BIO-CNG FROM MUNICIPAL SOLID WASTE

A Pathway for Sustainable Waste Management and Green Energy

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Maps used in this document are not to scale.

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INTRODUCTION

Bio-CNG, a clean and renewable source of energy, is produced through anaerobic digestion of organic waste. It can be used as fuel in vehicles and in industrial applications; for cooking; and could be a means for mitigating climate change. By transforming organic waste into Bio-CNG, waste disposal challenges can be addressed.

Organic waste constitutes 40-60 per cent of the total municipal solid waste generated in India; there exists, thus, a huge potential for producing Bio-CNG. But the production, use and efficiency of Bio-CNG is dependent on effective segregation of waste – which remains low in India.

Organic waste is processed either through composting or biomethanation (anaerobic method which produces Bio-CNG). Composting dominates the sector, Biomethanation is underutilised: of the 1,18,612 tonne per day capacity for organic waste processing, only 4,360 is for biomethanation.

What is needed is improved infrastructure, effective segregation practices, and policy support. Scaling up Bio-CNG technology can enhance sustainable waste management practices and facilitate a shift toward a circular economy.

Municipal Solid Waste (MSW) management has become a critical issue for urban India. With rapid urbanisation and galloping consumption patterns, the volume of waste generated in Indian cities has increased significantly. As of August 2024, according to the Swachh Bharat Mission (SBM) dashboard, urban India generates approximately 0.15 million tonne of of MSW daily, with organic waste constituting about 40-60 per cent of the total waste stream.[1]

The country's existing waste management infrastructure is inadequate to handle this volume effectively, leading to various environmental and health challenges. Traditional waste disposal methods such as open dumping dominate the waste management landscape in India. This methods are associated with severe environmental impacts, including greenhouse gas (GHG) emissions. Dumpsites are a key source of methane, which is a potent GHG with a global warming potential that is 28-36 times that of carbon dioxide over a 100-year period.

Mismanagement of waste, including poor segregation practices, exacerbates the problem. The SBM dashboard data indicates that an estimated 82 per cent of the generated waste in urban areas is treated scientifically, while the remaining is left unprocessed – the last Swachh Surveskshan survey has revealed below par performance in waste processing.[2]

Segregation of waste at source remains a challenge. Despite various government initiatives and awareness campaigns, only a small fraction of urban households practice effective waste segregation. In fact, the lack of proper segregation becomes a key hindrance in putting into operation pathways such as the use of Bio-CNG in sustainable waste management.

What is Bio-CNG?

Bio-CNG offers a promising solution for both waste management and renewable energy production. Bio-CNG is produced by anaerobically digesting organic waste, transforming it into a clean and renewable energy source. The process involves segregating and pre-treating organic waste, followed by biogas generation, purification, and compression into Bio-CNG.

Bio-CNG can find potential use as fuel in vehicles, for cooking, and in industrial applications. By transforming municipal solid waste (MSW) into Bio-CNG, waste disposal challenges may be addressed. There are also additional co-benefits of reducing fossil fuel dependence and mitigating climate change. Studies suggest that the total upstream GHG emission savings from a one-tonne Bio-CNG plant is 40,926 kg CO_2eq.[3]

But despite all this potential, the adoption of Bio-CNG technology in India has not happened at scale. The current infrastructure for processing organic waste into Bio-CNG is limited, with only a few operational plants across the country. These plants often face challenges related to segregated feedstock supply, contamination and technological inefficiencies.

This study aims to explore the Bio-CNG sector in India – especially with reference to its production from MSW. It provides an overview of the current state of MSW management, assesses the potential for Bio-CNG production, and examines the technological, financial and regulatory aspects of Bio-CNG projects in the country. The study also analyses case studies of operational plants, identifies their key challenges, and proposes recommendations for scaling up Bio-CNG production.

Managing wet (organic) waste

Two commonly used methods for processing wet biodegradable waste are composting and biomethanation.

Aerobic method – composting

Composting is a traditional and widely adopted technique for processing wet waste. It involves the breakdown of organic materials by naturally occurring microorganisms in the presence of oxygen, under controlled temperature and moisture conditions. Composting can be applied at various scales, from household-level to large-scale plants. The time required for composting varies by region, with higher temperatures generally reducing the process duration. The end product, compost, serves as an excellent organic fertiliser.

Composting is the predominantly practised method across urban local bodies (ULBs); it is especially popular with smaller ULBs generating up to five tonne per day (TPD) of waste as it requires minimal infrastructure and is easier to manage. But it becomes a challenge for ULBs processing between 50 to 1,000 TPD of waste: in these cities, besides infrastructure and space constraints, the compost produced seems to have low market value, and does not contribute to operational cost recovery.

Anaerobic method – biomethanation

Biomethanation is another technically viable option for processing wet waste. It involves the anaerobic fermentation of organic materials in the absence of oxygen, with controlled temperature, moisture and pH levels. The process includes sequential microbial activities: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The end products are biogas and digestate or fermented organic manure (FOM). Biomethanation is suitable for both small- and large-scale plants, depending on the amount of waste generated.

Composting vs biomethanation

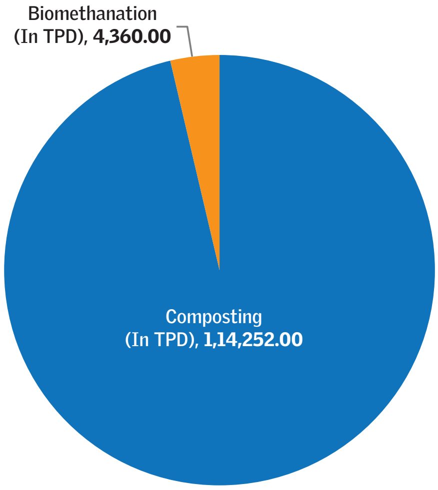
Comparatively speaking, composting is the more widely accepted method across the country because of its ease of handling and simpler processes. According to the Ministry of Housing and Urban Affairs (MoHUA) dashboard, India generates approximately 75,706 tonnes of organic waste per day.[4] However, there are only 2,586 treatment plants across 4,900 Urban Local Bodies (ULBs).[5] The total reported capacity for wet waste processing stands at 1,18,612 TPD, with composting plants accounting for 1,14,252 TPD and biomethanation plants handling only 4,360 TPD (*see Graph 1*). The data also indicates a strong preference for composting over bio-CNG or bio methanation solutions.

