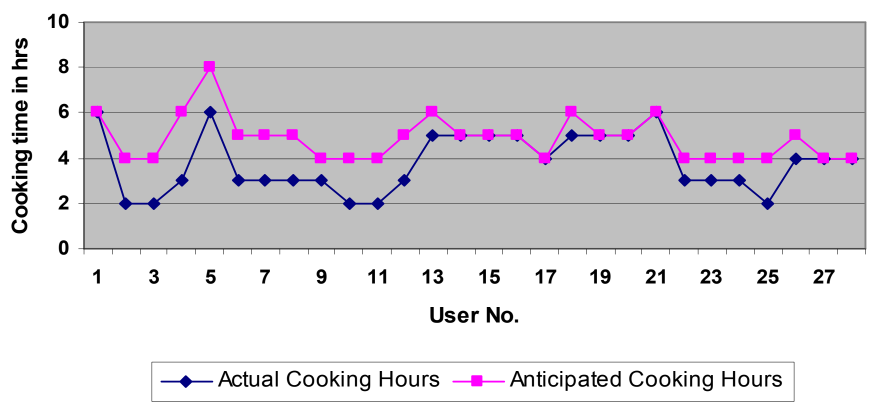
Figure-3.2 : Biogas Use Pattern



The above graph (Figure) on biogas use pattern suggests that the produced gas, in totality, was not sufficient to meet the anticipated demand. The users reported that the use of biogas would have been more than the existing hours if there was sufficient gas. Figure 3.2 shows that there is gap between present use of biogas and the anticipated use (demand).

The following figure illustrates the actual and anticipated cooking hours in the studies households. As can be seen in the figure, the anticipated cooking time is more than the existing stove burning hours in majority of the cases (20 out of 29 households). The demand can be fulfilled if the average efficiency of existing plants is increased from the existing 70% to 79%.

Figure-3.3: Actual and Anticipated Cooking Time in Hours



4. PHYSICAL STATUS AND FUNCTIONING OF BIOGAS PLANT

The study attempted to evaluate the overall performance of biogas plant on the basis of: (a) existing physical status and functioning of its different components, (b) present level of benefits being achieved (the gas and bioslurry being produced), (c) response of respective plant users whether their expectation prior to the installation of biogas came true after the plants are operational (evaluated in terms of gas demand and supply), and (d) level of users' satisfaction on the impacts of biogas plants on them.

4.1 Plant Components

Both the fixed dome and floating drum designs of biogas plant generally consist of the following components. General findings of the field investigation on these components are briefly described hereafter:

4.1.1 Inlet Tank with Mixing Device and Inlet Pipe

In general, rectangular or square inlet tanks with one end truncated to accommodate the inlet pipe were constructed (refer to the photographs given below) in Pakistan in floating drum plants; while cylindrical or oval tanks with a mixing device were constructed in fixed dome plants. Bricks were used to construct base and walls, which were plastered with cement-sand mortar. Poly-ethylene, PVC or Reinforced cement concrete pipes of diameter ranging from 10 cm to 20 cm were used to convey feeding materials to the digester. The quality of workmanship involved in construction was satisfactory with some rooms for further improvements. None of the floating drum plant was fitted with mixing device. Quality of workmanship meets the required standards in majority of the cases and the finishing touch was at satisfactory level. Users have, on their initiative, used a wedge with handle to block the flow of slurry during mixing. In most of the cases in floating drum plants, the inlet tank is under-sized. The size of inlet tank needs to be adjusted to facilitate easy mixing of water and dung.

Photo 4.1: Inlet of Floating Drum Plant

Photo 4.2: Inlet of GGC Plant (big)

Photo 4.3: Inlet of GGC Plant (small)

4.1.2 Digester Attached with Gas Holder – floating steel drum or fixed concrete dome

It was not possible for the study team to verify the quality of construction and compliance of the design at the field by direct observation of the digester tank as it was filled with slurry. However, the exposed top portion of the round wall was observed to assess the quality of construction. A common defect observed in most of the floating drum plants was the relative positioning of MS drum and the inner-edge of round wall. May be because of the fact that the person who constructed the digester and the one who fabricated and installed MS drum were different, the relative positioning of these two structures were not perfectly maintained. This indicates the lack of standardization in one hand and need of effective training on construction in the other.

Cracks in digester wall were observed to be common problems in most of the plants. The users reported that the earthquake that devastated the entire northern region of the country in 2005 was also responsible for such cracks.

The thickness of steel sheet used to fabricate gas holder was less than the required. Thinner sheet is prone to leakage due to corrosion and lack of routine maintenance activity. The weight of drum made up of thinner sheet was less resulting in less gas pressure. 3 users complained that the gas holders were blown up especially in the morning necessitating them to add counter weights on top of the steel drums to counter-balance the gas pressure. Most of the users were seen to have added additional weight by placing loads on top of the steel drums as can be seen in the following photographs.

Photo 4.4: Load added on top of drum to build pressure. Drum is tied with the poles.

Rather than securing in position with the help of vertical shaft in the centre, which is a standard practice in floating drum plants, the MS drums are secured by clamping them in three vertical poles fixed in the digester walls (as shown in Photo 4.4 above). In most of the cases these poles and clamping were prone to damage. The shape of top of MS drum (spherical, conical, and flat) varied from one plant to the other.

Photo 4.5: Drum with Flat top

Photo 4.6: Drum with conical top

Photo 4.7: Drum with spherical top

One of the common defaults observed in GGC biogas plants was the absence of top filling over dome. Top-filling over dome is important to counterbalance the gas-pressure as well as to insulate the plant to minimise temperature fluctuations. Exposed surface of concrete is prone to temperature fluctuations that may lead to minute cracks endangering biogas leakage.

Photo 4.8: Exposed Dome

4.1.3 Gas Outlet Pipe

Gas produced in digester and stored in the gas holder is conveyed to the pipeline through a main gas outlet pipe. The position of this outlet pipe in MS drum varies – some has it in the middle and others have it in the edges. The gas outlet pipes are not fixed to the drum properly, and therefore, these gas pipes remain constantly at higher risk of sabotage.

The gas outlet pipes in fixed dome plants are properly secured with the construction of turret.

4.1.4 Outlet (Displacement Chamber) System

The fixed dome plants consists of a outlet tank, also referred to as displacement or hydraulic chamber, to provide necessary pressure to biogas flowing to point of application. The outlet system consists of an outlet opening known as manhole, a tank called outlet displacement chamber and overflow opening of suitable dimension at proper height in the outlet wall. The manhole is provided at a point diametrically opposite to the inlet pipe to avoid short-circuiting of feeding. This opening serves a number of purposes: as a manhole or gate for entry and exit of people during plant construction and maintenance, for emptying the digester for cleaning, for stirring the slurry using long pole or rod is case it forms scum in the top, and to facilitate the outward movement of displaced slurry due to gas accumulation in gas holder and inward movement of slurry from displacement chamber at the time of gas utilization so that there would be sufficient pressure for the gas to reach the points of utilization.

In majority of the cases, outlet tank were constructed at a raised ground to avoid inundation during rainy season and hence, outlet walls were exposed over the ground. In such cases, outlet walls were not property supported with compacted soils from outside to counter-balance the pressure of slurry exerted from inside. Outlet walls were susceptible to cracks in plants where such support was not provided. The quality of workmanship in general was good.

4.1.5 Slurry Pits (Composing Pits)

The slurry coming out of the outlet displacement chamber discharges into the slurry pit which is also known as storage or composting pit. This pit is very important to safeguard and add the nutrient value of the slurry coming out of the biogas digester. The size of such composting pit should at least be equal to the volume of the biogas digester. Two pits are preferable as it eases operation. The depth of pit should be kept minimal to avoid accidents. In majority of the plants, compost pits were not constructed. The slurry coming out of the displacement chamber was either conveyed to the near by watercourse (pond or stream) or left to flow here and there. Even in cases where slurry pits were constructed, the volume of pit was very small and composting was not done properly.

4.1.6 Pipeline and Fittings

The gas conveyance system in a biogas plant usually consists of main gas valve placed at the top of gas holder immediately after the main gas outlet pipe to control flow of gas to the point of application, a pipeline with required fittings, a water condensation system known as water outlet or water trap and gas taps to control flow of gas to gas stove.

Different types of main gas valves were in use as per their availability in the local market. In majority of the cases, local valves, typically manufactured to be used in water supply systems, were in use. Though gas valve is one of the important components in biogas plant, users in the surveyed plants were not aware of such importance. It is manifested by defects like gas leakage, broken knob, slipping handle etc. in the main valves. Majority of the owners (76%) reported that these valves usually remained open all day long and were not operated regularly.

Photo 4.9: Improper system of pipe lines to convey biogas to point of application

Gas from the gas holder was conveyed to the point of application through plastic pipe of 10 to 15 mm diameter. However, some of the users, especially in fixed dome plants have used GI pipe of ½” diameter. Plastic pipes in all the cases remained exposed over ground and were supported by wooden poles, houses or natural trees throughout its alignment like the electric or telephone cables. Pipes remained exposed to natural sunlight as they were hung from one tree to other. Continuous exposure to sunlight makes pipe more vulnerable to damage as pipe tends to become more brittle and tougher. There were higher risks of vandalism of pipeline in one hand and leakage of gas in the other. Most importantly, as the profile of pipe is not maintained with proper slope, condensed water tends to clog the pipeline and interrupt the flow of gas. One of the major drawbacks of pipe conveyance system in floating drum plants is the absence of water trap in the alignment. None of these plants was observed to have water trap. Likewise, gas taps have not been used in any plant to regulate the flow of gas to gas-stove. In general, the conveyance system in fixed dome plants was satisfactory where as it is poor and highly vulnerable to damages and vandalisms in floating drum plants.

Two users of the community biogas plant in DI Khan reported that they were encountering problem of slurry in pipelines. It was interesting that the problem was typically for these two users though there are other five more users receiving gas from the same pipelines.

4.1.7 Gas Stove and Gas Lamps

Locally manufactured gas stoves designed for LPG or natural gas were used even for biogas. Though slight modifications such as adjusting of gas jet were reported to be carried out, most of the stoves were not operating at desired efficiency. Problematic stoves were reported to be the main difficulty for the biogas users. Wide-spread damage of gas-regulating knob, heavy corrosion of the frame, clogging of burner holes and low pressure yellow flame with less calorific value were observed to be the main problems. These stoves lack primary air intake.

Photo 4.10: Different types of Biogas Stoves in use

Biogas lamp was reported to be installed in one of the households under study. However, it has now been taken out because of many problems such as breakage of glass cover, mantle and clay part. As most of the biogas plants under study were located in electrified areas, lighting was not the preferred choice of the users.

4.2 Condition of Biogas Plants

The existing condition of different components of biogas plant was observed in detail during the field investigation to assess the quality of construction, effectiveness of maintenance activities carried out and the operational status prior to categorizing them. The existing physical status of different components of biogas plant have been categorized in three different headings viz. good (functioning without defects), fair (defective but functioning) and poor (defective and not functioning) in qualitative manner, dependent on the physical observation of the plant made by the members of the study team during field investigation. The categorization has been made based upon the following indicators:

Table-4.1: Indicators for Categorization of Biogas Plants

Category	Indicators
Condition of Plant as a whole	
Good (functioning without defects)	• All the plant-components are constructed with good workmanship complying with the basic minimum quality standards • All the plant-components are operational without any technical problem • Location and relative orientation of plant components meet the basic minimum standards of site lay-out • Location of plant is managed in such a way that it is at reasonable distances from kitchen (point of gas application), water source, cattle shed and main access way.
Fair (defective but functioning)	• Plant-components are constructed with moderate workmanship. Plants are constructed without giving due attentions to the quality norms and standards • Plant-components are operational with one or more technical problems • Location and relative orientation of plant components do not meet the basic minimum standard of site lay-out, however, the non-compliance do not affect gas production seriously • Location of plant is either very near or reasonably far from kitchen (point of gas application), water source, cattle shed and main access way.
Poor (defective and not functioning)	• Plant-components are constructed with poor workmanship. Plants are constructed without giving due attentions to the quality norms and standards and in many cases it violets basic minimum standards • Plant-components are not operational and there are one or more technical problems • Location and relative orientation of plant components do not meet the basic minimum standard of site lay-out, and the non-compliance affect gas production seriously • Location of plant is quite far from kitchen (point of gas application), water source and cattle shed and vary near to main access way.
Condition of Inlet	
Good (functioning without defects)	• Constructed in firm ground and quality of construction meet the basic norms and standards usually adopted. The finished product reflects the work of a qualified mason. • The location of inlet pit is managed in such a way that the opening of inlet pipe to the digester is exactly placed in opposite side (at 180 degrees) of the manhole in fixed dome plants. • Inlet opening is placed in such a manner that inserting of pole or rod is possible to de-block the inlet pipe in case of some blockages • Height of pit facilitates comfortable mixing of dung and water • No cracks or other construction defects are visible • No technical problems that affect the functioning of the inlet seriously are encountered
Fair (defective but functioning)	• Constructed in firm ground however, the quality of construction violets one or more basic norms and standards usually adopted. The finished product reflects the work of a mason who is not trained properly to construct biogas plant. • The location of inlet pit is placed in such a way that the opening of inlet pipe to digester is not exactly in opposite side (at 180 degrees) of the manhole.

