Technologies for Energy Recovery from Faecal Waste

Technical and Financial Analysis – Anaerobic Digestion

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BILL & MELINDA GATES foundation

EVI Sustainable Solutions for the Environment

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Abbreviations and Acronyms:

BOD	Bio-chemical Oxygen Demand
COD	Chemical Oxygen Demand
DS	Dry Solid
FS	Faecal sludge
IT	Income Tax
INR	Indian Rupees
Liq	Liquid
MNRE	Ministry of New and Renewable Energy
MTV	Mobile Toilet Van
O&M	Operation and Maintenance
Q1	Quarter 1 (April-June)
Q2	Quarter 2 (July-September)
Q3	Quarter 3 (October-December)
Q4	Quarter 4 (January - March)
SLM	Straight line method
TDS	Total Dissolved Solid
WWT	Waste Water Treatment

About the Author

This report is created under the Bill and Melinda Gates Foundation's Water, Sanitation, and Hygeine ("WSH") initiative. The work strives to inform future WSH opportunities aiming to improve faecal sludge management on technical and financial feasibility of resource recovery efforts under different scenarios in Indian Cities. However the context of the work is global and models presented here can be customized to suit local conditions.

Please direct comments or inquiries about the contents of this report to the following individuals at Emergent Ventures India:

Sunil Sharma sunil.sharma@emergent-ventures.com
Atul Sanghal atul@emergent-ventures.com

About EVI

Founded in 1999, Emergent Ventures was established with the twin goal to accelerate action against climate change and to foster sustainable development. EVI works with the governments, government supported institutions, international development organizations and industries in public and private sector to deliver consultancy services across the full spectrum of sustainable development issues.

EVI's team comprises of professionals from technology, finance, policy and strategy areas with expertise and experience in energy & climate policy, corporate sustainability, carbon markets, sustainable transportation, waste management, and renewable energy (wind, solar, biomass). With a mix of market understanding, sectoral expertise and innovative analytics, it works throughout the life cycle of programs.

EVI is currently working on over 300 diverse projects across geographies in Asia (India, Srilanka, Bangladesh, Pakistan, Singapore, Malaysia, Thailand, Indonesia, Philippines, Nepal, Bhutan), Africa (Nigeria, Egypt, Algeria), Americas (USA, Mexico) and Europe. EVI clients include governments, UN Organizations, international donor agencies, NGOs and corporate. EVI covers sectors - Oil & Gas, Utility, Cement, Steel, Textile, Fertilizer, Pharmaceutical, Hospitality, Aviation, Financial, Food & Beverage among others including companies in fortune 500 list. EVI is considered thought leader in its domain of work.

Summary

This is a technical cum financial analysis report on the use of FS for energy recovery purpose. Out of the five technology areas planned for the study namely Gasification, Hydrothermal Carbonization, Pyrolysis, Anaerobic Digestion and Fermentation, Anaerobic digestion has been evaluated in this part of the study. The technology has been evaluated on its suitability to use FS for resource recovery and financial viability. The analysis also provides a plug and play tool to project developers to calculate the levelized cost of biogas production in different scenarios. The biogas can be used in thermal application, cooking, lighting, power generation or transportation. This can be a good alternative to LPG or CNG. Following are the construct of the report.

Chapter 1: Technology Analysis provides details of the technology under consideration, process description and its raw feed requirement. It also focuses on suitability of FS as raw feed and its pre-processing requirement so that FS can be used for production of biogas comparable to commercial fuels like LPG or CNG.

Chapter 2: Financial Analysis provides the levelized cost of biogas fuel produced by using Anaerobic Digestion process under various scenarios of FS procurement. The financial performance has been evaluated for following FS procurement models:-

Model 1 - FS Collection using Mobile Toilet Vans

Model 2 - FS Collection and transportation - with own infrastructure

Model 3 - FS Collection and transportation - outsourced

The levelized cost of biogas can be compared with the LPG or CNG or other fuel it would replace for energy recovery. For example, if biogas is used in transportation, its cost can be compared with that of CNG to see whether it is a viable proposition. The price of biogas can also be fixed based on the fuel it would replace to see whether it is a viable venture for a biogas producer or an energy producer.

Chapter 3: Conclusion discusses the results and presents the social and behavioral challenges associated with technology and financial viability of the project. As per the analysis, the cost of biogas production using FS sourced from MTVs is more profitable however it entails higher upfront capital requirement in infrastructure.

Chapter 4: Limitation provides the limitation of model in terms of technology and financial viability of the process.

1. *Technology Analysis*

1.1. Technology Description

Anaerobic digestion is a series of processes in which micro-organisms metabolize biodegradable material in the absence of oxygen. It has been widely used to treat waste streams because of the volume and mass reduction of the waste that takes place during the process. The end product of the process is a gas that has considerable calorific value and a biologically stable substrate that has high nutrient content and can be used as manure. Thus biogas technology from human wastes has multiple benefits – better sanitation, bio-energy and manure. The diagram below shows the basic schematic of the digestion process considered for the analysis in this study.

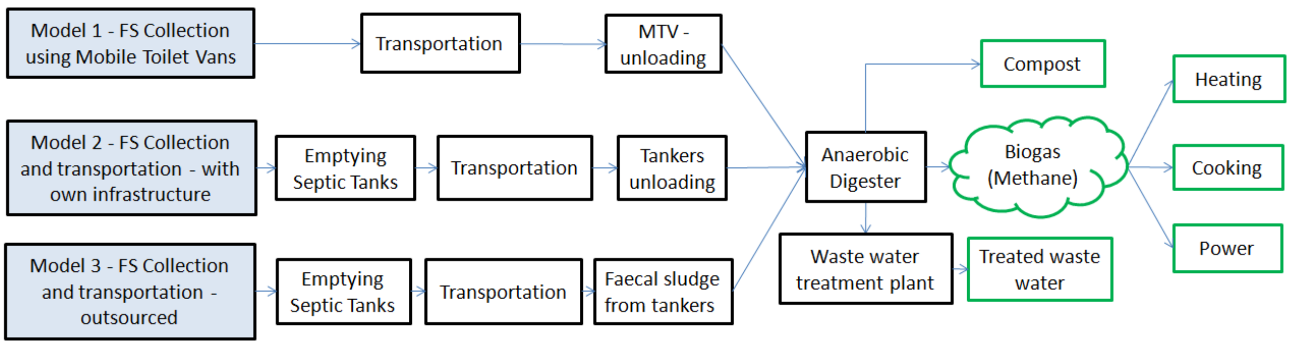

FIGURE 1: BASIC SCHEMATIC OF ANAEROBIC DIGESTION PROCESS

Anaerobic digesters can be designed and operated using following process configurations:-

TABLE 1: ANAEROBIC PROCESS FLOW CONFIGURATION

Parameter	Type 1	Type 2
Process	Batch	Continuous
Temperature	Mesophilic	Thermophilic
Complexity	Single stage	Multistage

A combination of the above mentioned configurations can be used. However following process configurations have been selected for analysis:-

1) **Continuous Process**: - In case of batch process, several chambers have to be created based on sludge retention time[1] in digester and this will result in more land area requirement and high cost of construction. This will not be the case with continuous process. Since FS sludge

[1] Approximately 30 chambers have to be created for 30 days of retention time

is procured on continuous basis from various sources hence continuous process is suitable for anaerobic digestion.

