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Abstract

With rise in population and the ongoing urbanisation drive, the urge to ensure energy security both for the rural and urban areas has emerged as a major challenge in India. The demand for energy has increased in all spheres of life, e.g. for cooking, cultivation, production purposes, transportation, and so on. Although through various government initiatives, adoption of liquefied petroleum gas (LPG) for cooking has increased, given the vast population, use of biofuels is expected to continue for poorer households. Generation of biogas from cattle waste in India has intensified through policies, but the same from human waste is still in a nascent stage. The present study explores the possibilities of recovering energy and nutrients from human waste by discussing the present system of human waste collection, treatment and disposal in India, followed by the reasons behind the failures of the past initiatives (e.g., Ganga Action Plan, GAP). It further focuses on a few alternative systems and their technical feasibility. It is concluded that various ongoing policies, viz., National Mission for Clean Ganga (NMCG), 'Swachh Bharat Mission' (SBM) - should be coordinated for integrating collection and treatment of human waste for generation of renewable energy.

Keywords: *human waste management, urban wastewater management, renewable energy, resource recovery, biogas generation, public health management, government policy, technology adoption, energy policy, India,*

JEL Classification: I18, Q40, Q48

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1. Introduction

With rise in population and urbanisation, the urge to ensure energy security both for the rural and urban areas has emerged as a major challenge in India (IEA, 2015). The demand for energy, as reflected from consumption of energy products, has increased in all spheres of life, e.g. for cooking, cultivation, production purposes, transportation, and so on (GoI, 2015a). While import of energy products, mostly crude petroleum and coal, have increased considerably over the period (GoI, 2015a) owing to fall in energy price and other factors. The potential adverse effects on the environment are only too obvious (Srinivasan and Ravindra, 2015). Exploring possibilities of enhancing domestic production of energy is one of the objectives of the government (MoP&NG, 2014). For sustainable reduction in import dependence on fossil fuels (hydrocarbon) by 2030, we need to explore enhancing production possibilities of all alternative sources of energy which are technologically and financially feasible. One possible solution is to augment generation of renewable energy from biomass, which is also on the rise, given the sustainability perspective in mind.

As a basic activity across all types of households, the case of energy use for cooking deserves mention here. Direct use of biomass as source of energy for cooking is a common practice in India (IEA, 2006). Mostly, fire-wood and chips, agricultural waste and dung cake (cow and buffalo) are used as cooking fuel both in rural as well as urban households. In addition, apart from households, a large demand for cooking fuel comes from hotels and restaurants where using biofuel is not rare even in cities and towns in India (Shrimali et al., 2011). The evolving scenario in rural and urban areas over 1983-84 to 2011-12 has been shown with the help of Table 1, from which several important policy conclusions emerge.

First, in rural areas fire-wood and chips continue to serve as predominant source of energy for cooking throughout this period. Second, during 1980s, and early half of 1990s fire-wood was also predominant source of cooking fuel among urban households. However, with greater penetration of liquefied petroleum gas (LPG) in subsequent period, the demand for other form of energy sources, namely, coke and coal, fire-wood and chips as well as kerosene has fallen gradually in urban areas. The adoption rate of LPG has gradually increased in rural areas as well over the years. Third, dung cake is still used as fuel for cooking both in urban and rural areas, but its importance has gradually waned in both areas over the period. Fourth, the scenario on adoption of Gobar gas (biogas) as fuel has not taken off in both the regions. Use of biomass waste (livestock and human waste) could clearly be intensified as a source of clean fuel after conversion. Finally, the relative use of charcoal and kerosene for cooking has also declined over the last two and a half decades, with growing availability of more ‘handy’ alternatives.

Table 1: Distribution of Households by Primary Source of Energy for Cooking in India
(percentage of total number of households by residence)

Source of Energy	1983-84		1987-88		1993-94		1999-2000		2004-05		2009-10		2011-12	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Coke and coal	2.4	16.6	1.9	10.7	1.4	5.7	1.5	4.1	0.8	2.8	0.8	2.3	1.1	2.1
Fire-wood and chips	77.0	46.0	79.0	37.0	78.2	29.9	75.5	22.3	75.0	21.7	76.3	17.5	67.3	14.0
Gas (coal, oil or LPG)	0.2	10.3	0.8	22.3	1.9	29.6								
LPG							5.4	44.2	8.6	57.1	11.5	64.5	15.0	68.4
Gobar Gas (biogas)					0.3	0.1	0.3	0.1	0.2	0.0	0.2	0.0		
Dung cake	14.5	2.9	13.8	3.1	11.6	2.4	10.6	2.1	9.1	1.7	6.3	1.3	9.6	1.3
Charcoal					0.0	0.2	0.0	0.1	0.0	0.0	*	*		
Kerosene	0.8	16.7	1.5	19.2	2.0	23.2	2.7	21.7	1.3	10.2	0.8	6.5	0.9	5.7
Electricity							0.1	0.4	0.0	0.2	0.1	0.3		
Others	5.4	7.6	3.1	7.3	3.8	2.6	2.7	0.7	3.3	1.1	2.4	1.1	4.9#	1.5#
No cooking arrangement					0.7	6.3	1.1	4.3	1.3	4.9	1.6	6.5	1.3	6.9
Not reported					0.0	0.1	0.0	0.0	0.3	0.3	**	**		
Total	100.3	100.1	100.1	99.6	99.9	100.1	99.9	100.0	99.9	100.0	100.0	100.0	100.0	100.0

Notes: *-included in 'Others', ** - included in 'Total', #- includes gobar gas, charcoal, electricity and others
Source: Compiled from NSSO Report Nos. 410, 464, 511, 542, 567 (NSSO, 2015)

There are several factors which influenced the penetration of LPG as source of cooking fuel in urban areas, namely – convenience, emergence of nuclear families and double-income households, lower pollution effect, devolution of subsidy by government, easy access, portability and so on. A predominant source of growing fuel subsidy burden of the government is associated with domestic sales of LPG at a subsidised price, although in recent period an inclination towards reforms is noticed (IISD, 2014). The annual devolution on fuel subsidy and its percentage distribution is explained with Table 2. While from 2002-03 to 2013-14, the subsidy to kerosene has declined from 46.3 to 26.2 percent, the corresponding figure for LPG has increased from 53.7 to 73.8 percent in that order. Being highly dependent on imported crude oil (80 percent of crude throughput is imported in India), rising volatility in international crude oil prices and exchange rate of Indian Rupee, the recent developments forced the government to take hard decision to partially withdraw the subsidy from domestic sale of LPG by restricting the number of subsidised refills in a year to twelve cylinders for each household for both in rural and urban areas (Jain *et al*., 2014). However, a concern area is that the demand for cooking fuel may again shift towards coke and coal and fire-wood and chips at least for those households who are at the margin and cannot afford to purchase LPG at market price if there annual LPG consumption exceeds statutory limit. On the other hand, a large section of the society does not have access to LPG connection and use biofuels as a source of cooking fuel. However, adoption of LPG not only depends on affordability of initial cost of connection but also purchasing refills (though subsidised by the Central Government). In the Union Budget Speech 2016-17, Finance Minister has allocated Rs. 2000 crore to provide LPG connection to 1.50 crore BPL households. The scheme will continue for another two years to provide 5 crore free LPG connections to Below Poverty Line (BPL) households under *Pradhan Mantri Ujjwala Yojana* (The Hindu, 2016). However, the scheme does not address the issue of affordability of purchasing LPG refills. Therefore it is expected that using biofuels for cooking will continue for those who cannot afford to purchase LPG cylinders at subsidised rate. Use of biofuels for cooking is a potential cause of indoor air pollution in India and causes large scale morbidity and mortality among women and children (Kankaria *et al*., 2014; Sukhsohale *et al*., 2013).

