Technologies for Energy Recovery from Faecal Waste

Technical and Financial Analysis – Gasification

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BILL & MELINDA GATES foundation

EVI Sustainable Solutions for the Environment

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Abbreviations and Acronyms:

FS	Faecal sludge
IRR	Internal rate of return
IT	Income Tax
kW	kilo watt
Liq	Liquid
MNRE	Ministry of new and renewable energy
MTV	Mobile toilet van
NPV	Net present value
O&M	Operation and maintenance
P&M	Plant and machinery
PBDIT	Profit before depreciation interest and tax
PBIT	Profit before interest and tax
PBT	Profit before tax
PLF	Plant load factor
Rs	Indian Rupees
SFC	Specific fuel consumption
SLM	Straight line method

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 purposes. Out of the five technology areas planned for the study namely Gasification, Hydrothermal Carbonization, Pyrolysis, Fermentation and Anaerobic Digestion, gasification has been evaluated in this part of the study. The technology has been evaluated on its suitability for FS use for energy recovery and financial viability. The analysis also provides a plug and play tool to project developers to see financial viability of the chosen technology in different scenarios. Following is 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 made usable under the technology.

Chapter 2: Financial Analysis details out financial performance of the gasification technology under various scenarios of FS procurement and scales of power generation. The financial performance has been evaluated for following FS procurement models:-

Model 1 - FS Collection and transportation - outsourced

Model 2 - Direct procurement of FsDF from fuel producers

Model 3 - FS Collection using Mobile Toilet Vans

Model 4 - FS Collection and transportation - with own infrastructure

The financial performance has been gauged using industry acceptable indicators i.e. NPV, Project IRR and Equity IRR. The financial analysis also provides the levelized cost of FS derived fuels from various FS procurement models. This section also provides the impact of variations in critical input parameters on financial indicators.

Chapter 3: Conclusion discusses the results and presents the challenges in the areas of technology and financial viability of the project. As per the analysis, the cost of FS derived fuel from MTV based fuel procurement model is the lowest however it entails higher upfront capital requirement in infrastructure. The gasification system integrated with FS procurement from MTV results in highest profit.

The next profitable model is FS collection and transportation through own infrastructure (Model 4). In this model, the developer can further maximize the profit by sharing its own infrastructure for other services like MSW transportation, waste water transportation etc. Having own infrastructure also assures all time supply of FS and better control on its management.

1. Technology Analysis

1.1 Technology Description

The gasification process converts carbon containing matter into producer gas by means of a thermo-chemical reaction. This constitutes thermal degradation of fuel in the absence of oxygen leading to formation of solid, liquid and gaseous products. The products of the process are Producer gas and ash/tar/char (depending on gasifier type)[1]. Producer gas is primarily hydrogen, carbon monoxide and other gaseous constituents, the proportions of which can vary depending upon the conditions in the gasifier and the type of feedstock.[2] The typical composition of producer gas is CO 15-22%, H2 10-20% with other gases making the rest. The basic process is illustrated as below:

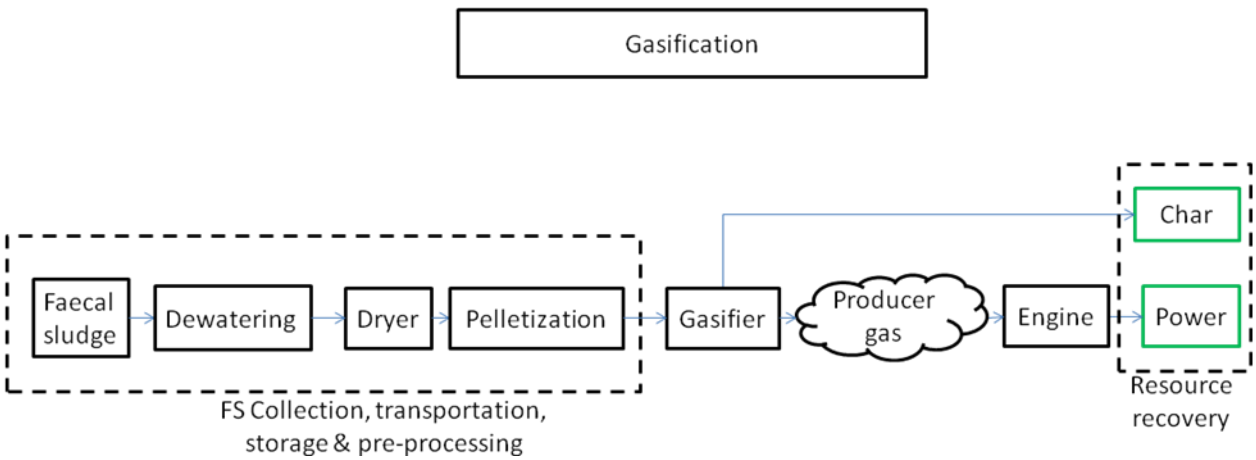

FIGURE 1: BASIC SCHEMATIC OF GASIFICATION PROCESS

The key design feature of a gasification system is the residence time of reacting mixture apart from the temperature zones created inside the reactor. The cracking of high molecular weight molecules in the reactor decides the efficiency of gas generation and generation of tar. The gasifiers have been used to gasify a wide range of fossil i.e. coal and non-fossil fuels e.g. wood and wood waste, agriculture residues etc. globally. Producer gas is a good fuel for thermal and power generation applications. The key components of gasification cum power generation unit are fuel and ash handling system, gasification reactor, gas cooling and cleaning system, prime mover for generation of power namely gas engine or a diesel engine coupled with an alternator.

In India, a number of gasifier technology providers are present namely Ankur Scientific Technologies, The Combustion, Gasification and Propulsion Laboratory (CGPL) at Indian Institute of Science (IISc), The Energy and Research Institute (TERI), Cosmo Powertech, Radhey Renewable Energy Development etc.

