Technologies for Energy Recovery from Faecal Waste

Technical and Financial Analysis – Hydrothermal Carbonization

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BILL & MELINDA GATES foundation

EVI

Sustainable Solutions for the Environment

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Abbreviations and Acronyms:

CSR	Corporate Social Responsibility
DS	Dry Solid
FS	Faecal Sludge
FsDF	FS Derived Fuel
HTC	Hydro-Thermal Carbonization
INR	Indian Rupee
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
Q1	Quarter 1 (April-June)
Q2	Quarter 1 (July-September)
Q3	Quarter 1 (October-December)
Q4	Quarter 1 (January - March)
RRS	Resource Recycling System
SFC	Specific Fuel Consumption
SLM	Straight Line Method
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 purposes. Out of the five technology areas planned for the study namely Gasification, Hydrothermal Carbonization, Pyrolysis, Fermentation and Anaerobic Digestion, Hydrothermal Carbonization (HTC) 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 calculate the levelized cost of FsDF fuel in different scenarios. The fuel then can be utilized for energy recovery using appropriate technology such as combustion, gasification etc. 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 available in fuel form.

Chapter 2: Financial Analysis provides the levelized cost of FsDF fuel produced by using HTC technology 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 fuel has been calculated considering processes such as collection and transportation, dewatering and waste water treatment, and hydrothermal carbonization. This analysis also provides the overall levelized cost of fuel (FsDF) produced.

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.

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

1. *Technology Analysis*

1.1 Technology Description

Hydrothermal carbonization is a technology to produce dried, uniform solid fuel from bio-resources such as food residues, sewage sludge, animal manures, fecal sludge, agricultural residues, high moisture content solid wastes like sewage sludge and MSW. It uses high-temperature and high-pressure steam to convert waste of various shapes and characteristics into a uniform product which is almost odorless, free from pathogens and can be used as fuel for heating or power generation.

This process takes the sludge with the moisture content of 80% into a rector and at 200 deg C 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, which is mechanically dehydrated down to the moisture content of 50-60% due to improved drying performance of the product. The dehydrated solid residues also show significantly improved drying performance, and 48 hours natural drying is enough to obtain fuel with the moisture content less than 10%[1]. This system also called RRS is developed by Tokyo Institute of Technology[2].

The basic process is illustrated as below:

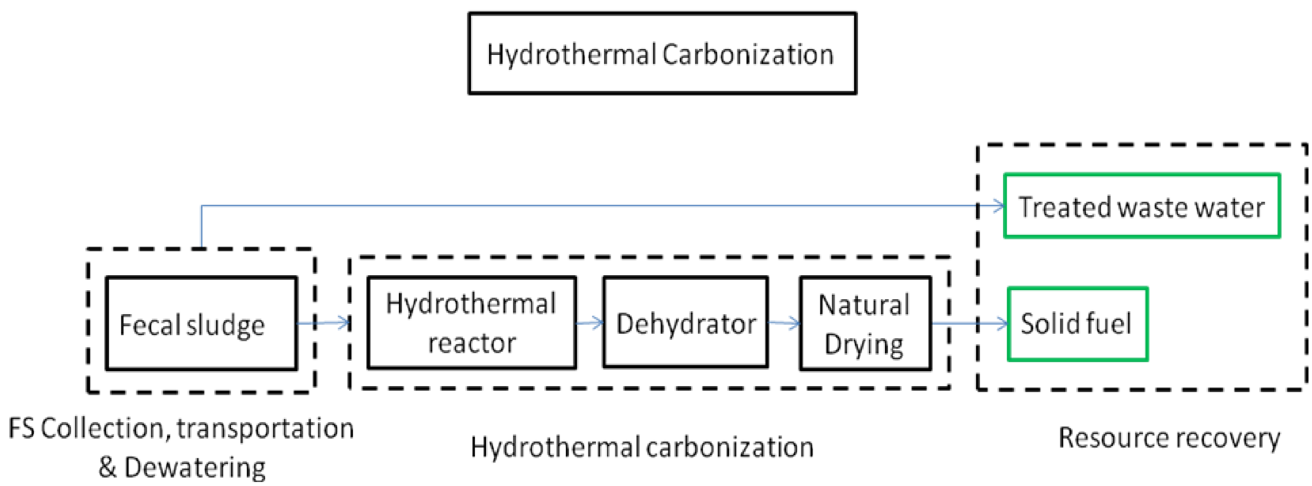

FIGURE 1: BASIC SCHEMATIC OF HTC PROCESS

[1] Z.L. Jiang1, D.W. Meng1, H.Y. Mu2 and K. Yoshikawa1, Experimental Study on Hydrothermal Drying for Sewage Sludge in Large-Scale Commercial Plant, Journal of Environmental Science and Engineering, Volumn 5, Number 7, July 2011, 900-909