Table 2: Year-wise Subsidy on PDS Kerosene & Domestic LPG (including Freight Subsidy)* (Rs. Crore)

Year	PDS Kerosene		Domestic LPG		Total
2002-03	2112	(46.3)	2446	(53.7)	4558
2003-04	2671	(42.1)	3680	(57.9)	6351
2004-05	1154	(39)	1803	(61)	2957
2005-06	1063	(39.6)	1620	(60.4)	2683
2006-07	979	(38.4)	1571	(61.6)	2550
2007-08	984	(36.9)	1685	(63.1)	2669
2008-09	980	(36.2)	1730	(63.8)	2710
2009-10	962	(34.5)	1830	(65.5)	2792
2010-11	936	(32)	1991	(68)	2927
2011-12	868	(28.7)	2155	(71.3)	3023
2012-13	746	(27.1)	2007	(72.9)	2753
2013-14	681	(26.2)	1920	(73.8)	2601

Note: Figure in the parenthesis shows the percentage share in Total Subsidy
* -The freight subsidy is for far-flung areas under Freight Subsidy Scheme 2002
Source: Petroleum Planning & Analysis Cell (PPAC) Website

Given this background, the present study explores the possibilities of recovering energy and nutrients from human waste and arranged along the following lines. First, the potential for using human waste as a source of energy is briefly noted. The present framework of human waste collection, treatment and disposal in India is analysed next, followed by the underlying factors behind the failures of the past initiatives. After noting the private initiatives, the analysis briefly discusses a few alternative systems and their technical feasibility. Finally, based on the analysis, a few policy observations are drawn.

2. Why Focus on Human Waste as a Source of Energy?

Biowaste management has emerged as a standard proactive in developing countries now (Vögeli *et al*., 2014). International experience shows that energy and nutrients could be recovered from human waste through anaerobic digestion (Muzenda, 2014). Biogas digester could produce biogas from human waste (also known as septage) which could be used directly as cooking fuel and indirectly through conversion to electricity. The composition of biogas in terms of percentage contribution is shown with the help of Table 3. Among the constituents, methane and hydrogen are the two combustible gaseous components of biogas, which are mixed with two inert gases (Carbon Dioxide and Nitrogen) and water vapour. Apart from livestock waste, human waste is also a valuable resource which could provide energy and fertiliser (Schuster-Wallace et al., 2015).

Table 3: Composition of biogas

Substances	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon Dioxide	CO_2	30 - 40
Hydrogen	H_2	5 - 10
Nitrogen	N_2	1 - 2
Water vapour	H_2O	0.3
Hydrogen Sulphide	H_2S	Traces

Source: Yadav and Hesse (1981)

Generation of biogas from cattle waste in India has intensified over the years through provision of finances, subsidies etc. Riek *et al*. (2012) noted the monetary as well as non-monetary benefits of enhancing biogas usage in the Indian context. Among the monetary benefits, annual household cash-saving through reduction in kerosene purchase requirement deserves mention. On non-financial benefits, health benefits (lesser expenses due to reduced ailments), social benefits (lower time cost in terms of reduced kitchen working hours or efforts in gathering woods) and global/ local environmental benefits (lower release of greenhouse gases in the environment, lesser indoor air pollution) deserves mention. In addition, non-proper management of cattle / livestock waste (collection, storage, and usage) results in groundwater pollution (through seepage) and pollution of surface water through runoff (Mukherjee, 2008). Livestock waste is one the major sources of groundwater nitrate pollution in India (Mukherjee, 2012; Kumar and Shah, undated).

It has been noted that the potential yield of single human waste based biogas plant will be lower than cattle waste based system (Kattein, 2014). The comparison of yield patterns is reported in Table 4. On the other hand, the potential for biogas is highest from the poultry segment. Therefore, a composite feedstock based biogas system could potentially yield the desired output of biogas instead of a single feedstock based system, which makes more economic sense.

Table 4: Gas Production potential of various types of dung

Types of Dung	Carbon – Nitrogen Ratio (C/N) (ideal: 20-30)	Gas Production Per Kg Dung (m3)
Cattle (cows and buffaloes)	24	0.023 - 0.040
Pig	18	0.040 - 0.059
Poultry (Chickens)	10	0.065 - 0.116
Human	8	0.020 - 0.028

Source: Kattein (2014)

The present system of human waste collection and disposal system is not adequate and generates several public health hazards (Shah and Sajitha, 2012; Sarkhel, 2012). Several studies have linked to under five mortality rate of children and stunting of height with poor sanitation and inadequate water supply in India (von Medeazza and Chambers, 2013). Given the huge gap between the generation of waste and its collection and disposal mechanism, runoff from open dump sites often contaminates the environment. This is particularly high for chemical contaminates that reach wells and surface water sources of drinking water, leading to public health concerns (UNICEF and FAO, 2013). The inadequate disposal of human waste spreads many faecally-transmitted infections, including diarrhoea, soil- transmitted helminths, giardia, ascaris, hook worms, trichuris and so on (von Medeazza and Chambers, 2013). World Bank (2013) estimated the total cost of environmental degradation in India at about Rs. 3.75 trillion (US$80 billion) annually, equivalent to 5.7 percent of GDP in 2009, of which inadequate water supply and sanitation cost at around at Rs. 0.5 trillion. If human waste based biogas system is scaled up at least in those areas which are not covered (either totally or partially) by organised sewer system that could potentially provide substantial public health benefits, apart from generation of fuel for cooking and electricity.

3. Potential uses of Human Waste

3.1 Direct uses

3.1.1 Non energy uses (as fertiliser)

The possible recycling of human waste provides a wide range of opportunities for the policymakers, a major component of which would be to boost agricultural productivity. Untreated municipal wastewater is used in agriculture in both developed and developing countries (Mukherjee and Nelliyat, 2006). While the nutrient benefits of domestic sewage provides a viable option for farmers from semi-urban and urban areas to adopt municipal wastewater based agricultural practices, which may also give rise to serious environmental and public health hazards apart from environmental impacts in terms of groundwater pollution and biological accumulation of various emerging pollutants (D'itri *et al*., 1981). Hussain *et al*. (2002) note that:

> 'In both developed and developing countries, the most prevalent practice is the application of municipal wastewater (both treated and untreated) to land. In developed countries where environmental standards are applied, much of the wastewater is treated prior to use for irrigation of fodder, fiber, and seed crops and, to a limited extent, for the irrigation of orchards, vineyards, and other crops. Other important uses of wastewater include, recharge of groundwater, landscaping (golf courses, freeways, playgrounds, schoolyards, and parks), industry, construction, dust control, wildlife habitat improvement and aquaculture. In developing countries, though standards are set, these are not always strictly adhered to. Wastewater, in its untreated form, is widely used for agriculture and aquaculture and has been the practice for centuries in countries such as China, India and Mexico… Thus, wastewater can be considered as both a resource and a problem.'

