Technologies for Energy Recovery from Faecal Waste

Technical and Financial Analysis – Fermentation

August, 2013

BILL & MELINDA GATES foundation

EVI Sustainable Solutions for the Environment

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Abbreviations and Acronyms:

AD	Anaerobic Digestion
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DS	Dry Solid
FS	Faecal Sludge
IT	Income Tax
INR	Indian Rupees
KLD	Kilo Litre per Day
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.

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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, Fermentation 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 biodiesel production in different scenarios. The biodiesel can be used as transport fuel or for other purposes. 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 biodiesel.

Chapter 2: Financial Analysis provides the Levelized cost of Biodiesel produced by using fermentation 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 biodiesel can be compared with diesel that it would replace for energy recovery.

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 biodiesel production using FS sourced from MTVs is more profitable however it entails higher upfront capital requirement in infrastructure.

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

1. Technology Analysis

1.1. Technology Description

Fermentation is the process by which micro-organisms breakdown organic matter to simpler organic compounds such as alcohol and organic acid as well as inorganic compounds like carbon dioxide and hydrogen. The fermentation takes place inside the anaerobic digester. The process is stopped after acetogenesis stage by using inhibitors and controlling the operation parameters. Acetic acid produced after acetogenesis stage is further converted to fatty acids by using engineered strains of Saccharomyces or Escherichia (microorganism). Fatty acid is used as raw feed with methanol for production of biodiesel in bioreactor. Methanol can be produced from methane generated from anaerobic digestion of residual stream.

The diagram below shows the basic schematic of the digestion process considered for the analysis in this study. This diagram also includes FS procurement models.

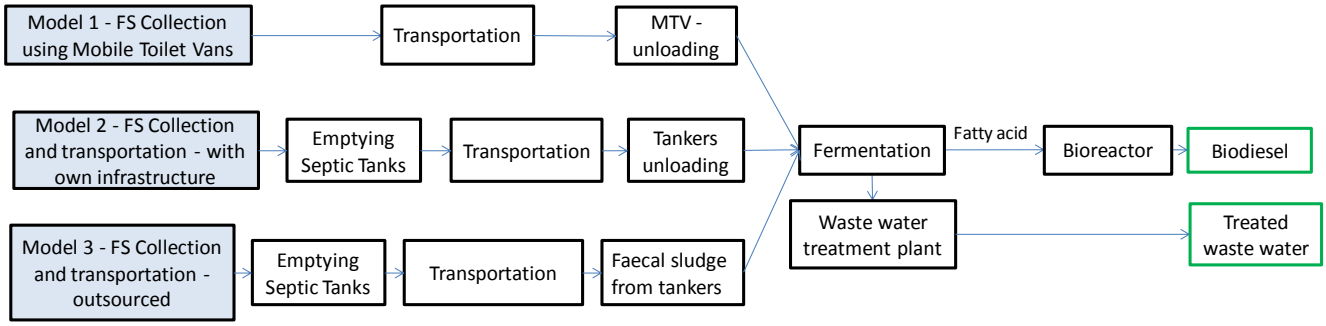

FIGURE 1: BASIC SCHEMATIC OF BIODIESEL PRODUCTION PROCESS

1.1.1. Microbiology and Biochemistry of Biogas Generation

The two key steps in production of biodiesel from fecal sludge are (1) Fermentation (2) Production of biodiesel.

Fermentation

Fermentation process involves production of fatty acids from fecal sludge. In a fermenter, following three processes occur- hydrolysis, acidogenesis and acetogenesis.

In the hydrolysis process, macro molecules like proteins, poly saccharides and fats that compose the cellular mass of the excess sludge are converted into molecules with a smaller atomic mass that are soluble in water. The hydrolysis process is carried out by exo-enzymes excreted by fermentative bacteria.

The soluble compounds produced through hydrolysis are degraded into carbon dioxide, hydrogen, alcohols and organic acids in the Acidogenesis stage in the presence of facultative anaerobes.

In the third step, acetogenesis, the products of the acidification are converted into acetic acid, hydrogen, and carbon dioxide by acetogenic bacteria.

Due to the anaerobic condition, the process has a tendency to go to Methanogenesis stage and form methane and carbon dioxide. However this process is interrupted by controlling operation parameters (like pH, temperature, air exposure) and adding chemical inhibitors like iodoform. The accumulated acetic acid after Acetogensis stage is converted into fatty acids with the help of engineered microorganisms (like engineered Saccharomyces or E.coli)[1].

Production of Biodiesel

Biodiesel are esters of fatty acids which are produced by the transesterification of fatty acids in the presence of methanol. Methanol can be produced from methane generated from anaerobic digestion of residual stream. Transesterification is the reaction of a fatty acid with an alcohol to form esters and glycerol. The biodiesel reaction takes place in the presence of catalyst such as sodium hydroxide. The main byproduct is glycerol.