	• Inlet opening is placed in such a manner that inserting of pole or rod is not possible to de-block the inlet pipe in case of some blockages • Height of pit is either high or low which obstruct comfortable mixing of dung and water • Some cracks or other construction defects are visible • Some technical problems that affect the functioning of the inlet to some extent are encountered
Poor (defective and not functioning)	• Constructed in damage-prone ground and the quality of construction violets basic norms and standards usually adopted. The finished product reflects the work of a mason who lacks skills and knowledge to construct biogas plant. • The location of inlet pit is placed in such a way that the opening of inlet pipe to digester is placed very near to the manhole opening • Inlet opening is placed in such a manner that inserting of pole or rod is not possible to de-block the inlet pipe in case of some blockages • Height of pit is either very high or very low which obstruct comfortable mixing of dung and water • Serious cracks or other construction defects are distinctly visible • Technical problems that affect the functioning of the inlet seriously are encountered
Condition of Digester and gas holder: In the case of fixed dome plants, as the main structure remained underground, it was not possible to observe the quality of construction and construction defects in detail. Only physical observation of the exposed portion was possible. Indicators are selected which could be easily verified.	
Good (functioning without defects)	• Located in firm ground with no vulnerability of flood, land-erosion or other natural and manmade disasters • Enough top filling to safeguard the structures against damage. If plant is constructed above ground to minimize the risk of flood and higher water table, it is well protected from all side with stabilization measures. • The relative positioning of round wall and MS drum is perfect. • The MS drum is made up of thicker sheet – less prone to corrosion. • The drum easily moves up and down without any obstructions.
Fair (defective but functioning)	• Located in firm ground with little vulnerability of flood, land-erosion or other natural and manmade disasters • Not enough top filling to safeguard the dome against damage, some portion of the dome is exposed and the exposed portion does not illustrates signs of poor workmanship (distorted shape, minute cracks etc.). • If plant is constructed above ground to protect it form flood and higher water table, it is not properly protected from all side with stabilization measures. • The relative positioning of round wall and MS drum is not maintained. • The MS drum is made up of thinner sheet – prone to corrosion. • The vertical movement of the drum is not smooth.
Poor (defective and not functioning)	• Location of digester and dome is highly vulnerable to flood, land-erosion or other natural and manmade disasters • No top filling to safeguard the dome against damage, dome is exposed and the exposed portion illustrates signs of poor workmanship (distorted shape, minute cracks etc.). • If plant is constructed above ground to protect it form flood and higher water table, it is not protected from all side with stabilization measures • The relative positioning of round wall and MS drum is very poor. • The MS drum is made up of very thin sheet – extremely prone to corrosion. • The vertical movement of the drum is very difficult.
Condition of Outlet (displacement chamber) only for fixed dome plants	
Good (functioning without defects)	• Located in firm ground with no vulnerability of flood, land-erosion or other natural and manmade disasters • Outer sides of the walls are supported properly with compacted soil or stabilization measures to counter-balance the pressure of slurry and walls do not have any cracks or defects • Protected with good covering • Outlet opening is located in such a manner that there are no chances of flood water entering into the outlet chamber in case of water logging • Outlet opening facilitates the flow of slurry easily to the composting pit • The relative orientation of the plant suits with the engineering requirements
Fair (defective but functioning)	• Located in firm ground, however, it is vulnerable to flood, land-erosion or other natural and manmade disasters • Outer sides of the walls are not properly supported with compacted soil or stabilization measures to counter-balance the pressure of slurry and walls have minor cracks or defects • No covering is provided • Outlet opening is located in such a manner that there are chances of flood water entering into the outlet

	chamber in case of water logging • Outlet opening is partially blocked with dried slurry or other obstructions that hinders easy flow of slurry to the composting pit • The relative orientation of the plant do not suits with the engineering requirements, it is distorted or adjusted to suit with the site condition compromising the quality
Poor (defective and not functioning)	• Location is highly vulnerable to flood, land-erosion or other natural and manmade disasters • Outer sides of the walls are not supported with compacted soil or stabilization measures to counter-balance the pressure of slurry and walls have major cracks or defects • No covering is provided, there is high risk of animal and children to fall in the chamber • There are high chances of flood water entering into the outlet chamber in case of water logging • Outlet opening is blocked with dried slurry or other obstructions that interrupt flow of slurry to the composting pit • The relative orientation of the plant violets the engineering requirements, it is distorted or adjusted heavily to suit with the site condition compromising the quality
Condition of Main Gas Valve	
Good (functioning without defects)	• Good quality gas valve is used, which is functioning trouble-free without any gas leakages • Gas valve is fitted at right place in the pipeline and is protected against further deterioration or damages • Gas valve is easy to operate and regular greasing/oiling is done
Fair (defective but functioning)	• Locally available moderate quality gas valve is used, which is functioning without any gas leakages • Gas valve is not fitted at the right place and is not protected against further deterioration or damages • Gas valve is either tight or too loose to operate and regular greasing/oiling is not done
Poor (defective and not functioning)	• Locally available gas valve is used, which has one or more technical defects (gas leakage, broken knob, slipping handle etc.) • Gas valve is not fitted at the right place and is highly vulnerable to deterioration or damages • Gas valve is very difficult to operate and greasing/oiling is not done at all
Condition of Pipeline	
Good (functioning without defects)	• Gas pipeline is aligned in such a way that the length is minimized • Either GI pipe of 15mm diameter or good quality plastic pipe of diameter more than 20mm is used • Pipes are buried under ground at right depth to protect them from vandalism and further damages • Minimum fittings are used and the joints are properly sealed off
Fair (defective but functioning)	• Gas pipeline is not aligned through the shortest route rather another route is followed • Flexible plastic pipe with diameter less than 20mm is used. • Pipes are aligned over-ground and remain hanging from one tree to other or one pole to other or one house to other at considerable height from ground level • There are high risks of pipe vandalism and damages • There are numbers of joints along the pipe alignment • Even with one or more of these defects, pipeline is functioning
Poor (defective and not functioning)	• Gas pipeline is not aligned through the shortest route rather zigzag and longer route is followed • Flexible plastic pipe with diameter less than 20mm is used. • Pipes are aligned over-ground and remain hanging from one tree to other or one pole to other or one house to other at lower height from ground level. • Pipes are damaged or vandalized along its alignment • Leakages are observed along the pipeline • Pipeline is not in operation due to one or many of these defects
Condition of Gas Stove	
Good (functioning without defects)	• Gas stove is operating without any trouble and there are no pending maintenance works • The stove burns with blue flames and at adequate pressure • Burner rests on firm metal frame free from rust
Fair (defective but functioning)	• Gas stove is operating but there are one or few pending maintenance works • One of the burners in double burner stove does not work • The stove burns with blue flames and at low pressure • The burner holes are clogged and the metal frame has rust in it
Poor (defective and not functioning)	• Gas stove is not operating and there are few pending maintenance works • The stove burns with yellow flames and at low pressure • The burner holes are clogged and the metal frame has rust in it
Condition of Gas Lamp	
Good (functioning without defects)	• Gas lamp is operating without any trouble and there are no pending maintenance works • The lamp burns with bright light and at adequate pressure

	• The metal frame is free from rust
Fair (defective but functioning)	• Gas lamp is operating without but there is one or more pending maintenance works • The lamp burns with relatively deem light and at low pressure • The metal frame has rust
Poor (defective and not functioning)	• Gas lamp is not operating and there are one or more pending maintenance works • The lamp does not burn at all • The metal frame has heavy dust
Condition of Slurry Pit	
Good (functioning without defects)	• Two slurry pits with capacity at lease equal to the volume of digester are constructed at a reasonable distance from the outlet overflow • Slurry in the pit is mixed with other organic material as composts • Slurry pit is covered with shades to avoid direct sunlight over it
Fair (defective but functioning)	• Only one slurry pits with smaller dimensions is constructed at a reasonable distance from the outlet overflow • Slurry in the pit is not mixed with other organic material as composts • Slurry pit is not covered with shades to avoid direct sunlight over it
Poor (defective, not functioning)	• Either slurry pit is not constructed or pit is too small to accommodate the quantity of slurry flowing into it • Slurry flows elsewhere around the pit

The following table shows the categorization of general condition of biogas plant and its components based upon the above-mentioned criteria.

Table-4.2: General Physical Condition of Biogas Plants

Plant Component	Plant under study different category		
	Good (functioning without defects)	Fair (defective but functioning)	Poor (defective and not functioning)
	Nos.	Nos.	Nos.
Biogas Plant as a whole	7	23	8
Inlet tank	5	24	9
Digester and dome (gas holder)	11	19	8
Outlet (displacement chamber)[3]	8	2	
Pipeline	12	18	8
Main gas valve	4	23	11
Gas lamp[4]			1
Gas stove	8	22	8
Slurry pit	3	11	24

It is evident form Table-4.2 that there are lot of rooms for further improvements in biogas plants and their components. The poorest component was observed to be the slurry pit as 63% of the pit falls under poor category. One of the striking facts is that the users' did not bother to repair and maintain the MS drum once it encountered leakage, rather abandoned or dismantled the plants. The plants were dismantled and MS drums were taken out to sell to scavengers in three cases. One of the users was busy in developing the biogas plant as a recreational fountain after taking out the MS drum and refilling the digester pit.

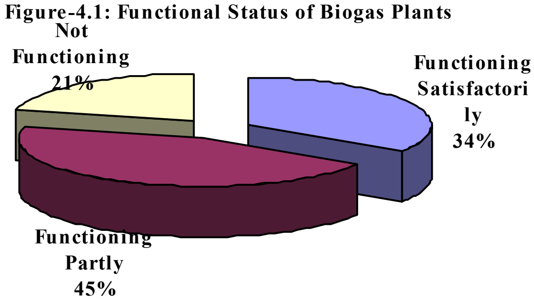
Photo 4.11: Different Conditions of Non-operational Biogas Plants

[3] Applicable only to 10 fixed dome plants
[4] Only one lamp installed

4.3 Functional Status

The outcome of the study indicated that despite number of defects and weaknesses, the functional status of biogas plants on an average was satisfactory. Out of the 38 plants under analysis, 13 (34%) plants were functioning satisfactorily, 17 (45%) plants were functioning partly and the remaining 8 (21%) plants were not functioning at all during the time of field investigation. The following pie-diagram illustrated the functional status of biogas plants under study:

Figure-4.1: Functional Status of Biogas Plants



Out of the 8 defunct plants, 3 were not functional for the last 3 years, 2 for 2 years, 1 for one year, and the remaining 2 for less than a year. The reasons for non-functioning as reported by the respondents were[5]:

- Plants were abandoned because of migration of whole family members: 3 cases
- Problem of foul odour in kitchen and difficulty in mixing dung and water (considered to be unhealthy) leading to abandoning of plant and switching back to LPG (well-off farmer)-1 case
- Technical cause (the drum never came up!!) – 1 case
- Leakage in steel drums – 6 cases

The following reasons were also reported by the users which contributed to failure of their biogas plants.