Gurwitz (1991) recounted the evolution of the municipal wastewater management practice for agriculture in the European Commission, which adopted Directive 86/278 for this purpose way back in 1986. The proposed directive mandates recyclable sludge for reuse in agriculture. The wastewater management framework is arranged in the following manner:

> 'The proposed directive addresses the challenges of municipal waste water and sewage sludge management on three fronts. First, it requires minimum treatment standards for municipal waste water prior to its release into the environment. Second, the proposed directive prohibits the discharge of sewage sludge at sea by pipeline or ship… Finally, the proposed directive establishes a Regulatory Committee to oversee waste water management.'

Ensink *et al*. (2002) noted that in Pakistan, the application of nitrogen, phosphorus, and potassium through wastewater exceeded agronomic recommendations for the crops being cultivated. On the positive, accumulation of heavy metals have been almost negligible, barring the exception of lead, copper and manganese. It is known that the overexposure of crops to nitrogen, phosphorus, and potassium through wastewater makes the crops more susceptible to pests and diseases, thereby leading to lower productivity (Morishita 1988). However, the positive outcome in Pakistan motivated Ensink *et al*. (2002) to conclude that rather than making treatment facilities legally binding in developing countries, other options to minimise the negative impacts of untreated wastewater irrigation should be explored. Such a policy is precisely crucial in the rural and semi-urban belts, which are characterised by absence of heavy industries, and groundwater consumption for drinking is not prevalent. Andreoli et al. (undated) noted the realised benefits of the agricultural use of the wastewater sludge in Brazil, but reported the obstacles involving the logistics related aspects. Zhang *et al*. (2016) reported the improvements and benefits from wastewater treatment in China, though there is further scope for improving the implementation of discharge standards and sludge treatment and recycling rates.

3.1.2 Source of energy (through incineration)

The human waste and other form of wastes can be recycled as a source of energy through incineration, but certain basic requirements has to be fulfilled. These includes, the energy content of the waste (i.e., lower calorific value), specific composition of the waste (e.g., plastic, food items), stability of the waste load generation to ensure viability of the incineration plant etc. The first criteria is crucial because both the, 'potential energy production and income from energy sale depends heavily on the energy content (net calorific value) of the waste' (World Bank, 1999). It has been noted that incineration of waste can be performed using various technologies, and each one of them have their specific merits and demerits (Bontoux, 1999).

One concern however is that waste incineration involves high investment costs with high operating and maintenance expenditures, as a result of which, 'net treatment cost per metric ton of waste incinerated is rather high compared to the alternative (usually, landfilling)' (World Bank, 1999). Costs under this mechanism also increase owing to multiple factors, e.g., capacity of plants (low-capacity plants are relatively more investment-intensive), compliance requirement with advanced emission control policies etc. The cost as well as composition of the waste and the regulatory environment may influence the choice of developed and developing countries to adopt incineration technique differently. Tang (2012) notes that in China the benefit outweighs the cost under certain scenarios, but the result is quite sensitive to variations in borrowing and technology-related cost. On the other hand, while the operation is viable in the EU, the costs display a rising trend owing to the increasingly stringent emission limit requirements (Bontoux, 1999). The incineration initiatives can be financed through tipping fees, imposition of general levy, public subsidies, and combinations thereof (World Bank, 1999).

There are several methods for dewatering and drying of sewage sludge to raise dry matter content at the level which is manageable for further uses (e.g., land-application, incineration) and also acceptable in hygienic level (acceptable level of pathogens). Among alternatives, mechanical dewatering could achieve a dry matter content of 20 percent and the end product has high pathogen content and therefore unsuitable for land-application and incineration (Rostmark and Oberg, 2013). To reduce content of water and pathogen to acceptable level, drum-drying and belt-drying are common heat based methods. However, these are expensive due to high energy demand and the use of consumables like polymers and cooling water. Rostmark and Oberg (2013) proposed freeze-thaw treatment combined with convective drying of sewage sludge as an alternative which is not only cost and time efficient but also secure from a health perspective. The dewatered / dried septage is incinerated, resulting into associated benefits.

3.2 Indirect uses through conversion into clean fuel

3.2.1 Direct uses of biogas

India is presently trying to energise the rural economy by enhancing the rural non-farm employment opportunities and also by enhancing access to concessional loans for entrepreneurial ventures. For example, the Finance Minister has allocated Rs. 1,700 crore in the Union Budget 2016-17 to set up 1500 Multi Skill Training Institutes across the country under the *Pradhan Mantri Kaushal Vikas Yojana (PMKVY)*. However, securing availability of uninterrupted energy and power sources for machines is still the major challenge for India in general (Ahn and Graczyk, 2012), and particularly so for smooth operation of small-scale industries. Generation of biogas can be a major solution in this regard. Setting up composite feed stock (cattle and human waste) based biogas plants not only hone entrepreneurial skills of rural youths but also open up employment opportunities for unskilled rural youths. The system could provide sustainable solution to access to energy for cooking, lighting, lifting water for drinking and irrigation, and also provide fuels for industrial machineries and motor vehicles. Providing sustainable access to sewage and sanitation is a challenge for a large section of rural populace in India. Environmental impacts as well public health hazards related to sewage and sanitation are substantial. Moreover, open storage of livestock waste results in both local (water pollution) and global (emission of Green House Gases) environmental problems. Given the energy scarcity, nurturing all available options for energy security should be ideal policy decision.

Biogas can also be directly used in industrial applications to replace current fossil fuels, provided initial supports are provided (Arvola *et al*., 2012). After conversion of the human waste into biogas, it has multiple applications. For instance, compressed biogas could be used for operating various types of internal combustion engines (Rajendran *et al*., 2012). It can also be a major source of cooking fuel and lighting, especially in the rural areas, where both the animal and human waste consists of a significant load. The initiatives have led to positive results in various parts of the country, including rural belts (Dube, 2014). The biogas technology is capable of providing a sustainable solution for major environmental problems, e.g., soil degradation, deforestation, desertification, CO_2 emission, indoor air pollution and so on (Minde *et al*., 2013) as well as various public health hazards in India. However, in the rural belt, failure in biogas plant operations are not entirely uncommon, primarily owing to various reasons, e.g., 'poor quality of construction and construction materials, non-availability of repair and maintenance services' (Jadhav *et al*., 2015). There is a need to focus on the safety and maintenance in the existence operations.

3.2.2 Indirect uses of bio gas

The generated biogas can further be utilised for generation of electricity. While the peak electrical power output is lower with CH_4-fuelling than with petrol (Jawurek *et al*., 1985), in regions where electricity generation is costlier for various reasons, e.g., unfavourable terrain and climatic conditions, logistic problems (e.g., hill areas), transportation issues (areas far away from refineries) etc., the former offers a viable alternative, given the adverse logistics costs associated with the alternatives. Under those circumstances, electricity generation from biogas is a cost-efficient option. The system works efficiently in several parts of the country as dairy-biogas-generator system is easy to install and maintain even in rural areas, provided care on certain aspects, e.g., adequate water supply, proper construction of the biogas plant, installing proper capacity of gas-holder in relation to gas usage etc. have been taken (IEI, 2012).

3.2.3 Co-benefits

Sludge generated by the biogas plant is rich in plant nutrients and hygienic for further use. Semi-liquid sludge can be dried and stored for future use as fertiliser. The biogas system has potential to mitigate methane emission which is a Green House Gas and having global warming potential 21 times higher than CO_2. Disposal of untreated sewage is one of the major causes of groundwater and surface water pollution. Unlike traditional sewage treatment plants, biogas plants do not need electricity and therefore it provides sustainable solution for sewage treatment even in remote areas, without access to power supply network. Given the fact that using biofuels for cooking is a major cause of indoor air pollution, causing serious health risks primarily to rural women and children (Sukhsohale *et al*., 2013), biogas is a safe and clean fuel and an alternative to LPG and PNG.