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[1] http://gcep.stanford.edu/pdfs/energy_workshops_04_04/biomass_overend.pdf
[2] http://www.fossil.energy.gov/programs/powersystems/gasification/howgasificationworks.html

1.2 Raw Feed Characteristics

1.2.1 Feed Stock Requirement for Gasification

Raw feed type is an important aspect of designing a gasifier. Gasifiers need to be customized to match the properties of available raw feed for ensuring performance at the best levels. In general, raw feed characteristics important for biomass gasification are[3]:

1) **Energy content**: Fuels with high energy content (high calorific value on a dry basis) are advantageous as they produce producer gas with high calorific value on gasification. Some high energy gasification feed stocks are wood (13-15 MJ/kg at moisture level 20-25%) and charcoal (29-30 MJ/kg at moisture level 2-7%). The gasification technology is proven for above mentioned feed stocks. Hence the calorific value of feed stock should ideally be higher than 13 MJ/kg.
2) **Moisture content**: High moisture content in the feedstock results in lower calorific value of the produced gas since heat used to evaporate water is unavailable for the reduction reactions. If produced gas is to be used for combustion for heating purpose, a moisture content of 40-50% in the feedstock can be tolerated. However, if the gas is to be used in a gas engine, moisture content in fuel needs to be brought down below 20%.
3) **Ash content & Ash fusion temperature**: Ash in biomass feedstock melts, causing slagging or clinker formation. High ash content can cause excessive slagging, tar formation, and eventually blocking of the gasifier. In general, no slagging is observed with fuels having ash contents below 5-6%. Severe slagging can be expected for fuels having ash contents of 12% and above. For fuels with ash contents between 6% and 12%, the slagging behavior depends to a large extent on the ash melting temperature. If temperature at which the ash melts is lower than gasifier temperature, slag formation will result. Therefore, fuels with low ash content and high ash fusion temperature are suited for gasification.
4) **Bulk density:** Fuels with high bulk density are advantageous because they represent a high energy-for-volume value. Low bulk density fuels give rise to insufficient flow under gravity, resulting in low gas calorific value.
5) **Form of Fuel:** The form of the fuel drives changes in the design of reduction area of gasifier. For example, a co-current flow gasifier would need fuel in pulverized form while a moving bed gasifier cannot work on pulverized form and would need fuel in lumps. Similarly, a fluidized bed gasifier would require fuel to be in small particles (less than 5 mm).

The typical characteristics of some gasifier feedstock are provided in the table below. The most commonly used gasifier designs are Updraft and Downdraft. The requirements of fuel characteristics for each of these designs are also given below.

[3] http://www.fao.org/docrep/t0512e/T0512e0b.htm

TABLE 1: CHARACTERISCTIC OF FEEDSTOCK FOR BIOMASS GASIFICATION

Characteristics	Requirements of gasification[4]		Common feedstock for gasification		
	Updraft gasifier	Downdraft gasifier	Rice Husk	Wood	Bamboo[5]
Net calorific value	Higher, the better		13.2 MJ/kg (3154 kcal/kg)[6]	13-15 MJ/kg	16.2 MJ/kg
Moisture	<50%	<15-20%	14 %	20-25%	13%
Ash	<15%	<5%	20% (High ash content, low slagging due to high fusion temp.)	<1%	3.9%
Ash fusion temperature	>1250 deg C	>1250 deg C	1440 deg C	>1300 deg C[7]	1400-1450 deg C
Bulk density	>400 kg/m3	>500 kg/m3	340-400 kg/m3[8]	300-550 kg/m3	300 kg/m3
Form of fuel	Pellet size (5-100 mm)	Pellet size (20-100 mm)	-	Size ranging from 8x4x4 cm. - 1x0.5x0.5 cm	-

1.2.2 Characteristics of Available FS

FS has certain characteristics, like moisture content, quite different from those of normal gasification feedstock. It will therefore have to be pre-processed to make it suitable for feeding to the gasifier. Pre-processing is also required to make it odor free and free from pathogens. The requirements of pre-processing and associated challenges will vary according to the source of FS. At present following sources have been identified for study:-

1) FS collected from septic tanks (septage)

2) FS collected from mobile toilet vans (MTV)

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4 http://www.iafbc.ca/funding_available/programs/livestock/documents/LWTI-1_FR_App3.pdf
5 http://www.bambootech.org/files/Gasification%20of%20Bamboo26.pdf
6 http://www.energymanagertraining.com/kaupp/Article24.pdf
7 http://www.celsico.com/products/celsico-wood-pellets/quality/quality-criteria-at-a-glance european-norm-and-certification-schemes/wood-pellets-quality-criteria.html
8 http://www.ricehusk.com/content/menu_112/faq

3) FS derived fuel bought from fuel producers like waste enterprisers

1) FS collected from septic tanks

Calorific value: The calorific value of FS does not change much due to change of source. Even the age of FS does not have significant impact on calorific value. [9] The calorific value of FS at 17MJ/kg TS has been found to be close to that of regular biomass fuels.

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%. Therefore this will need to be reduced to requirements of the specific gasification system (below 20% for generating electricity).

Solid content: The solid content of FS collected from septic tanks is about 2-4%. This is very low compared to the one collected from MTVs and pit latrines. This low solid content would require much larger volume of septic tanks collected and transported to the pre-processing site. This would also mean overall higher operating cost.

2) FS collected from Mobile Toilet Vans (MTV)

Calorific value: As stated above, the calorific value of FS does not change much due to change of source and the age of FS.

Moisture: A ten seat MTV has got 2000 liter[10] 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[11]. 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[12]. 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%)

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[9] Full Potential of faecal sludge by Teddy Nakato, FSM 2 Durban, Oct 2012

[10] http://trade.indiamart.com/details.mp?offer=3952505291

[11] 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

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

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.

Solid content: The solid content of FS collected from MTVs is about 2-3%. This would vary though with the local practice of use of water during toilet use. This is still very low solid content for using in a gasification system.

3) **FS derived fuel bought from fuel producers like Waste Enterprisers**

The FS derived fuel procured from fuel producers can be directly used in gasifier. However the FS derived fuel has not been tested in gasifiers so far. The pre-processing activity also requires thermal drying at high temperature. This will make the FS free from pathogens also.

1.2.3 Gap Analysis

There is a significant gap between what is available as-is and what is needed for gasification of FS. Therefore, FS needs to be processed before it is considered suitable for gasification. Following presents the gap between as-is and the gasification requirements.

TABLE 2: GAP ANALYSIS OF CHARACTERISTICS

Characteristics	Requirements of gasification		As-is FS	
	Updraft gasifier	Downdraft gasifier	From Septic Tank	From MTV
Moisture	<50%	<15-20%	96-98 %	97-98%
Ash	<15%	<5%	29% in TS	
Ash fusion temperature	>1250 deg C	>1250 deg C	1150-1200 deg C	
Bulk density	>400 kg/m3	>500 kg/m3	-	-
Form of fuel	Pellet size (5-100 mm)	Pellet size (20-100 mm)	Water from the top and sludge from the bottom	Sludge form

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

1.3. Pre-processing of FS

The major issue with handling of FS for energy recovery purpose is its water content which requires first attention before further processing to contain bad odor, presence of full range of pathogens and reforming it to an easy to handle, store and use product.