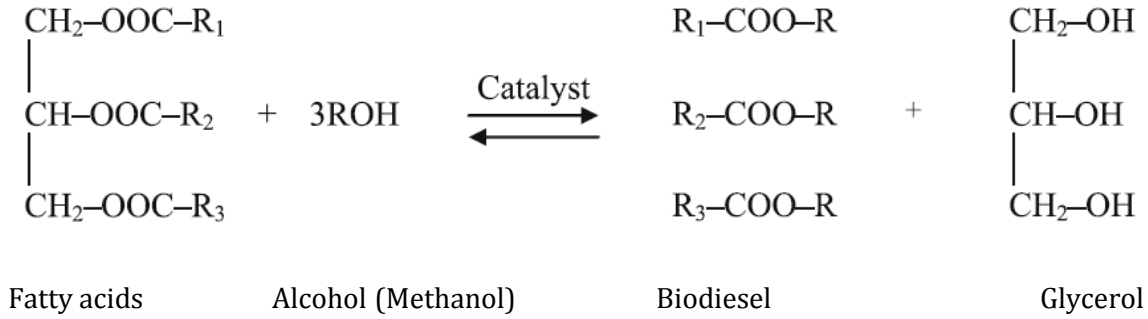

FIGURE 2: CHEMICAL REACTION FOR PRODUCTION OF BIODIESEL

1.1.2. Products of Fermentation

The three main products of fermentation are biodiesel, glycerine and compost.

1) **Biodiesel: -** Biodiesel is one of the main products of fermentation of fecal sludge. This can be blended with diesel. Fermentation process produces around 10% of the biodiesel from fecal sludge on weight basis.

2) **Glycerol: -** Glycerol is produced after transesterification of fatty acids in bioreactor. The Glycerol yield is 1% of dry FS processed on weight basis. Glycerol is used in pharmaceutical and personal care products industry.

[1] Yinjie J. Tang; Conversion of fecal waste to biofuels by engineered microbes

3) **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.

4) **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 be treated before any possible use.

1.2. Raw Feed Characteristics

1.2.1. Feed Stock Requirement for Production of Biodiesel

1) **Lipid content: -** The lipid content should be high for production of fatty acid during Acetogenesis stage of fermentation. The higher content of fat or lipid in raw feed results in higher yield of fatty acid and in turn higher production of biodiesel.

2) **pH value: -** The optimum acetic acid production is achieved when the pH in the fermenter is around 4. A neutral pH will lead to the methanogenisis process which is not desired in the present case.

3) **Water content: -** If the sludge is too diluted, the solid particles will settle down into the digester and if it is too thick, the particles impede the digestion of fatty acids on the upper part of fermenter. In both cases, acetic acid production will be lower than optimum. Hence water to solid FS ratio of 6:10 has been considered.

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

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 is considered to 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**

   Lipid content: - The average lipid or fat content in fecal sludge is 7gm/day[2]. It is approximately 10% of FS generated by human being (considering 250 gm FS generation per person per day with 25% solid).

   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 faecal 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)**

   Lipid content: - The average lipid or fat content in fecal sludge is 7gm/day[3]. It is approximately 10% of FS generated by human being (considering 250 gm FS generation per person per day with 25% solid).

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

   Moisture: A ten seat MTV has got 2000 liter[4] 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[5]. The average value of per person per day excreta generation is 250 gm. Normally, feces are made up of 75 percent water and 25 percent solid matter[6]. Hence the moisture content from the MTV can be estimated as below:-

[2] http://en.wikipedia.org/wiki/Fecal_fat_test
[3] http://en.wikipedia.org/wiki/Fecal_fat_test
[4] http://trade.indiamart.com/details.mp?offer=3952505291
[5] 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
[6] http://www.britannica.com/EBchecked/topic/203293/feces, EAI Estimates

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 1: GAP ANALYSIS OF FS CHARACTERISTICS

Characteristics	Requirements of Anaerobic digester (Mesophilic)	From Septic Tank (As-is-FS)	From MTV (As-is-FS)
Lipid content	High	~10%	~10%
pH value	6 to 7	4.6 to 8.4	4.6 to 8.4
Water to solid FS	6:10	49:1	49:1
Toxic material	No	Yes	Yes
Temperature	30 to 38 °C	10 to 40°C	10 to 40°C

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) **Lipid content: -** The lipid content can be maximized by mixing FS with wastes having high lipid contents.

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 kills 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°C. In the case external heating along with thermal insulation can be provided to digester to maintain the temperature range of 30 to 38°C.

1.3.1. Characteristics of Processed FS

Characteristics of FS after pre-processing are given below:

TABLE 2: CHARACTERISTICS OF FS

Characteristic	FS after pre-treatment
Lipid content	High
pH value	6 to 7
Water to solid FS	6:10
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 makes 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 transportation 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 faecal 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 Fermentation

The production of biodiesel from FS requires production of acetic acids from Acetogenesis stage of fermentation. The process of digestion should be stopped after Acetogenesis stage otherwise it leads to production of methane. The acetic acid gets converted into fatty acids in the presence of engineered microorganism. This fatty acid is utilized for production of biodiesel in bioreactor.

There are various challenges associated with each stage:-

Process up to Methanogenesis stage

Fermentation is a continuous process and it forms methane after acetogenesis stage. However this should be inhibited by controlling operation parameters like pH, temperature etc and/or by adding chemical inhibitors otherwise acetic acid is not produced.

Separation of acetic acid from the fermented broth

Fermented broth is a mixture of microbial cells, unutilized sludge, organic acids like acetic acid, etc. Separation of purified and concentrated acetic acid requires many separation techniques like membrane technology and this involves additional cost. Separation of chemical inhibitors used in fermentation from acetic acid is also a challenge.