- Lack of proper training to users on operation and maintenance (5 users)
- Poor workmanship during construction (4 users), no supervision during construction (4 users)
- Sub-standard quality of construction materials and appliances (3 users)
- Non-availability of repair and maintenance services/lack of follow up services (3 users)
- Difficult to carry out repair works (Steel drum too heavy) (3 users)

As the users claimed the lack of effective training on O&M to be one of the major reasons for the plant failure, attempt was made to assess the relationship between the types of training received and functional status of biogas plants. The following table shows the outcome.

Table-4.3: Relationship between Training Received and Functional Status of Plant

Type of Training Received	Functional Status of Plant (No of Plants)			
	Not Functioning	Partly Functioning	Functioning Satisfactorily	Total
No training received	8	7	4	19
Training not provided but leaflet/booklet/manual provided		1		1
On the spot instructions from mason/company supervisors etc		9	5	14
Short term O & M training (7days or less)				0
Long term O & M training (more than 7 days)				0
Short Training provided by other NGOs (not the service provider)			4	4
Total	8	17	13	38

[5] Some respondents whose plants do not function gave more than one reasons

It is apparent from Table-4.3 that training received and functional status of biogas plant have direct relationship. For example, the users in all the 8 biogas plants that were not functioning did not receive any training.

Likewise relationship between quantity of feeding received and functional status of biogas plants has been shown in Table-4.4.

Table-4.4: Relationship between Quantity of Feeding and Functional Status of Biogas Plants

Quantity of Feeding Received (% of prescribed quantity)	Functional Status of Plant (No. of Plants)			
	Not Functioning	Partly Functioning	Functioning Satisfactorily	Total
Less than 20%	6	2	0	8
<20% but >40%	2	13	1	16
<40% but >60%	0	2	1	3
<60% but >90%	0	0	6	6
More than 90%	0	0	5	5
Total	8	17	13	38

As shown in Table-4.4, all the 8 non functional plants received less than 40% of the prescribed feeding. Likewise, 11 out of 13 plants that are functioning satisfactorily received more than 60% of the prescribed feeding. The outcome indicated that the quantity of feeding and functional status of plant have direct relationship.

4.4 Efficiency of Biogas Plant

Attempts have been made to assess the efficiency of biogas plants. Efficiency of biogas plant is the ratio of input to output. Cattle dung added into the biogas plant have been considered as input and gas produced per day as a result of anaerobic digestion in the digester is the output. The amount of gas being produced was estimated from total burning hours of gas stove installed therein. While calculating the gas production, it is estimated that one kg of dung produces 40 litres of gas and one biogas stove consumes 350 litres of gas per hour (keeping in view the lower gas pressure). In totality, the theoretical amount of gas production from all the biogas plants under study based upon the daily feeding is 57.8 cum of biogas per day. Total biogas production based upon the gas being used is 40.8 cum per day. The calculated **performance efficiency** of biogas plants collectively is, therefore, 70%. All the 10 fixed dome plants had efficiency more than 95%. The average efficiency of floating drum plants was 58%. However, when viewed form the overall size of biogas plant (an average of 4.7 cum gas production/day), the efficiency of biogas plant is only 26%.

The lower input to output ratio of floating drum plants suggested one or more of the following facts:

a. **The feeding material fed into the digesters was not fully digested and escaped out of the plant prior to its full digestion either because of short-circuiting (as a results of dead volumes in digester-floor) or higher water-dung ratio in the feeding.** The likelihood of this fact is low viewing the lesser quantity of feeding in the digester. The digesters were receiving only 36% of the dung required theoretically. The water-dung ratio was also correct in 65% of the plants.

b. **The produced gas was not stored in the gasholder, rather escaped in the atmosphere because of leakages in steel drums.** The probability of this statement is high, given the lack of routine maintenance of steel drums. All the users replied that the drums were not painted to protect them against rusting. Given the age of drums more than 4 years in 47% of the cases, the likely happening of this hypothesis could not be ruled-out.

c. **The weight of the mild-steel drum (gas storage tank) was less which resulted in lifting of drum beyond the slurry level in the digester because of more upward pressure of biogas than the downward force exerted by the weight of drum.** The chance of gas escape because of the hanging drum is high viewing the thickness of the drum. The responses of 3 users substantiate this hypothesis who told that the drums were blown up especially in the morning necessitating them to add counter weights on top of the steel drums to balance the gas pressure.

d. **Biogas produced in the digester was not conveyed to the point of application efficiently because of the technical and operational defects in various components of biogas plant.** The possibility of this assumption is high given the condition of biogas plant and its components in majority of the cases. There are lots of rooms for further improvements in the gas conveyance and utilization systems of the plant especially in pipelines and appliances. Problem with main gas valve, leakages in pipeline, water accumulation in pipe due to absence of water outlet, leakages from stove, absence of gas tap to control and regulate flow of gas to gas stove, and low efficiency of stove especially due to defective operating knobs, absence of primary air-intake and clogging of burner-holes; are some of the issues that might have resulted in lesser burning hours of gas stove.

e. **The total burning hours of gas stove and lamp were reported wrongly by the users.** This statement, though probable, will have not much significance on affecting the efficiency of plant as the variation on burning hours would not be much given different triangulation methods used to verify the responses of the users.

The following table illustrates the efficiency of various types of biogas plant under study based upon the quantity of gas production as per actual feeding and actual quantity of gas being used.

Table-4.5: Efficiency of Biogas Plants

Efficiency of biogas plant	Type of Biogas Plant			
	Floating drum	Fixed dome	Plastic	Total
Nil (No gas production)	7	0	1	8
Less than 20%	3			3
>20% but < 40%	4			4
>40% but < 60%	9			9
>60% but < 80%	3			3
>80% but < 90%	1			1
More than 90%		10		10
Total	27	10	1	38

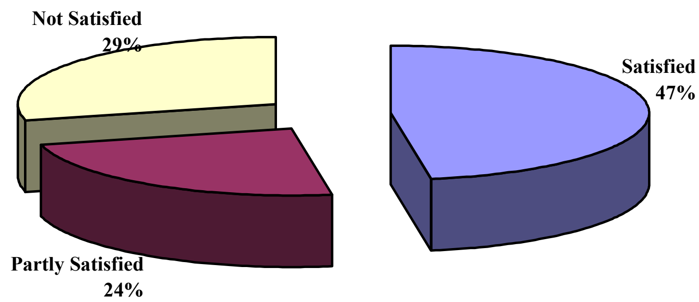
It can be seen from Table-4.5 that in most of the cases with floating drum plants (23 plants out of 27) actual amount of gas production is less than the expected, which indicates lower efficiency of plants (58%). Interestingly, all the 10 fixed dome plants had efficiency more than 90%.

4.5 Users' Perception

4.5.1 Perception on Plant Performance

The respondents were encouraged to evaluate the performance of their plants by asking various direct and indirect questions. There responses have been analyzed carefully to come to a conclusion on whether the respective users' were satisfied with the output from and impacts of their plants on them. On being asked if they were satisfied with the functioning of their biogas plants, 18 (47%) responded that they were satisfied, 9 (24%) responded that they were partly satisfied and the remaining 11 (29%) respondents responded that they were not satisfied.

Figure 4.2: User's Level of Satisfaction



The reasons for full satisfaction were reported to be:

- Easy cooking/lighting (15 hhs)
- Less work to make dung cake/collect firewood (15hh)
- Enough gas for cooking (13 hhs)
- Nutrient fertilizer (12 hhs)
- Economic benefit (9 hhs)
- Health benefits (4 hhs)
- Environmental Benefits (2 hhs)
- Trouble free functioning of plant (2 hh)
- Workload reduction/time saving (2 hh)

The reasons for not satisfying were:

- Not enough gas during winter (11 hhs)
- Not enough gas through out the year (10 hhs)
- No gas production from the plant (8hhs)
- Non-availability of maintenance services (5hh)
- Substandard quality of construction materials and appliances (4 hh)
- Poor quality of construction (3 hhs)
- More added works (1 hhs)

It was attempted to examine if there was any correlation between the efficiency of biogas plant based upon the actual gas being received as described in heading 4.4 above, and the level of users' satisfaction as responded by them. The results of analysis have been illustrated in Table-4.6 below:

Table-4.6: Relationship between User's Satisfaction and Plant Efficiency

Efficiency of Plant	Users' Level of Satisfaction			Total
	Not Satisfied	Partly satisfied	Satisfied	
Nil (No gas production)	8			8
Less than 20%	1	1	1	3
>20% but < 40%	1	3		4
>40% but < 60%		4	5	9
>60% but < 80%	1	1	1	3
>80% but < 90%			1	1
More than 90%			10	10
Total	11	9	18	38

It is clear from Table-4.6 that users directly relate their level of satisfaction with the efficiency of biogas plant. All the 8 plants whose efficiency is nil responded that they are not at all satisfied with the functioning of their plants. Interestingly, one of the users was satisfied with the performance of his plant despite its efficiency less than 20%. It is because of the realization of the user that the plant is not functioning because of the less feeding from their part. In contrary, 1 respondent whose plant is functioning with more than 60% efficiency was not satisfied with his/her plant.

Users' satisfaction is also reflected in their answers to the question on whether they will advice others to install biogas plants in which 94% have replied in positive. Only 2 users told that they will not advice others to install biogas plant. The main reason mentioned for not advising others to install biogas plant was reported to be the non-functioning of their plants.

Interestingly, two of the users whose biogas plant was not functioning during the time of field survey reported that he would not like to adapt the technology again even if new designs are introduced. The others told that they would prefer new designs than floating drums.

4.5.2 Perception on Merits and Demerits of Biogas

Users were also asked to mention three main merits and demerits of biogas plants based upon their experience with the technology. Weights were then allocated according to the number of responses. The highest was given 5 points while subsequent two answers were allocated 3 points and 1 point each. The result of analysis has been summarized in the following table.

Table-4.7: User's Perception on Merits of Biogas Plant

Merits	Score
Easy and comfortable cooking	85
Avoids difficult tasks of collecting fuel wood and preparing dung cakes	82
Saves time and reduces workload	78
Health benefits	74
Nutrient rich fertilizer	73
Economically beneficial	64
Fuel saving	58
Comfort in cleaning cooking vessels	55
Environment friendly/Protection of forest	50
Helps to enhance quality of rural life	47
Utilizes waste materials	46
Easy to handle/operate	42
Readily available cooking fuel	38
Eliminates the problem due to wet-firewood during rainy season	32
Clean kitchen and cooking environment	21
Encourages livestock development	19
Enhances prestige in society	12
Safe to use	9
No need of storage place for firewood	5

Similar scores were given to the demerits of a biogas plants. The following table shows that result of analysis.

Table-4.8: User's Perception on Demerits of Biogas Plant

Demerits	Mean
Not suitable for cooking chapatti (bread)	62
Not suitable for bigger cooking vessels	57
Less gas during winter	42
Gas finishes when cooking	38
Tension due to problematic components	32
Smells bad due to gas leakage	12
Mixing of dung and water is unhealthy	8
Maintenance difficult	8
Socially not acceptable	6
High investment cost	6
Less tasty food	3

The respondents rated easy and comfortable cooking, liberation from difficult task of firewood collection and making dung cakes, time saving and workload reduction, nutrient rich fertilizer, health improvement and nutrient rich bio-fertilizer as main merits, while non-suitability of biogas stoves to cook chapati, and accommodate bigger cooking pots, significant reduction of biogas during winter, tension due to problematic components of biogas plants, foul smelling in kitchen when gas leaks, cumbersome and unhygienic process of mixing dung and water to be the main demerits of biogas technology.