Following steps are envisaged for the water reduction purpose:

Step 1: Thickening/Sedimentation

Thickening is carried out in a sedimentation tank or in a sedimentation pond (if adequate land area is available). Water can be removed from top, leaving sludge with 95% water content[13].

Step 2: Dewatering

Dewatering reduces the water content further so that the solids content of the sludge is about 20%[14].

Synapse has identified three potential low-tech systems for dewatering of excess water. All of these systems are capable of producing concentrated solids with a TS of 10%-15% and can take input sludge that contains TSS between 1% and 5% (solid content in septic sludge is less 5%). These three systems are

a) FCK-315 Rotary Thickener,

b) Integrated Engineers CFU-20 belt thickener, and

c) FloTrend Polymate and Sludgemate gravity dewatering box.

As per Synapse, the FCK-315 system provides the best performance in terms of cost. It is also the most compact system and could easily fit onto a small trailer. For these reasons, the FCK-315 rotary thickener has been selected for dewatering purpose.

Step 3: Thermal drying

To reduce the moisture level to less than 10%, thermal drying is used. Thermal drying also kills pathogens in FS and makes it safer for use. Common technologies available are[15]:

1) Belt dryer: Produces upto 90-94% solids

2) Drum dryer: Produces upto 92-96% solids

3) Fluidized bed dryer: Produces upto 94-98% solids

All three technologies are suitable for sewage sludge and hence can be used to handle fecal sludge as well. The overall process is summarized in the figure below:

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[13] http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/11.asp
[14] http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/11.asp
[15] http://www.esi-projekte.de/selection_criteria_for_sludge_drying_plants.pdf

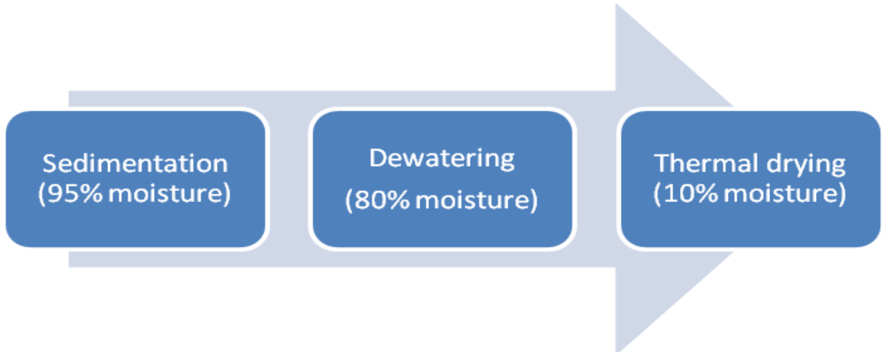

FIGURE 2: SCHEMATIC OF DRYING PROCESS

Step 4: Densification through Pelletization

The low bulk density of FS will need to be increased through pelletization. Pellets of diameter 6mm and length 15-25mm will need to be produced[16]. A dryer-pelletizer system is utilized in a few projects to dry as well as pelletize sewage sludge[17]. Such technology can be applied to FS.

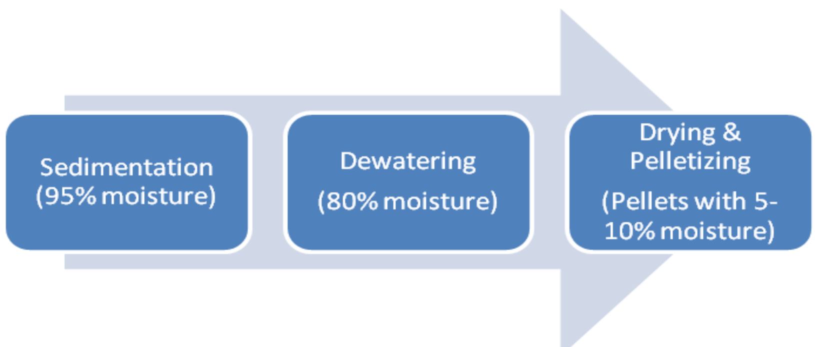

FIGURE 3: SCHEMATIC OF DRYING + PELLETIZING PROCESS

These steps however should be treated as a bucket of methods to pre-process as-is FS and combination of many or all of these should be considered taking into account the source and type of FS available. There are several techniques available to carry out each method presented here. For example, thermal drying can also be accomplished by using solar heating or as a combination of solar and steam drying etc.

Globally, many organizations are testing different methods of pre-processing FS. Some of the methods in more advance stages are –

Waste Enterprisers method

[16] http://www.mam.gov.tr/bigpower/fullpaperS/01.pdf
[17] http://nett21.gec.jp/rerss/data/rerss-01.html

The process entails collecting FS from pit latrines and septic tanks, processing it to a pelletized fuel fit for energy application in boilers and kilns. The calorific value of the fuel has been found to be higher than other waste fuels like sawdust and rice hulls.

Trucks deliver the waste to the company's factories. There, it is dried, treated, and transformed into solid fuel pellets. They are currently testing locally fabricated screw presses for mechanical dewatering and are designing the solar greenhouses with rugged materials and limited infrastructure[18]. The treatment process, which is compliant with EPA standards, removes pathogens using heat, desiccation, and UV rays, making the fuel completely safe to handle and burn. That fuel can then be sold to power plants and other heavy users of fuel.[19]

LaDePa

This system is being tested at eThekwini municipality in Africa. The system takes in the dried waste sludge and converts it to fuel grade pellets. In the process, it also removes all the harmful pathogens present in the waste by the use of infrared rays. Features of LaDePa technology have been provided below.

Features of LaDePa[20]

- 1 -2 TPH containerized mobile plant
- Can operate on engine or electric grid power
- 30-35% solids processed to a +90% solid product
- Sterlized product + 5 minutes at +200 degC
- Engine required 160 kW
- Fuel required (Diesel) – 7-8 liter/hour
- Feed – 1000 kg/hr @ 30-35% solid
- Product – 300 kg/hr @ 80-85% solid
- Resident time – 8 minutes
- Dry product discharge for bagging

Hydrothermal treatment[21]

This process takes the sludge into a rector and then at 200 degC and 2MPa saturated steam is supplied to the reactor. Mixing process is then conducted by a stirrer in the reactor for about one hour while holding the temperature and pressure. After finishing the holding period and discharge of the steam, wet uniform product can be extracted, and then can be easily dried due to improved drying performance of the product. The product is discharged after extracting steam. The product is a power like substance which is left to dry in the open. This system also called RRS is developed by Tokyo Institute of Technology.