[2] http://yk.wtert.jp/index.php?option=com_content&view=article&id=107&Itemid=161&lang=en

1.2 Raw Feed Characteristics

1.2.1 Feed Stock Requirement for Hydrothermal carbonization

Following are the raw feed requirement for hydrothermal carbonization process:-

1) **Moisture content:** The moisture content of sludge should be less than 80%. The higher moisture content requires more steam for drying purpose which will increase the cost of drying.
2) **Low in chlorine content:** The organic chlorine in high combustion temperature, without further treatment, will be released to the atmosphere as dioxin, and will promote the corrosion and clogging in exhaust gas line. This will have negative impact on the life of equipment and environment.
3) **pH Value:-** The pH – value of the feed should be below 7[3]. pH value higher than 7 (high alkali) will lead to agglomeration problem.

1.2.2 Characteristics of Available FS

FS has certain characteristics, like moisture content, quite different from those of normal HTC feedstock. It will therefore have to be pre-processed to make it suitable for feeding to the HTC reactor for drying. 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)

1) **FS collected from septic tanks**

   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 HTC system (below 80% for further drying in reactor). This can be done by dewatering free water from FS.

   Chlorine content: The chlorine content of fecal sludge is very less unless it's mixed with plastic components like bottle etc during handling. This should be avoided.

   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 7.

2) **FS collected from Mobile Toilet Vans (MTV)**

   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

[3] Lübeck, Future sludge treatment: Hydrothermal Carbonisation (HTC), 7.09.2011
[4] http://trade.indiamart.com/details.mp?offer=3952505291

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:-

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 this need to be reduced to requirements of the HTC system (below 80% for further drying in reactor).

Chlorine content: The chlorine content of fecal sludge is very less unless it's mixed with plastic components like bottle etc during handling. The chances of this are higher in MTV where users may flush pouch of tobacco (gutkha[7]) in toilet. This should be avoid or removed before HTC process.

pH value:- The pH value of fecal sludge is between 4.6 to 8.4. This need to be treated with lime in case it's acidic or pH is less than 7.

1.2.3 Gap Analysis

The main gap between what is available as-is and what is needed for HTC of FS is excess moisture content. Therefore, FS needs to be dewatered before it is considered suitable for HTC process. Following presents the gap between as-is and the HTC requirements in general.

TABLE 1: GAP ANALYSIS OF CHARACTERISTICS

Characteristics	Requirements of HTC reactor	As-is FS	
		From Septic Tank	From MTV
Moisture	<80%	96-98 %	97-98%
Chlorine content	Less	Less	Less

[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

[7] http://en.wikipedia.org/wiki/Gutka

pH	<7	4.6-8.4	4.6-8.4

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 is excess moisture content in FS available from septic tank or MTV. This excess water need to be dewatered before further processing in HTC reactor.

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[8].

Step 2: Dewatering

Dewatering reduces the water content further so that the solids content of the sludge is about 20%[9].

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: Chlorine

The chlorine content in FS is low however the presence of foreign particles such as plastic material may result in Dioxin formation at high temperature heating. Hence this should be removed before HTC treatment.

Step 4: pH balance

The pH of sludge should be checked and treated accordingly to bring it below 7. This can be done by doing acidic treatment.

[8] http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/11.asp
[9] http://www.unep.or.jp/ietc/publications/freshwater/sb_summary/11.asp

1.3.1. Characteristics of processed FS

Moisture content: The moisture content of FS dewatered will be less than 80%.

Chlorine content: The chlorine content in FS is low after removal of any foreign particles such as plastic.

pH value: pH value after treatment will be less than 7.

Characteristics of FS after pre-processing are given below:

TABLE 2: CHARACTERISTICS OF FS

Characteristics	FS after pre-treatment
Moisture content	<80%
Chlorine content	Lower
pH	<7

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.

Dioxin Production

Dioxins are produced at 250-600 deg C, so HTC temperature should not increase beyond 205 deg C to avoid dioxin production.