4. Present System of Human Waste Collection, Treatment and Disposal in India

Before going into the detailed description on the present system of sewerage collection, treatment and disposal in India, it would be worthwhile to explore the availability and access of latrine facility in India.

4.1 Availability and Type of Latrine Facility in India: Census of India - 2011

According to the Census of India (2011) figures, 53.08 percent households do not have latrine facility within their premises (Rural - 69.27 percent, Urban - 18.64 percent), of which 93.89 percent of households have no options but to go for open defecation (Table 5). Overall 49.84 percent of total households go for open defecation in India (Rural - 67.33 percent, Urban - 12.63 percent). Of those households who have latrine facility within the premises, only 77.63 percent have water closet latrine, 20.11 percent have pit latrine and the rest have other types of latrine. Depending on the system of latrine available for the households, the collection, treatment and disposal widely vary. Table 5 also displays that only 11.95 percent of total households

(Rural – 2.2 percent and Urban – 32.68 percent) in India are connected to piped sewer system. Therefore, access to centralised treatment and disposal facilities are available mainly for urban areas in India and that also for only one third of the total urban households in India. Therefore, need for investment in infrastructure for providing improved sanitation facility is huge and given the population growth rate, ever expanding (Mukherjee and Chakraborty, 2016). In addition to limited access to latrine facility, inadequate access to water supply forces people to go open defecation. In a recent survey, NSSO reports that only 42.5 percent of rural households and 87.9 percent urban household have access to water for use in toilets (NSSO, 2016).

Over the period, the Government have attempted to improve the current scenario by introducing a set of policies. First, through the Provision for Urban Amenities in Rural Areas (PURA) initiative since 2004 the Government attempted to ensure both livelihood opportunities and urban amenities to improve the quality of life in rural areas. A total of 500 projects were recommended for coverage during the 12^{th} Plan period under PURA grant scheme fund of Central Government (GoI, 2011a). The access to sanitation and waste disposal, in the rural areas, is one of the core objectives by the Government under this scheme. In fact as many diseases among the underprivileged might be a function of inadequate waste disposal, the success of schemes like National Rural Health Mission (NRHM) and National Urban Health Mission (NUHM) are also crucially dependent on these initiatives.

Second, the '*Nirmal Bharat Abhiyan*' (NBA) was launched from 2012 for accelerating sanitation coverage in rural areas. The initiative attempted to augment sustainable human waste disposal to by increasing the incentives for individual household latrines (IHHL) by linking the process with other ongoing programmes like Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), where creation of infrastructure through provision of 100-days of work to the rural population is being followed (GoI, 2014). There is considerable scope for utilising the MGNREGA provision for creation of sanitation infrastructure, especially by linking the same with the local state-specific initiatives (IIT, 2009). The 'Swachh Bharat Mission' (SBM) launched subsequently in 2014 takes these initiatives further, where in addition to creation of sanitation facilities for all, the need for solid and liquid waste management by the states through adoption of suitable and sustainable technologies would play a crucial role in coming days. The steps provide a unique opportunity for creation of a biogas generation facility in rural areas at village / bloc level, which will facilitate the aforesaid direct and indirect benefits. There is room to augment these initiatives in urban areas as well, with public-private-partnerships (PPPs) for efficiency and financial sustainability of the model. Moreover, awareness, voluntary involvement of stakeholders, and cumulative familiarity will be key to the success for these programmes, as evident from a survey conducted by the NSSO during May-June 2015 on 'Swachhta' in the country:

> '… out of 3,788 villages surveyed, 13.1 per cent villages in India were found to have community toilets. .. Out of the sample villages, at all India level, 1.7 per cent villages were found to be having the community toilets but not using them. 82.1 per cent of all the community toilets available in the villages were being used for defecation or washing purpose.' (PTI, 2016)

Table 5: Availability and Type of Latrine Facility in India: Census of India – 2011

Description	Total		Urban		Rural	
Population - 2011	1,210,193,422		377,105,760	[31.16]	833,087,662	[68.84]
Total Number of Households	246,692,667		78,865,937	[31.97]	167,826,730	[68.03]
Average Family Size (Number of Person)	4.91		4.78		4.96	
Households not having latrine facility within the premises	130,955,209	(53.08)	14,703,818	(18.64)	116,251,391	(69.27)
Of which						
Alternative source: Open defecation	*122,957,510*	*(49.84)*	*9,960,011*	*(12.63)*	*112,997,499*	*(67.33)*
Alternative source: Public latrine	*7,997,699*	*(3.24)*	*4,743,807*	*(6.02)*	*3,253,892*	*(1.94)*
Households having latrine facility within the premises	115,737,458	(46.92)	64,162,119	(81.36)	51,575,339	(30.73)
Distribution of Households by Type of Latrine Facility						
Water closet	89,852,052	(36.42)	57,235,228	(72.57)	32,616,824	(19.43)
Of which						
Flush/ pour latrine connected to septic tank	*54,758,885*	*(22.2)*	*30,087,437*	*(38.15)*	*24,671,448*	*(14.7)*
Flush/ pour latrine connected to piped sewer system	*29,471,391*	*(11.95)*	*25,775,247*	*(32.68)*	*3,696,144*	*(2.2)*
Flush/ pour latrine connected to other system	*5,621,776*	*(2.28)*	*1,372,544*	*(1.74)*	*4,249,232*	*(2.53)*
Pit latrine	23,279,128	(9.44)	5,597,143	(7.1)	17,681,985	(10.54)
Of which						
Pit latrine with slab/ventilated improved pit	*18,813,022*	*(7.63)*	*5,066,323*	*(6.42)*	*13,746,699*	*(8.19)*
Pit latrine without slab/open pit	*4,466,106*	*(1.81)*	*530,820*	*(0.67)*	*3,935,286*	*(2.34)*
Other latrine	2,606,278	(1.06)	1,329,748	(2.07)	1,276,530	(2.48)
Of which						
Night soil disposed into open drain	*1,314,652*	*(0.53)*	*942,643*	*(1.2)*	*372,009*	*(0.22)*
Service latrine - Night soil removed by human	*794,390*	*(0.32)*	*208,323*	*(0.26)*	*586,067*	*(0.35)*
Service latrine - Night soil serviced by animal	*497,236*	*(0.2)*	*178,782*	*(0.23)*	*318,454*	*(0.19)*

Notes: Figure in the parenthesis shows the percentage of total number of households by residence
Figure in the bracket shows the percentage of total population/ households
Source: Census of India - 2011

4.2 Conventional system of human waste collection, treatment and disposal in India

For households having water closet toilets and connected to sewerage network, wastewater is collected through pipelines and treatment is carried out in Sewage Treatment Plants (STPs) before it is disposed off to either on land for irrigation or into river. For households having water closet toilet with septic tank and other than connected to sewerage network, the sludge is collected once in two or three years (depending on the size of the septic tank) either by scavengers (manual collection) or through mechanical collection (suction through pipeline attached to pump and tanker) and collected sludge is carried through tankers (similar to water tanker / oil tanker) and disposed off into rivers or on land fill sites. Apart from removal of sludge from septic tanks, sludge is also collected from open well based latrine system and other service latrine systems on regular interval and disposed off on local drains or on land. The wastewater carried through open drains are often not treated and disposed off into water bodies. Open defecation and pit latrines are major threats for water pollution and pose severe public health hazards. In India each year a significant number of people and children die due to various water borne diseases e.g., cholera, typhoid, hepatitis, which can be curtailed by controlling sanitation loopholes.