4.5.3 Suggestions for Future Program

The respondents were encouraged to give suggestions for the effective implementation of future biogas program in the country based upon their experience with biogas technology. The responses received from them were:

a. Increase subsidy to benefit the poorer section of communities (17)
b. Introduce methods to increase gas production during winter months (15)
c. Change the existing design and introduce more users friendly models (14)
d. Provide training and orientation to users on operation and maintenance of biogas plant (12)
e. Improve the quality of biogas stove (11)
f. Ensure proper site selection for the construction of plant for the safe disposal of slurry (8)
g. Select only households having enough land to use bio-slurry while installation of biogas plants (8)
h. Launch promotional activities to aware the people on importance and benefits of biogas plant (5)
i. Introduce facility to produce electricity from biogas (5)
j. Establish service centres/formulate effective maintenance mechanisms (4)
k. Reduce the cost of installation (4)
l. Make provision of mixture device in inlet tank (4)
m. Introduce biogas plants that can be shared by 2 or more families (4)
n. Avail credit facilities for the potential users (4)
o. Encourage users to construct two slurry pits compulsorily (3)
p. Use iron pipe instead of plastic gas pipe (2)
q. Increase the size of plant/gasholder (2)
r. Make arrangements to store biogas in cylinder (2)
s. Commercialize the biogas plant with the introduction of community/institutional plant (2)
t. Decide installation and size of plant based upon available feeding materials (1)
u. Install plants according to family size (1)

v. Improve construction quality and workmanship (1)
w. Improve the quality of main gas valve/use good-quality valves (1)

The responses as summarized above indicated that the users perceive subsidy as one of the motivating factors for the promotion and extension of biogas technology. They also strongly pointed out the need for effective training on operation and maintenance as well as proper after-sale services.

5. IMPACTS OF BIOGAS ON USERS

5.1 Impacts on Time Saving and Workload Reduction

5.1.1 Cooking

The finding of the field investigation indicated that biogas plants have positive impact on reduction of time for cooking household meals. Maximum, average and minimum time-savings after the installation of biogas plant were reported to be 1.5 hours, 50 minutes and 25 minutes per day respectively. Interestingly, two households were found to have incurred more time for cooking after they started using biogas. The reason for added time was reported to be the cooking in single burner stove that took longer hour than the twin-mouth conventional firewood kiln previously in use. Among the 30 households whose plants were operational, 4 households reported that they did not experience any time saving. However, 8 households saved time in the range of 15 min to 30 minutes, 9 households saved 30 min to 1 hour and the remaining 9 households saved more than 1 hour per day.

5.1.2 Collection of Water

It was observed that collection of additional quantity of water to mix dung and water to feed into biogas plant was not a problem for all the households as water sources especially the hand pumps were readily available in the courtyards of the biogas households. The maximum distance of water source from the biogas plant was not more than 45 meter. Water source was available within 10 m in 12 households, within 10-20 m in 14 households and within 20-45 m in the remaining 4 households. 22 households experienced a slight increase in total time allocated to collect water after the installation of biogas plant. The added average time has been calculated to be 8 minutes/households/day, which was not that significant.

5.1.3 Plant Feeding

Mixing of dung and water is an added work to be carried out each day. In an average, one household was reported to need 15 more minutes to carry out this task. 3 households complained that the work of mixing dung and water to feed into the biogas plant was unhygienic and cumbersome task.

5.1.4 Collection of Fuel

Firewood, dried dung cakes and agricultural wastes especially cotton stalk, maize stalk and remains of fodder, were reported to be the main conventional fuel sources used in the biogas households for cooking. Some households used LPG (9 hhs) for this purpose. Most of the households (82%) who used firewood for cooking before the installation of biogas plant collected fuel wood from their own lands. 6% bought it from market or mobile vendors, 12% hh collect it from both the sources. When asked if they have experienced any changes in allocated time to collect fuel before and after the installation of biogas plants, 7 of them replied that there was no difference while the remaining experienced decrease in time. The total time saving per household per day ranges from 24 min to 65 minutes, with an average of 40 minutes.

5.1.5 Cleaning of Cooking Vessels/Utensils

All the 30 respondents reported that they have experienced a significant duration of time saving to clean cooking vessels in absence of black soot that used to be a major problem while cooking food using fuel wood. The time saved to carry out this task ranged from 20 minutes to 1 hour depending upon the number of family members and types of food being cooked. The average time saving in this case was reported to be 31 minutes/household/day.

5.1.6 Caring of Animals

When asked if the users have felt any difference in time allocated for cattle care before and after the installation of biogas plants, majority of the respondents (26 out of 30) replied that they did not experienced any changes. According to the remaining 4 respondents, more time was needed to care cattle because they are now forced to stall-feed the cattle to produce more dung to feed into the digester. Such added time ranged from 15 minutes to 30 minutes, the average being 3 minutes/hh/day, which is quite insignificant.

5.1.7 Summary on Time Saving

Besides the above-mentioned six activities related to biogas plant, users did not feel any difference in allocated time before and after the installation of biogas plants. The total time saving after the installation of biogas plants as responded by the users has been summarized in the following table.

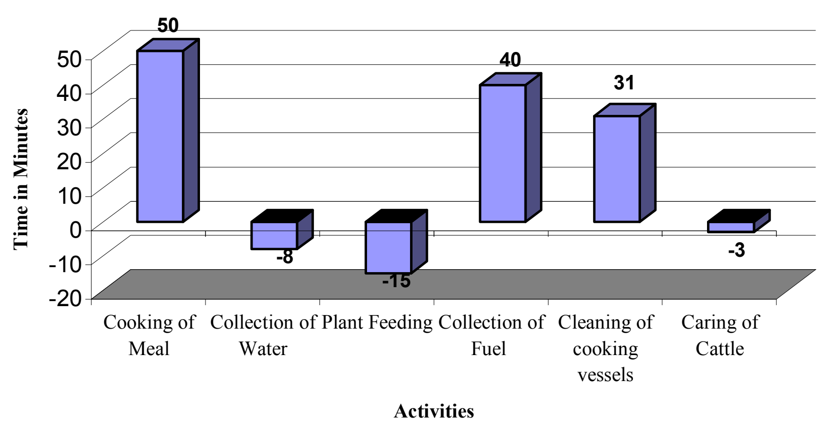
Table-5.1: Time Saved after the Installation of Biogas Plant

Activity	Average time saving/min/day*
Cooking of Meal	50
Collection of Water	(8)
Plant Feeding	(15)
Collection of Fuel	40
Cleaning of cooking vessels	31
Caring of Cattle	(3)
Average time saving	95 minutes (1 hour 35 minutes)

** Numbers inside bracket indicated time added*

The following figure illustrates the graphical representation of the time being used in various biogas related activities by the biogas households under study.

Figure-5.1: TIme Used for Biogas Related Activites



The findings of the study therefore revealed that, in general, a family saved an average of 1 hour 35 minutes per day as a result of biogas plant. The study also discovered that rural women, who are mainly responsible to carry out much of the biogas related activities as mentioned above, rarely have an opportunity to decide themselves what to do with the saved time. In subsistence agricultural economics like in Pakistan, time was reported to be reallocated to other activities that benefited the family unit and it is within this unit that those choices are made. Whether biogas reduced the drudgery, therefore, is debatable. What is done is that they substituted the drudgery of firewood collection, cooking in smoke-filled environment and cleaning vessels with black soot, for activities that helped in producing economic gain for the family. Even though majority of the respondents agreed that there was considerable time saving from biogas plant installation, none of them was in a position to say exactly how much additional financial earnings they made out of that or how much drudgery they reduced.

5.2 Impact on Saving of Conventional Fuel Sources

Saving in the quantity of cooking fuel is directly an economic benefit of biogas plant to the concerned household. Theoretically, based on effective heat produced, a plant producing 2 cum of biogas each day can replace about 270 to 300 kilograms of firewood per month depending upon its quality. In monetary values, if the quantity of gas is used to replace fuel wood, it saves Rs.810 to Rs.900 per month. The field finding revealed that 40.8 cum of biogas is produced by the operational plants under study per day. This saves about 200 kgs of firewood per day. The average saving of firewood was therefore 2433 kg/year/hh which results in monetary saving of Rs. 7299.

The study attempted to assess the quantity of conventional fuel used in the biogas households before and after the installation of biogas plant. The findings have been summarized in the following tables.

Table-5.2: Saving of Conventional Fuel after the Installation of Biogas Plant

Particulars	Quantity used before the installation of biogas plant	Quantity used after the installation of biogas plant	Saving/deficit
Firewood			
Average quantity used per hh/day	4.68	1.6	3.08
Liquid Petroleum Gas			
Average quantity used per hh/day	0.13	0.02	0.11
Dried Dung Cake			
Average quantity used per hh/day	3.9	0.9	3
Agricultural residues			
Average quantity used per hh/day	2.72	0.9	1.82

Based upon the quantity of saving of conventional fuel sources, yearly monetary saving because of the use of biogas has been given in the following table.

Table-5.3: Financial Gain from Saving of Conventional Fuel

Conventional Fuel	Quantity use and saving (kg/year/hh)			Average cost in Rs./kg	Total Saving in Rs./hh/year
	Before	After	Saving		
Firewood (kg)	1709	584	1125	3	3375.00
LPG (kg)	47	7	40	48	1920.00
Dried Dung (kg)	1424	329	1095	1.6	1752.00
Agricultural residues (kg)	993	329	664	1.4	929.60
				Total	**7976.60**

Average financial saving from biogas plant was calculated to be Rs. 7976.6 per year/household, which a significant amount. The maximum saving was reported to be Rs. 23140, where as the minimum was Rs. 240. The following table shows the financial saving in the biogas households under the study.

Table-5.4: Financial Saving in Biogas Households

Amount saved (in RS.)/month	No of HHs	% of HHs
Zero saving	8[6]	14
Saving less than RS. 500	1	7.5
Saving RS. 501 to 1000	2	44
Saving RS. 1001 to 1500	1	27
Saving RS. 1501 to 2000	1	27
Saving RS. 2001 to 5000	9	27
Saving More than 5000	16	6
Total	38	100

Table-5.4 clearly points out that all the biogas households whose plant is operational are experiencing financial benefit from biogas plants. Responses of all of the respondents mentioning that they experienced tangible financial benefit from biogas plants is encouraging in a situation that people often tend to overlook such gain because of the fact that biogas plants do not earn cash rather it only saves cash. This response also justifies validity of the calculation on financial benefits as shown in Table-5.3.

The responses of users on being asked if they have experienced any advantages of biogas over other conventional fuel sources have been summarized in the following table:

Table-5.5: Advantages of Biogas over Conventional Fuel Sources

Response	**% of respondents[7]**
Comfortable and easy cooking	79.4
Time saving/fast to cook	70.6
Environment friendly (no smoke)	61.8
Less costly	52.9
Better taste of food	41.2
Less heat while cooking (temperature in kitchen is not increased)	38.2
No ash and firewood in kitchen	32.4
Suitable in rainy season when firewood gets wet	26.5
More advanced and energy efficient	23.5
Anybody can cook/no need of constant blowing and less risk of burns	20.6
No need of constant care during cooking (other works can be done while cooking)	14.7
Prestigious cooking environment	5.9

Table-5.5 indicated that the users considered comfortable cooking, time saving, smoke-free cooking environment, reduction in expenditure and time saving to be the most advantageous things of cooking in biogas.

Among the few disadvantages mentioned by the users, not suitable for cooking chapatti and big-feast, (41.2%), problematic when biogas finishes in the middle of cooking (20.6%) problematic stove that adds

[6] Households with non-functional plants
[7] Respondents had more than one answer

tension during cooking (14.7%), bad smell in the kitchen when gas escapes (12%) and negative attitude of people on gas from dung (3%) were the major ones.

5.3 Impact of Bio-slurry

Biogas slurry when composed, stored, handled and applied properly is considered to be of high nutrient value. It is well-recognized fact that the economic benefit of biogas technology is greatly increased if the slurry bi-product is used effectively on farms. During field investigation process, it was observed that 63.33% users were using bio-slurry in one or other ways; where as the remaining 36.67% were not using it. Majority of the users (82%) who did not use the slurry drain it directly to surrounding areas or watercourses. Draining slurry to the watercourse means that the farmers are loosing nutrient fertilizer in one hand and in the other excessive accumulation of slurry in watercourse expedites the process of eutrification, which is environmentally hazardous. Among those who did not use slurry, 70% of them reported that they do not have arable land to use it. Slurry was not coming out of the plant in the case of the remaining 30% of the users.

Users who used slurry on farm reported that it is of high nutrient value than the farmyard manure. The use according to them were: use as organic manure without composting (65%), convey slurry directly to irrigation channel (15%), both of the above (10%), use as manure without composting as well as use to make dung cake for selling (10%). Though the users expressed their views that the production of crop has increased after the use of bio-slurry, they could not exactly quantify the increment.