2) **Mesophilic Temperature: -** In India, the climatic conditions are favorable for mesophilic digestion. In this case maintaining temperature of 30 to 38 degree C is easier. The temperature requirement for thermophilic digestion is around 45 degree to 57 degree C. Maintaining this temperature will result in extra cost in the form of external energy requirement. Further mesophilic systems are considered more stable compared to thermophilic systems.

3) **Single stage: -** In this case all of the biological reactions occur within a single tank. Though the control over biological reaction is less, this results in lower land area requirement and lower cost of construction. Hence this has been preferred.

1.1.1. Microbiology and Biochemistry of Biogas Generation

The biogas generation from any waste is the result of microbial metabolic activities. There are three main classes of bacteria; one, aerobic bacteria which need oxygen to grow; two, facultative anaerobic bacteria which can metabolize and grow with or without oxygen and three, obligate anaerobic bacteria which can grow only in absence of oxygen. Biogas is produced through a series of bio-degradative steps. The first stage is achieved by fermentative bacteria, also called hydrolytic and fermentative stage. This group of bacteria hydrolyzes complex biopolymers into simpler organic acids, alcohols, and CO_2. The second group of bacteria called acetogenic bacteria, act upon long chain fatty acids, alcohols and produce acetic acids, CO_2 and H_2. In the third and final stage the methanogens utilize hydrogen produced by the earlier groups and convert acetate and CO_2 into methane. Some species even act upon acetate and form methane.

There are four key biological and chemical stages of anaerobic digestion:

1) Hydrolysis
2) Acidogenesis
3) Acetogenesis
4) Methanogenesis

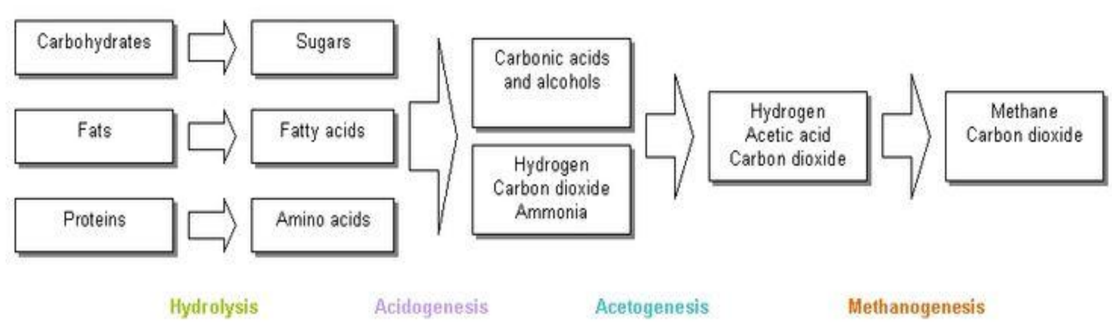

FIGURE 2: ANAEROBIC DIGESTION PROCESS

1.1.2. Products of Anaerobic Digestion of FS

The three main products of anaerobic digestion are biogas, digestate, and water.

1) **Biogas: -** Biogas production is one of the most important benefits of anaerobic digestion. Biogas yield is one cubic feet per user per day. The typical composition of biogas has been provided below[2].

TABLE 2: TYPICAL COMPOSITION OF BIOGAS

Matter	%
Methane, CH_4	65-66
Carbon Dioxide, CO_2	32-34
Hydrogen Sulphide, H_2S	~1
Nitrogen, Ammonia	0-2

Methane is the only combustible constituent which is utilized in different forms of energy. A thousand cu. ft (~30 m3) of biogas is energy equivalent to 600 cu. ft of natural gas, 6.4 gallon of butane, 5.2 gallon of gasoline or 4.6 gallon of diesel oil. The important uses of biogas are for cooking, lighting through mantle lamp, electricity generation, transportation and heating in winter. However Biogas may require treatment or 'scrubbing' to refine it for use as a commercial fuel in particular for transport purposes or power generation. The level of cleaning would depend on the application it would be used. For example, transportation fuel would need higher degree of cleaning and purification compared to thermal application in an industry.

2) **Compost: -** Compost or manure is the solid remnants of the original input material to the digesters that the microbes cannot use. It contains good percentage of plant macro-nutrients (N-P-K) and many micronutrients. The content of plant nutrients in effluent and sludge are shown below:-

TABLE 3: PHYSIO-CHEMICAL PROPERTIES OF DIGESTED SLURRY FROM BIOGAS PLANT[3]

Parameters	State of material	
	Wet slurry	Dried manure (4-5 weeks of sun dry)
Total (Kjeldahl) Nitrogen	5.5%	2.1%
Phosphorus (P_2O_5)	4.2%	3.6%
Potassium (K_2O)	2.4%	1.9%
Total solids	6.5%	87.9%
Volatile solid with respect to TS)	2.1%	12.0 %

[2] Dr P K Jha, Recycling and reuse of human excreta from public toilets through biogas generation to improve sanitation, community health and environment

[3] Based on the information provided by Prof P K Jha

The daily production of manure for a various capacity of gas plants are provided below[4]:-

TABLE 4: MANURE YIELD FROM BIOGAS PLANT

Gas Plant size (cu. m/day)	Manure yield (kg/day)
2	4-8
3	6-12
4	8-16
5	10-20
7.5	15-30
10	20-40

The average manure production is 2-4 kg/cu. m of biogas production. The higher side of this range has been considered in the plug and play model.

3) **Waste Water:-**The final output from anaerobic digestion systems is water, which originates both from the moisture content of the original waste that was treated and water produced during the microbial reactions in the digestion systems. This water may be released from the dewatering of the sludge. However this water will have elevated level of BOD and COD which need to treat before any use of water.

1.2. Raw Feed Characteristics

1.2.1. Feed Stock Requirement for Anaerobic Digestion

Following are the raw feed requirement for Anaerobic digestion process[5]:-

1) **C/N ratio:-** A C/N ratio ranging from 20 to 30 is considered optimum for anaerobic digestion. A higher C/N ratio will result in lower production of gas as the nitrogen would be consumed by methanogens for meeting their protein requirements and not react on the left over carbon content of the material. A lower C/N ratio would result in formation of ammonia (NH4) and increase pH value of the content in digester. This would have toxic effect on methanogens population.

2) **pH value:-** The optimum biogas production is achieved when the pH in the digester is between 6 and 7. A higher value of pH would have toxic effect on methanogen population. Any lower value of pH may inhibits or stop the digestion process.

3) **Water content:-** The recommended solid to water ratio is 1:1. If the dung is too diluted, the solid particles would settle down into the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production would be less than optimum.

4) **Toxic material:-** The content shouldn't have any toxic material or harmful material to bacteria in the digester.

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[4] 3-Cubic meter biogas plant, A construction manual, Published by Volunteers in technical assistance, Table 2, pg 17

[5] http://www.fao.org/sd/egdirect/egre0022.htm

5) **Temperature: -** Mesophilic digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C, where mesophiles are the primary microorganism present.