[18] http://www.waste-enterprisers.com/news-resources/
[19] http://www.inc.com/magazine/201211/issie-lapowsky/big-idea-2-marketplace-solve-sanitation-crisis.html
[20] http://www.parsep.com/pages/DEM-1-Ladepa-Prototype-2.pdf
[21] http://yk.wtert.jp/index.php?option=com_content&view=article&id=107&Itemid=161&lang=en

These are new technology areas where companies are testing and conducting trials to suit FS requirements and much more data is needed to prove the compatibility of these technologies specific to FS pre-processing needs.

1.3.1. Characteristics of processed FS

Moisture content: The moisture content of FS dried through the process described in Figure 2 will be between 5-15%.

Bulk density: The bulk density of dried fecal waste sourced from public toilets has been found as 190 kg/m^3 (22).

Ash content: Ash content of a dried septage + public toilet sludge mixture has been measured by Waste enterprisers in Africa, as 29% (for fuel with 85-95% solid content).

Ash fusion temperature: Measured in Africa, the ash fusion temperature for dried septage + public toilet sludge mixture is about 1142 degC.

Calorific value: Net calorific value of a dried septage + public toilet sludge mixture has been measured by Waste enterprisers in Africa, as 18.5–22 MJ/kg (on dry solids basis). The figures for sewage sludge range between 10-16 MJ/kg of dried form.

Characteristics of FS after pre-processing are given below[23]:

TABLE 3: CHARACTERISTICS OF FS[24]

Characteristics	FS derived fuel
Net calorific value	18.5 -22 MJ/kg
Moisture content[25]	5 -15%
Ash	29%
Ash fusion temperature	1361°C
Bulk density[26]	190 kg/m3
Others	Pathogens, odor free

[22] http://pustaka.litbang.deptan.go.id/publikasi/as102094.pdf
[23] Energy Alternatives India
[24] As per the information provided by Ashley Murray from Waste Enterprisers and Calorific value results published by Teddy Nakato.
[25] The water content of FS collected from septic tank is as high as 96%.
[26] http://pustaka.litbang.deptan.go.id/publikasi/as102094.pdf

The bulk density and size of fuel pellets has to be taken care of by pelletization process during the pre-processing of FS.

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.

High moisture content

Another challenge is related to dewatering of sludge. If natural drying is used then huge parcels of land will be needed. The thermal drying process is more energy intensive, which will adversely affect economics of the plant.

High ash content

High ash content of feedstock causes slagging and excessive tar formation leading to blocking. Feedstock with more than 12% of ash (e.g. Alfalfa) has been found to fail during gasification[27]. Ash content upto 5-6% is desirable to prevent slagging in the gasifier. FS with an ash content of 29% will potentially pose high slagging issues.

Dioxin Production

Dioxins are produced at 250-600 deg C, so gasifier temperature should be elevated enough to avoid dioxin production and at the same time, lower than the ash fusion temperature to prevent slag formation.

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.

[27] http://etd.lsu.edu/docs/available/etd-04272011164628/unrestricted/Thesis_Akshya_Sharma.pdf

Storage: For a facility to operate without breaks, storage capacity for fecal sludge will need to be maintained on site for a contingency situation. Storage might pose a problem due to the large volume required and high smell of fecal waste.

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

Removal of pathogens and odor: Pathogens and odor etc need to be removed from FS before handling in plant. This can be done through high temperature drying process which will be costly.

Competitive biomass fuels: In areas with abundance of locally available biomass which is proven successful in gasification, FS might find difficult to prove its attractiveness as gasification operators would resist switching from an already proven fuel.

1.4.2. Challenges in Gasification of FS

There is no proven operational data on the use of FS derived fuels in gasifiers anywhere in the world. The effect of FS derived fuel on the gasification efficiency, composition of producer gas, presence of tar, ash fusion problems and life of equipment is not known completely. As stated earlier, gasifiers are required to be customized to meet the state of fuel type.

There are many technical challenges with gasification process itself which might accentuate with FS[28]:-

1. The high ash content and lower ash fusion temperature of FS can result in clinker formation inside the gasification chamber. This will require frequent cleaning of gasification system and hence will result in higher O&M cost.
2. Getting the producer gas is not difficult, but obtaining it in the proper state is the challenging task. The physical and chemical properties of producer gas such as energy content, gas composition and impurities vary time to time. All the gasifiers have fairly strict requirements for fuel size, moisture and ash content. Inadequate fuel preparation is an important cause of technical problems with gasifiers[29].
3. Fecal sludge consists of large quantity of pathogenic microorganisms and falls under the lower alkaline range in terms of pH[30]. In order to reduce or minimize the amount of microbes in the fecal sludge, alkali treatment is performed and the pH of the sludge is increased till 11-12. This high alkali FS will lead to agglomeration problem.
4. The usual tar composition from the outlet of the biomass gasifiers[31] are usually 1000 mg/m3. High tar content in the producer gas will have negative impact on the gas engine. Hence the producer gas from the gasifier has to be cleaned properly to achieve the

[28] By Guangxi Yue, Proceedings of the 20th International Conference on Fluidized Bed Combustion
[29] http://www.eai.in/ref/ae/bio/bgt/cons/constraints_gasifiers.html
[30] http://en.wikipedia.org/wiki/Fecal_pH_test
[31] http://www.eeci.net/results/pdf/Technical-Report-version-3_8-final.pdf; page 16

standard[32] of 50 mg/m3. The cleaning of producer gas from gasifiers is a tedious and expensive process. Lesser tar composition can be achieved by using high efficient gasifier technology or cleaning process.