Process for conversion from acetic acid to fatty acid

Conversion of acetic acids to fatty acids is being performed from engineered strains of Saccharomyces or Escherichia. Microorganisms always have a tendency to use up the Acetyl CoA formed from acetic acid in TCA /citrate cycle or Gluconeogenesis cycle. This leads to production of other types of by-products. Engineered microorganisms are mutated forms of microbes wherein the acetyl CoA is converted to fatty acid by following the fatty acid metabolism pathway instead of the /citrate cycle or Gluconeogenesis cycle. However the effectiveness of such engineered

microorganisms is subjected to further research. Engineered microorganisms are very sensitive to operation parameters such as pH, temperature etc. Any change in operation parameters will alter the process for production of fatty acids from acetic acid.

Socio-cultural issue

Human excreta are malodorous and associated with social and cultural taboos. There are misconceived perceptions among people about products generated from human waste. People generally consider those as unhygienic and impure.

Fatty acid yield from settled sludge

Settled sludge of septic tank has high content of solid. It can be used for fatty acid production 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 fatty acids. 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 fatty acid production. 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 biodiesel produced from Fermentation of FS. The fermentation takes place inside the fermenter. The process is stopped after acetogenesis stage by using inhibitors and controlling the operation parameters. Acetic acid produced after acetogenesis stage in the fermenter is further converted to fatty acids by using engineered microorganism. Fatty acid is used as raw feed with methanol for production of biodiesel in bioreactor. Methanol can be produced from methane generated from anaerobic digestion of residual stream.

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 the same, the operation and maintenance cost has been taken as 5% of the capital cost which is relatively high.

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) **Procurement from septic tanks using 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, but there is no separate policy or regulation for septage management in India at present[7]. Hence septic tanks have been considered as one of the source 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. In this model, the financial return could be maximized by outsourcing tankers for other activities like transportation of waste water, sewage etc.

2) **Procurement from MTV: -** In urban India, approximately 17% people lives in slums[8], where they don't have proper access to sanitation. In that case, mobile toilet vans along with community based toilets could be the based feasible option. Deployment of MTVs in the slum areas will provide access to fresh human excreta.

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.

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

The base model has been prepared for 100 liter per day production of biodiesel plant.

Figure 3 below shows the basic model of Biodiesel production under various FS procurement sources. The key steps have been delineated to demonstrate the source of FS and production of biodiesel.

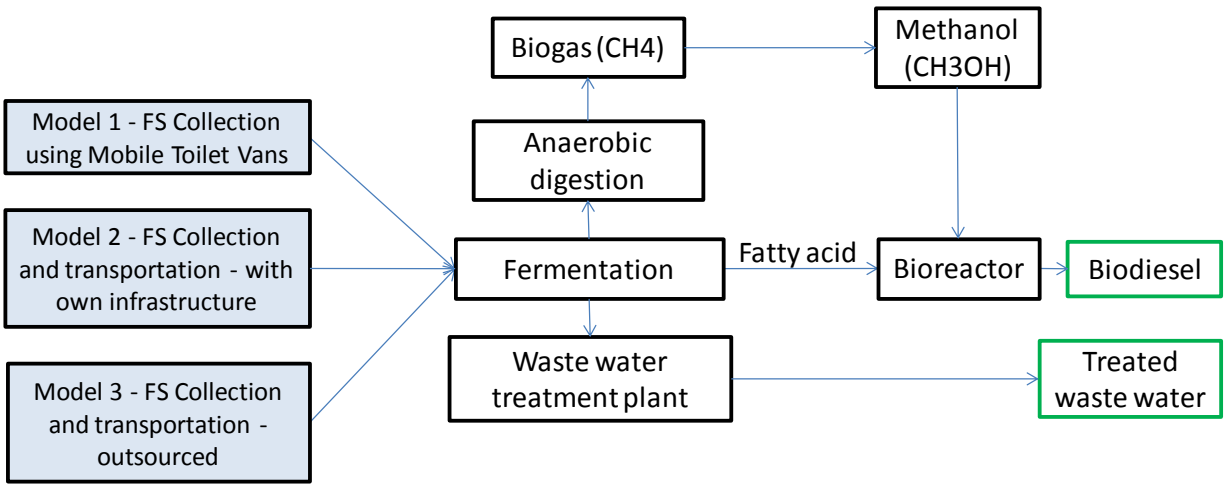

FIGURE 3: PROCESS FLOW DIAGRAM FOR PRODUCTION OF BIODIESEL FROM FAECAL SLUDGE

THE PROS AND CONS FOR EACH FS PROCUREMENT METHOD HAVE BEEN PROVIDED IN THE TABLE BELOW.

TABLE 3: 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 biodiesel 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 developer.	• 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, waste water transportation etc to maximize the return.	• 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 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 biodiesel.
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 cost streams are considered for estimation of Levelized cost of Biodiesel production.

TABLE 4: KEY COST FACTORS

Particulars	Model 1	Model 2	Model 3
Capital cost of MTV	√	X	X
Capital cost for truck	X	√	X
Capital cost for WWT plant	√	√	√
Capital cost of Biodiesel plant	√	√	√
Land cost	√	√	√
O&M cost of truck	X	√	X
O&M cost of MTV	√	X	X
O&M cost of WWT plant	√	√	√
O&M cost of Biodiesel 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	√

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

TABLE 5: 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 usage of MTV	√	X	X
3	Revenue from sale of treated waste water	√	√	√

2.3. Capital Cost

In the present case the project cost has been considered for a 100 liter biodiesel production plant. The project cost includes the cost of fermenter and bioreactor.