Interestingly, despite nearly 50% of ULBs lacking proper treatment facilities, the reported wet waste processing capacity appears to be overestimated. This suggests either inflated capacity figures, inefficient plant operations, or potential underutilization of existing facilities.

Biomethanation requires less space and time, but is costlier than composting. It is less labor-intensive, as it relies on automated technology and skilled humanpower. The by-products – biogas digestate or fermented organic manure – have high market value, allowing for operational cost recovery and profit generation.

Graph 1: Capacity-wise distribution of composting and biomethanation

Composting is the more widely accepted method across the country



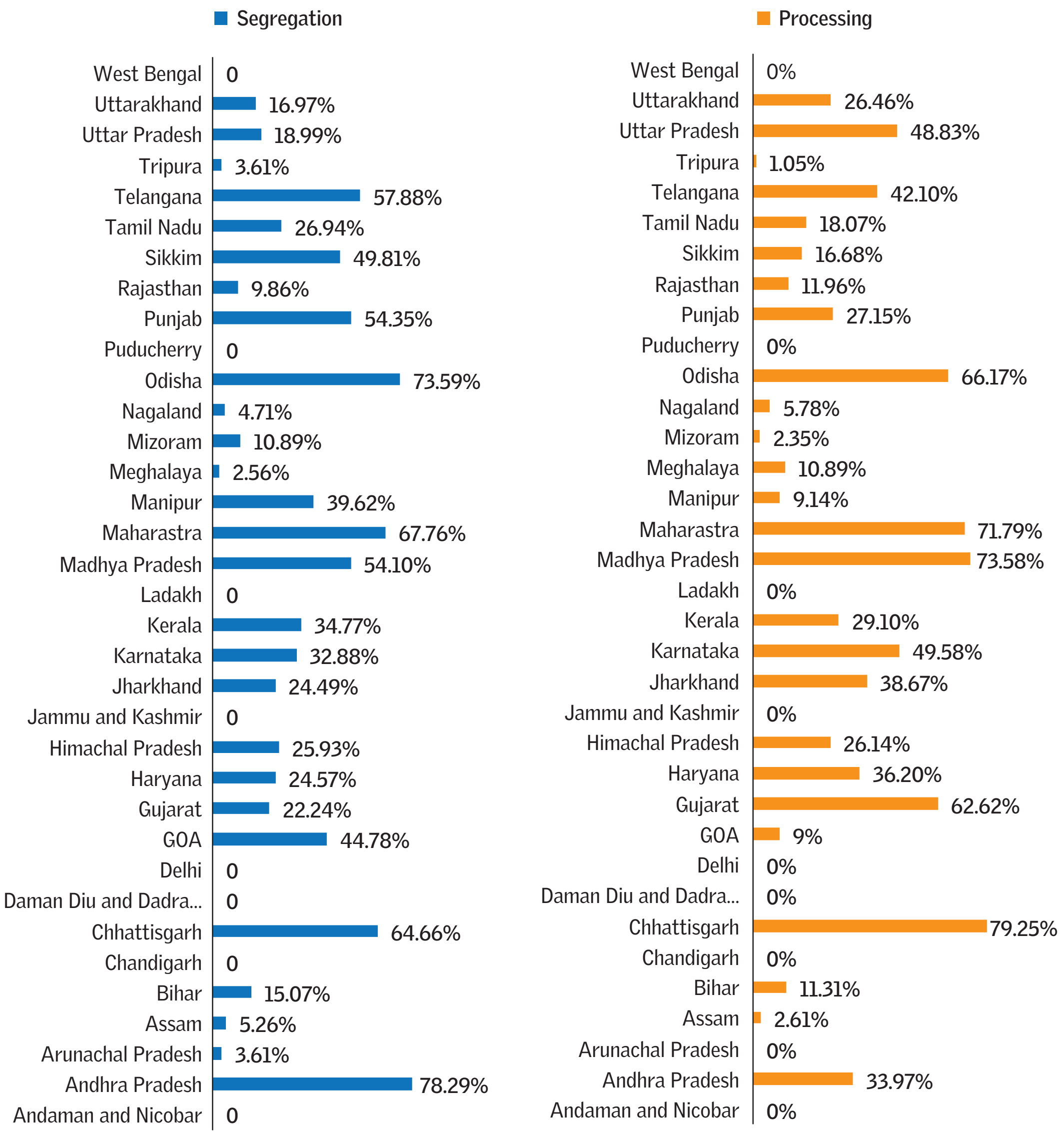
Source: SBM dashboard access at https://sbmurban.org/swachh-bharat-mission-progess

Segregation and processing of waste

It is clear that there is an urgent need for improved infrastructure, technology adoption, and better waste segregation practices to effectively manage and utilise municipal organic waste. Effective segregation is crucial for the success of any waste processing technology – especially so for Bio-CNG, which requires over 90 per cent segregation of municipal organic waste.

Graph 2: State-wise segregation and processing

Most states and Union territories are found wanting on these scores



Source: Swachh Survekshan 2023

The Swachh Survekshan 2023 results have shown that only Andhra Pradesh and Odisha have achieved more than 70 per cent segregation. States and Union territories such as Andaman and Nicobar Islands, Arunachal Pradesh, Chandigarh, Delhi, Jammu and Kashmir, Ladakh, Puducherry and West Bengal either did not participate in the Survekshan 2023 survey, or reported no significant processing (*see Graph 2*).[6]

The data also indicates that cities that do have access to technology, continue to struggle with effective processing of their waste. According to the Survekshan 2023 report, many cities have claimed high processing rates, but often these do not reflect the reality on the ground.

2

BIO-CNG FROM MSW: POTENTIAL AND CURRENT STATUS

India has a potential to generate 2,523 tonne per day (TPD) of Bio-CNG from municipal waste. But current production is a mere 46 TPD. CSE researchers estimate that India manages to generate just 1.82 per cent of its total Bio-CNG potential from municipal solid waste.

Cities generating over 500 TPD of waste have the highest potential for producing Bio-CNG – they should be prioritised for installing Bio-CNG projects.