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.

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.

Not a proven technology at commercial scale: The HTC technology is itself a very new technology and further it has not been implemented at commercial scale for processing of FS. Hence the viability of technology with FS as feedstock is still uncertain.

Intensive energy requirement in drying: As per the information provided by Yoshikawa Laboratories, 5 tonne of FS sludge with 80% moisture requires 1.5 ton of saturated steam at 200deg C for drying purpose. A boiler needs 180 L of heavy fuel per day in order to generate the required steam for treatment of 5 tonne of FS per day. The heavy fuel energy input is almost half of the energy recovered from the process. Any reduction in calorific value of FS may result in negative energy flow.

1.4.2. Challenges in Hydrothermal Treatment of FS

There is no proven operational data on the use of FS as raw feed in hydrothermal carbonization process. There are some publications which recommend the operating temperature, pressure and holding time for efficient drying of FS sludge by using hydrothermal carbonization process. However this is still a matter of further research.

Following are major hindering factors:-

1. As discussed above, the HTC process requires high energy in drying. This may not be economical when the price of heavy fuel oil goes up or calorific value of FS goes down or market price of FsDF is less.
2. Any change in operating parameters like pressure, temperature or holding time may result in poor quality of FsDF.
3. Fecal sludge consists of large quantity of pathogenic microorganisms and falls under the lower alkaline range in terms of pH[10]. 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.

[10] http://en.wikipedia.org/wiki/Fecal_pH_test

4. Dioxin formation:- Dioxin formation might take place when plastic is heated beyond 250 degC in this process. This is harmful and should be treated before emitted into atmosphere.

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 FsDF by using hydrothermal carbonization technology. The cost associated with collection, transportation and dewatering has been considered while calculating the levelized cost. The benefits associated with FS collection, sale of treated waste water and MTV usages have also been considered in this model. The analysis has been done for 20 years of lifetime of hydrothermal reactor. The plug and play model provides the levelized cost of fuel for intermediate stages as well as for overall process.

2.2. Various Models for FS procurement

Sustainable FS procurement is critical to the success of the program. Three 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. 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[11]. 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 maximize 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 [12], 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.

The base model has been prepared for 5 tonne of HTC reactor or RRS reactor.

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

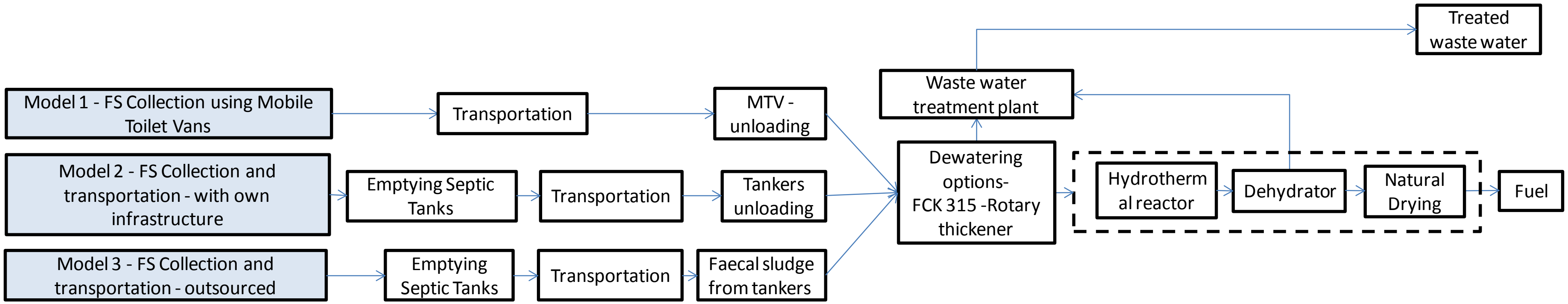

FIGURE 2: PROCESS OF FLOW DIAGRAM OF HYDROTHERMAL CARBONIZATION SYSTEM

Figure 2 shows the basic model of FsDF production from various sources. The key steps have been delineated to demonstrate the requirement of collection & transportation, dewatering and drying of FS in HTC.

TABLE 3: FS PROCUREMENT MODELS – PROS AND CONS

Index	Assumptions	Pros	Cons
Model 1	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 HTC plant for further 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 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.
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	• 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	• 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

	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.	system avoided. Project developer doesn't have to deal with individual household septic tank owners.	on third party supplier.