4.2.1 Status of Wastewater Generation and Treatment in Metropolitan Cities, Class-I Cities and Class-II Towns in India

As per the data released by the Central Pollution Control Board (CPCB), only 32.49 percent of total sewage generated from Class I Cities (having population more than 0.1 million) is treated before their disposal into river or land for irrigation (Table 6). For Class II Towns (having population 0.05 to 0.1 million) only 8.67 percent of the total sewage generated is treated before disposal. Situation is much worse in other urban agglomeration of smaller sizes. In addition, even when the municipalities undertake large investments in sanitation infrastructure, the intended benefits may not follow due to improper planning, involvement of multiple agencies, ad-hoc selection of technologies without keeping the location-specific characteristics into consideration etc. (GoI, 2008).

Table 6: Status of Wastewater Generation and Treatment Capacity in Class I Cities and Class II Towns in India: 2009

Cities Category	Numbers	Population	Sewage Generation (in million litre daily, mld)	Sewage Treatment capacity (in mld)	Sewage Treatment capacity as Percentage of Sewage Generation
Metropolitan Cities (having population more than 1 million)	35		15,644	8,040	51.39
Class I Cities (having population more than 0.1 million) (includes Metros)	498	22,76,82,872	35,558.12	11,553.68	32.49
Class Ii Towns (having population 0.05 to 0.1 million)	410	3,00,18,398	2,696.70	233.7	8.67

Source: CPCB (2009)

Recognising the nature of the problem, Sulabh (undated) noted that:

> 'In India out of about 4700 towns / cities, only 232 have the sewerage system, and that too only partial. Most of the untreated waste water is, therefore, discharged into rivers or other water bodies. In rural areas it is a common practice to discharge waste water/sullage without collection. There is no question of treatment/recycle or even reuse of waste water/sullage as people are not aware of this technology.'

IEA (2015) reported that generation of urban energy from municipal waste, which is a simultaneous outcome of the rise in India's cities, is still underutilised, as only 20 percent of the total urban wastewater is currently being treated.

4.3 What is the status of technology adoption in human waste treatment in India?

In India, the sewerage collected through sewerage channels are treated at the Sewage Treatment Plants (STPs). For example, following are the technologies adopted under Ganga Action Plan (GAP) for treatment of sewerage. Table 7 shows that Activated Sludge Process (ASP) is the predominant technique for water treatment (shares 57.63 percent of installed capacity), followed by Trickling Filter (TF, 15.25 percent) and Oxidation Pond (OP, 15.22 percent).

Table 7: Treatment Technology Adopted Under Ganga Action Plan

Treatment Technology	Total Number	Treatment Capacity (in mld)	Percentage of Total Treatment Capacity (%)
Oxidation Pond (OP)	11	134.04	15.22
Activated Sludge Process (ASP)	12	507.5	57.63
Trickling Filter (TF)	5	134.26	15.25
Rotating Biological Rope Contractor (RBRC)	1	0.33	0.04
Up Flow Anaerobic Sludge Blanket (UASB)	3	55	6.25
Aerated Lagoon (AL)	3	49.5	5.62
Total	35	880.63	100.00

Source: CPCB (undated)

The treated sewage is disposed off into rivers and/ or land for irrigation. The sludge is generally dumped into land fill sites or agricultural land, thereby working as a natural nutrient (Ayub and Khan, 2011).

4.4 Natural system

In developing countries and LDCs, traditionally wetlands are used as decentralised wastewater treatment system in rural and semi urban areas. Wastewater and sewage generated from human settlements flows to wetlands through gravity and there aerobic biological organisms break down organic material (pollutants) and cleanse the wastewater. Presence of various aquatic plants and microorganisms accelerates the process of bio-degradation. Due to their enriched nutrient contents, these wetlands are often used as source for irrigation, fish farming, duck keeping and as recreation purposes. The East Calcutta Wetlands is an example in the context. The wetlands cover 125 square kilometers, and include salt marshes and salt meadows, as well as sewage farms and settling ponds. The wetlands are used to treat Kolkata's sewage, and the nutrients contained in the waste water sustain fish farms and agriculture (Ghosh, 2005).

5. Past Initiatives for Recovery of Energy from Human Waste in India – a failure story

5.1 Initiatives taken under the Ganga Action Plan (GAP)

The GAP was launched in 1985 for abating pollution and improving water quality, through 261 schemes spread over 25 Class I towns of UP, Bihar and West Bengal. The operation focused on interception and diversion and treatment of sewage generated in these three states and '34 Sewage Treatment Plants (STPs) with a treatment capacity of 869 mld have been set up under the Plan' (GoI, 2009).

While the extent of the achievements under this plan has been debated, it needs to be recognised that GAP has indeed contributed towards improving the environmental sustainability and lowering the extent of water pollution. GoI (2009) summarises the achievements under this initiative as the following:

> 'Despite the problems of operation and maintenance, river water quality has shown discernible improvement (in terms of DO and BOD) over the pre-GAP period. This has to be seen in the background of a steep increase in population with concomitant increase in organic pollution load. In the absence of Ganga Action Plan, there would have been further deterioration in these parameters… The high BOD values in some of the towns are attributed to increased population and partial interception and diversion under GAP schemes.'

The observed failure or put mildly, underperformance of the GAP, can be attributed to several factors. First, the scheme focuses only on the wastewater of towns flowing through the drains to Ganga, but not the waste flowing from the sewer system or other similar activities adversely affecting the water quality. The modest outlook naturally affected the final output, underscoring the efforts (GoI, 2009). Second, the tree cover in the Ganga basin has been depleted significantly over the last two decades owing to conversion of lands to roads, agricultural fields, venues for residential and commercial operations etc., which has in long run led to soil erosion, and in turn increased sedimentation and deposit on the river bed (GoI, 2009). Third, the pollution load from non-point sources, a major determinant of water pollution, has not been considered in the scheme (Das and Tamminga, 2012). Fourth, the run-off from agricultural fields, which carried non-biodegradable pesticides into Ganga was not included in the mandate (GoI, 2009). Fifth, inadequate sustainable urbanisation planning and check on industrial pollution led to extra pollution load with creation of every new settlement or expansion of the existing centres along the river (CSE, 2013; GoI, 2009). Sixth, while the Class-I towns on the banks of Ganga was monitored, smaller cities as well as rural areas were not considered, as a result of which a large chunk of pollutants were never adequately covered under the scheme (GoI, 2009). The problem was compounded by the inefficient management reflected through underutilisation of treatment plants in several cities along the river (CSE, 2013). Also technical and electrical faults plague the STPs (CPCB, undated). Seventh, a number of parameters such as heavy metals, pesticides, nitrogen and phosphorous were kept outside of monitoring schedule, which cumulatively crated a major adverse effect on the water quality of the river (GoI, 2009). Finally, it is a well-known fact that, 'Rivers without water are drains', but limited effort has been made to discipline the indiscriminate pulling of water from the river for irrigation and drinking purposes (CSE, 2013). The reduced flow led to further deposition of the slit and other harmful chemical compounds, which aggravated the scenario and undervalued the GAP efforts.