At least 60 tonne of municipal solid waste is needed to produce every two tonne of Bio-CNG, ensuring sustainability and energy production at scale. The yield of Bio-CNG depends on the quality and composition of the waste, which can vary widely.

States like Madhya Pradesh and Maharashtra are the biggest contributers to Bio-CNG production, while others – such as Uttar Pradesh, Delhi and West Bengal – have shown very little progress despite holding high potential.

Traditionally, in relatively larger cities where generation of biodegradable waste is more than 100 tonne per day (TPD), composting as a method of treatment has not been very successful. There are multiple factors that are responsible for this. In most of the cases, there is only one option for managing such large quantities of wet organic waste: windrow composting. This process requires a lot of space,

Figure 1: Roles and responsibilities of various ministries

Source: Combined from different Ministry initiatives heavy earth equipment, under-the-shed facility and regular monitoring; most importantly, the final product struggles to find a market. Therefore, both from technological and economic point of view, composting has proven to be a relatively difficult option for bigger cities.

Compared to this, cities that have adopted biomethanation have had multiple benefits. The final product in this process – biogas or Bio-CNG – has a lot more potential for marketability. Bio-CNG requires less space and goes through a built-in protocol for monitoring. Apart from the gas, it also generates FOM (fermented organic manure) as a by-product.

The support and incentives offered by the government through initiatives such as GOBARDhan under the Swachh Bharat Gramin programme (*see Figure 1*) are helping propel the adaption of biomethanation. Under the GOBARDhan scheme, an allocation of Rs 10,000 crore has been made in 2023-24 for establishing 200 compressed biogas (CBG) plants, in which 75 is to be setup in Urban area and 300 community and cluster plants.[7]

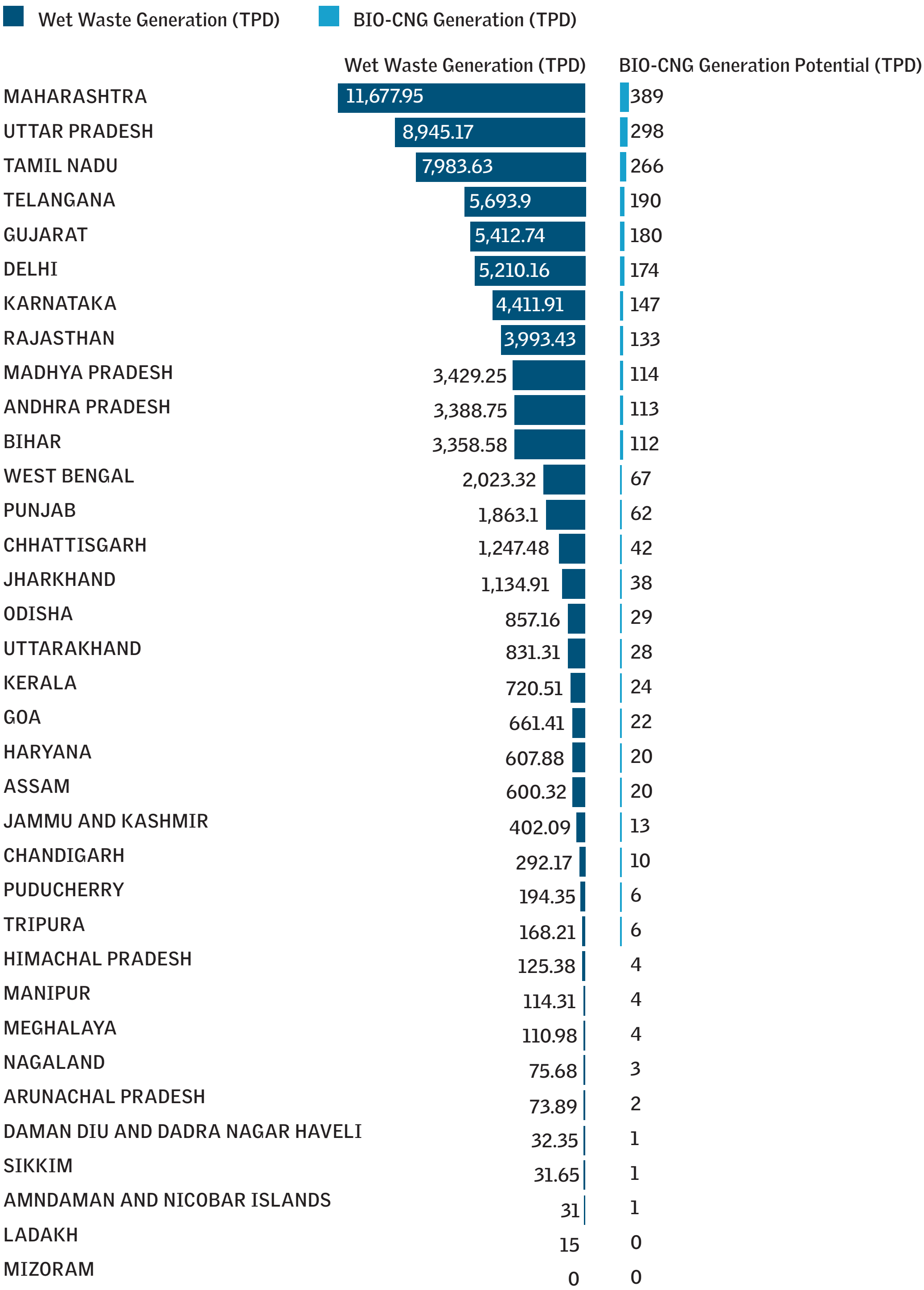
As per the yield estimates of CBG production from different waste sources under the SATAT initiative (a scheme for promotion of compressed biogas)[8], municipal solid waste is considered to have a higher yield compared to cow dung, press mud and chicken litter for the same quantity of input. However, the actual yield of MSW may vary significantly depending on the quality of the feedstock. Given the heterogeneity of wet organic MSW, its biogas yield would depend on the specific characteristics of the waste.

According to data from SATAT, 20 tonne of feedstock is required to generate one tonne of Bio-CNG from segregated organic waste. Data from plants that are operational, however, puts the feedstock need at 25-30 tonne. Based on this, the CSE research team estimates that urban India can generate about 2,523 TPD of Bio-CNG, with Maharashtra holding the biggest potential (*see Graph 3*).