1.2.2. Characteristics of Available FS

FS will be procured from following two sources:-

1) FS collected from septic tanks (septage)

2) FS collected from mobile toilet vans (MTV)

The characteristics of available FS from different sources have been provided below:-

1. **FS collected from septic tanks**
   C/N ratio:- The C/N ratio is 8 for human waste[6].

   pH value:- The pH value of fecal sludge is between 4.6 to 8.4.

   Moisture: FS collected from septic tanks is high on water content. The water content of FS sourced from septic toilets is as high as around 96%. This can be done by dewatering free water from FS.

   Toxic material: The toxic content of fecal sludge is very less unless it's mixed with toilet cleaning agent, acid etc during cleaning of toilet. This should be avoided.

   Temperature:- In india, the climatic condition is suitable for mesophilic type of anaerobic digestion system. However the temperature within the geography varies a lot with season. Hence the temperature of FS sludge collected will be in the range of 10-40 degree C.

2. **FS collected from Mobile Toilet Vans (MTV)**
   C/N ratio:- The C/N ratio is 8 for human waste[7].

   pH value:- The pH value of fecal sludge is between 4.6 to 8.4.

   Moisture: A ten seat MTV has got 2000 liter[8] of storage capacity and on an average 500 people use this on daily basis. It is also found that per person water usage is normally 4 liter per use. Hence FS sludge from MTV of carrying capacity of 2000 liter should be discharged on daily basis in order to maintain the hygiene and cleanliness. The discharge frequency of MTV largely depends on water quantity used by individual users[9]. The average value of per person per day excreta generation is 250 gm. Normally, feces are made up of 75 percent

[6] http://www.fao.org/sd/egdirect/egre0022.htm
[7] http://www.fao.org/sd/egdirect/egre0022.htm
[8] http://trade.indiamart.com/details.mp?offer=3952505291
[9] Based on discussion with Prof P. K. Jha, working as an expert for evaluating proposals submitted to the Ministry of New &Renewable Energy, Government of India in the field of biogas and solid wastes management sectors

water and 25 percent solid matter[10]. Hence the moisture content from the MTV can be estimated as below:-

MTV carrying capacity = 2000 liter per MTV

Average number of Daily usage = 500 person per day

Per person excreta generation = 250 gm per day

Per person solid excreta generation = 250*25% = 62.5 gm per day

Total FS (solid) generation (Daily) = 500 * 62.5/1000 = 31.25 kg per day

Hence, total solid content = 31.25/2000 = 1.56% (approximately 2%)

Hence the moisture content in MTV sludge is approximately 98%. It is similar to water content when compared to septic tanks therefore the excess water need to be dewatered.

Toxic material: The toxic content of fecal sludge is very less unless it's mixed with toilet cleaning agent, acid etc during cleaning of toilet. This should be avoided.

Temperature:- In india, the climatic condition is suitable for mesophilic type of anaerobic digestion system. However the temperature within the geography varies a lot with season. Hence the temperature of FS sludge collected will be in the range of 10-40 degree C.

1.2.3. Gap Analysis

Following presents the gap between as-is and the Anaerobic digestion (mesophilic) requirements of FS in general.

TABLE 5: GAP ANALYSIS OF FS CHARACTERISTICS

Characteristics	Requirements of Anaerobic digester (Mesophilic)	From Septic Tank (As-is-FS)	From MTV (As-is-FS)
C/N ratio	20 to 30	8	8
pH value	6 to 7	4.6 to 8.4	4.6 to 8.4
Solid to liquid ratio	1:1	49:1	49:1
Toxic material	No	yes	Yes
Temperature	30 to 38 °C	10 to 40°C	10 to 40°C

[10] http://www.britannica.com/EBchecked/topic/203293/feces, EAI Estimates

In the following section, a detailed discussion is presented on the methods of processing of as-is FS.

1.3. Pre-processing of FS

Following need for pre-processing has been identified based on gap analysis in the earlier section:-

1) **C/N ratio:-** The optimum C/N ratio can be achieved by mixing animal waste or biomass with FS in appropriate ratio. The C/N ratio of various types of wastes is provided in the table below.

TABLE 6: C/N RATIO OF ORGANIC MATERIALS

Raw Materials	C/N Ratio
Duck dung	8
Human excreta	8
Chicken dung	10
Goat dung	12
Pig dung	18
Sheep dung	19
Cow dung/ Buffalo dung	24
Water hyacinth	25
Elephant dung	43
Straw (maize)	60
Straw (rice)	70
Straw (wheat)	90
Saw dust	above 200

Choice of mixing can be made depending on the availability of above raw materials and the need of the process. It has been observed that saw dust works very effectively for mixing.

2) **pH value:-** The pH value of fecal sludge is between 4.6 to 8.4. This need to treated with lime in case it's acidic or pH is lower than 6.

3) **Water:-** The excess water can be separated by using sedimentation method. The excess water can be removed from the top of digestion tank.

4) **Toxic material:-** Any presence of acid or toilet cleaning agent will kill bacteria. Hence the use of these toxic materials should be avoided. The sludge should also be free from foreign particles.

5) **Temperature:-** In india, the climatic condition is favorable for mesophilic anaerobic digestion. However in certain region and in certain season the temperature may go below 10 degree C. In the case external heating along with thermal insulation can be provided to digester to maintain the temperature range of 30 to 38 degree C.

1.3.1. Characteristics of Processed FS

Characteristics of FS after pre-processing are given below:

TABLE 7: CHARACTERISTICS OF FS

Characteristics	FS after pre-treatment
C/N ratio	20 to 30
pH value	6 to 7
Solid to liquid ratio	1:1
Toxic material	No
Temperature	30 to 38 °C

1.4. Challenges

1.4.1. Challenges in Pre-processing of FS

Collection and transportation

The key challenge in pre-processing of FS is to collect, transport and take it to the processing facility. Large quantities of water present in the septage make the job even more difficult. The presence of water also puts pressure on the economics of the process as such quantities would mean good money is spent on the transport part in the form of capital investments and also during operation and maintenance of the fleet.

The solution to this problem is to have in-situ treatment solutions where treated waste water is good for use i.e. landscaping, construction activities etc. However this means that users of treated waste water are available in close neighborhood and immediately avoiding need to transport water to a facility for storage. Whether or not this choice is available would impact the economics of the project significantly.

Other Challenges

Labor: Availability of local labor to operate a facility processing fecal sludge might pose an issue due to psychological or socio-cultural reasons. Any direct handling of FS sludge should be avoided due to presence of pathogens.

Availability & collection: Availability of FS might be an issue in areas where an on-site storage facility such as septic tank is not present.

Use of toilet cleaning agents:- Acid or toilet cleaning agents are used for toilet cleaning which impacts the bacteria growth in the digester. Apart from that in many cases detergents including soap, antibiotics, organic solvents, etc. are also mixed with toilet sludge and this has negative impact on bacteria growth. This should be avoided.