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

TABLE 4: KEY COST FACTORS FOR MODELS

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 dewatering system	√	√	√
Capital cost for drying system	√	√	√
Land cost	√	√	√
O&M cost of truck	X	√	X
O&M cost of MTV	√	X	X
O&M cost of WWT	√	√	√
O&M cost of dewatering system	√	√	√
O&M cost of drying	√	√	√
Cost of transportation from sanitation site to plant site	√	√	X
Cost of transportation of treated waste water	√	√	√
Procurement cost of FS sludge from third party	X	X	√

2.3. Sources of Revenue

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 depend on FS procurement models:-

1) **Revenue from emptying of septic tank:-** Household owners in cities pay for emptying their tanks to emptier.
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. This also promotes recycling of water. 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 calculation of Fs derived fuel cost from various FS procurement models.

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	√	√	√

2.4. Capital Cost

In the present case the project cost has been referred to for a typical 5 tonne HTC system. The need for other infrastructure has been identified accordingly. The breakup of capital cost has been provided below for all FS procurement models:-

TABLE 6: 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
Total capital cost for MTVs	USD	185,185	Calculated
Capital cost of dewatering system	USD	15,000	FCK-315, Rotary thickener Synapse. The cost has been taken when volume is high.
Capital cost for WWT plant	USD	18,519	For 50KLD system - http://www.cseindia.org/node/3770
Capital cost of RRS technology (HTC)	USD	25,000	Cost provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Land cost	USD	5,400	Land cost might change significantly for specific scenarios

Total Cost	USD	**249,104**	**Calculated**

TABLE 7: 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 dewatering system	USD	15,000	FCK-315, Rotary thickener Synapse. The cost has been taken when volume is high.
Capital cost for WWT plant	USD	18,519	For 50KLD system - http://www.cseindia.org/node/3770
Capital cost of RRS technology (HTC)	USD	25,000	Cost provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Land cost	USD	5,400	Land cost might change significantly for specific scenarios
Total Cost	**USD**	**126,881**	**Calculated**

TABLE 8: CAPITAL COST FOR MODEL 3: FS COLLECTION AND TRANSPORTATION - WITH OWN INFRASTRUCTURE

Parameters	Unit	Value	Reference
Capital cost of dewatering system	USD	15,000	FCK-315, Rotary thickener Synapse. The cost has been taken when volume is high.
Capital cost for WWT plant	USD	18,519	For 50KLD system - http://www.cseindia.org/node/3770
Capital cost of RRS technology (HTC)	USD	25,000	Cost provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Land cost	USD	5,400	Land cost might change significantly for specific scenarios
Total Cost	**USD**	**63,919**	**Calculated**

The number of MTVs and trucks has been estimated based on the daily requirement of FS sludge at HTC plant. The calculation for the same has been provided in the plug and play model. The dewatering system, FCK-315, has been selected based on recommendations provided by Synapse. Synapse has provided two separate costs for FCK-315 system. The cost of system is $49,000 when purchased in single unit however the price can be reduced to $15,000 when volume is high[13]. Hence in the present case the lower cost has been taken assuming the equipments would be purchased in bulk for various sites.

Almost 45KLD of waste water will be separated by FCK-315 dewatering system. Hence a waste water treatment plant of 50 KLD has been considered for treatment.

In India, the average BOD and COD of sewage water are 185 and 481 respectively[14]. Similar characteristics have been assumed for waste water generated from dewatering system in the present case. The standard defined as per "The Environment (Protection) Rules, 1986", for usage of water for irrigation or construction purpose is 100 and 250 for BOD and COD respectively[15]. This requirement can be met by the proposed waste water treatment plant which reduces BOD by 61% and COD by 64%[16] which reduced BOD and COD to 72 and 173 respectively.

The selected hydrothermal technology has been developed by Yoshikawa Laboratory[17] in Japan. This has been used in commercial scale for treatment of waste from medical facilities in Hokkaido, Japan. Similar facility has been also tested in China for treatment of MSW and sewage sludge[18]. Hence this technology has been selected for treatment of FS. The cost and operation related parameters are provided by Yoshikawa Laboratory.