5. Poor carbon conversion of fuel means low utilization of fuel in gas conversion and high carbon in ash residues.

1.4.3. Challenges in Producer gas and Byproducts Use for Energy Recovery

The products of gasification need to be processed further to make them suitable for their intended energy recovery use. Post-processing requirements for each of the gasification products are detailed out below:

Producer gas usage

a) Direct combustion: If producer gas is to be directly burnt to produce thermal energy, then tar and acid gases will need to be removed to meet emission regulations. The gas needs to be cooled and tested for moisture content and cleaned of moisture to enhance calorific value. The following systems will be typically required:

i) A water quench for immediate cooling of the hot gas to avoid formation of complex molecules like dioxins. The quench is designed to cool the gases through an injected spray of water. Typical gas outlet temperatures range from 70 degC to 90 degC.

ii) A packed bed tower scrubber using caustic solution to neutralize acid gases and remove moisture.

iii) A venturi scrubber to remove particulates.

iv) An H_2S absorber used for removal of H_2S, which is then removed for sulphur recovery.

b) Use in gas engines: For use in gas engines, the gas has to be completely cleaned of moisture, fine particulates, heavy metals, and any other impurities that might be detrimental to the working of the engine. The following systems will be minimally required:

i) A water quench for immediate cooling of the hot gas to avoid formation of complex molecules like dioxins. The quench is designed to cool the gases through an injected spray of water. Typical gas outlet temperatures range from 70 degC to 90 degC.

ii) A packed bed tower scrubber using caustic solution to neutralize acid gases and remove moisture.

iii) A venturi scrubber to remove particulates.

[32] Non-Conventional Energy Resources by B H Khan; Page 210 (http://books.google.co.in/books?id=Vps3P-S85o8C&pg=PT229&lpg=PT229&dq=allowable+limit+of+tar+in+gas+engine&source=bl&ots=6tO01j2dhO&sig=nX0-iThaC3i_hOH51a4zcXS5zyo&hl=en&ei=ILh1TYPoGoOrcY_3lYoF&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEYQ6AEwBw#v=onepage&q=allowable%20limit%20of%20tar%20in%20gas%20engine&f=false)

iv) An H_2S absorber used for removal of H_2S, which is then removed for Sulphur recovery.

v) Filters for entrapment of heavy metals and fine particulates.

vi) Siloxanes (compounds widely used in industrial processes and consumer products) have been observed in gas produced during gasification of sewage sludge[33]. These compounds adversely affect the efficiency of gas engines. Gas produced during FS gasification will have to be tested and subjected to a siloxane removal system to ensure that siloxane concentration is within tolerance value of the gas engine.

vii) The gas produced from sewage sludge gasification has also been seen to contain traces of hydrogen cyanide stemming from the nitrogen component of sewage sludge34. This will need to be separated by use of gas scrubbers.

Ash & char

Handling and disposal of Ash is a major issue due to its less density. It can't be disposed in open area and need to be transported to a suitable landfill area away from population. However the Ash produced can be used for a variety of applications, after chemical analysis and appropriate processing and this will also address the ash disposal issue.

a) Fertilizer production: Ash produced from gasification needs to be analyzed for heavy metal content. If heavy metal concentration is within safe limits, it can be used as a fertilizer or feed additive for farm animals.
b) Use in cement industry: Previous research has indicated that physical, chemical, and mineralogical characteristics of gasification ash meet the requirements for use in cement[35]. Chemical analysis will need to be performed for ash obtained from FS gasification to ascertain its compatibility with cement.
c) Briquettes manufacturing: Since the char has got calorific value and hence it can be converted in briquettes and used for heating purpose.

Sulphur

H_2S gas has to be removed from producer gas to avoid the corrosion inside the gasification chamber. The removed H_2S can be processed to recover sulfur for use in manufacturing sulfuric acid, medicine, cosmetics, fertilizers and rubber products.

[33] http://www.gesui.metro.tokyo.jp/gijyutou/gn20/nenpou2008/6-2.pdf
[34] http://www.gesui.metro.tokyo.jp/gijyutou/gn20/nenpou2008/6-2.pdf
[35] http://upetd.up.ac.za/thesis/available/etd-04102007-171940/unrestricted/dissertation.pdf

2. Financial analysis

2.1 Description of Plug & Play Excel Model

The plug and play model has been prepared to demonstrate financial performance using different indices e.g. NPV, Project IRR and Equity IRR. The indices are widely acceptable industry benchmarks. The model also provides the cost of FS derived fuel (FsDF) for various FS procurement models. The cost and revenue streams change with the change in FS procurement models adopted. The model has been made to adapt various scenarios of FS procurement while calculating the fuel cost.

The key aspects of the model are FS procurement, FS pre-processing needs, conversion into fuel grade material and its use for energy recovery. The model has been prepared for various FS procurement models. FS collection, transportation and pre-processing needs have been identified for each case. In this study, FsDF is used in gasifier to generate producer gas which is further utilized for power generation in a gas engine.

The base model has been prepared for 32 kW gasification-power generation systems. Similar type of gasification system is used by Husk Power Systems (HPS) in India[36] but with only agriculture residues i.e. rice husk.

2.2. Various Models for FS procurement

Sustainable FS procurement is critical to the success of the program. Four types of procurement models have been identified for FS. The key aspects of FS procurement model are FS collection and transportation from FS sources, its pre-processing and conversion into ready-to-use fuel for energy recovery. Each model presents different scenario of capital expenditure requirement, need of man power, revenue and operating cost streams. These are explained below:

[36] http://blogs.independent.co.uk/2010/12/10/how-to-make-electricity-from-rice-husk/