The project cost for fermenter has been referred from recently approved projects from MNRE of similar scale. However these costs are provided for various capacities of biogas production plants. Since bio-digesters and fermenters perform similar process, the cost of fermenter in the present case has been estimated based on the raw feed requirement to produce desired

quantity of bio-diesel. Following information has been used for estimation of capital cost of fermenter:-

1. Biodiesel yield[9] from dry FS as 10%
2. Per person per day biogas production has been taken as 1 cu. ft
3. Per person daily FS discharge has been taken as 250 gm with 25% solid

TABLE 6: ESTIMATATION FOR CAPITAL COST FOR FERMENTER

S.No.	Particulars	Value	Unit
1	Production capacity	100	liter/day
2	Biodiesel yield	10%	%
3	FS (Dry) required	1,000	kg/day
4	Average cost of fermenter[10]	131.13	USD/kg of dry FS
5	**Project cost for Fermenter**	**131,136.4**	**USD**

The cost of bioreactor for production of biodiesel has been taken from a reference project for production of biodiesel from Jatropha seed. It has been assumed here that the plant cost for biodiesel production from FS is similar to the biodiesel production from Jatropha. However the cost for given production capacity should be verified from suppliers.

TABLE 7: ESTIMATION FOR CAPITAL COST FOR BIOREACTOR

S.No.	Particulars	Value	Unit
1	Production capacity of reference plant	250	liter/day
2	Installation cost[11] of reference plant	250,000	INR
3	Average Installation cost of reference plant	18.52	USD/liter
4	Production Capacity for analysis	100	liter/day
5	Project cost for bioreactor	1,851.9	USD

The total project cost for 100 liter of biodiesel production plant is $132,988 (excluding land). This cost includes the cost of fermenter and bioreactor. The breakup of capital cost for 100 liter system has been provided below for all FS procurement models:-

TABLE 8: 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	#	25	Estimated based on MTV carrying capacity and daily usage. Refer to plug and play model

[9] Kartik Chandran, Resource recovery from faecal sludge an elemental approach, Focal Sludge management Conference, Durban, October 2012
[10] Refer to project sheet of plug and play model
[11] http://www.bioenergy.org.nz/documents/liquidbiofuels/Pilot_Plant_for_Biodiesel-leaflet1.pdf

Total capital cost for MTVs	USD	185,185	Calculated
Capital cost of Biodiesel plant	USD	132,988	Refer to plug and play model
Capital cost for WWT plant	USD	18,519	For 50KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biodiesel plant. Assumed land cost as INR 0.3 million INR or 5555 USD per bigha (approx 2500 sq. m.).
Total Cost	USD	**342,092**	**Calculated**

TABLE 9: 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	2	Refer to the plug and play model for calculation
Total capital cost for trucks	USD	62,963	Calculated
Capital cost of Biodiesel plant	USD	132,988	Refer to plug and play model
Capital cost for WWT plant	USD	18,519	For 50 KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biodiesel plant. Assumed land cost as 0.3 million INR or 5,555 USD per bigha (approx 2500 sq. m.).
Total Cost	**USD**	**219,870**	**Calculated**

TABLE 10: CAPITAL COST FOR MODEL 3: FS COLLECTION AND TRANSPORTATION - OUTSOURCED

Parameters	Unit	Value	Reference
Capital cost of Biodiesel plant	USD	132,988	Refer to plug and play model
Capital cost for WWT plant	USD	18,519	For 50 KLD system - http://www.cseindia.org/node/3770
Land cost	USD	5,400	Approximately 2000-2500 sq. m. land area will be required for biodiesel plant. Assumed land cost as 0.3 million INR or 5,555 USD per bigha (approx 2500 sq. m.).

Total Cost	**USD**	**156,907**	**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 11: VARIATION RANGE FOR CRITICAL INPUT PARAMETERS

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

2.6. Results and Discussion for production of Biodiesel

The levelized cost of biodiesel has been calculated for three types of FS procurement models. The plug and play model also provides the levelized cost of biodiesel for individual processes like collection and transportation, dewatering and biodiesel plant. The revenue streams applicable for all models have also been considered while calculating the levelized cost of

biodiesel. This helps to identify the most cost intensive process and at the same time provides opportunity to take necessary measures to reduce the overall levelized cost of biodiesel.

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

Levelized Cost of Biodiesel:

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

TABLE 12: LEVELIZED COST OF BIODIESEL

Model	Collection and transportation	Dewatering & WWT	Biodiesel	Overall cost
Model 1 - FS Collection using Mobile Toilet Vans	-1.02	-0.45	0.21	**-1.26**
Model 2 - FS Collection and transportation - with own infrastructure	-0.10	-0.45	0.21	**-0.34**
Model 3 - FS Collection and transportation - outsourced	0.42	-0.45	0.21	**0.18**

All values in (USD/liter)

It is evident that model 1 and model 2 are profitable for production of biodiesel. However the profit from Model 1 is greater than the profit from model 2. This is mainly because of revenue collection from per person use of MTV. Model 3 is also profitable at the given market price of commercial diesel. The market price of commercial diesel is $0.83 per liter which is much higher than the Levelized cost of biodiesel production.