5.2 Other Initiatives

The Sulabh International Social Service Organisation has contributed significantly by recycling the human waste into biogas through an efficient plant model from their public toilet complexes, which has been approved by the Ministry of Non-conventional Energy Sources (Sulabh, undated). It has constructed, '200 biogas plants of 35 to 60 cum capacity', spread across the country. The Sulabh model ensures automatic collection of the human waste from the public toilets, which leads to production of one cubic foot biogas from human excreta per person per day in the designated chamber. The biogas thus generated by Sulabh is widely utilised for cooking, lighting through mantle lamps, electricity generation and so on.

It has also contributed significantly by coming out with duckweed-based cost-effective waste water treatment in rural and urban areas, through financial and regulatory supports from Ministry of Environment & Forests, Government of India and Central Pollution Control Board. Taking note of the success, Sulabh (undated) noted that:

> 'Although duckweed is found in ponds and ditches, due to almost complete absence of any know-how of this technology in the country, the potential of duckweed for the waste water treatment, its nutrient value and economic benefits have not been fully exploited… (duckweed-based plant) has great ability to reduce the BOD, COD, suspended solids, bacterial and other pathogens from waste water. Reduction of BOD, COD in effluents varies from 80-90% at the retention time of 7-8 days.'

Jha (undated) praised the Sulabh Biogas plant Effluent Treatment (SET) for its cost efficiency, wastewater generation capacity (maximum 5000 lts per day), no need for manual handing, aesthetic acceptability, technical and financial viability due to very low operational and maintenance expenses, ecological sustainability etc. However, acceptance of the generated biogas still suffers from perceptional (reluctance due to perceived threat on hygiene, non-use during cooking for any religious occasions etc.) sentiments.

In addition, of late, individual players have shown increasing inclination to secure efficient waste management and contribute in the NBA process. For instance, the initiative undertaken by the Sanawar School in Shimla deserves mention, where the wastewater treatment have made the institute water surplus (The Alternative, 2013). Another example is the commissioning by The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Germany (BMUB) of *Waste to Energy Project* in Nashik, Maharashtra that generates 2,100 cubic meter biogas daily from 10-15 tonne municipal solid (bio-degradable) waste and 10-20 tonne fresh septage from community toilets (GIZ *et al*., 2014). The biogas is used to generate electricity (3200 kWh daily) which is given to the Nashik Municipal Corporation. In addition, the project generates daily 1.5 to 2 tonne sludge (manure) and 25-30 tonne treated effluent which is further used for aerobic composting process.

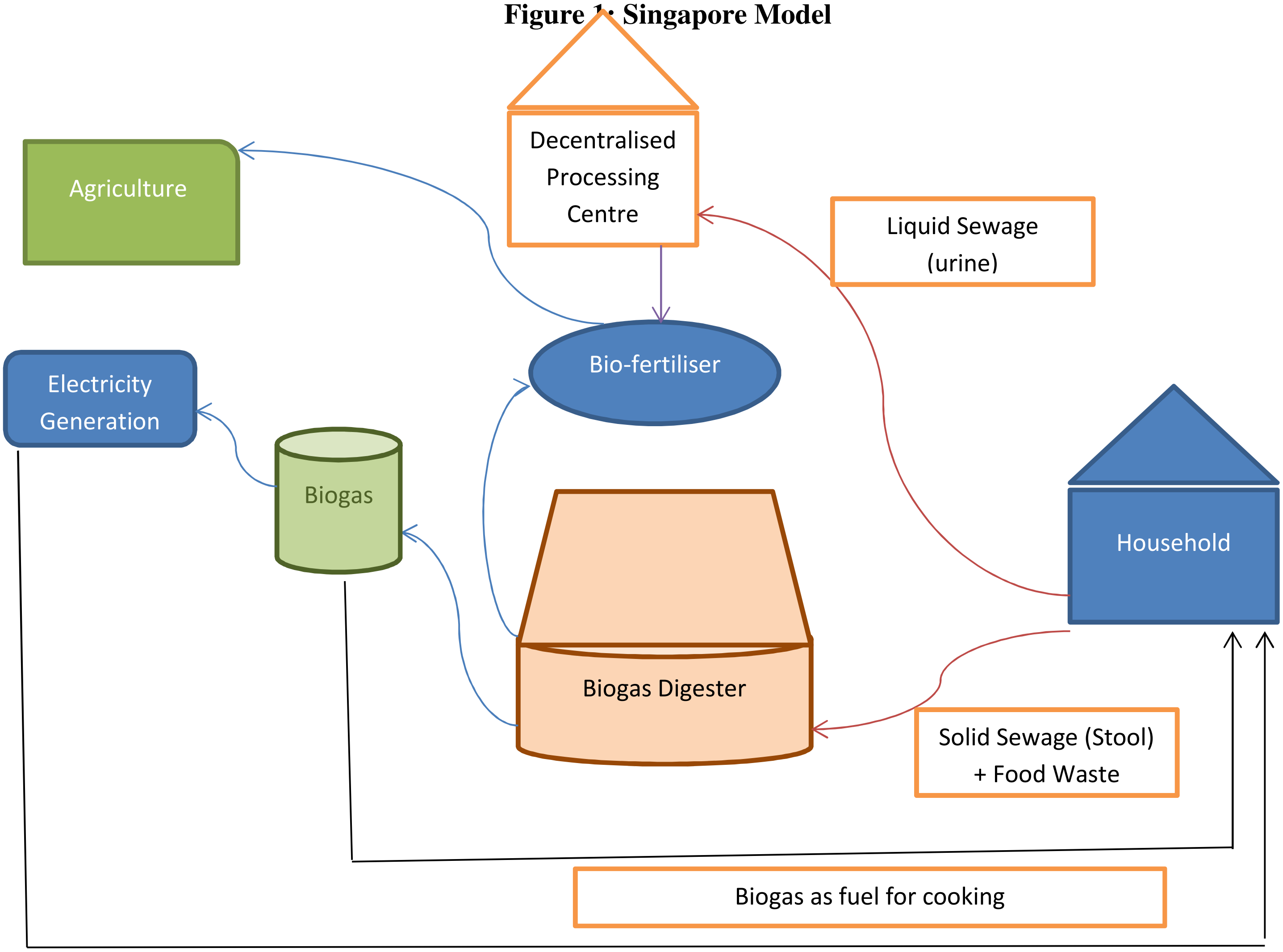
In 2008-09, Ministry of New and renewable Energy (MNRE) initiated installation of medium size mixed feed biogas plants for generation, purification and bottling of biogas with active participation of private individual (entrepreneurs) (MNRE, undated). At present, there are 11 biogas bottling projects of various capacities (varying from 500 m3/day to 20,000 m3/day, or 200 kg/day to 8,000 kg/day) have received central financial assistance for production of compressed biogas (CBG) in CNG cylinders. It shows that for a typical biogas bottling project of 1000 m3/day capacity, payback period will be 5-6 years without subsidy and 3-4 years with subsidy.

6. What kind of alternative system the present study is proposing?

Given the nature of feed stock used in the biogas plant, process of drying /enriching the solid content of sewage and end use, there are several alternative technologies available for human waste based biogas system.