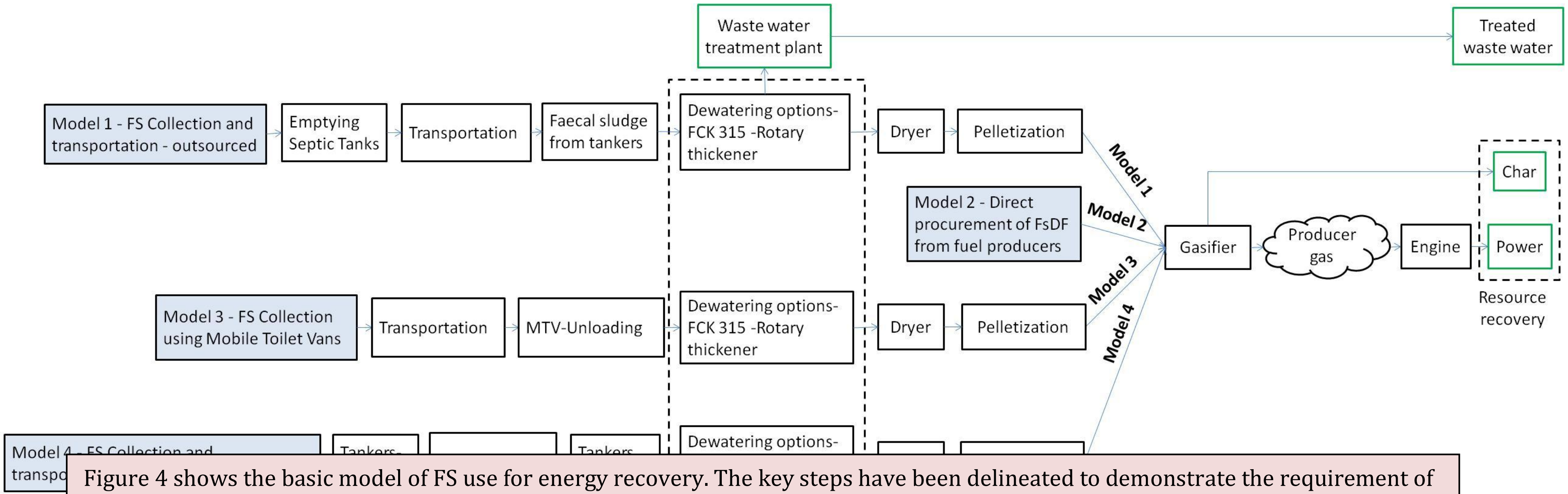

Figure 4 shows the basic model of FS use for energy recovery. The key steps have been delineated to demonstrate the requirement of collection & transportation, pre-processing of FS and finally conversion to energy. There may be different methods and technologies that can be used to complete each of these steps. It is also possible to combine several steps using one single technology. The appropriateness of technology use would depend on not only the FS characteristics but also the economics of the model.

TABLE 4: FS PROCUREMENT MODELS – PROS AND CONS

Index	Assumptions	Pros	Cons
Model 1	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.
Model 2	In this model, FS derived fuel will be procured directly from its producers e.g. waste enterprisers model.	• No capital investment for collection, transportation, storage and pre-processing of FS • Quality and quantity of FS derived fuel (FsDF) can be assured • Easy to handle as it will be free of pathogens and fuel grade.	• High cost of FS derived fuel. Impacts the project's financial profitability significantly.
Model 3	MTVs will be employed 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 plant for further pre-processing.	• 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 4	This model is similar to Model 1, however the emptying, collection and transportation network is owned and run by project developer.	• The revenue generated from emptying of FS remains with the project developer. • Supply of FS can be projected well as this doesn't depend on third party supplier. • Project developer can share the tanker service with other business like Sewer sludge 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 financial model

The short description of Models is tabulated below for ease of reference:

TABLE 5: MODEL DESCRIPTION

SN	Model	Description
1	Model 1	FS Collection and transportation - outsourced
2	Model 2	Direct procurement of FsDF from fuel producers
3	Model 3	FS Collection using Mobile Toilet Vans
4	Model 4	FS Collection and transportation - with own infrastructure

The levelized cost of FsDF has been calculated for a period of 20 years, similar to plant lifetime of gasification system. Following costs and revenue streams are considered for estimation of FsDF cost for various FS procurement models.

TABLE 6: KEY COST FACTORS FOR MODELS

Particulars	Model 1	Model 2	Model 3	Model 4
Capital cost of MTV	X	X	√	X
Capital cost for truck	X	X	X	√
Capital cost for WWT plant	√	X	√	√
Capital cost of dewatering system	√	X	√	√
Capital cost for drying system	√	X	√	√
Capital cost for pelletization unit	√	X	√	√
Land cost	√	X	√	√
O&M cost of truck	X	X	X	√
O&M cost of MTV	X	X	√	X
O&M cost of WWT	√	X	√	√
O&M cost of dewatering system	√	X	√	√
O&M cost of drying	√	X	√	√
O&M cost of pelletization unit	√	X	√	√
Cost of transportation to plant site	X	X	√	√
Cost of transportation of treated waste water	√	X	√	√
Procurement cost of FS sludge from third party	√	X	X	X
Procurement cost of FsDF from supplier	X	√	X	X

2.3. Sources of Revenue

There are several revenue streams identified relevant to the program. The availability of revenue streams would depend on the FS procurement model chosen. The various revenue streams as applicable are explained below:
Following revenue streams are applicable for all selected FS procurement models:-

1) **Revenue from sale of power:-** It is assumed that the net power generated from system will be sold to third party on prevailing tariff rates. In the present model, the tariff applicable has been considered at par with that of renewable power in the country.
2) **Revenue from sale of char:-** The process will also generate char as by product which has got significant market value and therefore makes the list.

Following revenue streams depend on FS procurement models:-

1) **Revenue from emptying of septic tank:-** Household owners in cities pay for emptying their tanks to emptiers.
2) **Revenue from per person usage of mobile toilet van (MTV):-** At present, people pay at public toilet on per usage basis. This revenue is utilized for proper maintenance of public toilets which results in maximum usage and hence maximum revenue generation. Similar type of mechanism can be introduced for MTV also. However the success of this mechanism is yet to be tested as most of the MTVs are employed in slum areas where it's free to use.
3) **Revenue from sale of treated waste water:-** As per the verdict given by Supreme court of India, all the construction companies have to use waste water instead of ground water in construction work. Hence there is a readily available market for the sale of waste water generated from the dewatering of FS sludge. However this need to be treated properly which adds extra cost to the operating expenses.

The above mentioned revenue streams have been considered for estimation of Fs derived fuel cost from various FS procurement models.

TABLE 7: SOURCES OF REVENUE FOR VARIOUS FS PROCUREMENT MODELS

SN	Revenue Source	Model 1	Model 2	Model 3	Model 4
1	Revenue from sale of power	√	√	√	√
2	Revenue from sale of char	√	√	√	√
3	Revenue from septic tank emptying[37]	X	X	X	√
4	Revenue from per person toilet usage of MTV[38]	X	X	√	X
5	Revenue from sale of treated waste water	√	X	√	√

2.4. Capital Cost

In the present case the project cost has been referred from a typical 32 kW biomass (rice husk) based gasifier-power generation system. The model presents two Approaches to consider capital cost requirement. Approach 1 is based on actual project costs if available and Approach 2 is based on a pre-defined capital structure in case actual project costs are not available. As is evident actual project costs are preferred over estimated project costs as the project cost variations with capacity may not be linearly linked in real time as used in Approach 2. The following project cost break up as per industrial standard will be used in both Approaches:

i. Land: 20%
ii. Civil: 10%
iii. Plant & Machinery: 70%

[37] Applicable only for Model 4 of FS procurement model
[38] Applicable only for Model 3 of FS procurement model