In terms of actual realization, data from operational plants indicates that only 46 TPD capacity of Bio-CNG plant based on segregated municpal solid waste has been installed across the country – Madhya Pradesh has the maximum contribution of 17.7 TPD (*see Graph 4*).[9] States which have huge potential for generating Bio-CNG from MSW – like Uttar Pradesh, Delhi, Telangana, West Bengal, Rajasthan, Haryana and Bihar – have not shown any progress on setting up any plants. CSE researchers estimate from these figures that India manages to generate just 1.82 per cent of its total Bio-CNG potential from municipal solid waste.

Graph 3: State-wise wet organic waste generation per day and Bio-CNG potential

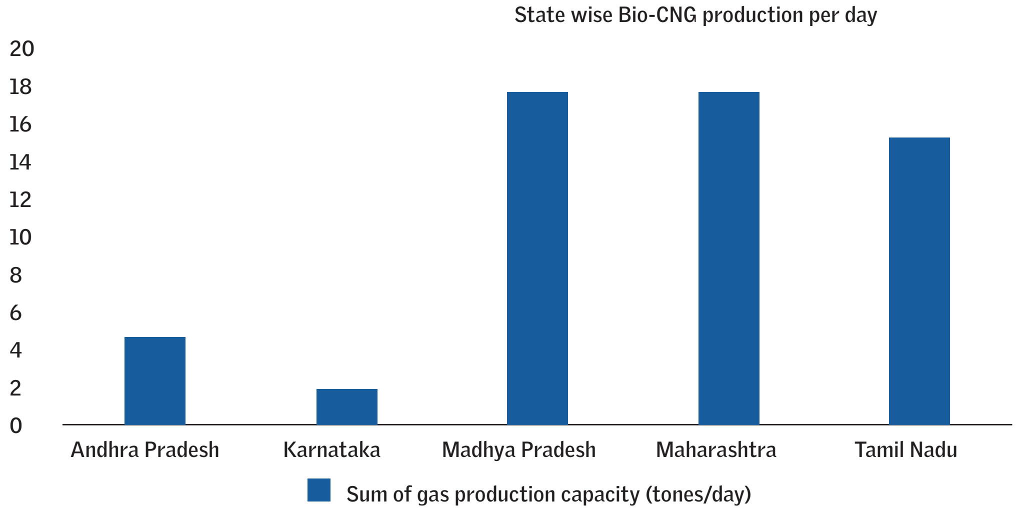
Maharashtra seems to be heading the chart



Source: Calculated by CSE

Graph 4: State-wise Bio-CNG installed capacity (daily) from municipal solid waste

Madhya Pradesh is producing the most



Source: https://gobardhan.co.in/

To achieve the target of installing 75 Bio-CNG plants across the country, cities have been grouped into four categories depending on the wet waste being generated by them (*see Table 1*). As the table shows, Bio-CNG generation potential increases as we move from Category I to Category IV. The highest potential is observed in cities under Category IV, generating over 500 TPD of waste which includes Delhi, Ahmedabad, Surat, Greater Mumbai, Chennai etc . The potential, of course, is more as cities in states like West Bengal have not updated their data in the SBM portal.

This indicates that there lies a considerable opportunity for putting in place Bio-CNG plants in these cities to utilise segregated wet municipal waste, and producing renewable energy in the form of compressed natural gas. Category IV cities should be prioritised while planning as the primary targets for establishing large-scale Bio-CNG plants, after ensuring that the requisite collection and source segregation systems are in place.

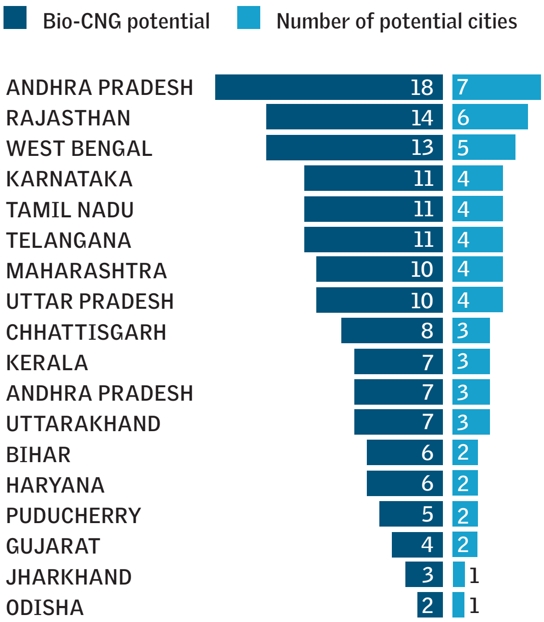
Table 1: Category wise waste city distribution and Bio-CNG potential

Categories	Wet waste generation per city (tonne per day, or TPD)	Number of cities	Total wet waste generation (TPD)	Total Bio-CNG potential (TPD)
Category-I	50-100	60	4,616	154
Category-II	100-250	61	9,623	321
Category-III	250-500	27	9,619	320
Category-IV	Above 500	17	27,626	920
Total		**165**	**51,484**	**1,715**

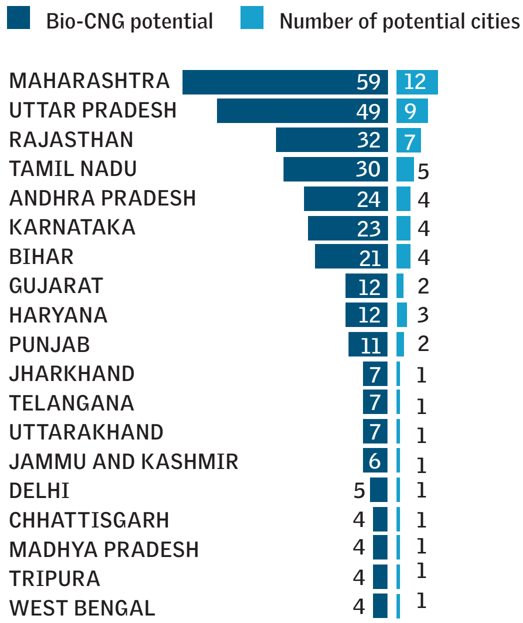
Source: Analysis based on data available on SBM portal

Graphs 5 a-d: State-wise generation by different categories of cities and their Bio-CNG potential