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

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

For Model 1

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

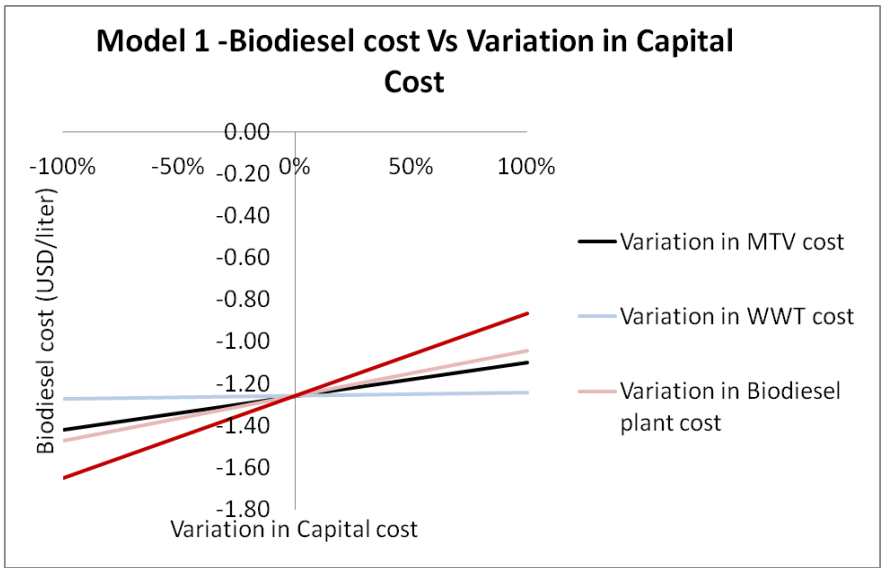

FIGURE 4: VARIATION IN CAPITAL COST ON BIODIESEL COST

The levelized cost of biodiesel production varies with variation in MTV cost and biodiesel plant cost. However this variation is not very significant.

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

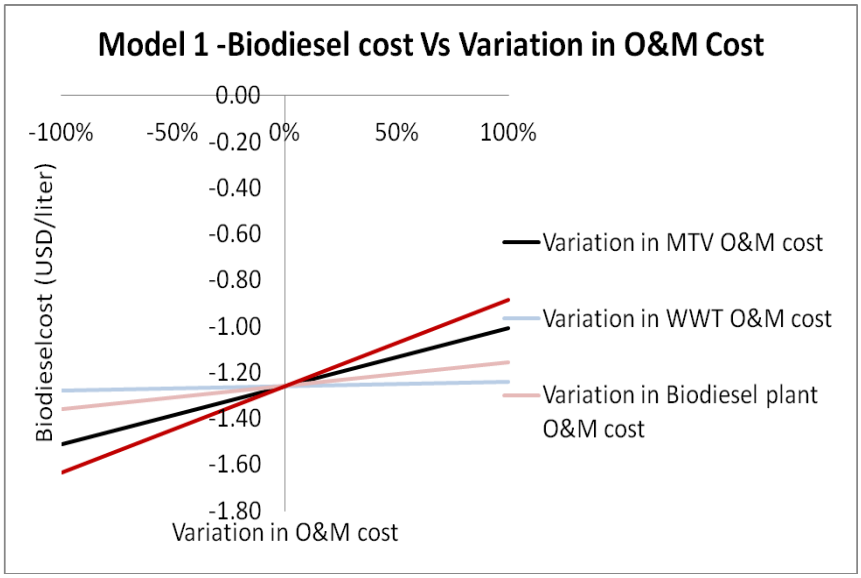

FIGURE 5: VARIATION IN O&M COST ON BIODIESEL COST

Large variation has been observed 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 significantly depending on the operating scenarios. However this doesn't have major impact on levelized cost of biodiesel.

3. **Impact of variation in revenue**

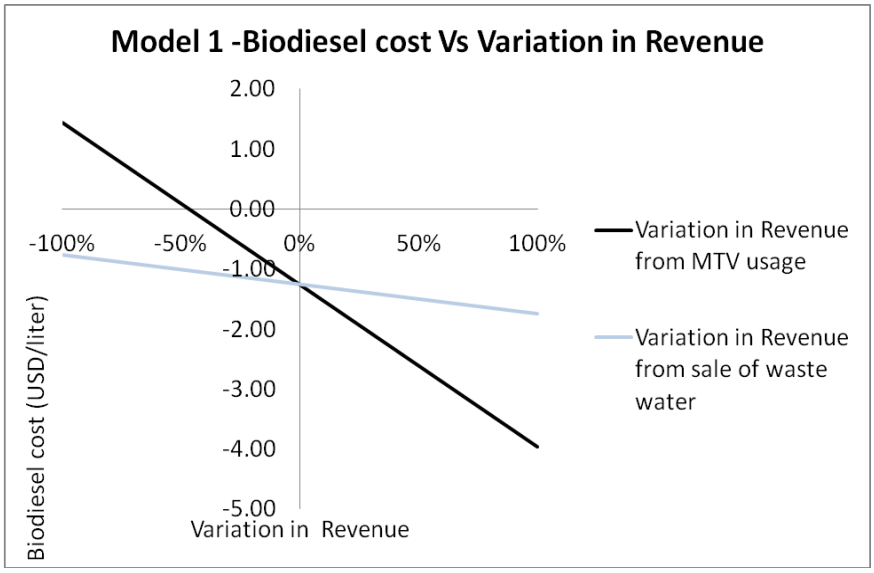

FIGURE 6: VARIATION IN REVENUE ON BIODIESEL COST

The profit from Model 1 is greater than the profit from other 2 models and this is mainly because of revenue collection from per person use of MTV. Any variation in revenue collection from MTV use has major impact on biodiesel production cost. Levelized cost of biodiesel production becomes positive when MTV per person usage charges is reduced to 2 USD cent per use or below.