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 8: VARIATION RANGE FOR CRITICAL INPUT PARAMETERS

SN	Input Factor	Base Scenario	Range from	Range To	Interval
1	Plant capacity	32 kW	1 kW	100 kW	1 kW
2	Plant Load Factor	80%	70%	90%	5%
3	Plant running hours	22 Hours	6 Hours	24 Hours	2 Hours
4	Calorific value – FS	3000 kcal/kg	2800 kcal/kg	6000 kcal/kg	100 kcal/kg
5	Calorific value – Biomass	3000 kcal/kg	2000 kcal/kg	4000 kcal/kg	100 kcal/kg
6	Gasifier efficiency	75%	60%	90%	5%
7	Engine efficiency	32%	25%	40%	1%
8	Fuel mix	75:25	0%	100%	25%
9	Power tariff	6 Rs/kWh	4 Rs/kWh	10 Rs/kWh	1 Rs/kWh
10	Debt Equity ratio	70:30	70:30	50:50	-
11	Debt interest rate	12%	10%	15%	1%
12	Discount rate	16%	12%	16%	1%
13	Currency conversion	54 Rs/USD	49 Rs/USD	56 Rs/USD	1 Rs/USD
14	Debt repayment period	6 years	6 years	10 years	1 year
15	Escalation on O&M	5%	4%	10%	1%
16	Escalation on transportation cost	5%	4%	10%	1%
17	Escalation on cost of drying	5%	4%	10%	1%
18	Escalation on cost of palletization	5%	4%	10%	1%
19	Escalation on revenue	5%	4%	10%	1%
20	Escalation on FS (liq) price	5%	4%	10%	1%
21	Escalation on diesel price	5%	4%	10%	1%
22	Escalation on Salary	10%	4%	10%	1%

2.5. Results and Discussion

The result from plug and play model has been summarized for base case (32kW gasifier) for various models for FS procurements models. This section details out results of financial analysis and provides a discussion around its various facets. For ready reference of the reader, Model description is presented here again.

Model 1 - FS Collection and transportation - outsourced

Model 2 - Direct procurement of FsDF from fuel producers

Model 3 - FS Collection using Mobile Toilet Vans

Model 4 - FS Collection and transportation - with own infrastructure

Also the revenue streams are presented as below:

Revenue 1: from sale of power

Revenue 2: from sale of char

Revenue 3: from septic tank emptying

Revenue 4: from per person toilet usage of MTV

Revenue 5: from sale of treated waste water

Cost of FS pellets:

The financial model considers various ways of providing fuel to the gasification process. The cost of FS pellets differs due to difference in capital cost, operational cost and revenue streams associated with the FS procurement model. The levelized costs of FS pellets are summarized as below:

TABLE 9: COST OF FS PELLETS

S N	Model	FS pellet cost (USD/kg)
1	Model 1	0.19
2	Model 2	0.20
3	Model 3	0.04
4	Model 4	0.15

As is evident Model 3 is most viable amongst all and procuring FS pellets from third parties comes out to be the most expensive method. The cost of FS pellets in Model 3 is also comparable to the cost of other biomass residues available and used in the gasification process worldwide such as rice husk, wood and wood residues. For example, cost of rice husk ranges between 3.7 cent/kg and 5.5 cent/kg in India based on availability and its competing use in the region.

Net Present Value (NPV) and IRR:

The NPV has been calculated for 32kW gasification system for various types of FS procurement models. The results have been summarized below.

TABLE 10: NPV AND IRR RESULTS

S N	Model	NPV	Project IRR	Equity IRR
1	Model 1	-140221	-	-
2	Model 2	-153317	-	-
3	Model 3	27355	33.5%	69.8%
4	Model 4	-88088	-	-

Model 3 of the FS procurement model is the best model based on the used information in the present plug and play model. It is also evident that the cost of FsDF is the lowest for model 3 and this results in positive NPV for model 3.

It has been further analyzed that the NPV is zero when FsDF cost (with FsDF to other biomass ratio 75:25) is reduced to 0.069 USD/kg. The possibility of reducing fuel cost to 0.069 USD/kg has been analyzed below for all FS procurement models:-

TABLE 11: BREAKEVEN POINT ANALYSIS

Model	Breakeven point
Model 1	-By reducing O&M cost for dewatering from 81000 USD/year to 27744 USD/year. Or -By increasing the selling price of waste water from USD 11.11 per tanker to USD 38 per tanker. This would be big jump from what is currently the market price of treated waste water.
Model 2	-The fuel procurement cost from supplier itself is 0.20 USD/kg which is much higher than 0.069 USD/kg. Hence without subsidy or any external grant, it is not possible to make NPV zero.
Model 3	-NPV is positive but it is very sensitive to fee charged for MTV usage.
Model 4	-By increasing toilet emptying fee from USD 14.81 per tanker to USD 37.17 per tanker. Or -By increasing the selling price of waste water from USD 11.11 per tanker to USD 28.04 per tanker.

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

For Model 1

1. Variation in project cost has little impact on NPV.
2. Variation in O&M cost for gasification and waste water treatment plant has little impact on NPV.
3. NPV is more sensitive to O&M of dewatering system. The annual O&M cost for dewatering system is $81,000 per annum which is much more than its capital cost. This should be reduced.
4. NPV is more sensitive to revenue from power compared to the revenue generated from sale of treated waste water and revenue from sale of char.

NPV is zero under following scenarios:

TABLE 12: BREAK EVEN CASE FOR MODEL 1

Case	Dewatering O&M	Revenue from sale of power	Revenue from sale of waste water
Unit	**USD/year**	**USD/unit**	**USD/tanker**
Break-even	28,024	0.23	37.85
Base case	81,000	0.11	11.1

The possibility of such variation need to be evaluated based on discussion with supplier and market survey. Government intervention is required to support the higher tariff.