Photo 5.1: Unused-bioslurry vs. proper use of bioslurry through irrigation canal

Bioslurry has been found to be beneficial in replacing the use of chemical fertilizers. Among 29 households under analysis, 15 (52%) did not experience any saving of chemical fertilizer and the remaining 14 (48%) reported that they saved considerable quantity of chemical fertiliser by replacing it with bioslurry. As responded by the user, the saving of fertilizer varies from 25 kg per year to 450 kg per year, the average being 52 kg per year per household. Therefore, a biogas household saved Rs. 780 per year. Reduction in fertilizer not only saves money spent to purchase it but also helps to safeguard soil fertility.

6. FINANCIAL AND ECONOMIC ANALYSIS

6.1 Financial Analysis

Financial analysis is the most commonly used tool that helps to decide whether a user benefits from installation of a biogas plant and, if so, by how much. The basic underlying assumption of financial analysis is that people will adopt a new technology only if they expect to have a positive impact in their financial situation. In financial analysis for biogas plants in the present case, all costs and benefits are valued from the point of view of the users.

Benefits and costs of biogas plant will vary depending upon the use of inputs and outputs by the particular user. For the present purpose rather than analysis the costs and benefits at the individual user's level, an average values as calculated based upon the outcome of field investigation have been used.

The financial analysis of different sized biogas plant under study has been done with the following major assumptions:

- Though a biogas plant lasts for more than 30 years depending on the quality of construction materials and workmanship, the economic life span period of biogas plant was taken as 10 years mainly because any cost and benefit accrued after 10 years will have insignificant value when discounted to the present worth.
- Cost of construction of biogas plant was based upon the responses from the users under study and different costs are summed up to calculate the average cost per plant
- Operation and maintenance cost has been taken as per the actual amount spent by the users as responded during the field investigation. Operation and maintenance costs are taken to be Rs. 1680 and Rs. 306 as per the calculation based upon the responses from the users.
- Annual income from plant included saving on conventional fuel sources and saving on chemical fertilizer because of the use of bio-slurry. The saving of time because of the installation of biogas plant was not considered as no evidence was found to justify that the time is used in other income generating activities. Moreover, it did not include added nutrient value of slurry and other health, social or environmental benefits. The relationships between the quantity of gas produced, the quantity of conventional fuels saved and the value of such savings for different plant sizes were based on the following assumptions:
    - 0.040 cum of gas was produced per kg of fresh dung
    - 1 cum of gas was equivalent to 4.5 kgs of firewood given the quality of firewood used in Pakistan
    - The cost of fuel was the average of all the cost as responded by the users which is Rs. 7976.60 per plant per year for average plant capacity of 5 cum gas production per day as calculated based upon size of sampled plants.
    - Saving in chemical fertilizer because of the use of slurry was Rs. 780 per household per year
- The salvage value of biogas plant was not included in the benefit stream of financial analysis because after 10 years of operation, the plant or its parts will not be re-saleable.
- All investment costs for the plant were assumed to be expended in the first year and all maintenance costs and all resulting benefits were assumed to be constant over the 10 years life of the plant.

In such calculation, quantity of conventional fuels saved has been taken into consideration not the value of total gas produced as equivalent to the cost of fuels. The following tables show the financial analysis of the average size of 5 cum gas production per day.

Table-6.1 : Financial Analysis (At the reported cost of Installation)

Parameters	Floating drum plant (5 cum gas production/day)		Fixed Dome Plant – 6 cum overall volume; 2 cum gas production/day	
	Without subsidy	With subsidy	Without subsidy	With subsidy
FIRR in %	19	39	29	42
NPV in Rs.	8125	19285	14755	20112
B/C Ratio	1.79	2.4	2.1	2.46

The financial analysis done above was based on the existing cost of installation of biogas plants incurred at the year when these plants were installed. As mentioned earlier, some of the plants are more than seven years old. The cost of installation, therefore, will increase to a significant amount if it is to be considered at present value. Moreover, the cost of installation is expected to increase if plants are constructed to meet the anticipated quality of construction. For example, thicker MS sheet to fabricate gas holder, gas taps, water trap and systematization of pipelines etc. will add certain cost. It is therefore anticipated that the increase in cost of plant will be 20%. The subsidy has been assumed to be Rs.6000 in both the cases. The following table shows the result of financial analysis based on the increments is cost of installation.

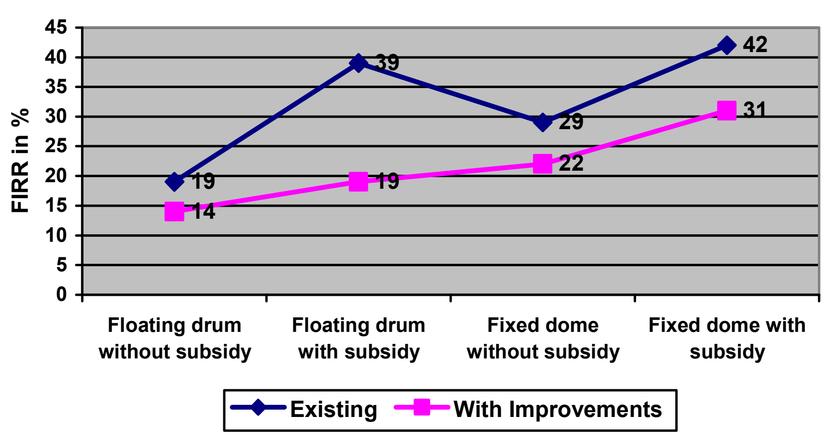
Table-6.2: Financial Analysis (At Added cost for Quality Improvement Options)

Parameters	Floating drum plant (5 cum gas production/day)		Fixed Dome Plant – 6 cum overall volume; 2 cum gas production/day	
	Without subsidy	With subsidy	Without subsidy	With subsidy
FIRR in %	14	19	22	31
NPV in Rs.	2870	8228	10826	16183
B/C Ratio	1.6	1.8	1.9	2.19

The FIRR of biogas plants calculated based upon the cost of installation was above 12%, the discount rate assumed, in all the cases. This indicated that the return on investment made for the installation of biogas plant was above the opportunity cost in the capital market. The outcome of the analysis indicated that biogas plants are financial viable even without subsidy. Even after allowing 20% for the improvement options, the FIRR in all the cases are above 12%.

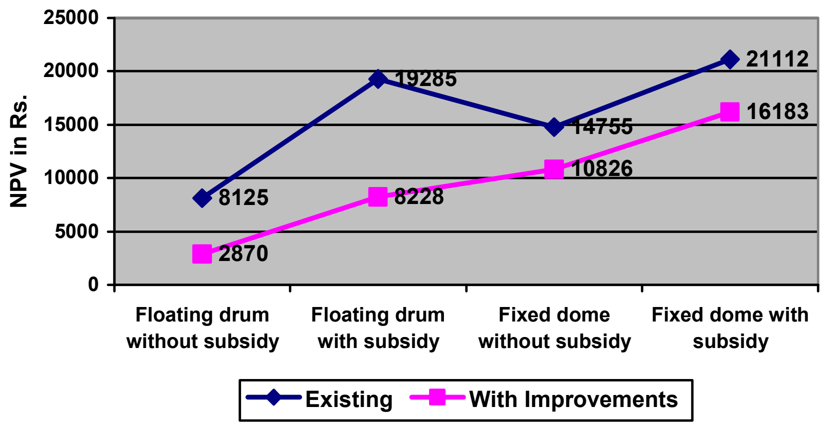
The results have been summarized in the following figure:

Fig-6.1: FIRR of Floating drum and Fixed dome plants



The Net Present Value, the present value of net cash flow, at 12% discount rate is positive in all the cases as shown in the following graph. This also indicated that both the types of biogas plants are financially viable even if subsidy is not provided.

Fig-6.2: NPV of Floating drum and Fixed dome plants



The benefit-cost ratio in the first case (with the existing system) ranges from 1.79 for floating drum plants without subsidy to 2.46 for fixed dome with subsidy; indicating that the biogas plants are viable even without subsidy. Even with the improvement options, the benefit cost ration ranges from 1.6 to 2.19. Conclusively, in all the cases the B/C ratio exceeds one, which indicates the financial viability of all the biogas plants in the given conditions.

6.2 Economic Analysis

Some of the benefits and cost of biogas plants are not limited to the users. For example, if a large number of biogas plants are installed in a community, the non-users will also be benefited due to a cleaner community and conservation of forest in the area. Such benefits and costs that accrue even outside of the user's household is a subject matter of economic analysis. A single biogas plant does not significantly affect the economy as a whole. Therefore, economic analysis may not be relevant for a single plant but is of an immense importance at the community program level where the impact of the program on the economy is assessed.

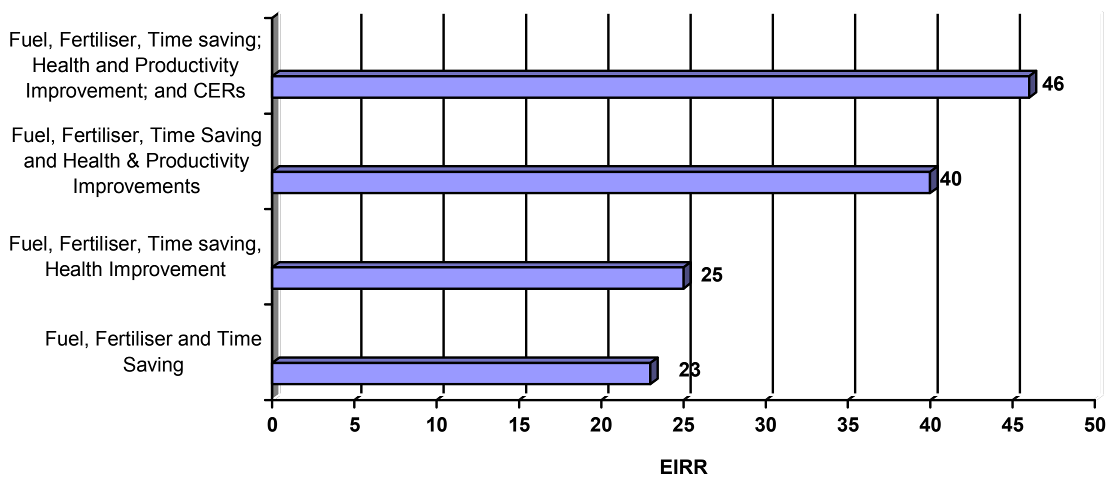
In analyzing the economic viability of biogas program some intangible benefits like environmental impacts such as protection of forest, land-productivity improvement, reduction in carbon emissions(potential CER values) etc; reduction in smoke-borne diseases and improvement in general health; improvement in economic condition due to employment opportunities and proper use of saved time; increased yield of crop with the use of nutrient-rich bio-slurry; social prestige and satisfaction etc. should be valued. Difficulties involves in identifying all these items of benefits and adjusting their market prices to reflect social preferences have been the major limitation of the economic analysis. The situation requires some level of generalization, simplifications, and even some restrictive assumption.

Due to the limited scope of this study, the economic analysis had to rely both on primary and secondary data. These data provide a reasonable basis for the economic analysis. The principal assumptions relate to the conversion from financial prices to economic prices. Economic benefits resulting from improved sanitation through toilet attachment and employment generation were left out of consideration. The analysis is based on calculating the economic internal rate of return (EIRR) for the net annual benefits associated with the biogas plant. All investment costs for the plant were assumed to be expended in the first year and all maintenance costs and all resulting benefits were assumed to be constant over the 10 year life of the plant. It is thus expected that the economic internal rates of return (EIRR) of an investment into household biogas would be much higher than FIRR, once other non-cash benefits are also included. These benefits will likely include the following:

- Time saved by women and children in the collection of firewood and the making of dung cakes as well as time saved through faster cooking and cleaning equivalent to Rs.22/day/household (assuming 1 hour 35 minutes savings per day at Rs 14 per hour).
- Health benefits to family members from reduced indoor smoke equivalent to Rs 500/yer (assume).
- Benefits from increased productivity of land valued in terms of quantity of bio-slurry produced, approximately Rs 3,650 (Per day 1 kg of dry manure @ Rs.1/kg) for a 6 m^3 plant.
- Benefits to the global environment as a result of reduced greenhouse gas emissions (2.2 tons of CO_2 equivalents per year at $10 per ton) equivalent to Rs.1320/pant/year.