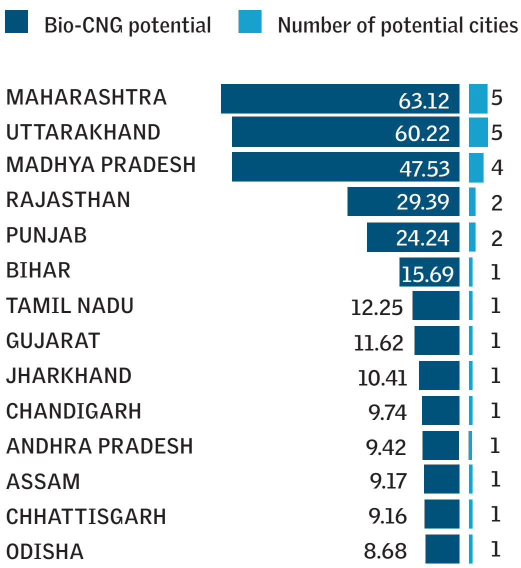
A: State wise number of city having wet waste generation between 60-100 TPD and their Bio-CNG potential



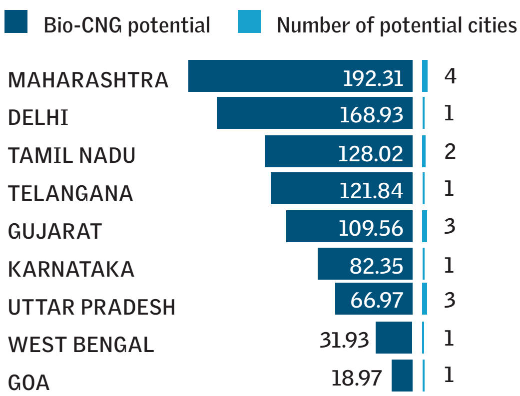
B: State wise number of city having wet waste generation between 100-250 TPD and their Bio-CNG potential



C: State wise number of city having 250-500 TPD daily wet waste generation and their Bio-CNG potential



D: State wise number of city having greater than 500 TPD daily wet waste generation and their Bio-CNG potential



Source: Calculated by CSE, 2024

3

BIO-CNG GENERATION AND BY-PRODUCT UTILISATION: THE PROCESS

To process biodegradable waste efficiently, the prerequisite is regular and continuous availability of segregated feedstock. Characterisation and composition of the waste are also critical.

Effective troubleshooting is important – it ensures plant stability and optimal biogas production, thus reducing the environmental impacts.

Biogas and digestate FOM (fermented organic manure) are the two by-products in anaerobic digestion, or processing of organic waste. Biogas is upgraded to compressed biogas (CBG), which has to meet a BIS standard for use in vehicles, industry and as a natural gas substitute. Digestate has applications in agriculture – it can reduce dependency on chemical fertilizers.

To process biodegradable waste efficiently, the prerequisite is regular and continuous availability of segregated feedstock. Characterisation and composition of the waste play a crucial role and should be decided on and done in the planning stage itself.

The steps in Bio-CNG generation

Segregating waste and receiving the segregated waste: Collecting and transporting segregated biodegradable waste on a regular basis from various sources across the city is crucial when considering the establishment of a Bio-CNG plant based on municipal solid waste. For a Bio-CNG plant to run effectively, it is essential that it should receive biodegradable waste that is segregated to the tune of over 90 per cent.

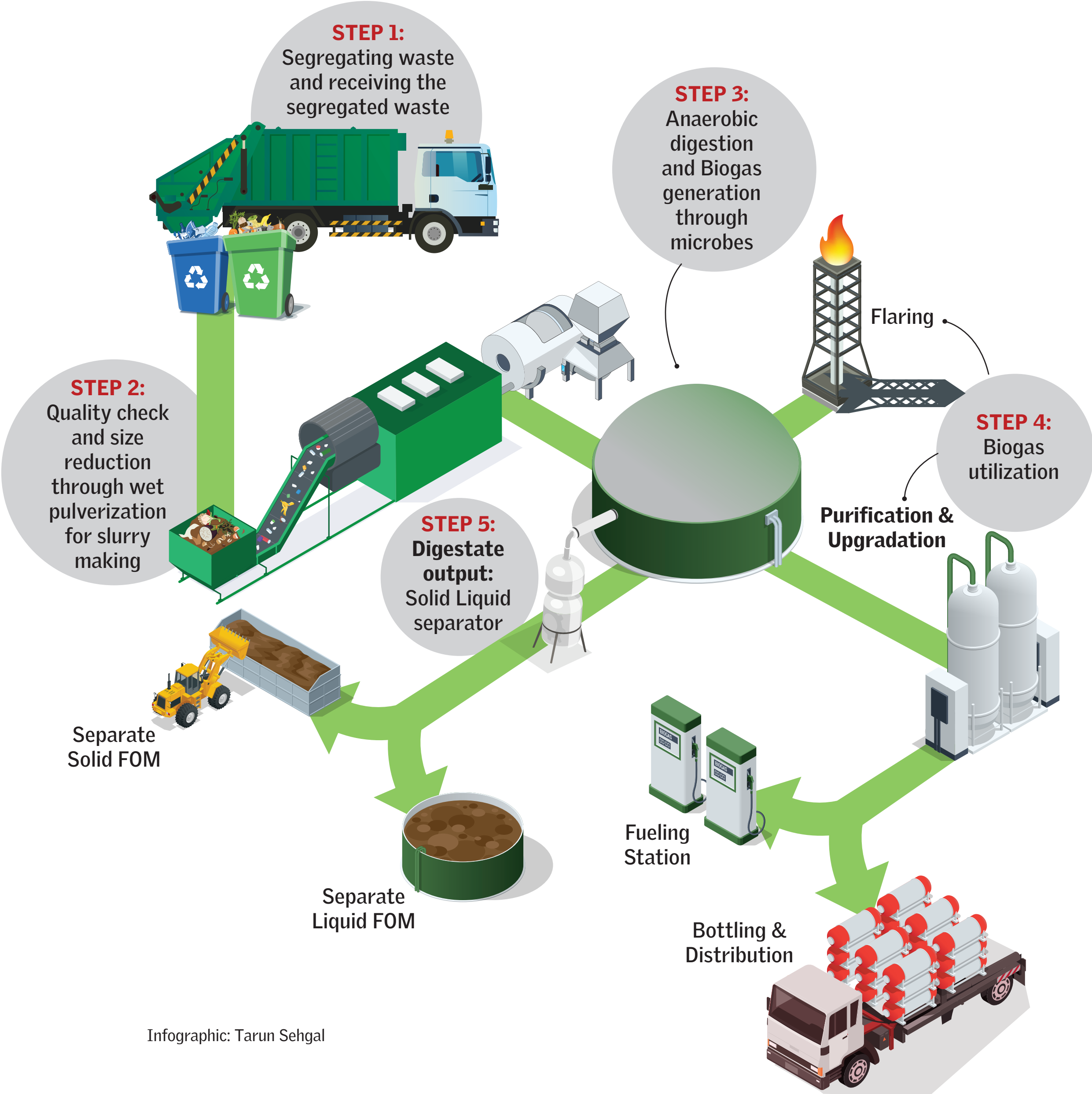
Pre-treatment: The municipal solid waste received at the site requires initial feed preparation before undergoing further treatment and digestion. Most digestion systems necessitate pre-treatment of waste to achieve a uniform feedstock. For anaerobic fermentation, the pre-processing step involves mechanically sorting non-digestible materials. This separation ensures the removal of undesirable material which can hamper the overall process.