For Model 2

1. Variation in gasification plant cost has little impact on NPV.
2. Variation in FS procurement cost has significant impact on NPV.
3. NPV is more sensitive to revenue from power compared to the revenue generated from sale of treated waste water and revenue from sale of char.
4. NPV is zero under following scenarios:

TABLE 13: BREAK EVEN CASE FOR MODEL 2

Case	FS Pellet price	Revenue from sale of power
Unit	**USD/kg**	**USD/unit**
Break-even	0.069	0.24
Base case	0.20	0.11

For Model 3

NPV for model 3 is positive. However the sensitivity analysis shows that NPV is more sensitive to variation in O&M cost of dewatering system and revenue collected from MTV per person usage. Breakeven point analysis shows that NPV is zero under following scenarios:

TABLE 14: BREAK EVEN CASE FOR MODEL 3

Capital cost	MTV cost	WWT cost	Dewatering plant cost	Gasification plant cost
Unit	**USD**	**USD**	**USD**	**USD**
Break-even	18,760	214,394	210,876	41,871
Base case	7,407	18,519	15,000	21,600

O&M Cost	MTV cost	WWT cost	Dewatering plant cost	Gasification plant cost
Unit	**USD/year**	**USD/year**	**USD/year**	**USD/year**
Break-even	110	12,396	92,099	5,141
Base case	56	1,296	81,000	1,350

Revenue	MTV usage	Revenue from sale of power	Revenue from sale of waste water
Unit	**USD/person**	**USD/unit**	**USD/tanker**
Break-even	0.03	0.085	5.5
Base case	0.04	0.11	11.11

For Model 4

Sensitivity analysis for model 4 shows that it is more sensitive to variation in O&M cost of dewatering system and revenue collected from sale of power. Breakeven point analysis shows that NPV is zero under following scenarios:

TABLE 15: BREAK EVEN CASE FOR MODEL 4

Case	Dewatering O&M	Revenue from sale of power	Revenue from sale of waste water	Revenue from toilet emptying
Unit	**USD/year**	**USD/unit**	**USD/tanker**	**USD/tanker**
Break-even	47,466	0.19	28	37.17
Base case	81,000	0.11	11.1	14.81

3. Conclusion

1. Characteristics of FS collected from various sources:- The calorific value of FS doesn't changes much due to change in source and the age of FS. However the moisture or water content might vary. Hence dewatering and drying are major challenges when handling with FS.
2. Characteristics of FS after pre-processing:- Calorific value of FS is better than the calorific value of other types of biomass presently used in gasification system. The moisture content can also be reduced to 5-15% by thermal drying process. However the high ash content and lower ash fusion temperature are concern. This will result in clinker formation inside the gasification chamber. Hence the existing gasifier system needs to be customized such that the temperature remains below the ash fusion temperature.
3. There are risks associated with gasification technology itself as this technology is not very established in India. Hence the testing of technology with FS is very important before running the plant on commercial scale. Following stages for development FS based gasifier can be considered:-
    a. Testing of FS sludge collected from Septic tanks and MTV for calorific value, ash content, bulk density and ash fusion temperature. Identification of suitable existing dewatering, drying and pelletization technology.
    b. The results from above can be compared with the requirement of gasification system. In this stage a sample fuel obtained from MTV and Septic tanks can be tested in research lab. This will help to select the suitable type of gasification system as well as customization of gasification system for maximum efficiency. In this stage, the dewatering, drying and pelletization techniques also need to be economized and made suitable for FS.
    c. The FsDF can be tested in the existing gasifier. The characteristic of existing gasifier is desired to be similar to the alpha stage recommendation on gasifier. The performance of FsDF needs to be evaluated and if required the characteristics of FsDF, like moisture content or ash content by mixing with other types of biomass etc, need to modify. This may take several round of testing. This will result in development of pre-processing techniques.
    d. A small scale customized gasifier based on (b) stage results; need to be tested on FsDF at full scale. The prototype needs to further modify based on the actual operational performance.
    e. The gasification system can be fully integrated with FS collection, transportation and pre-processing activities. This can be released on commercial scale.
4. Land requirement:- The land requirement for pre-processing (dewatering and drying) may cost extra.
5. Availability of FS:- Availability of FS can't be assured all the time as this is largely depends on individuals. However this risk can be minimize by following ways:-
    a. Running gasifier for less hours say 6 hours/day
    b. Co-firing FsDF with biomass in gasifier
    c. Using FsDF in biomass gasifier during lean season when biomass availability is lower

6. Chemical treatment of FS[39]:- The FS can be stabilized by using chemical treatment also and this will be cheaper compared to thermal treatment. However this will result in high alkali content in the FS which will result in agglomeration problem. This aspect need to be further evaluated.
7. The MTV model (Model 3) is the most successful model for a small scale gasification unit. However the success of this model depends on the maximum utilization of MTV. This can be assured by providing proper maintenance of MTV vans. A provision of pay and use, similar to public toilet, can be implemented there. However this is yet to be tested.

   The next profitable model is FS collection and transportation through own infrastructure (Model 4). In this model, the developer can further maximize the profit by sharing its own infrastructure for other services like MSW transportation, waste water transportation etc. Having own infrastructure also assures all time supply of FS.

[39] Page 2, http://iqtma.uva.es/instrat/Presentaciones_pdf/Chapter%208-%20Sludge.pdf

4. *Limitation*

Collection and transportation

1. Only 4 sources for FS procurement have been selected in this Plug and Play model.

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 high. This aspect has not been considered in the Plug and Play model.

Pre-processing

9. Only one method for dewatering has been considered i.e. FCK-315-Rotary thickener. Local resource based methods for dewatering should also be evaluated. This should help in bringing down the cost further.

10. The capacity of FCK-315 dewatering process is 136 KLD whereas the required capacity is 45 KLD. Hence the selected capacity of dewatering system is oversized and the capacity should be selected appropriately. This will reduce the capital cost and O&M cost of dewatering system.

11. It has been assumed that solar drying will used for drying purpose and the cost for drying has been assumed as USD 1.9 per ton. However this drying process has high retention time and it need a large open area for sun drying. The impact of retention period and area required for drying has not been considered in this plug and play model.

12. The waste heat generated from engine can also be used for drying and this will reduce the cost of drying. This has not been considered in the present model.

13. The cost of pelletization has been considered as USD 9.3 per ton similar to the cost of pellization for biomass. However this assumption needs to be verified.

Gasification

14. The plug and play has been developed for urban India. This need to be further updated with country specific data for global use.

15. The plant capacity can be varied from 1 kW to 100 kW and the Plug and play model facilitates option for manual entry of project cost for a given capacity of gasification system. In the absence of this a linear interpolation is used for estimation of project cost. However the linear interpolation will not provide the accurate cost.

16. The project cost considers only plant & machinery cost, civil cost and land cost. It is assumed that other costs like pre-feasibility cost, engineering design cost, supervision cost, escalation of cost due to delay in construction, contingency cost etc.

17. Escalation rate has been assumed similar to WPI which is 5%. However it is subjected for variation.

18. The debt equity ratio of 70:30 and 50:50 has been considered for Indian scenario. However in actual there may be slight variation.

19. Straight line method (SLM) depreciation has been considered in this model. Since the model has been prepared for internal evaluation and hence the selection of depreciation rate based on SLM is appropriate. The depreciation rate can be changed as per IT act but there will be very less variation in the result.