For Model 2

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

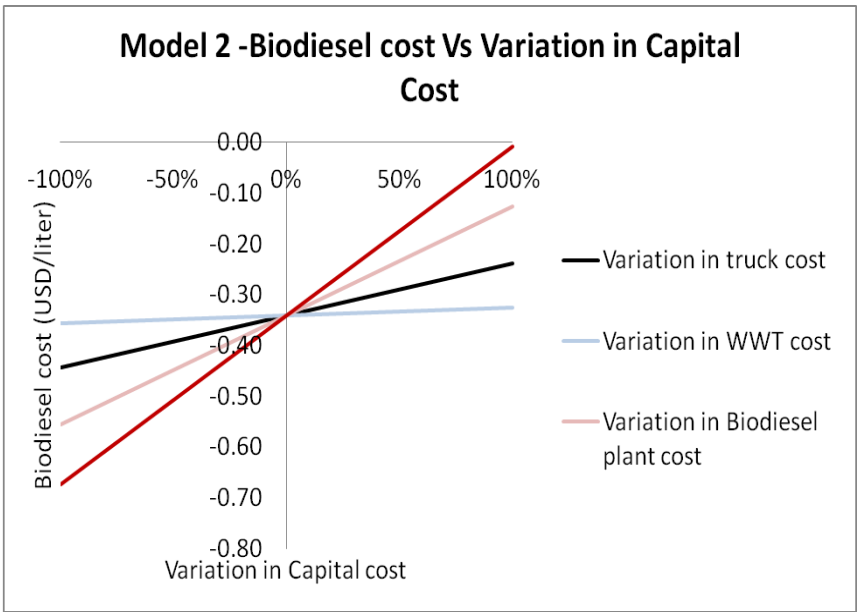

FIGURE 7: VARIATION IN CAPTIAL COST ON BIODIESEL COST

Levelized cost of biodiesel production varies with variation in truck cost and biodiesel plant cost. However this variation is not very significant. It is also evident from above that cumulative variation of 100% in project cost couldn't make the biodiesel production cost positive. However the possibility of such variations should be confirmed after discussion with suppliers.

2. Impact of variation in O&M cost

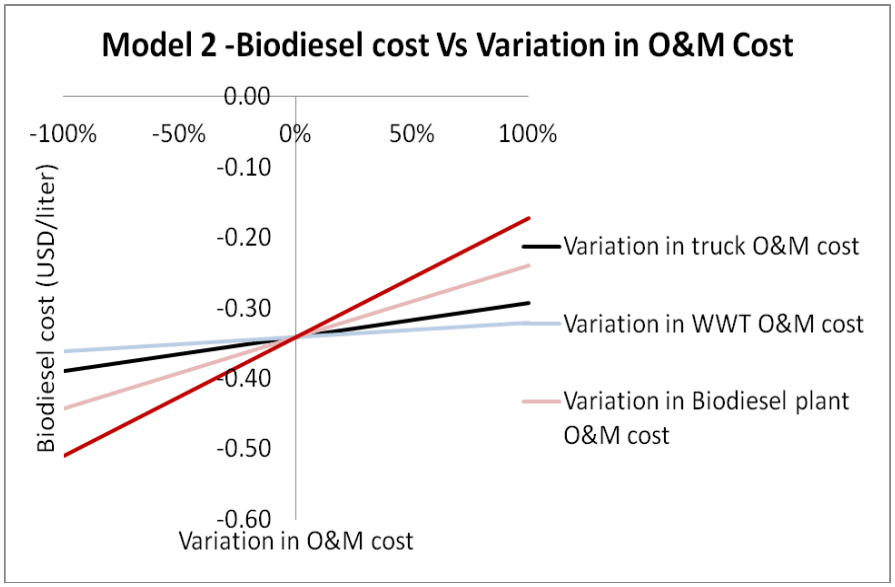

FIGURE 8: VARIATION IN O&M COST ON BIODIESEL COST

Large variation has been observed 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 significantly depending on the operating scenarios. However this doesn't have major impact on levelized cost of biodiesel.

3. **Impact of variation in Revenue**

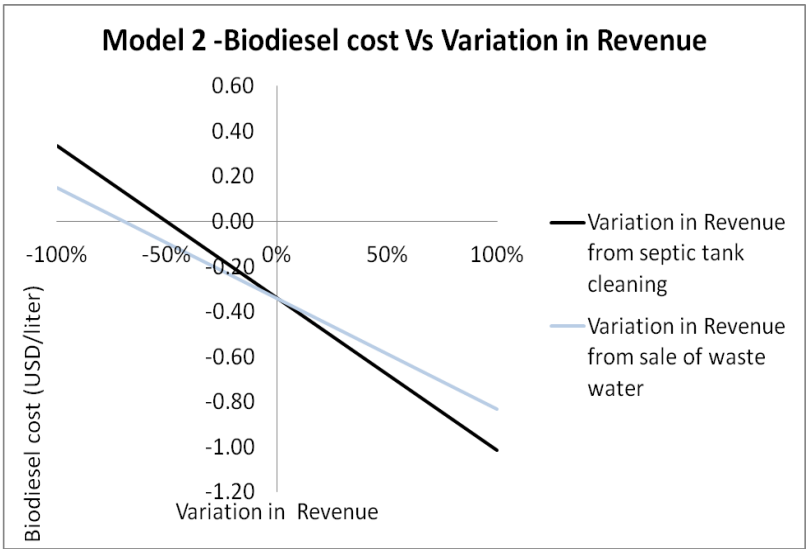

FIGURE 9: VARIATION IN REVENUE ON BIODIESEL COST

It is evident from the figure above that any variation in revenue collection from septic tank cleaning and sale of waste water has major impact on biodiesel production cost. Levelized cost of biodiesel production becomes positive when septic cleaning charge is reduced to $7.32 per cleaning from $14.81 per cleaning or when the revenue from sale of treated waste water goes down from $11.11 to $3.36 per tanker.