1.4.2. Challenges with Anaerobic Digestion

Anaerobic digestion is the most favorable and proven technology for energy generation from FS. However there are certain challenges with various process parameters of anaerobic digestion:-

Temperature

In India, there temperature varies a lot with season and hence the maintaining a temperature range of 30 to 38 degree C is essential for optimum biogas production. Biogas production is bound to go down during winter months of the year.

Long retention period

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. Considering the climatic conditions of India, a retention time of 30 days for mesophilic is desirable. Thus, a digester should have a volume of 30 times the slurry added daily.

Maintaining optimum C/N ratio

The C/N ratio of human excreta is eight which is much lower than the optimum C/N ratio. Hence the FS should be mixed with other types of waste with higher C/N ratio on continuous basis. The rate of mixing should result in optimum C/N ratio otherwise this may result in lower production of gas.

Socio-cultural issue

Human excreta are malodorous and associated with social and cultural taboos. There are misconceived perceptions among people about biogas generated from human waste. People generally consider it as unhygienic and impure. They do not accept use of biogas for religious purposes.

Biogas yield from settled sludge

Settled sludge of septic tank has high content of solid. It can be used for biogas generation provided such solid content has higher contents of non degraded part. In case of older settled sludge, solid contents are already in degraded form making less scope for further degradation by microbes and thus less chance of production of biogas. However, in case of fresh sludge from septic tank, biogas can be produced without much difficulty, after removing liquid part. However, such fresh sludge is rarely observed in case of septic tank. Most of the septic tanks are emptied only when tanks are filled and there is blockage of passage of water through toilet pan into the tanks. Any sludge of more than one year duration has very low biologically non degraded solid contents making unsuitable for biogas generation. Hence the septic tanks should be cleaned on frequent basis.

2. *Financial Analysis*

2.1. Description of Plug & Play Excel Model

The plug and play model has been prepared for calculation of levelized cost of biogas produced from Anaerobic Digestion of FS. The normal lifetime for household type of anaerobic digester is 10-15 years. However the lifetime for large scale or commercial scale of plant has been taken as 20 years and the analysis has been done for this period. In order to ensure longer lifetime, operation and maintenance cost has been taken as 5% of the capital cost (without subsidy) which is relatively high. The product yield and other relevant input parameters have been taken from similar type of waste to energy processes. There may be scenarios when the plant would require complete overhaul and need additional investment after a few years of operations if operation & maintenance is not done as demanded by the system. However, this scenario has not been built in the plug and play model.

2.2. Various Models for FS Procurement

Sustainable FS procurement is critical to the success of the program. Three types of FS procurement models have been considered. Each model presents different scenario of capital expenditure requirement, need of man power, revenue and operating cost streams. These are explained below:

1. **FS Collection and transportation - with own infrastructure: -** In India 38% of urban households have septic tanks. This number of septic tanks is expected to grow steeply in the next few years. There is no separate policy or regulation for septage management in India at present[11]. Septic tanks have been considered as one of the key sources for FS procurement. Further the collection of FS by using own tankers is financially viable compared to the FS collection from third party septic tank emptier. Hence the same has been considered in this FS procurement model. This would however depend on utilization level of tankers. The financial return could be maximized by outsourcing tankers for other activities like transportation of waste water, sewage etc.

2. **FS Collection using Mobile Toilet Vans: -** In urban India, approximately 17% people live in slums[12], where they don't have proper access to sanitation. Open defecation is still significantly prevalent in Indian cities. In line with MDG, Government of India has taken targets to make cities OD free. Providing community toilets and MTVs are immediate alternatives to OD. Deployment of MTVs in the slum areas will provide access to fresh human excreta which is not degraded unlike septage and therefore has good potential of biogas production.

3. **FS Collection and transportation – outsourced:-** In this model, FS will be procured from third party septic tank emptier. Emptier will sell the FS emptied from household septic tanks to project developer. Project developer doesn't own the infrastructure required for FS collection and transportation. Project developer however processes FS procured from emptier to convert into fuel grade in-house.

The base model has been prepared for 500 m3 daily production of biogas plant.

Figure 3 below shows the basic model of biogas production under various FS procurement sources. The key steps have been delineated to demonstrate the source of FS, production of biogas in the biogas plant.

[11] http://www.urbanindia.nic.in/programme/uwss/Advisory_SMUI.pdf
[12] http://articles.timesofindia.indiatimes.com/2013-03-22/india/37936264_1_slum-population-slum-households-rajiv-awas-yojana

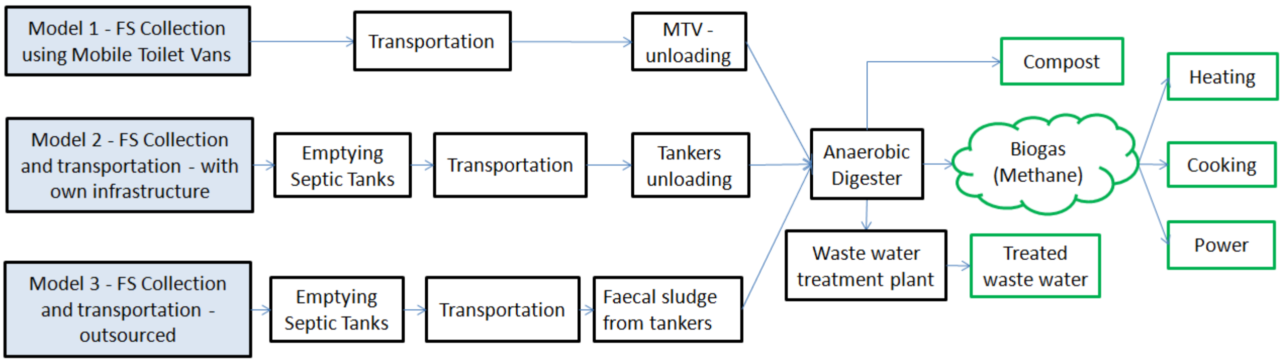


FIGURE 3: PROCESS FLOW DIAGRAM FOR ANAEROBIC DIGESTION PROCESS

The pros and cons for each FS procurement method have been provided in the table below.

TABLE 8: FS PROCUREMENT MODELS - PROS AND CONS

Index	Assumptions	Pros	Cons
Model 1	MTVs will be deployed by project developer at various locations in the city for people who don't have direct access to any formal sanitation system. The FS collected from MTV will be transported to the biogas plant.	• Access to fresh FS and hence high carbon content and good energy potential present. • Supply of FS will be consistent with high FS solid content.	• Handling of FS will be a challenge due to its form, odor, presence of pathogens and distributed nature of its availability. • Scaling up FS availability would be difficult. • Higher capital costs due to procurement of MTVs and high variable cost associated with operation and maintenance of MTV. • MTV model has not been very successful in many cities. This is mainly due to poor maintenance of MTVs. Hence the cost of maintenance will be high for proper functioning and mass acceptability of MTVs.
Model 2	In this model, FS will be procured directly from septic tanks owner by project developer. In this case, the emptying, collection and transportation network is owned and run by project	• Emptying of FS from septic tanks generate revenue for the project developer. • Project developer can share the tanker service with other business like Sewer sludge transportation,	• Higher capital costs due to procurement of emptying tankers and high variable cost associated with operation and maintenance of emptying system. • The project profitability or loss from collection and transportation also impacts

	developer.	waste water transportation etc to maximize the return.	the overall cost of FsDF production. • Lower carbon content in case septic tank is emptied after a long time. This will result in lower production of biogas.
Model 3	In this model, FS will be procured from third party septic tank emptier. Emptier will sell the FS emptied from household septic tanks to project developer. Project developer doesn't own the infrastructure required for FS collection and transportation. Project developer however processes FS procured from emptier to convert into fuel grade in-house.	• The capital cost is reduced due to no investment in collection, transportation and storage infrastructure. • Direct fixed cost of man power engagement and running the collection and transportation system avoided. • Project developer doesn't have to deal with individual household septic tank owners.	• Project developer pays for the emptier's service. • Project developer will not have access to the potential revenue from septic tank emptying from households. • Supply of FS may not be consistent as this depends on third party supplier.