Figure 6.3 below show how the EIRR of a 6 m^3 biogas plant increases as the different benefits are added.

Fig-6.3: EIRR of a 6 m3 biogs plant at different benefits



Based on the assumptions used for this economic analysis, it is clear that there is an economic justification for the subsidy of Rs.6,000 per plant proposed in the feasibility study. Furthermore, it is unlikely that the Pakistani farmers would have sufficient financial incentives to adopt the biogas plants. The earlier financial analysis clearly indicated how sensitive the FIRR is to the price of biomass. As most farmers do not directly purchase biomass, their perception is that the price of biomass is at or near zero. As a result, their perceived FIRR is negative. When the other principal non-market benefits of the biogas plant are added, the EIRR rises to 46 percent. This provides an additional justification for the subsidy for the biogas plants.

7. SELECTION OF BIOGAS MODEL FOR PAKISTAN

7.1 Criteria for Selection

To successfully achieve anticipated objectives of biogas programme, it is imperative that the best suited model/design of biogas plant is selected for the wide-scale dissemination. Varieties of models/designs of biogas plants are being used in different countries in the world with successful track records. As reported earlier, there are two models being installed in Pakistan-the floating drum and fixed dome model adopted from Nepal. Based upon the performance of the existing plants and experiences from other biogas countries, attempts have been made to select the best model for the wide-scale dissemination of the biogas technology in the country.

The following factors have been considered to evaluate the suitability of biogas plant assuming that the adaptability of any biogas plant in a given context depends mainly upon these factors.

a. Climatic and geo-physical parameters
    - Ambient temperature
    - Geo-physical conditions of the soil
    - Condition of ground water-table

b. Technological Parameters
    - Structural strength against different load conditions (structural durability)
    - Methods of construction/supervision
    - Time and effort in quality control
    - Methods of operation and maintenance
    - Applicability/adoptability of the design in different geographical context for mass dissemination
    - Prospects for sharing of technical information and know-how

c. Affordability of potential farmers to install biogas plant
    - Availability of construction materials
    - Availability of human resources (skilled and unskilled) at the local level
    - Cost of installation, operation and maintenance
    - Transportation facilities

d. Purpose of the use of the products from biogas plant
    - Use of gas for cooking, lighting and/or operating a duel-fuel engine
    - Use of slurry as organic fertiliser

e. Performance of existing models, if any, in the local and/or regional conditions
    - Existing physical status and functioning
    - User's level of satisfaction

f. Quality and quantity of available feeding materials
    - Type of feeding materials (cattle dung, pig manure, human excreta etc.)
    - Availability of water for mixing
    - No. of cattle/pig per household

The following table shows the relative merits and demerits of four potential biogas plant models based upon the above described criteria.

Photo 7.1: Chinese Fixed Dome Model

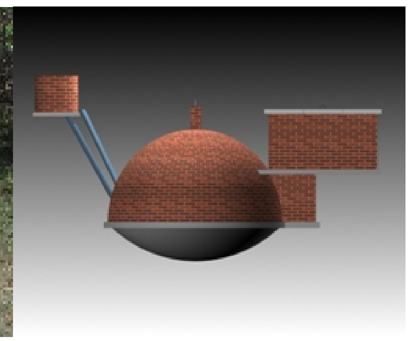


Photo 7.2: Nepalese GGC Model **Photo 7.3: Floating Drum Model** **Photo 7.3: Deenbandhu Model**

Table-7.1 : Evaluation of Potential Models for Pakistan

Evaluation Criteria	Chinese Model	Floating drum design	Indian Deenbandhu Model	Nepalese GGC Model
Climatic and Geological Conditions				
Ambient Temperature	-Not the whole area above dome is filled. -Risk of temperature fluctuation in digester is relatively low.	--Top filling is not possible -Risk of temperature fluctuations in the digester is relatively high.	+The whole area above the dome is filled with 15-20 cm of soil layer. +Less risks of temperature fluctuations in digester.	++Top filling over dome is 50 cm. +The whole area above the dome is filled. ++Very little risks of temperature fluctuations in digester.
Condition of Soil	+Suitable for Lateritic and cohesive soils like clay. --Unsuitable for soils with less cohesive strength such as conglomerate, silt and sandy soil.	++Suitable for all types of soil.	++Suitable for all types of soil. --Unsuitable for areas where earthquake are common (major part of Pakistan)	+Suitable for all types of soil. - If soil is sticky, like red laterite, difficult to make earthen mould for casting gas holder.
Condition of Ground Water Table	+More suitable for areas with low water table. +Also suitable for areas with higher water table.	+Best suitable for areas with low water table.	+Suitable for both areas. ++Best suitable for areas with high water table	-Less suitable for areas with high water table. +Best suitable in areas with low water table especially in the hilly regions.

Technological Parameters				
Structural Durability				
Inlet Chamber and Inlet Pipe	-Prone to flood water entering. -Difficult to ensure quality mixing -Prone to leakage as inlet pipe penetrates the dome	+Effective to allow grits and soils to settle down. -Designed to rest on back-filled surface wakening the durability.	+Effective to allow grits and soils to settle down. +Comfortable in mixing, makes the condition of mix suitable for anaerobic digester (better quality mix)	+Comfortable in mixing, makes the condition of mix suitable for anaerobic digester (better quality mix)
Digester and Gas Holder	+Digester base, walls and the gas holder are monolithic, hence no joints in between them. Structurally very sound. -Inlet pipe passes through the concreting area in the dome making it prone to gas leakage. -Manhole at the top increases the risk of gas leakage. -Difficult to break scum -Two manhole openings (access points) increase the risk of gas leakage and add the complexities in construction.	-Difficult to break scum -Deep and slender digester pit requiring thicker walls. -MS drum prone to corrosion in moist and humid conditions. -Higher wear and tear of steel support due to frequent movement of steel drum.	++ Spherical shapes at the bottom and the top is best for load bearing purpose +Closed top of gas holder is less prone to gas leakage. +Manhole in the side eliminates the risk of gas leakage from the top. +Arch frame over the manhole is structurally sound. -The small size of manhole opening makes it difficult to enter into the digester.	+Closed top of gas holder is less prone to gas leakage. +Manhole in the side eliminates the risk of gas leakage from the top. +Manhole in the side with adequate height provides best situation to enter into the digester to monitor the construction and break the scum. + higher resistance of gas holder against ground tremors -Joints in the base and bottom of dome makes the structure less stronger
Outlet Tank	+Circular structure more durable and less chance of formation of dead volumes in the corners -The overflow opening is designed to be below the ground level which increases the risk of flood water entering into the tank and makes the flow of slurry difficult.	- No outlet tank in the existing design -The overflow opening in top of round wall without mechanism to ensure safe disposal of slurry results in dirty walls.	-Rectangular structure, chances of formation of dead volume and cracks in the corner if backfilling is not provided -The overflow opening is designed to be below the ground level which increases the risk of flood water entering into the tank and makes the flow of slurry difficult.	-Rectangular structure, chances of formation of dead volume and cracks in the corner if backfilling is not provided +The overflow opening is designed to be above the ground level which facilitates flow of slurry by gravity and decreases the chance of flood water entering into the tank.
Methods of Construction				
Digging of Pit	---Very very complicated excavation to maintain verticality of cutting	-the depth of excavation is deep requiring frameworks/ scaffoldings	--Very complicated excavation to make the bottom spherical.	+No complications in excavation
Construction of Base	-Bit complicated base concreting as it calls for slope adjustment -Consumption of more construction materials	+Easy in preparing the base --Consumption of more construction materials as PCC is often done	--Very complicated base concreting as it demands spherical shape and properly adjusted collar --Consumption of more construction materials	+Easy in preparing the base + Consumes less materials, broken bricks bats are used
Construction of Digester	+Digester wall is constructed very quickly.	-Skilled person needed to construct	-Skilled person needed to construct	+Construction is easy; mason with a skill to

	Less time consuming. -Bit cumbersome as heavy moulds have to be fitted in place -If by mistake or because of natural constraints more excavation is done, it consumes more concrete -Difficult to take out mould after concreting -Labour intensive to mix and pour concrete	--Not suitable in areas where brick is not available and stone are widely used, such as areas in northern Laos -Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming	-Fixing of curvature constructing of arch needs careful attentions --Not suitable in areas where brick is not available and stone are widely used, such as areas in northern Laos -Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming.	construct masonry walls can do it with a little orientation. ++ Suitable for both brick and stone masonry walls +Construction of digester wall can be finished in one day, no need to wait for the brick to set. Less time consuming. -Care has to be given to maintain the wall perfectly vertical
Construction of Gas Holder	+Gas holder is constructed very quickly, less time consuming -Bit cumbersome as heavy moulds have to be fitted in place -Construction of manhole in the top needs more skills and care -Removal of mould from manhole after concreting is difficult -Labour intensive to mix and pour concrete	++ Mild Steel gas holders could be fabricated in workshops and fixed in sit. + Easy to install and consumes less time and efforts.	-Only limited number of brick layers could be constructed in one day to allow the brick to set properly, time consuming -Hooks and counterweights are needed for each and every freshly laid brick, which is a cumbersome task to do -Scaffoldings are needed from inside and outside to close the dome which adds more complications -Joints between bricks should be filled well to make it gas tight – more care is needed -Cracks developed during construction have to be monitored properly and work has to be stopped if cracks appear. Masons tend to violet this in quest to complete work quickly.	--The whole part of the digester has to be filled with soil to erect a framework for casting concrete for the gas-holder which is very cumbersome job demanding more unskilled labours -Templates have to be used to shape the soil mould; carrying of such moulds though not very difficult is an added job. -Made up of concrete, consumes more construction materials -Labour intensive to mix and pour concrete
Inlet and Outlet Tanks	-Construction of inlet is complicated as it has to be attached properly with the concrete digester -Circular outlet tank, relatively difficult to construct -Overflow opening is below the ground level, construction of drain needed to facilitate the slurry flow.	-Inlet tank is constructed on back-filled soil in order to gain steep angle for the inlet pipe + No need of outlet tank	+No major difficulties in constructing inlet tank. +Rectangular tank, easy to construct +Overflow opening is above the ground level, slurry flows by gravity -Care needed to fix the mixing device properly	+No major difficulties in constructing inlet tank. +Rectangular tank, easy to construct +Overflow opening is above the ground level, slurry flows by gravity -Care needed to fix the mixing device properly
Time and Efforts in Quality Control during construction	- Constant supervision needed	+ Comparatively lesser extent of work	- Constant supervision needed	- Constant supervision needed