In Figure 1, the flow diagram of the Singapore Model has been provided, as developed by Residues and Resource Reclamation Centre (R3C) at Nanynag Technological University (NTU), Singapore. In this technology "No-Mix Vacuum' toilet collects liquid from solid wastes separately. The solid waste along with kitchen waste is sent to bioreactor / biogas digester for biogas generation. The biogas is collected and used as cooking fuel. The demerits of the technology is that it requires complete revamping of the present sewage collection system where both solid, liquid and along with washing water is collected and transported to either safety tank or centralised sewage channel. The cost of investment in vacuum toilet and pipelines could be substantial.

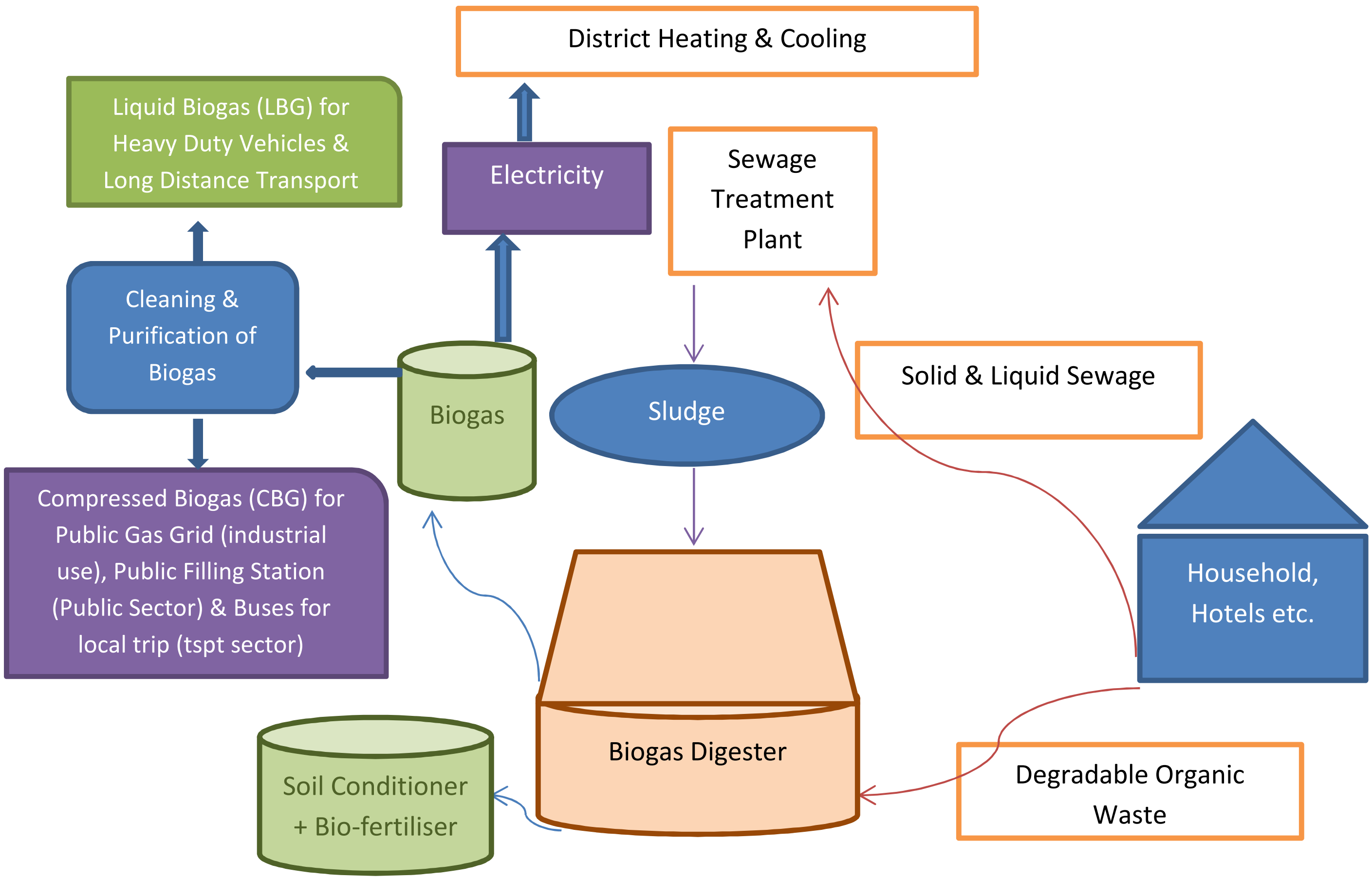
Figure 1: Singapore Model



Source: Computed

In the second technology, which is prevalent in many cities in Sweden, both solid and liquid waste from toilet is collected and go to STPs for initial treatments. The solid sludge generated in STPs along degradable organic waste from households are fed to biogas digester for biogas generation. The biogas is used to generate electricity and also after cleaning and purification as Compressed Bio-Gas (CBG) for industrial and public transport use and Liquefied Bio-gas (LBG) as heavy duty vehicles. Demerits of this technology is that it requires STPs for initial treatment which may not be feasible in rural areas due to low population density, non-existence of infrastructure for sewage collection and adequate logistic arrangements for transportation to STPs.

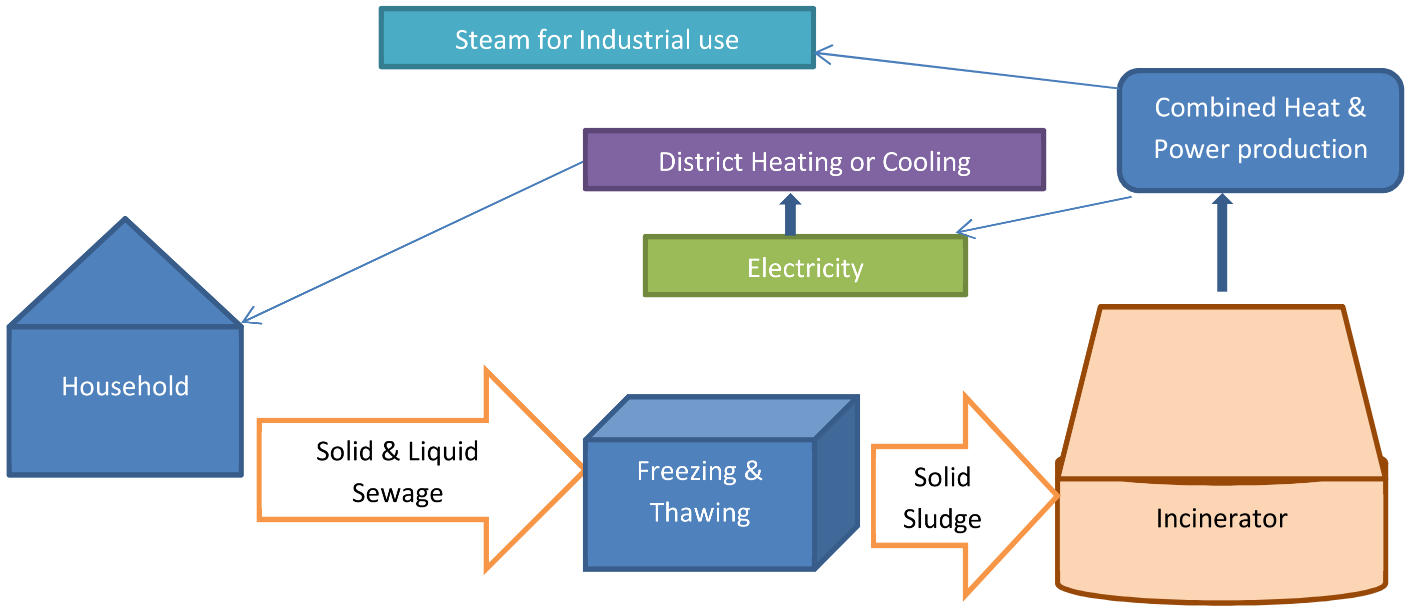
Figure 2: Swedish Model – I: Biogas (through digester)



Source: Computed

The third technology is in line with Rostmark and Oberg (2013) where both liquid and soil waste from toilets go through freezing and thawing process for condensation before it is incinerated to generated combined heat and power. Generated electricity is used for district heating and cooling and steam is supplied for industrial use. The demerit of this technology is that it requires freezing and thawing of sewage before it is incinerated. The process is costly for temperate climate regions like India.