Following costs and revenue streams are considered for estimation of levelized cost of Biogas production.

TABLE 9: KEY COST FACTORS FOR ANAEROBIC DIGESTION

Particulars	Model 1	Model 2	Model 3
Capital cost of MTVs	√	X	X
Capital cost for trucks	X	√	X
Capital cost for WWT plant	√	√	√
Capital cost of Biogas plant	√	√	√
Land cost	√	√	√
O&M cost of trucks	X	√	X
O&M cost of MTVs	√	X	X
O&M cost of WWT plant	√	√	√

O&M cost of Biogas plant	√	√	√
Cost of transportation from sanitation site to plant site	√	√	X
Cost of transportation of treated waste water	√	√	√
Procurement cost of FS sludge from third party	X	X	√

2.3. Sources of Revenue

Following sources of revenue have been considered in the present analysis.

TABLE 10: SOURCES OF REVENUE FOR VARIOUS FS PROCUREMENT MODELS

SN	Revenue Source	Model 1	Model 2	Model 3
1	Revenue from septic tank emptying	X	√	X
2	Revenue from per person toilet use of MTV	√	X	X
3	Revenue from sale of treated waste water	√	√	√
4	Revenue from sale of compost	√	√	√

2.4. Capital Cost

In the present case the project cost has been considered for a 500 cu. m biogas generation plant. The project cost has been referred from recently approved projects from MNRE of similar scale. MNRE also provides 50% capital subsidy on biogas plant (excluding land cost)[13] and has been considered here too. The average project cost is approximately 16000 INR/cu. m or $289/cu. m. The capital cost also includes the cost of facility required for post-processing of gas i.e. cleaning and purification units.

The breakup of capital cost for 500 cu. m system has been provided below for all FS procurement models:-

TABLE 11: CAPITAL COST FOR MODEL 1: FS COLLECTION USING MOBILE TOILET VANS

Parameters	Unit	Value	Reference
Capital cost for one MTV	USD	7,407	Based on information provided by third party
Number of MTVs required	#	28	Estimated based on MTV carrying capacity and daily usage. Refer to plug and play model
Total capital cost for MTVs	USD	207,407	Calculated
Capital cost of Biogas plant	USD	144,721	http://www.mnre.gov.in/schemes/r-d/rd-projects/

[13] http://www.mnre.gov.in/schemes/r-d/rd-projects/

Capital cost for WWT plant	USD	37,037	For 100KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biogas plant. Assumed land cost as INR 3 Lac INR or 5555 USD per bigha (approx 2500 sq. m.).
Total Cost	USD	**394,566**	**Calculated**

TABLE 12: CAPITAL COST FOR MODEL 2: FS COLLECTION AND TRANSPORTATION - WITH OWN INFRASTRUCTURE

Parameters	Unit	Value	Reference
Capital cost for one truck	USD	31,481	Based on report published by IRC, Bangalore
Number of trucks required	Number	3	Refer to the plug and play model for calculation
Total capital cost for trucks	USD	94,444	Calculated
Capital cost of Biogas plant	USD	144,721	http://www.mnre.gov.in/schemes/r-d/rd-projects/
Capital cost for WWT plant	USD	37,037	For 100 KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biogas plant. Assumed land cost as 0.3 million INR or 5,555 USD per bigha (approx 2500 sq. m.).
Total Cost	**USD**	**281,603**	**Calculated**

TABLE 13: CAPITAL COST FOR MODEL 3: FS COLLECTION AND TRANSPORTATION - OUTSOURCED

Parameters	Unit	Value	Reference
Capital cost of Biogas plant	USD	144,721	http://www.mnre.gov.in/schemes/r-d/rd-projects/
Capital cost for WWT plant	USD	37,037	For 100 KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biogas plant. Assumed land cost as 0.3 million INR or 5,555 USD per bigha (approx 2500 sq. m.).
Total Cost	**USD**	**187,158**	**Calculated**

2.5. Others Input Parameters

The model presents opportunity to change critical input parameters through drop down list. This variation can be used for optimization of this model. Following input factors are subjected to variation in the present plug and play model:

TABLE 14: VARIATION RANGE FOR CRITICAL INPUT PARAMETERS

SN	Input Factor	Base Scenario	Range from	Range To	Interval
1	Capacity of biogas plant	500 cu. m./day	200	1000	100
2	Biogas production	1 cu. ft/person/day	1	4	1
3	Number of operating days	300 per annum	250	360	30
4	Solid to liquid ratio in biogas plant	1:1	1:2	2:1	
5	Manure yield	4 kg/day	2	4	1
6	MTV carrying capacity	2000 liter/MTV/trip	1600	2200	100
7	Truck carrying capacity	5000 liter/trip	2000	5000	500
8	Mileage of truck	4 km/liter	2	8	1
9	Number of man days per truck	3 #/truck	2	5	1
10	Average trips per truck	5 per day	3	10	1
11	Average distance travelled	20 km/ trip	5	30	5
12	Per person water use	4 liter	1	6	1
13	Project cost - Debt	70%	50%	70%	
14	Interest rate - Debt	12%	10%	15%	1%
15	Discount rate	16%	12%	18%	1%
16	Currency conversion	54 INR/USD	45	56	1
17	Debt repayment period	6 years	6	10	1

2.6. Results and Discussion for Anaerobic Digestion Process

The levelized cost of biogas has been calculated for three types of FS procurement models. The plug and play model also provides the levelized cost of biogas for individual processes like collection and transportation, dewatering and biogas plant. The revenue streams applicable for all models have also been considered while calculating the levelized cost of biogas. This will help to identify the most cost intensive process and at the same time help to take necessary measures to reduce the overall levelized cost of biogas.

Following revenue streams are considered:

Revenue 1: from septic tank emptying

Revenue 2: from per person toilet use of MTV

Revenue 3: from sale of treated waste water

Revenue 4: from sale of compost

Levelized cost Biogas:

The Levelized cost of Biogas has been provided below. This also provides the Levelized cost for individual processes.