Subsequently, the organic material proceeds to the shredding/crushing section, where it is crushed using a crusher and an appropriate amount of water is added to form a slurry. This process occurs before anaerobic digestion, enhancing the surface area and promoting accelerated degradation of the organic material.

Anaerobic digestion: Anaerobic digestion of biodegradable matter occurs in a closed space called digester under controlled conditions. Inside the digester, the feed is diluted to achieve the desired solid content and remains in the digester for a specified retention time. Various water sources – such as clean water, sewage or re-circulated liquid from the digester effluents – can be used for dilution. Typically, the solid concentration ranges from 6 to 10 per cent, but some systems have concentrations exceeding 20 per cent. In a batch reactor mode, for instance, the solid concentration can reach up to 40 per cent. A heat exchanger can be installed to optimise heat utilisation throughout the system, particularly for maintaining the desired temperature in the digester.

To ensure a progressive process that can handle varying feed compositions, either single-stage or multi-stage digesters should be considered for converting waste into biogas. Additionally, provisions should be made for adding necessary additives to the

Figure 2: Process of Bio-CNG generation from municipal wet waste



Infographic: Tarun Sehgal

digesters. The methane (CH_4) content of the biogas depends on the efficiency of the anaerobic digestion and the substrate composition: total methane concentration in raw biogas typically ranges between 55 to 65 per cent. There are factors which affects the bio-gas generation (see Table 2). Agitators should be included in the digesters to prevent the formation of floating layers, sedimentation of inert material, and phase separation of the organic waste slurry. Adequate instruments and analyses should be provided for monitoring the process.

Table 2: Factors affecting biogas generation

Understanding the key factors affecting biogas generation makes it easier to comprehend the parameters necessary for optimal performance

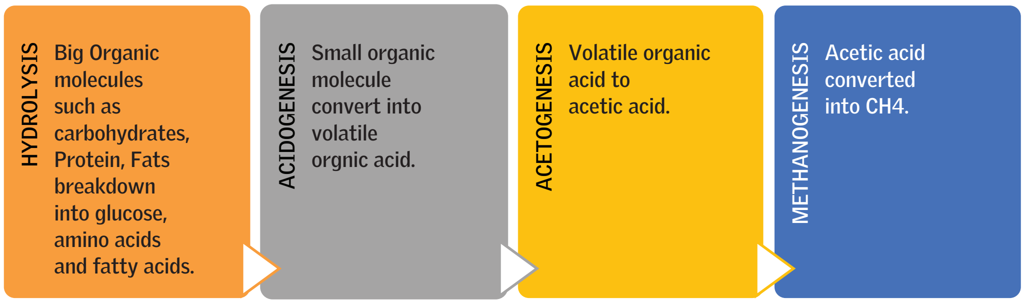
Factor	Description
Temperature	Mesophilic range: 25°C-40°C (preferably 35°C-37°C) Thermophilic range: Above 45°C (preferably 55°C-60°C) – Faster digestion, smaller reactors, better pathogen destruction
Ph	Optimal pH: 6.0-8.5 – Methanogens thrive around 7.0 - Higher pH can produce ammonia (NH_3), inhibiting methane production.
Carbon-to-nitrogen (C/N) ratio	Ideal ratio: 20:30 High C/N ratio: Rapid nitrogen consumption, reduced gas production Low C/N ratio: Ammonia accumulation, harmful to methanogens.
Toxicity	Methanogens sensitive to toxic compounds – chemicals and heavy metals can inhibit microbial activity and methane production
Organic loading rate	Each digester has an optimal rate – beyond this rate, increasing feed does not increase gas production.
Agitation	Ensures optimal mixing, prevents stratification and scum formation, and enhances gas release
Hydraulic retention time (HRT)	Average time feedstock stays in the digester – HRT inversely proportional to temperature Recommended HRT varies by region: 30 days: Andhra Pradesh, Goa, Kerala, Karnataka, Maharashtra, Puducherry and Tamil Nadu 40 days: Bihar, Gujarat, Haryana, Punjab, Jammu, Madhya Pradesh, Odisha, Rajasthan, Uttar Pradesh and West Bengal 55 days: Himachal Pradesh, North-Eastern States, Sikkim, Kashmir, other hilly areas with severe winters.

Source:

Anaerobic fermentation occurs in four stages, facilitated by different groups of microbes: hydrolysis (hydrolytic bacteria), acidogenesis (acidogenic bacteria), acetogenesis (acetogenic bacteria) and methanogenesis (methanogenic bacteria) (*see Figures 4*). Digesters are typically designed as single-stage or single-phase units, where all three stages occur in microenvironments within a single vessel. However, biphasic fermenters have also been developed, where the process up to acidogenesis occurs in the first phase at a slightly lower pH, and methanogenesis occurs in the second phase at near-neutral pH. This approach is considered more efficient in terms of pH and time management due to the ability to optimise each reaction separately.

The produced biogas consists mainly of methane, a greenhouse gas. Therefore, an emergency flare should be installed to burn the excess biogas in case of overproduction or process malfunction.