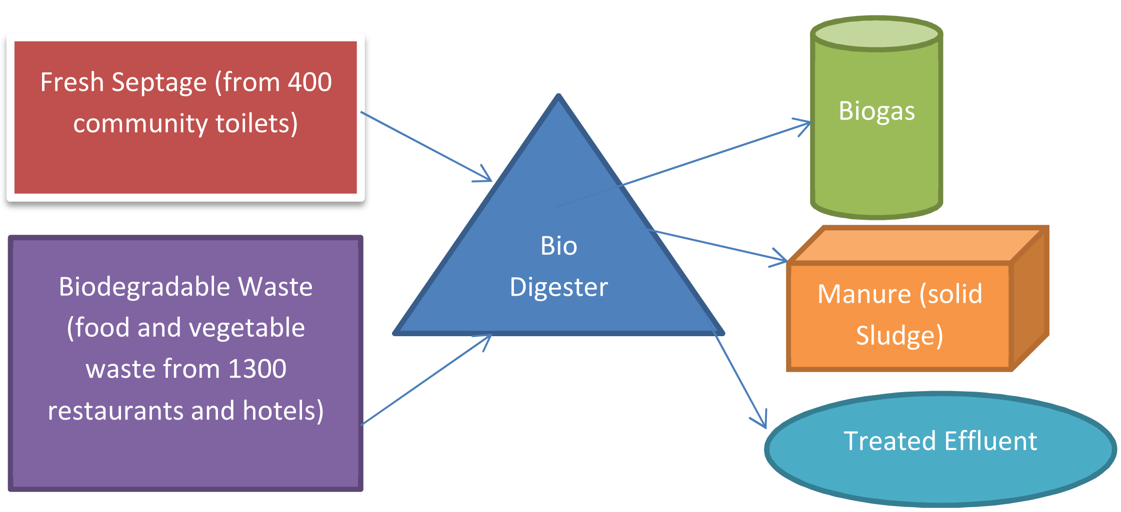
Figure 3: Swedish Model II - Incineration after Freezing and Thawing



Source: Computed

Figure 4 shows the operation of the Nashik model, which is a proven technology for India. This process does not require separation of solid from liquid waste as well as pre-treatment of sewage in STPs. As a result, it can provide a cost-efficient solution to be replicated in various parts of the country.

Figure 4: Waste to Energy – Nashik Model



Source: Computed

8. Policy Suggestions

India today is faced with multilayered problems. On one hand, it has been noted that a sizable section of people in India (like several other developing countries and LDCs in South Asia and Africa) still lack improved sanitation facilities, and have to defecate openly (World Bank, 2014). On the other hand, the country increasingly faces a major challenge to secure energy security, as with rising level of development, the demand for energy products simultaneously goes up (TERI, 2010). Finally, given the level of environmental challenges in the country, to which the inadequate waste disposal mechanism significantly contributes, adds the exposure of people to various water and air borne diseases leading often to under-productivity and even deaths (von Medeazza and Chambers, 2013).

As an option to reduce dependence imported hydrocarbon and address public health concenrs, the analysis so far clearly indicates that the possibility of generating biogas from human waste provides the country a unique opportunity to address the emerging energy security challenges and convert them into prospects. However, for that potential to be realised there is urgent need for ensuring policy convergence among existing government schemes, e.g., NBA, SBM, NRHM, NUHM, PURA, the relevant Missions under the Ministry of New and Renewable Energy, GAP, and so on. For instance, creation of improved sanitation facilities and efficient waste collection mechanism under NBA, SBM and PURA can be integrated with the objectives of biogas generation as expressed under *The National Renewable Energy Act* (GoI, 2015b) and the similar programmes. There is also need for greater coordination and concerted policymaking among the agencies in charge of these Missions. Once these linkages are established, it will be possible for the country to enjoy the scale as well as scope benefits of the integrated framework.

One major challenge facing the system is the possible financing of the human waste based biogas plants, as it involves a significant set-up cost. The first possible route for financing the initiative is through the National Clean Energy Fund (NCEF). A dedicated corpus fund has been created since 2010-11 by levying a Clean Environment Cess (earlier used to know as Clean Energy Cess) on both domestic and imported coal for supporting research and innovative projects in the field of clean energy technology. As on 2014-15, the reported accumulated corpus fund has reached Rs. 16,388.81 crore. In the guidelines for appraisal and approval of projects / schemes eligible for financing under the National Clean Energy Fund, it is mentioned that, 'Any project/scheme relating to Innovative methods to adopt to Clean Energy technology and Research & Development shall be eligible for funding under the NCEF (GoI, 2011b)'. Therefore, the initiatives with a technically and economically feasible model, that is self-sustainable in long run, may get benefited from this route.

Second, under the SBM launched on 2 October 2014, the Prime Minister clearly underlined the need for improving sanitation and cleanliness across the country, especially in rural India. The Mission also aims to improve Solid and Liquid Waste Management (SLWM) in Gram Panchayats. In the Union Budget 2016-17, the Finance Minister has announced that a policy for conversion of city waste into compost has also been approved by the Government under the Swachh Bharat Abhiyan (SBA), for which Rs. 11,300 crore has been allocated. The Government has also introduced a Swachch Bharat Cess of 0.5 percent on all services and it is expected that in future allocation under SBA will go up. As the collection and treatment of human waste are integrated, the initiative is expected to ensure the critical minimum input load for the biogas plants both in rural and urban area.

Third, the National Mission for Clean Ganga (NMCG) under Ministry of Water Resource, River Development and Ganga Rejuvenation aims to: (1) ensure effective abatement of pollution and rejuvenation of the river Ganga by adopting a river basin approach to promote inter-sectoral co-ordination for comprehensive planning and management, and (2) to maintain minimum ecological flows in the river Ganga with the aim of ensuring water quality and environmentally sustainable development (GoI, undated). Since disposal of sewage is one of the major reasons for deteriorating water quality of the river Ganga, it is likely that financing combined sewage treatment and biogas plant would be the priority of the mission. In Union Budget 2016-17, an amount of Rs. 2250 has been allocated for NMCG, which is likely to improve the future scenario.

Last but not the least, given the huge financing requirement and the competing demand on Government funds, there is need to promote participation from the private sector in line with the Sulabh experience, which will crucially contribute in betterment of the scenario. In addition, technological and advisory supports from foreign donor bodies as well as civil society organisations, as witnessed from the collaboration between GIZ and Nashik Corporation, should be encouraged.

Since the proposed system has distinct benefits to achieve Sustainable Development Goals (SDGs), the projects may be eligible for financing under Sustainable Development Finance (FICCI and UNEP, 2016).

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