TABLE 15: COST OF FS FUEL

Model	Collection and transportation	Dewatering & WWT	RRS technology	Overall cost
Model 1 - FS Collection using Mobile Toilet Vans	-0.22	-0.09	0.016	**-0.30**
Model 2 - FS Collection and transportation - with own infrastructure	-0.03	-0.09	0.016	**-0.11**
Model 3 - FS Collection and transportation - outsourced	0.13	-0.12	0.016	**0.02**

All values in (USD/cu. m)

As it is evident from above, model 1 and model 2 are viable as the production of biogas results in negative cost. For model 3 also the overall cost is approximately zero. However the profit from Model 1 is greater than other 2 models. This is mainly because of revenue collection from use of MTV. A comparison of biogas with different commercial fuels has been provided in the table below.

TABLE 16: ENERGY EQUIVALENT QUANTITY OF FUELS[14]

Name of the fuel	Natural gas	Butane	Gasoline	Diesel
Equivalent quantities to 30 cu. m of biogas	600 cu. Ft	6.4 gallon	5.2 gallon	4.6 gallon

A sensitivity analysis of +/-100% on capital cost, O&M cost and revenue has been performed.

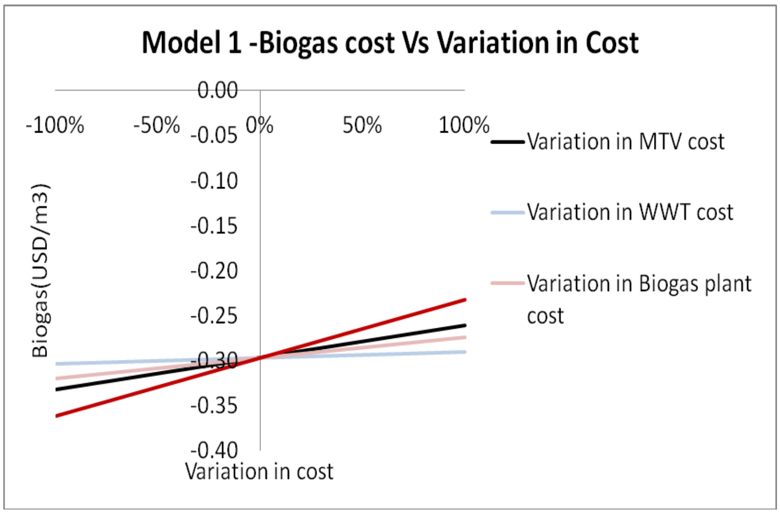
The outcome of the sensitivity analysis has been summarized below for all FS procurement models:-

[14] Dr P K Jha, Recycling and reuse of human excreta from public toilets through biogas generation to improve sanitation, community health and environment

For Model 1

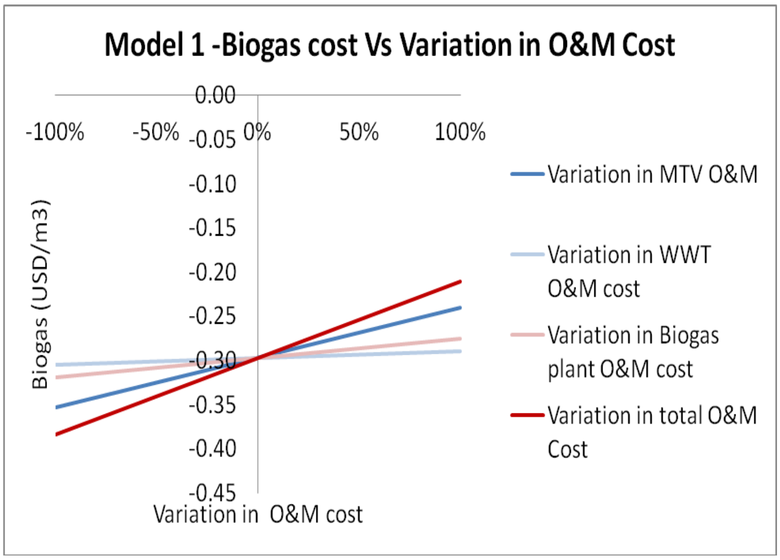
1. **Impact of variation in capital cost on biogas cost**

Capital cost has been taken from appropriate sources and the same has been confirmed with sector experts, hence a large variation in capital cost is not possible. It is also evident from the above figure that any such variation will not have major impact on the levelized cost of biogas production.



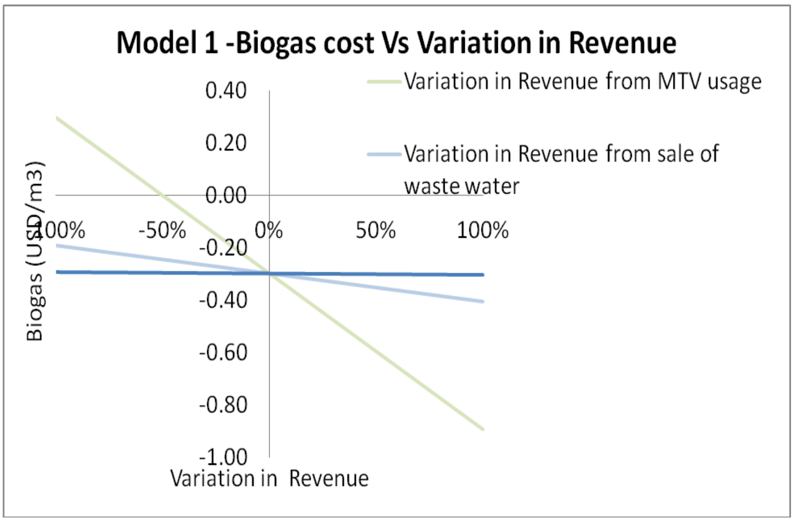
2. **Impact of variation in O&M cost on Biogas cost**

There are variations in O&M cost obtained from different sources. The O&M cost also varies with geography etc. Hence there are chances that O&M cost may vary depending on operating scenario on the ground. However this won't have major impact on levelized cost of biogas.



3. **Impact of variation in revenue on biogas cost**

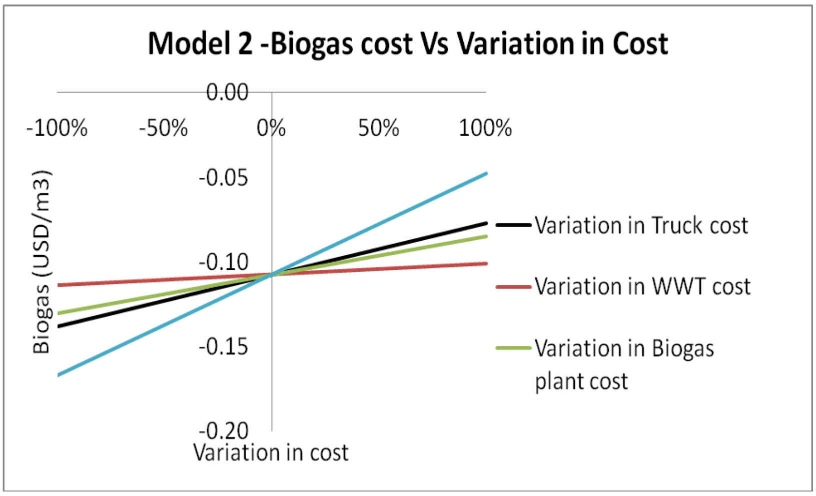
The profit from Model 1 is greater than the profit from Model 2 and this is mainly because of significant revenue collection from per person use of MTV. Any variation in revenue collection from MTV use will have major impact on biogas production cost. The levelized cost of biogas production will become positive when MTV per person usage charges is reduced to 1.25 INR/use or 2.3 USD cent/use or below.