For Model 3

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

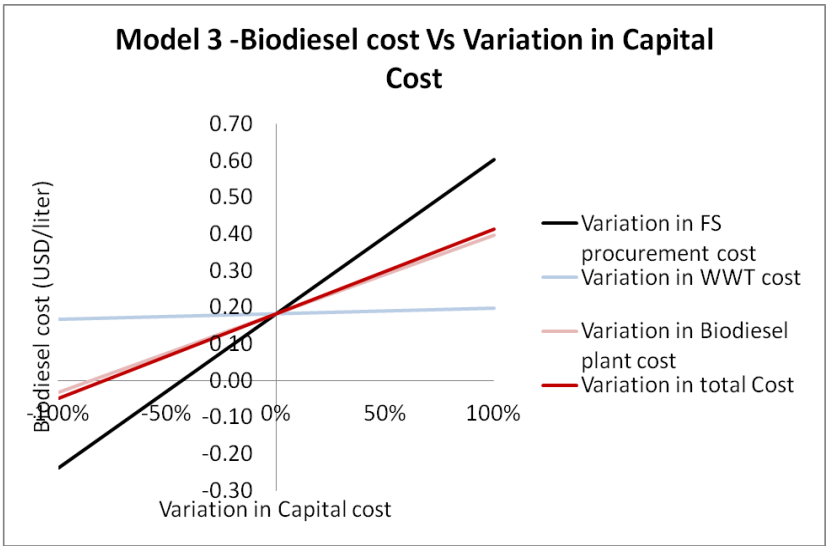

FIGURE 10: VARIATION IN CAPITAL COST ON BIODIESEL COST

Levelized cost of biodiesel production varies with variation in FS procurement cost from third party and biodiesel plant cost.

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

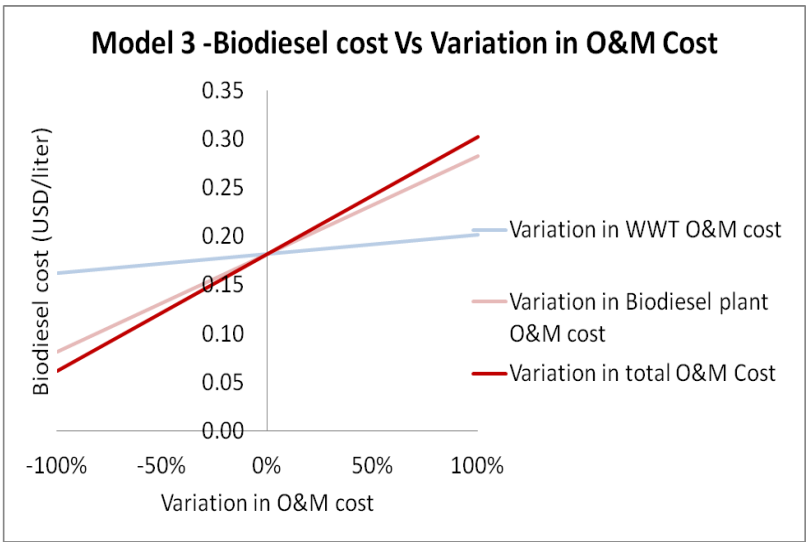

FIGURE 11: VARIATION IN O&M COST ON BIODISEL COST

Large variation has been observed 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 significantly depending on the operating scenarios. However this doesn't have major impact on levelized cost of biodiesel.

3. Impact of variation in Revenue

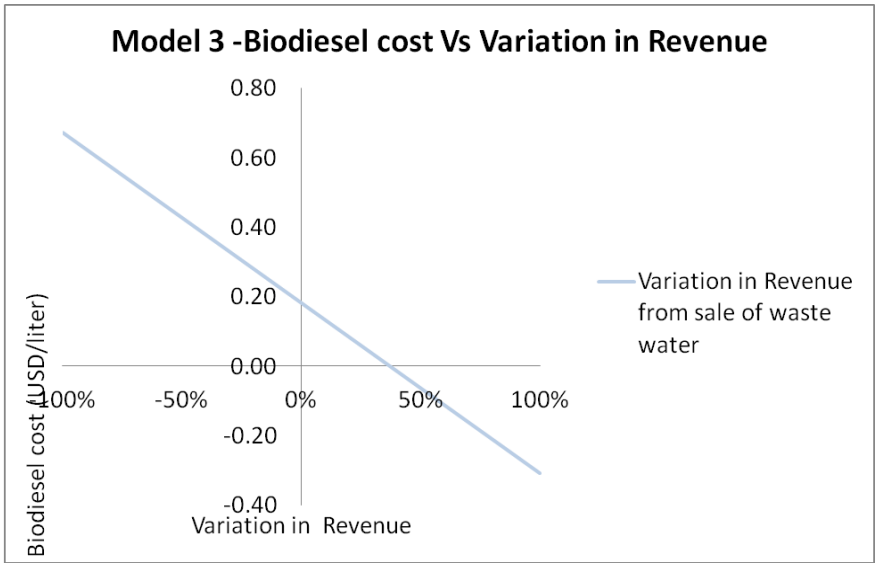

FIGURE 12: VARIATION IN REVENUE ON BIODIESEL COST

It is evident from the figure above that any variation in revenue collection from sale of waste water has major impact on biodiesel production cost. Levelized cost of biodiesel production becomes positive when the revenue from sale of treated waste water increased from $11.11 to $15.24 per tanker.