Operation and Maintenance				
Operational Activities	-Care need to be provided not to use more water while flushing pig sty or cattle stable. -Special attention needed to avoid grits and other unwanted materials from entering into the digester -Difficult to inspect and clean overflow opening (blocked overflow may invite slurry into the pipeline) -Difficult to break the scum layer	-Inlet remains at higher level making it difficult to mix dung and water. Difficult to break the scum layer -Adds time to collect and transport dung from the cattle shed to the inlet tank.	+Easy to inspect and clean over-flow opening +Relatively easy to break scum layer from manhole -Adds time to collect and transport dung from the cattle shed to the inlet tank	+Easy to inspect and clean over-flow opening +Easy to break scum layer from manhole -Adds time to collect and transport dung from the cattle shed to the inlet tank
Maintenance Activities	-Breaking of the seal at the manhole and repositioning it is difficult when the digester and gas holder need maintenance. -Repeated breaking of this seal may lead to gas leakage	--MS steel drum (gas holder) needs routine painting to protect it against corrosion/gas leakage. Difficult to unload and reload. -Emptying of digester is difficult as it is too deep.	+Emptying of digester is easy and it does not effect on structural stability	+Emptying of digester is easy and it does not effect on structural stability
Top-filling and protection of plant	-The whole structure above the dome could not be back-filled to allow monitoring of the manhole seal -Chances of mosquito breeding is high in the stagnant water	-The MS drum floats up and down. It is not possible to add top filling over the plant to protect it.	+The whole structure above the dome could be back-filled and protected well under ground	+The whole structure above the dome could be back-filled and protected well under ground
Applicability/Adoptability in different Geographical context	+Suitable for all areas where aggregates, sand and cement are available -Moulds could not be transported to rural areas hence, installation is limited only in areas with good transport facilities.	-Not suitable in areas where transportation is a problem. The MS drum has to be fabricated in workshop and transported to site.	-Not suitable in areas where bricks are not available or could not be transported easily	+Suitable for all the areas. Bricks could be supplemented by stone in areas where bricks are not available
Prospects for sharing of Technical Information and Know-how	-Little information exists on the R&D aspects of the plant model	+This model has become absolute and little information exists.	+Information are widely available which could be shared	+Information are widely available which could be shared
Affordability of Farmers to install biogas plant				
Availability of construction materials at the local level	+Cement, sand, aggregates and brick are available everywhere in Pakistan. The cost of brick is relatively higher. Cement is cheap.	+Fabrication of steel drum could be done elsewhere in Punjab and Sindh + Cement, sand, aggregates and brick are available	+ Cement, sand, aggregates and brick are available everywhere in Pakistan. The cost of brick is relatively higher. Cement is cheap.	+ Cement, sand, aggregates and brick are available everywhere in Pakistan. The cost of brick is relatively higher. Cement is cheap. +Bricks could be

		everywhere in Pakistan. The cost of brick is relatively higher. Cement is cheap.		supplemented with the use of stone, if available locally.
Availability of human resources	+Trained technical manpower is not available in Pakistan. Special training needed.	+ Trained technical manpower for fabrication of MS drum and construction works is available.	-Trained technical manpower is not available -Needs training	-Trained technical manpower is not available. -Needs training
Cost of Installation	USD 400 for 6 cum biogas plant	USD 425 for 6 cum biogas plant	USD 400 for 6 cum biogas plant	USD 350-400 depending upon the use of stone or brick for 6 cum biogas plant
Operation and Maintenance Cost	+Relatively low	-High	+Low	+Low
Transportation facilities	+Highly suitable for areas with good transportation facilities -Less suitable for areas without road networks as the moulds have to be transported	+Highly suitable for areas with good transportation facilities -Less suitable with areas without transportation facility	+Highly suitable for areas with good transportation facilities -Less suitable with areas where bricks has to be transported	++Suitable in all the parts of the country as bricks can be replaced with stones
Purpose of use of Products from plant	All the biogas plants under the framework of the study are designed for the same purposes.			
Performance of Existing biogas plants in local/regional context				
Existing physical status and functioning	-The physical status and functioning of the biogas plants installed in Pakistan are reported to be unsatisfactory.	-Very little information exists. -The present study suggested that only 34% of the plants in Pakistan are functioning satisfactorily	+60% of the biogas plants installed in India are functional and have good physical status. -54% of the biogas plants installed in Nepal are operational	+98% of the biogas plants installed in Nepal are operational and have good physical status.
Level of Satisfaction of Users	-Information on level of satisfaction of users does not exist.	+47% of the users are satisfied with the performance of their biogas plants in Vietnam	-No data was found no the level of user's satisfaction, however, users in Nepal are not satisfied with the performance of their digesters.	+83% of the users in Nepal are fully satisfied and 9% of them are partly satisfied +User's in Nepal prefer GGC more than Deenbandhu
Quality and Quantity of available feeding materials	-Modifications in inlet needed for cattle dung feeding -Design of smaller size (less than 6 cum) is not available.	++Suitable for cattle dung of feeding -Design of smaller size (less than 6 cum) not available.	+Best suited for cattle dung feeding +Design of smaller size (less than 6 cum) is also available.	+Best suited for cattle dung feeding +Design of smaller size (less than 6 cum) is also available.

Based upon the subjective evaluation of four different models of biogas plant those are potential to be disseminated under the framework of Biogas programme, objective ranking have been made as shown in Table 7.2. Each parameter has been ranked with allocating values from 1 to 5, symbolising the favourable condition in ascending order.

Table- 7.2: Evaluation Results

SN	Evaluation Criteria	Chinese Model	Pakistani Floating Drum Model	Indian Deen bandhu Model	Nepalese GGC Model
1	**Climatic and Geological Conditions**				
1.1	Ambient Temperature	4	2	5	5
1.2	Type of Soil	2	5	5	3
1.3	Condition of Ground Water Table	4	3	4	4
2	**Technological Parameters**				
2.1	***Structural Durability and functioning***				
2.1.1	Inlet Chamber and Inlet Pipe	3	4	5	5
2.1.2	Digester	5	4	5	3
2.1.3	Gas Holder	4	3	4	5
2.1.4	Outlet Tank	5	5	4	4
2.2	***Methods of Construction/ supervision***				
2.2.1	Digging of Pit	2	3	2	5
2.2.2	Construction of Base	4	5	2	5
2.2.3	Construction of Digester	4	5	3	5
2.2.4	Construction of Gas Holder	4	5	4	2
2.2.5	Inlet and Outlet Tanks	4	4	5	5
2.2.6	Time and Efforts in Quality Control	3	5	3	3
2.3	***Operation and Maintenance***				
2.3.1	Operational Activities	4	4	5	5
2.3.2	Maintenance Activities	4	2	5	5
2.3.3	Top-filling and protection of plant	3	2	4	5
2.4	***Applicability/Adoptability in different Geographical context (including suitability with locally available construction materials)***	***3***	***4***	***4***	***4***
2.5	***Prospects for sharing of Technical Information and Know-how***	4	3	5	4
3	**Affordability of Farmers to install biogas plants**				
3.1	Availability of construction materials at the local level	5	4	4	5
3.2	Availability of human resources	2	5	2	2
3.3	Cost of Installation	3	3	3	3
3.4	Operation and maintenance cost	4	3	5	5
3.5	Transportation facilities	3	3	4	5
4	**Purpose of the use of the Products from biogas**	5	5	5	5
5	**Performance of Existing biogas plants in local/regional context**				
5.1	Existing physical status and functioning	3	3	3	5
5.2	Level of Satisfaction of Users	3	3	3	5
6	**Quality and Quantity of available feeding materials**	3	5	5	**5**
	Total Marks obtained	**97**	**101**	**109**	**117**
	Ranking	**Fourth**	**Third**	**Second**	**First**

Note: ***5 points- Most Favorable Condition***
1 point- Least Favorable Condition

7.2 General Conclusion on Potential Models

The suitability of different models of biogas plant potential to be disseminated in Pakistan as discussed above were ranked (Table-7.2) based upon the criteria shown in the evaluation matrix (Table-7.1). The outcome of the ranking exercise revealed that there is not a wide difference on ratings among the four models under study. The GGC model being disseminated under the Biogas Programme in Nepal and recently piloted in Sialkot and DI Khan districts in Pakistan has been ranked to be the most suitable plant for mass dissemination in Pakistan. The suitability of this design for both brick and stone masonry works; simplicity in construction; higher resistance of gas holder against ground tremors, easy access for cleaning and maintenance of digester and gas holder; higher level of user's satisfaction; and proven track record of successful functioning in different countries under SNV's biogas programme make this model more suitable than others. Labour intensive construction of gas holder, relatively less suitability of the model in areas with high water table (because of flat bottom), and more time and efforts needed in quality control are the main shortcomings of this design.

Indian Deen-bandhu model has stood second in terms of its suitability in Pakistan because of its better structural design owing to the curved shaped base as well as digester and gas holder; fairly easy access to cleaning and maintenance of digester and gas holder; higher suitability in areas with high water table (because of spherical base); and availability of technical know-how in Cambodia (SNV supported programme) and the neighbouring country (India) which can easily be transferred, if required. Requirement of skilled persons for construction, higher risk of product to be poor because of the negligence from masons to monitor the minute cracks in masonry walls during construction, unsuitability of the design for stone masonry and prone to cracks even with slight tremors (because of the earthquake or any vibrations) are some of the major drawbacks of this model.

Floating drum model have proven track records in Pakistan and skilled persons are widely available in the local market that have knowledge and skills to construct this type of biogas plant. This model does not require intensive quality control efforts as in other models. However, higher rates of failure of existing biogas plants installed in various parts of the country, unavailability of smaller design to cater farmers with small cattle-holding, exposure of MS drum above ground level endangering the safety of the structure, difficulty in heat insulation to keep the digester temperature warm during winter and avoid temperature fluctuations, location of inlet tank above the backfilled soil increasing the risk of cracks/failure and difficulty in repair and maintenance of MS drum because of its bulky nature are the main shortcomings of this design which place this design in third rank.

Chinese fixed dome model has been ranked to be the least favourable model. The main favourable situations for this model have been the better structural strength, cheap cost of cement as well as availability of sand and aggregate which are the main construction materials, and less time for construction (less time consuming). Unsuitability of the model in soils with less cohesive strength, difficulty in transporting heavy moulds that are needed for the construction, requirement of skilled manpower for construction, difficulty in fixation and removal of the moulds and less effective inlet structure (designed for flushing pig-manure) are main weaknesses of this model.

In conclusion, the Nepalese GGC model is the best suited design of biogas plant for wide-scale dissemination of the biodigester technology in Pakistan. However, prior to the commencement of construction works, series of training programmes are needed to build the technical capacity of local manpower to construct and supervise the installation of biogas plants of this design. This necessitates considerable of time and efforts.

8. OVERALL CONCLUSION AND RECOMMENDATION

8.1 Conclusion

The general outcome of this study suggested that the existing biogas plants are functioning at a satisfactory level though there are lots of rooms for further improvement. Installation of about 6000 biogas digester across the country till the end of 2006 has been instrumental in popularization of the technology at the grassroots level. Moreover, the functional plants have been found to be effective tools for the promotion and extension of the technology. However, the higher rate of failure of these biogas plants has demotivated the neighbouring households to adopt biogas technology fearing waste of investment.

Though biogas technology has already created a ground at the rural communities in the country, this has happened with isolated efforts in an uncoordinated manner by some sector institutions especially PCRET. To effectively harness the high potential of domestic biogas plants across the country there is need of coordinated approach and collaborative efforts of the sector institutions.

The majority of the plants under study were under-fed as well as oversized. The average feeding rate was 9 kg per day per 1 cum gas production capacity biogas plant, which is only 36% of the required quantity. Though the available average quantity of dung per day per households was 101 kg, which is enough to install biogas plant of 4 cum gas production per day, larger size of 4.7 cum were installed in Pakistan. Operation and maintenance status of biogas plants in the sampled districts indicated that there is ample room for further improvements. There is high need to optimization of biogas plants. Out of the 38 plants under study, only 10 were operating at full capacity. The functional conditions of 13 (34%) plants were satisfactorily, 17 (45%) plants were functioning partly and the remaining 8 (21%) plants were not functioning at all during the time of field investigation. This data clearly illustrate that there are rooms for further improvements.

In terms of saving of conventional fuel sources, one biogas plant on average have contributed cutback of 3.08 kg of firewood, 0.11 kg of LPG, 3 kg of dung cakes/balls and 1.82 kg of agricultural residues per household per day. Such savings have resulted in monetary gain of Rs.7976.60 per household per year, which is a substantial amount.

Though the figures on conventional fuel saving are encouraging, the lower efficiency of biogas plants (58% for floating drum plants), oversized and under-fed digesters, many technical defects and widely-emerging problems related to operation and maintenance are hindering the speedy dissemination of the technology in Pakistan. In general, the outcome of this study revealed the following major findings:

- Installation of biogas plants have been done by the masons with minimal supervision from skilled technicians – indicates the competency of masons and fabricators!
- The quality of construction is erratic and sub-standard – no structured, quality control system, no quality standards are in place.
- There is no standardisation of gas holder (steel drum and appliances) which is manifested by different shapes and sizes of gas holders – e.g, some gas holders were having spherical top, some flat top, some conical top etc.
- The thickness of steel drum is too less (16-18 gauges) than required to withstand ear and tear as well as the gas pressure.
- There was total lack of training and orientation to users on routine operation and minor maintenance works.
- There was no mechanism for effective after-sales-services which has resulted in poor O&M condition.

- The MS drums, which need regular painting to protect them against the corrosion, were never painted - rather they were simply taken out and sold to scavengers/street whenever leakage was encountered.
- 63.33% of the users have been using bioslurry. The main reason for the remaining 36.67% not to use is the lack of agricultural land. All of those who used slurry reported that it has better nutrient value than FYM – except 2 who consider it to be the same as FYM. Interestingly, one of the users complained that the slurry is more stinky than FYM.