For Model 2

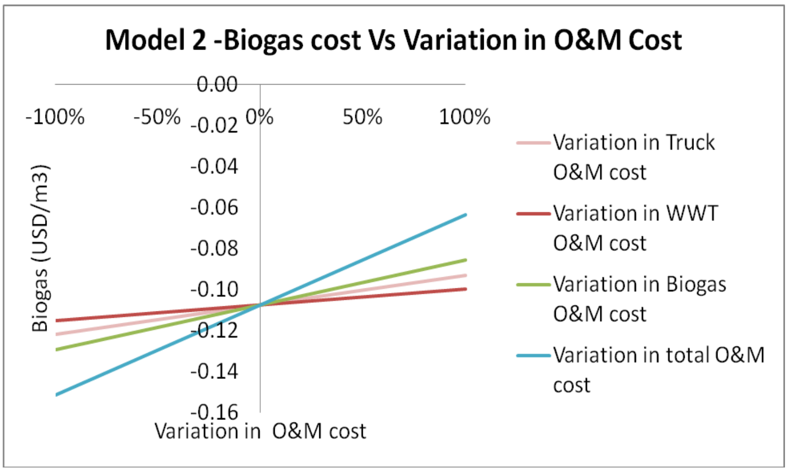
1. **Impact of variation in capital cost on biogas cost**

Capital cost has been taken from appropriate sources and the same has been confirmed with sector experts, hence a large variation in capital cost is not possible. It is also evident from the above figure that any such variation will not have major impact on the Levelized cost of biogas production.



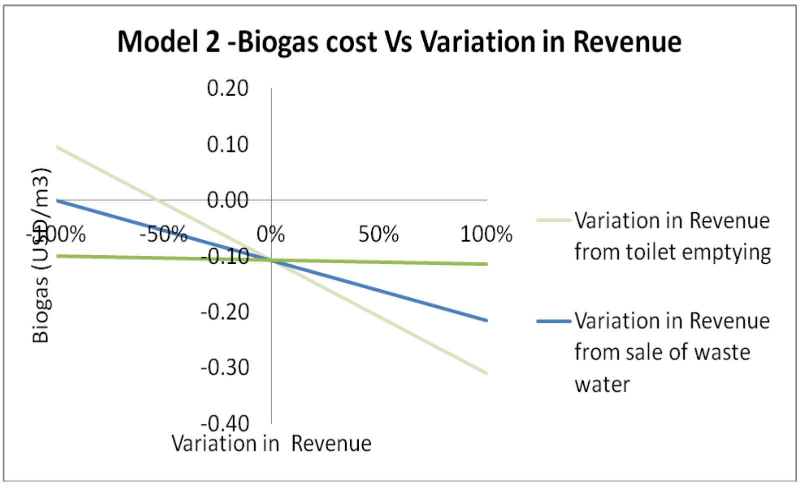
2. **Impact of variation in O&M cost on biogas cost**

There are variations in O&M cost obtained from different sources. The O&M cost also varies with geography etc. Hence there are chances that O&M cost may vary depending on operating scenario on the ground. However this won't have major impact on levelized cost of biogas.



3. **Impact of variation in revenue on biogas cost**

It is evident from the figure above that any variation in revenue collection from septic tank cleaning will have major impact on biogas production cost. The levelized cost of biogas production will become positive when septic cleaning charge is reduced to 4.62 USD per cleaning from 14.81 USD per cleaning.

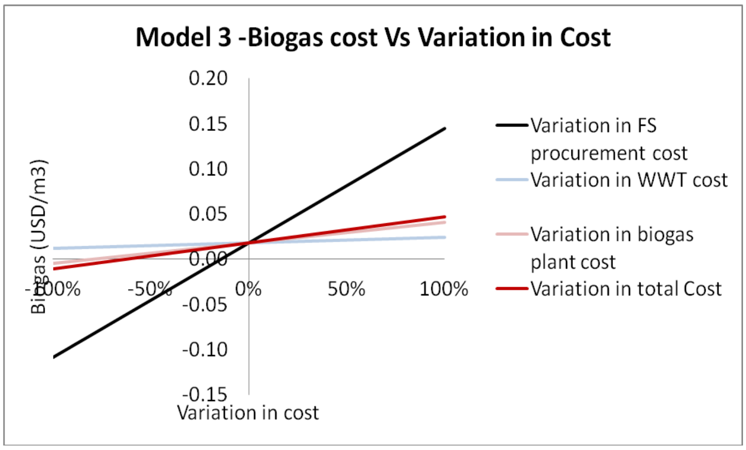


The septic cleaning charge varies a lot across the geography and hence the possibility of the same can't be ruled out. It's also evident from the above figure that the biogas production cost will be positive with zero earning from sale of treated waste water. This is possible in a scenario where there is no immediate market for treated waste water.

For Model 3

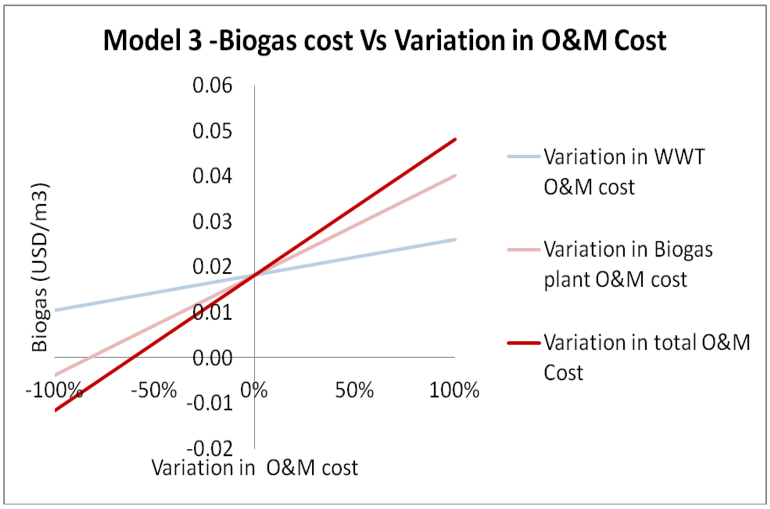
1. Impact of variation in capital cost on biogas cost

The levelized cost of biogas production is approximately zero even for model 3. However the cost of FS sludge procurement will have a significant impact on the levelized cost of biogas production.