Figure 4: The stages of anaerobic digestion



Source:

Table 3: Troubleshooting common operational problems of biogas plants

CSE researchers survey operational plants to understand some of the common problems

<table>
<tr><td colspan="3">Problem 1: Drop in gas yield</td></tr>
<tr><td colspan="2">Causes</td><td>Solutions</td></tr>
<tr><td colspan="2">• Drop in quality of substrates
• Drop in temperature
• Inhibitory compounds
• Non-homogenous substrate
• Reduction in methanogenic bacteria</td><td>• Assure substrate mixing and quality
• Check the heating system
• Check the level of potential inhibitory compounds
• Add digested slurry from another digester</td></tr>
<tr><td colspan="3">Problem 2: Drop in pH</td></tr>
<tr><td colspan="2">Causes</td><td>Solutions</td></tr>
<tr><td colspan="2">• Feeding rate is too high or variable
• Operating temperature has changed
• Agitation is not working</td><td>• Reduce the feed substrates until the system returns to normal
• Use only manure until the system returns to normal</td></tr>
<tr><td colspan="3">Problem 3: Drop in methane concentration</td></tr>
<tr><td colspan="2">Causes</td><td>Solutions</td></tr>
<tr><td colspan="2">• Drop in the quality of the substrate
• Drop of temperature
• Compounds inhibition</td><td>• Assure substrate mixing and quality
• Check heating system
• Check the level of potential inhibitor compounds</td></tr>
<tr><td colspan="2">Deviation in FOS/TAC ratio</td><td></td></tr>
<tr><td>FOS/TAC ratio</td><td>Causes</td><td>Solutions</td></tr>
<tr><td>> 0.6</td><td>Highly excessive biomass input</td><td>Stop adding biomass</td></tr>
<tr><td>0.5 – 0.6</td><td>Excessive biomass input</td><td>Add less biomass</td></tr>
<tr><td>0.4 – 0.5</td><td>Plant is heavily loaded</td><td>Monitor the plant more closely</td></tr>
<tr><td>0.3 – 0.4</td><td>Biogas production at a maximum</td><td>Keep biomass input constant</td></tr>
<tr><td>0.2 – 0.3</td><td>Biomass input is too low</td><td>Slowly increase the biomass input</td></tr>
<tr><td>< 0.2</td><td>Biomass input is far too low</td><td>Rapidly increase the biomass input</td></tr>
</table>

Source:

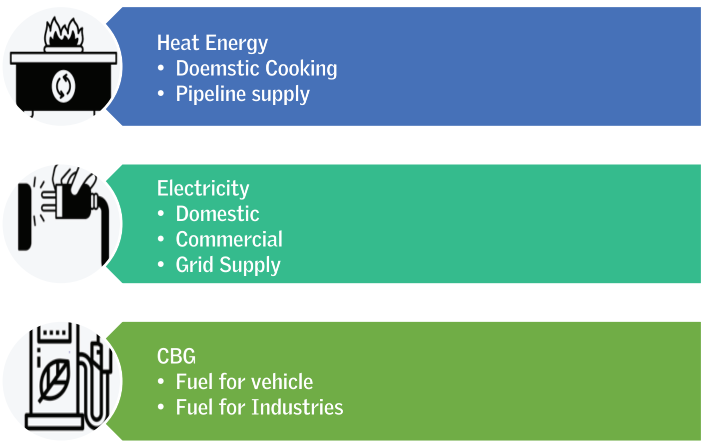
Product recovery and utilisation

Biogas: The primary end product of anaerobic digestion is biogas (55-60 per cent), which is produced within the digester and collected either in top-mounted biogas storage or storage balloons. Biogas mainly consists of methane (CH_4), carbon dioxide (CO_2), and small amounts of hydrogen sulfide (H_2S) and other gases. Methane is flammable and can be used as an energy source in various forms. Depending on the utility and capacity of its generation, the biogas can be used directly or upgraded and purified.

Applications of biogas: In its natural state, biogas has a variety of applications, including in cooking (similar to LPG), lighting, motive power, and electricity generation. It has the potential to replace up to 80 per cent of the diesel fuel required for diesel engines[10] and can serve as a complete substitute when used in biogas engines. This versatility makes biogas suitable for households and decentralised facilities.

However, for use as vehicle fuel and for other industrial needs, biogas must be purified and bottled to achieve a higher methane concentration. In India, heating applications, especially for cooking, are the most significant use of biogas, while globally, electricity generation is the primary application (*see Figure 5*).

Figure 5: Applications of biogas



From biogas to compressed biogas: In larger plants, biogas is further processed into compressed biogas (CBG) for better utilisation. This involves purification, upgradation and compression to remove toxic elements, increase methane concentration, and enhance energy content per unit volume. This CBG that is produced meets the IS 16087:2016 specifications of the Bureau of Indian Standards (BIS), and is stored and transported under high pressure (*see Table 4*).

Table 4: Required specifications for CBG

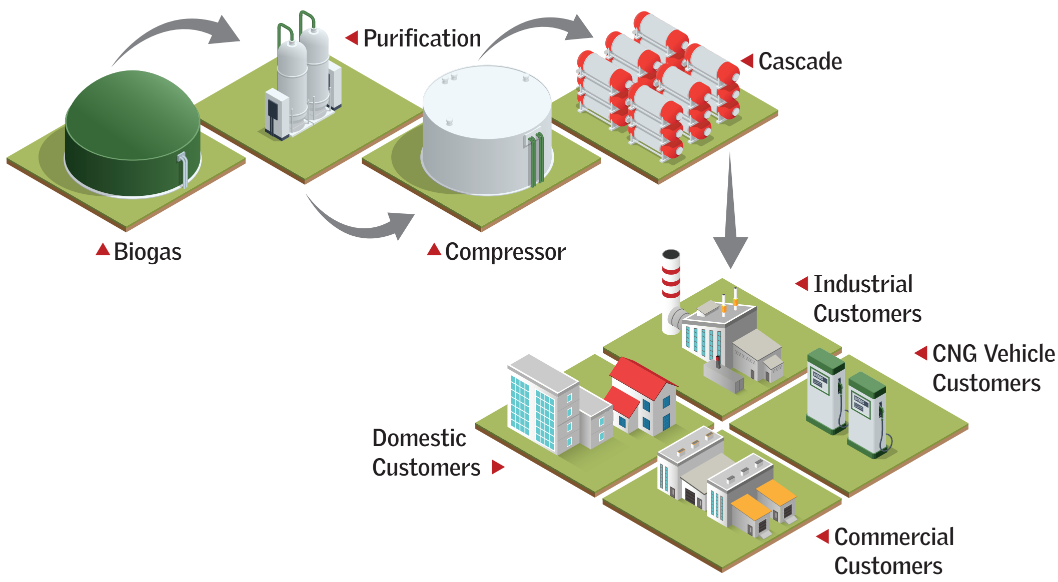
S No.	Characteristics	Requirements
1	Methane (CH_4), minimum %	90.0%
2	Only carbon dioxide (CO_2), maximum %	4%
3	Carbon dioxide (CO_2) + nitrogen (N_2) + oxygen (O_2), maximum %	10%
4	Oxygen (O_2), maximum %	0.5%
5	Total sulphur (including H_2S) mg/m^3, maximum %	20 mg/m^3
6	Moisture mg/m^3, maximum %	5 mg/m^3