The septic cleaning charge and selling price of treated waste water varies a lot across geographies and hence the possibility of the same can't be ruled out. Hence a proper due-

diligence is required before finalizing any model for procurement of FS and production of biodiesel to minimize the financial risk.

3. Conclusion

1. All the FS procurement models are resulting in profitable business of biodiesel generation using FS as raw feed. However the suitability of cost and revenue related values should be confirmed based on relevant market data.
2. The MTV model (Model 1) is the most profitable model for biodiesel production. The success of this model depends on the utilization level of MTVs. MTV use has been assumed as 500 per day per MTV. Any reduction in MTV use would hamper the profitability significantly. This can be assured by providing proper cleanliness and maintenance of MTVs.
3. The access to fresh human excreta from MTVs results in higher fatty acid yield compared to sludge collected from septic tanks and in turn results in higher biodiesel production from FS. Thus MTV model is advisable for implementation of biodiesel plant.
4. The biodiesel yield can also be maximized by mixing FS with other types of waste like Jatropha etc. However, such mixing of FS with other types of waste has not been considered in the present plug and play model.
5. The biodiesel yield is only 10% and hence a large quantity of dry FS is required for production of biodiesel. FS also has high water content at source which results in significantly high investment in MTVs/trucks for procurement of FS from its source. This also requires a huge population for meeting the FS demand. The present 100 liter biodiesel production plant requires 16000 people or 4000 households (assuming 4 members per house) for generation of FS which is significant considering the production capacity of biodiesel plant.

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. Subsidy from Government of India is available for such projects. Government of India should also provide performance based incentives in order to ensure the performance of such plants.

3. Large quantity of FS is required for production of biodiesel. Hence government may regulate by providing limited licenses in a given region. This would ensure availability of FS for such waste to energy plants at commercial scale.

4. 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.

5. 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.

6. 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 201212. 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 mandate on such waste to energy projects.

7. Following are the government policy for promoting use of biodiesel in India[13]:-

    a. 20% of fuel blend is prescribed for bio-diesel and bio-ethanol by 2017 under National Policy on Biofuels, 2008 though RFS (Renewable Fuel Standards).

    b. Biodiesel is exempt from excise duty (no other central taxes and duties are proposed to be levied).

    c. The petroleum ministry agreed on a price of $0.6/liter (30 INR/liter) of biodiesel purchased by oil companies.

    d. Custom and excise duty concessions are provided on plant and machinery for production of bio-diesel, as well as for engines run on biofuels for transport, stationary and other applications, if these are not manufactured indigenously.

    However the definition of biodiesel mentioned in policy doesn't include production of biodiesel from human waste. Hence this has to be included to avail all such benefits extended to bio-diesel.

[12] http://www.indianexpress.com/news/companies-bill-passed-with-mandate-on-csr-spending/1047290/1
[13] http://www.eai.in/club/users/Shweta/blogs/7575

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 are purchased for procurement of FS. However in local practice, people also purchase old trucks and modify them. However the cost of O&M is relatively higher in repaired trucks. 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 fatty acids and hence less production of biodiesel. The impact of this has not been considered in the present plug and play model.

Pre-processing

1. Fat/oil content of human excreta is lower compared to the fat/oil content of standard fuels used for production of biodiesel. Hence this should be mixed with other types of waste to increase biodiesel production. 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 having 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.

Fermentation (Production of Fatty Acid)

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. This would have impact on the production of biodiesel. The impact of temperature variation on fatty acid yield has not been considered in the plug and play model.

2. People use toilet cleaning agents or acid or mix soap, detergent with toilet sludge and this would have negative impact on bacteria population which would result in lower production of fatty acid. However the impact of the same has not been considered in the present plug and play model.

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

4. The process has to be stopped after Acetogenesis stage for maximum production of Acetic acid. The can be done by controlling the process parameters and/or by adding chemical inhibitors. The cost associated with these activities is not covered in this plug and play model.

5. The acetic acid should be converted to fatty acids in the presence of engineered microorganism. However the cost associated with the same has not been considered in the present plug and play model.

6. Maximum power is consumed during secondary treatment of sludge. However in the absence of rating of equipment, cost associated with power consumption has not been considered in the plug and play model. This has been assumed that the operation and maintenance cost would cover similar types of costs.

7. Small quantity of nitrogen and phosphorus will be recovered from the process. However the revenue from sale of those products has not been considered in the present plug and play model.

Bioreactor (Production of Biodiesel)

1. The cost associated with production of methanol from methane has not been considered in this plug and play model.

2. Glycerol is the by-product of the process. However its yield is only 1% and hence the revenue from sale of Glycerol has not been considered in the plug and play model.

3. Post-processing costs associated with production of biodiesel production has not been considered in the present plug and play model.