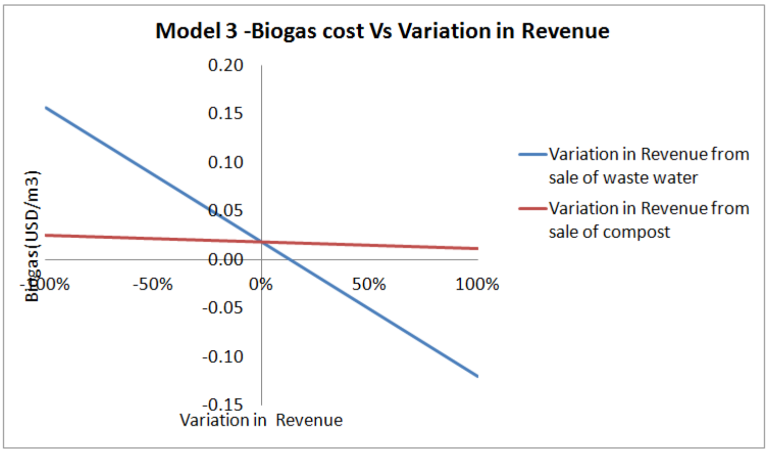
2. Impact of variation in O&M cost on Biogas cost

There are variations in O&M cost obtained from different sources. The O&M cost also varies with geography etc. Hence there are chances that O&M cost may vary depending on operating scenario on the ground. However this won't have major impact on levelized cost of biogas.



3. Impact of variation in revenue on biogas cost

The levelized cost of biogas production is approximately zero. However any variation in the revenue collected from sale of treated waste water will have major impact on biogas production cost.



Hence a proper due-diligence is required on applicability of different pieces of the model before finalizing any model for procurement of FS and production of gas to minimize the financial risk.

3. *Conclusion*

1. All FS procurement models are resulting in profitable business of biogas generation using FS as raw feed. However the availability of subsidy and other cost-revenue values should be confirmed based on relevant market data.
2. For Indian condition, continuous process, single stage mesophilic anaerobic digestion is preferred.
3. The MTV model (Model 1) is the most profitable model for biogas production. The success of this model depends on the utilization level of MTVs. MTV use has been assumed as 500 incidences per day per MTV. Currently, MTV model is not very successful in Indian scenario. This is largely due to poor maintenance of MTVs because of which people prefer open defecation to MTV use. Any reduction in MTV use will have serious impact on revenue collection and result in higher biogas production cost. This can be assured by providing proper cleanliness and maintenance of MTVs.
4. The access to fresh human excreta from MTVs will result in higher biogas yield compared to sludge collected from septic tanks. Hence the MTV model should be preferred for implementation of biogas plant. However, maintaining availability of enough FS only from MTVs is a challenge.
5. The biogas yield can also be maximized by mixing FS with other types of waste with higher C/N ratio. However such mixing of FS with other types of waste has not been considered in the present plug and play model.
6. In India, there are many unauthorized colonies where construction of individual septic tanks is not feasible due to lack of space in households. In these cases, a centrally located biogas plant can be constructed connected to each household through internal piping network. This will give access to fresh excreta from houses on continuous basis. As estimated 7000 people would be required for a 200 cu. m biogas plant per day. This requirement can be fulfilled by connecting roughly 1500 households (assuming 4-5 members in each family).
7. Anaerobic digestion is relatively simple technology compared to the other technologies such as gasification or pyrolysis for FS to energy conversion.

Policy & Regulation

1. Land acquisition is a major problem for waste to energy projects. Hence the government may facilitate and provide the land on lease basis to project promoters in areas nearby urban region to reduce transportation cost.

2. Government of India is providing subsidy for such projects. However there are large numbers of projects which are commissioned but not functional. Hence in order to

ensure the performance of such plants, the Government may provide performance based incentives.

3. Government may regulate by providing limited licenses in a given region. This will ensure availability of FS for such waste to energy plants at commercial scale without affecting their availability.

4. The use of biogas in transportation should be promoted by government. There may also be a provision for preferential tariff for power generated from FS based biogas plant to increase their financial viability.

5. Participation of private players may be encouraged by implementing PPP model for development of such waste to energy projects with Government and Private players sharing risks and returns.

6. Such waste to energy projects may have many co-benefits in the form of avoided cost in O&M cost of STP, reduction in expenditure on health & hygiene, enhanced economic activity besides avoiding cost of installation of STPs. These co-benefits may be identified and quantified. The avoided costs by municipalities may be transferred to such waste to energy projects in terms of additional incentives or subsidies.

7. The government has mandated spending by companies registered at least 2 per cent of their net profit towards corporate social responsibility (CSR) activities under Companies Bill 2012[15]. Such waste to energy projects may be included under the definition of CSR activities. More companies would be encouraged to invest a part of CSR expenditure on such waste to energy projects.

[15] http://www.indianexpress.com/news/companies-bill-passed-with-mandate-on-csr-spending/1047290/1

4. *Limitation*

Collection and transportation

1. Only three sources for FS procurement have been selected in this Plug and Play model. Other procurement models can also be explored.

2. Solid content in sludge collected from septic tanks and MTVs are considered as 2% which is largely to vary. The plug and play model has been developed for 2% solid content. Hence any reduction in solid content needs to be reassessed.

3. The MTV usage has been assumed as 500 per day per MTV. However this is subject to various parameters which are beyond the control of MTV owner. Any reduction in MTV usage needs to be reassessed.

4. Revenue from septic tank collection:- At present, residents pay cleaning charges to tanker emptying agencies. However this may cease off once they realize the commercial value of septic sludge.

5. O&M cost of MTV has been assumed as 3000 Rs/Month. This also includes the cost of care-taker (if any).

6. Revenue from per person usage in MTV:- As of now, the MTV model is not successfully working in India. This is due to poor maintenance of MTVs. Any further usage charges might result in low usage of MTV. This will have serious impact on revenue collection and this result in higher fuel production cost.

7. It has been assumed that FS will be procured from a radius of 10 km from plant site. In that case the plant location should be ideally in the center of urban area which is not possible. Hence the travelled distance need to assess based on actual distance from urban area.

8. It has been assumed that new trucks will be purchased for procurement of FS. However in local practice, people also purchase old trucks and modify it for carrying of septic sludge. However the cost of O&M is relatively higher. This aspect has not been considered in the Plug and Play model.

9. Carbon content is low in the sludge collected from septic tanks. In case of older settled sludge solid contents are already in degraded form, making less scope for further degradation by microbes and thus less chance of production of biogas. The impact of this has not been considered in the present plug and play model.

Pre-processing

1. The C/N ratio of human excreta is lower compared to the optimum C/N ratio. Hence this could be mixed with other types of waste to increase C/N ratio. This aspect has not been considered in the present model.

2. It has been assumed that the sludge collected from septic tanks and MTVs are sufficient resident time inside digester and this will help to separate solid from water. The water from top will be drained out from the system for further treatment. Hence a separate dewatering system has not been considered in this plug and play model.

Anaerobic Digestion

1. The digestion process largely depends on the operating temperature. In India due to climatic condition the temperature varies across the year and with location as well. This will have impact on the production of biogas.

2. People use toilet cleaning agents or acid or mix soap, detergent with toilet sludge and this will have negative impact on bacteria population which will result in lower production of gas.

3. Any deviation in key parameters like temperature and moisture will change the biogas yield both in terms of quality and quantity. The impact of the same has not been considered in the present plug and play model.