8.2 Recommendations

In general, the outcome of the study indicated that there are certain issues that need special considerations for speedy promotion and extension of biogas technology in Pakistan. These are summarized below:

8.2.1 Adoption of Best Model for Technology Dissemination

Though Pakistan has proven record of successful installation of floating drum design biogas plants, this technology has gradually become obsolete, in other parts of the world with the development of new models, especially the fixed dome models. The outcome of this study revealed that the fixed dome plants are performing better than the floating drum plants. Moreover, majority of the users who have seen and experienced both the types have strongly favoured the fixed dome models. The general assessment as described in Chapter-7 also supports that fixed dome plants have advantages over the floating drum design. For, wide-scale dissemination of biogas technology under the framework of the proposed biogas programme, it is recommended to adopt fixed dome models that has been in use in Nepal with necessary modification to suit the Pakistani context.

8.2.2 Standardisation and Improvement in the Quality of Construction

The success of biogas program depends much on the functioning of the installed plant which is directly associated with the quality of construction, besides some other variables like quality of after-sale-services, operation and maintenance mechanisms etc. The outcome of the study indicated that there is lot of rooms for improvement in installing quality plants to receive anticipated benefits. The following factors need due care if the existing floating drum plants are to be disseminated:

- There is high need for the modification of the design of biogas plants to suit the gas use pattern in Pakistan. The size of biogas plant should be decided based upon the anticipated gas demand which is about 4.7 hours per day. An average plant size of 2-2.5 cum gas production per day will be sufficient to meet this demand, which is about half of the size being installed in Pakistan at present (4.7 cum gas production/day). This will help in optimization of the plant and there by reduction in cost of installation.
- Equally important is the formulation of quality standards on construction, operation and maintenance of biogas plant giving special attention to the local conditions.
- Inlet needs to be standardized. The volume and height of the tank have to be constructed to facilitate the mixing process. It should not be considered simply as a mixing tank without giving due attention to its relative position with other components of biogas plant. Improvements in inlet is needed with installation of mixing device and proper placing of inlet pipe to ease inserting of pole or rod during the time of blockage and to discharge feed exactly opposite to manhole opening at the longitudinal centre line of the digester and outlet tank to maintain designed HRT.

- The fabrication of MS gas holder should be standardised. The thickness of plain steel sheet, dimension of different components, shape of drum and location of gas outlet pipe should be standardised for the optimal functioning of the gas holder.
- The installation of gas holder should be modified with a central vertical movable shaft as supporting pivot in place of external guiding poles.
- Gas conveyance system needs to be systematized. To ensure safety and avoid gas leakages, main gas valves of proven quality have to be installed and operated before and after the use of gas. Water trap has to be provided in the pipeline to drain condensed water inside the pipe which if not drain will obstruct the flow of gas. The pipeline should be profiled in such a way that the water trap is capable of draining the whole quantity of water accumulated inside. It is recommended to use ½" GI pipe for a shorter length of pipeline and ¾" for the longer length exceeding 100m. The dome gas pipe needs to be increased from ¾" to 1.5" to safeguard the clogging of pipe by slurry and facilitate the inserting of rod to clean during the time of blockage. Awareness raising training initiatives are needed to orient users on the importance of quality conveyance system.
- The problem with gas stove needs to be solved with proper research and development on the modification. There is need to orient and certify manufacturers to produce biogas appliances including gas stove. Primary air intake in stove is very important to regulate the flow and ensure effective burning. Gas taps and gas pressure gauges need to be installed to regulate the flow of gas to the stove.
- Slurry pit(s) should be considered as an integral part of biogas plant. To protect the nutrient value in the digested slurry it need to be collected in a pit and mixed with other household wastes. Composting of other household wastes with biogas slurry expedite the process of digestion. Compost pit should have volume at least equal to volume of digester. Two pits are highly recommended. The pits should be provided with shading.

8.2.3 Formulation of Repair and Maintenance Mechanism

Timely repair and maintenance help biogas plants to function effectively for a longer duration. The plant owners in most of the cases are not able to carry out required maintenance of all defective parts on time due to technical constraints. After-sale-service provisions therefore should be viewed as major tool to preserve the interest of the users and safeguard the fate of the plant against any further deterioration. It is obvious that early failure of biogas plant results adversely in the future extension program and business of the service providers too. All these necessitate effective post-construction services so that the efficiency, sustainability and reputation of the plants are guaranteed. It is therefore recommended that the initial phase of the biogas program in Pakistan include interventions to repair and maintain the already existing plants in different parts of the country. Such endeavours to retain and sustain the serviceability of the non-functional plants will be instrumental in getting appreciations from the users, which in turn will be beneficial for speedy promotion and extension of the technology. The existing pools of technical manpower that were trained by PCRET under the framework of their past and present Biogas Programmes could be mobilized for this purpose.

There is high need of user's training on operation and maintenance of biogas plant to ensure the continual functioning of biogas plant. As the main cause of failure of majority of the plants was observed to be the defective operation and maintenance practices such as; under-feeding, improper water-dung ratio, ignorance of users on feeding-requirements, improper use of main gas valve, zero maintenance of defective parts etc. users need to be made aware more seriously in these regards.

8.2.4 Linking Biogas Program with Government Initiatives

On the whole plans and policies on Biogas Technology as renewable sources of energy in Pakistan are yet to come in stronger form in the national planning framework so that the impact of consequent activities could be felt in lives of targeted communities and the country as a whole. The present programme being launched under PCRET should be taken as rays of hope and the proposed program should build on these positive rays of hope.

8.2.5 Private Sector Development

Private sector development should be viewed as a means to develop a more productive and efficient economy and to increase the economic participation of the population. In the case of production and use of biogas, the objective should be to let the sector develop by using the internal forces of demand and supply and by reducing external driving forces such as centrally planned production targets and subsidization in the long run. However, the immediate or short term driving force should be external driving force like subsidy. A condition for a successful privatization process should be that there are checks and balances between countervailing powers, because that dismisses the government sector from the need to intervene.

The objective of national policy on biogas program should be to provide a conducive environment for the private sector entrepreneurs to function effectively. Strengthening and capacity building of provide sector is the main pre-requisite for the promotion and extension of biogas technologies. Private sectors are the main vehicle to penetrate the program to the needy communities. The private sector should be provided with a clear-cut mandate to participate in biogas programs.

8.2.6 Program Integration

Biogas technology has a number of synergies with other development sectors like health, women's development, agriculture, forestry and livestock management. In addition to energy supply, biogas technology can be viewed as a time saving and environmental conservation technique. It can also be promoted to improve the quality of life for women by reducing the drudgery of fuel wood collection and cooking in smoke-filled kitchen. The synergies can be utilized effectively if biogas integrated functionally with other programs. Integration essentially means identifying these synergies and incorporating them in the process of implementation.

The main motivation for the installation of biogas facilities in Pakistan could be the use of slurry bi-product as organic fertilizer. The second motivation could be the improvement on the quality of life of the families, especially that of women. It is therefore recommended that the biogas program be integrated with the women's development, agriculture, health and other rural development programs. There are rooms, at present, to integrate biogas program with firewood saving and forest conservation programs.

Importantly, there is a need to develop and establish linkages between potential stakeholders for program integration at the policy level as well.

8.2.7 Linking Biogas Program with Poverty Alleviation

Biogas program should also be linked with the poverty alleviation efforts of the government. The analysis indicated that the following features are important in the success of biogas program to address the issue of poverty alleviation.

- For direct effects, they should be small scale, affordable and accessible to the poor.

- Increasing access to energy through dissemination of biogas plants can provide the means for freeing time and empowering the people. Where possible the biogas related services being delivered should allow either a manual drudgery task to be replaced, or provide an improvement in efficiency, which results in freed time. This allows an increase in earned income or other quality of life benefits. This also maximizes local benefits from biogas project in terms of education and health.
- Subsidy should continue as driving/motivating factor to penetrate the poorer strata of the society until a demand-driven market is propelled.
- Poor and marginalized people with strong willingness and commitments to be involved in biogas plant construction need to be given opportunity while imparting training and capacity building initiatives.

The field findings on socio-economic indicators such as educational status, land holdings, income from agricultural production and other sources indicated that biogas plants has been installed by well off farmers. To penetrate into small and marginal farmers and to make biogas technology more affordable, one of the major efforts would be to provide credit to spread loan period over a longer period of time, there by reducing the size of each payment. Given the relative newness of the technology in the rural areas, low level of awareness on the benefits of the technology and the lack of credit history of the majority of the target population financing institutions may be hesitant to provide biogas loans. A massive awareness campaign to disseminate the usefulness of the technology is needed. Group loans without collateral would be beneficial to include more small and marginal farmers under the framework of the biogas program.

8.2.8 Developing Effective Partnership

The proposed biogas program should formulate the modality of partnership agreement with other potential partners, based upon their areas of expertise and capacity to undertake specific assignments, with the assumption that it is the morally and sometimes legally binding documents to illustrate that two or more parties are working towards achieving shared and/or compatible objectives in which the parties:

- Share authority and responsibilities
- Invest time and resources for synergy
- Share risks and benefits
- Help each other to grow and institutionalize
- Enter into an explicit agreement or contracts that sets out terms

8.2.9 Orientation on Effective Use of Slurry

One of the factors noted during the field investigation is the higher level of awareness of users on effectiveness of bioslurry from biogas plant. It is therefore recommended that a training course for users be prepared and implemented on effective composting, handling and application slurry in the farms. There is need to make people aware of the benefits of attaching toilet to biogas plants by highlighting the major benefits such as improvement in environmental sanitation in and around the house, production of more gas, elimination of harmful pathogens after digestion of excreta into the digester and enrichment of bio-slurry by added nutrient value.

8.2.10 Motivation and Technology Promotion

Motivation is a vital component of any program like biogas that is aimed at a wider section of the population. The exact nature of motivation strategy must, however, be responsive to the specific needs of the area and situation. In the context of biogas program in Pakistan, motivation plays an important role when the technology is being introduced in some areas for the first time. Developing an effective motivation strategy becomes even more critical in areas where people developed unfavourable attitudes towards the technology because of various reasons especially the failure of the existing plants. Similarly, in areas where the general awareness among the people on biogas technology is low or not existent, there is a strong need to actively publicize it. The strategy for motivation in the context of Pakistan could be the following:

- Reliance on 'demonstration effects' form the existing functional plants and satisfied users
- Motivation through governmental and non-governmental officials
- Use of Local Resource Persons such as teachers, NGO workers, civil society leaders
- Use of local political and religious leaders
- Use of Village Institutions/Networks
- Use of Educational Institutions

8.2.11 Focus on 'Quality'

Non-functioning and poorly functioning biogas plants cause not only capital wastes but also harm the reputation of biogas technology and eventually to the desired establishment of permanent biogas sector. Therefore 'quality' should be the prime concern of the future biogas programme. The quality should basically relate to the following aspects of biogas programme implementation:

- **Quality of the design of biogas plant**: The biogas plant should be cost-effective; users' friendly; easy to construct, operate and maintain.
- **Quality of training and capacity building activities**: Correct training need assessment; proper selection of training participants, proper selection of facilitators, suitable training contents, session plans and scheduling; appropriate training methods; effective practical sessions; effective evaluation of training; timely follow-up of the evaluation findings.
- **Quality of promotion and extension works**: Potential customers should fully be aware and understand all the benefits and costs. They should be provided with factual data and information and should be aware of their roles and responsibilities for quality control.
- **Quality of the construction** (including selection of construction materials and appliances): Strict adherence of set quality standards on site selection, selection of construction materials and appliances and construction.
- **Quality of the operation and maintenance** by the users and technical backstopping from the installer: Effective training to users', timely follow-up visits by the installer.
- **Quality of after-sale-services** on behalf of the installers: Strict adherence of terms and condition of after-sale-service provisions including timely actions to the complaints from users, routine visits and problem-solving.
- **Quality of financial and administrative procedures and practices**: Proper utilisation of fund, timely disbursement of subsidy amount, proper book-keeping, less-lengthy procedures, fast, friendly and useful customer services.

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ANNEXES

Annex-1: Information on Sampled Plants

Annex-2: List of Persons Met

Annex-3: Questionnaires used for the Survey

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