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 9: VARIATION RANGE FOR CRITICAL INPUT PARAMETERS

SN	Input Factor	Base Scenario	Range from	Range To	Interval
1	Power tariff	6 Rs/kWh	4 Rs/kWh	10 Rs/kWh	1 Rs/kWh
2	Debt Equity ratio	70:30	70:30	50:50	-
3	Debt interest rate	12%	10%	15%	1%
4	Discount rate	16%	12%	16%	1%
5	Currency conversion	54 Rs/USD	49 Rs/USD	56 Rs/USD	1 Rs/USD
6	Loan repayment period	6 years	6 years	10 years	1 year

2.6. Results and Discussion

The levelized cost of fuel has been calculated for three types of FS procurement models. The plug and play model also provides the levelized cost of fuel for individual processes like

[13] Synapse dewatering investigation report omni-ingestor phase 2 milestone 1, July 27,2012
[14] Para 4.3, Table H, http://www.cpcb.nic.in/newitems/12.pdf
[15] http://cpcb.nic.in/GeneralStandards.pdf
[16] http://www.cseindia.org/node/3770
[17] http://yk.wtert.jp/index.php?option=com_content&view=article&id=107&Itemid=161&lang=en
[18] http://www.aplasbali2012.org/media/media/proceeding/4.5_Yoshikawa.pdf

collection and transportation, dewatering and RRS system. The revenue streams applicable for all models have also been considered while calculating the levelized cost of fuel. This will help us to identify the cost intensive process and at the same time it'll help us to take necessary measures to reduce the overall levelized cost of fuel.

Following revenue streams are considered:

Revenue 1: from septic tank emptying

Revenue 2: from per person toilet usage of MTV

Revenue 3: from sale of treated waste water

Levelized cost FsDF:

The levelized cost of FsDF has been provided below. This also provides the levelized cost for individual processes.

TABLE 10: COST OF FS FUEL (USD/KG)

Model	Collection and transportation	Dewatering & WWT	RRS technology	Overall cost
Model 1 - FS Collection using Mobile Toilet Vans	-0.10	0.08	0.09	**0.06**
Model 2 - FS Collection and transportation - with own infrastructure	-0.01	0.08	0.09	**0.16**
Model 3 - FS Collection and transportation - outsourced	0.04	0.08	0.09	**0.21**

As is evident Model 1 is the most viable for production of FsDF. This is mainly because of revenue collection from per person usage of MTV. This cost is also comparable to the cost of other biomass residue available in the region.

A sensitivity analysis of +/-100% on following parameters has been performed:-

1) Capital cost
2) O&M cost
3) Revenue

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 FsDF cost.
2. Variation in O&M cost has significant impact on FsDF cost

3. FsDF cost is more sensitive to O&M of dewatering system and O&M cost of RRS plant. 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. FsDF cost is more sensitive to revenue from MTV usage compared to the revenue generated from sale of treated waste water.

The FsDF cost is zero under following scenarios:

TABLE 11: BREAK EVEN CASE FOR MODEL 1

Case	Dewatering O&M	RRS O&M	Revenue from MTV usage	Revenue from sale of waste water
Unit	**USD/year**	**USD/year**	**USD/person**	**USD/tanker**
Break-even	39,207	14,375	0.05	25.32
Base case	81,000	56,167	0.04	11.1

The possibility of such variation need to be evaluated based on discussion with supplier and market survey.

For Model 2

1. Variation in project cost has little impact on FsDF cost.

2. Variation in O&M cost has significant impact on FsDF cost

3. FsDF cost is more sensitive to O&M of dewatering system and O&M cost of RRS plant. 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. FsDF cost is more sensitive to revenue from toilet emptying

5. The FsDF cost is zero when total O&M cost is reduced to 38,943 USD/year. However the possibility of such variation need to be evaluated based on discussion with supplier and market survey.

For Model 3

1. Variation in project cost has little impact on FsDF cost.

2. Variation in O&M cost has significant impact on FsDF cost

3. FsDF cost is more sensitive to O&M of dewatering system and O&M cost of RRS plant. 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. In this model there is only one source of revenue i.e. revenue from sale of treated waste water. Any variation in this revenue has significant impact FsDF cost is more sensitive to revenue from toilet emptying

5. The FsDF cost is zero when total O&M cost is reduced to 38,943 USD/year. However the possibility of such variation need to be evaluated based on discussion with supplier and market survey.

Energy ratio has been calculated to check whether the HTC process is generating net surplus energy or not. The calculation for the same has been provided below.

TABLE 12: ENERGY RATIO (ENERGY-OUT/ENERGY-IN)

Parameter	Value	Unit	Reference
Quantity of HFO used in boiler	180	Litre/day	As per information provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Calorific value of HFO	41200	kJ/litre	http://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html
Electricity-Reactor	25	kWh/day	As per information provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Electricity-Dehydrator	10	kWh/day	As per information provided by Prof Yoshikawa, Tokyo Institute of Technology, for RRS technology
Energy-in	7542000	kJ/day	Calculated
Quantity of FsDF produced	1000	kg/day	Calculated
Caloric value of FsDF	3000	kcal/kg	Calorific value of FS result from Uganda, Ghana, and Senegal by Teddy Nakato
Energy-output	12560400	kJ/day	
Energy ratio	**1.67**	Ratio	Calculated

Since the energy ratio is more than one hence the HTC process results in net surplus energy generation.

3 Conclusion

1. Quality of FsDF:- The calorific value of fuel derived from sewage sludge is approximately 2000 kcal/kg . Since calorific value of FS is better than sewage hence this may result in higher calorific value of FsDF fuel after HTC treatment. However this is yet to be tested on commercial scale. Excess heating or higher holding time may result in poor quality of fuel.

2. The MTV model (Model 1) is the most successful model for hydrothermal carbonization process. 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.

3. The production cost of FsDF in case of Model 1 can be reduced to zero in following conditions:-

Case	Dewatering O&M	RRS O&M	Revenue from MTV usage	Revenue from sale of waste water
Unit	**USD/year**	**USD/year**	**USD/person**	**USD/tanker**
Break-even	39,207	14,375	0.05	25.32
Base case	81,000	56,167	0.04	11.11

   The capacity of dewatering system is 25 GPM or 136 KLD whereas the process requirement is only 45 KLD. Hence the selection of appropriate size of dewatering system may reduce the capital cost and O&M cost of dewatering system by half. In that scenario, it's possible to have zero production cost for FsDF.

4. 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. The HTC technology is appropriate when moisture content is less than 80%. Hence dewatering of surplus water is major challenges when handling with FS.

5. Formation of Dioxin:- Present of chlorine rich material may result in formation of dioxin when heated above 250 degC. Hence the presence of foreign chlorine rich materials (plastic etc) should be removed before hydrothermal carbonization process.

Policy & Regulation

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

2. Government may allocate funds for design and development of such waste to energy projects on pilot scale similar to the funding allocated for wind and solar projects.

3. Government may also provide subsidy for such waste to energy technologies.

4. In order to ensure the performance of such plants, the Government may provide performance based incentives. This will ensure not only implementation but continuation of operation of these projects.

5. Government may consider FsDF a form of renewable energy source and benefits applicable to renewable energy projects may also be made available to FS waste to energy projects.

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

7. The use of FsDF or blending of FsDF with other types of fuel like biomass, coal may be made mandatory in industries. This will create market for FsDF fuel. There may also be a provision for preferential tariff for power generated from FS based plant to increase their financial viability.

8. 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.

9. 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.

10. The government has mandated spending by companies registered under companies law at least 2 per cent of their net profit towards corporate social responsibility (CSR) activities under Companies Bill 2012[19]. Such waste to energy projects may be included under the definition of CSR activities. More companies would be encouraged to invest a part of CSR expenditure on such waste to energy projects.

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

4 Limitation

Collection and transportation

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

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

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

4. Revenue from septic tank collection:- At present, residents pay cleaning charges to tanker emptying agencies. However this may not 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. 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.

HTC

11. The hydrothermal carbonization technology has not been tested on FS at commercial scale and hence this needs to be tested and proven at pilot scale.
12. The HTC technology is appropriate for sludge with less than 80% of moisture. This may not work properly when the moisture content is high. Hence in case of non-functioning of dewatering system, the HTC system may not work properly.
13. In case of higher heating or longer holding time, the process may result in poor quality of fuel.
14. The HTC process will also generate liquid fertilizer. However the revenue from the same has not been considered in this Plug and Play model.
15. Land cost has been assumed however this is largely to vary depending on location of project site. Hence this should be evaluated for project specific site before implementation of project. However sensitivity analysis has been performed on total cost to cover such variations.
16. A large land area is required for natural drying, storage of fuel etc. An additional area of 500 m2 has been considered for such purpose. However this need to reconsider based on scale of project.