Source: BIS

Purification and upgradation: Biogas production can be continuous. To maximise its efficiency as an energy source, we should focus on the methane concentration. Biogas purification and upgradation is crucial for several reasons (*see Figure 6*):

- It increases methane content.
- It reduces carbon dioxide levels.

Figure 6: Biogas purification and upgradation



Infographic: Tarun Sehgal

- It enhances the calorific value.
- Purification helps eliminate the corrosive effects of hydrogen sulfide (H_2S).

Various methods are available for purifying and upgrading biogas, including water scrubbing, chemical scrubbing, pressure swing absorption (PSA), membrane separation, and cryogenic methods. When it comes to the purification process, these methods function by using water, chemicals or any other materials that have the ability to absorb methane (CH_4) or carbon dioxide (CO_2). Among these methods, PSA and water scrubbing are the more widely recognised and used methods both nationally and globally.

But all these technologies come with their own set of challenges that are mainly associated with methane recovery percentage, capital cost, operating cost and ease of operation (*see Table 5*).[11]

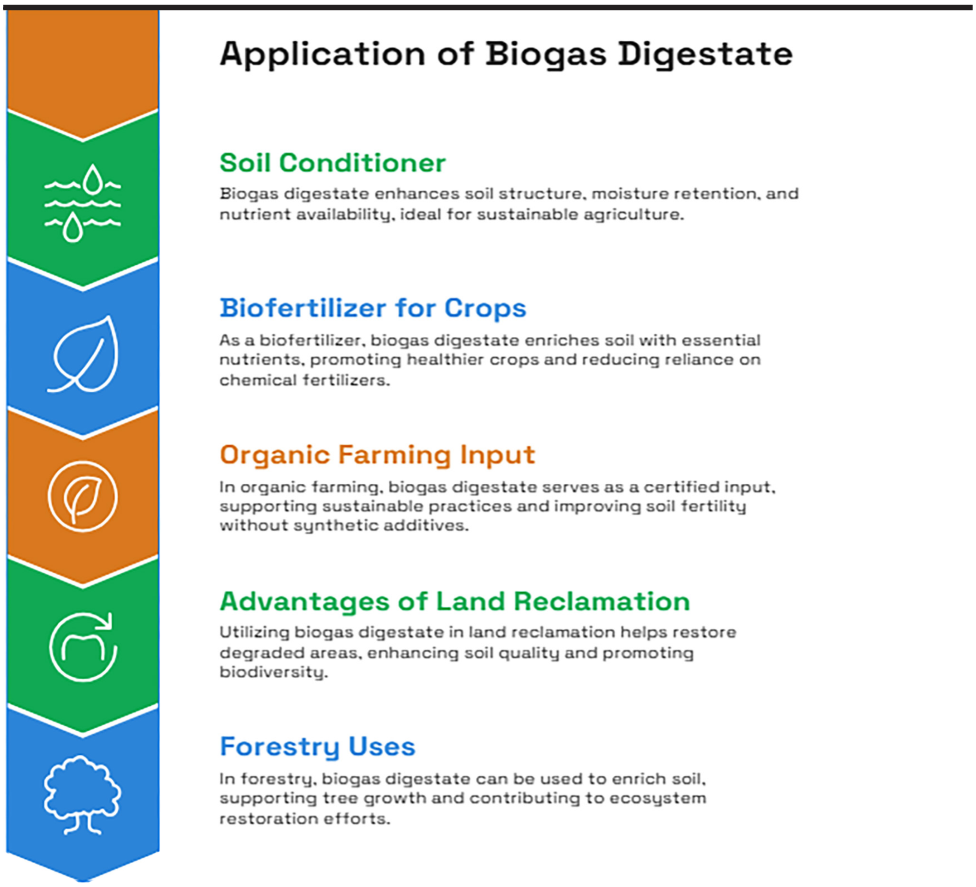
Table 5: Comparison of different biogas upgradation methods

Parameters	PSA system	Water scrubber	Mono-ethylammine (MEA)
Pre-H_2S removal required	Yes	No	Yes
Working pressure (bar)	4-7	4-7	No pressure
Methane loss	20-30%	5-10%	<0.1%
Methane content in upgraded gas	>96%	>97%	>99%
Electricity consumption (kWh/m^3)	0.25	<0.25	<0.15

The biogas, after purification and upgradation, undergoes additional compression to a pressure of 250 bar. This highly compressed form is known as compressed biogas (CBG). To use CBG as a substitute for compressed natural gas (CNG), the operator must adhere to the IS 16087:2016 standard[12] – this standard ensures that CBG is supplied to oil and marketing companies or made available through CBG dispensing units installed by oil and marketing companies within a 25-km radius.

CBG, enriched with methane, can serve as a viable alternative to traditional fossil fuels. It can be employed for various purposes such as generating heat and steam, producing electricity, co-generation, fueling vehicles, manufacturing bio-based chemicals, serving as a substrate in fuel cells, acting as a starting material in chemical processes, substituting for natural gas in residential and industrial applications, and injecting into the gas grid.[13]

Figure 7: Digestate application



Digestate: Digestate FOM (fermented organic manure) is the second by-product in anaerobic digestion. Making upto 20 per cent of the total feedstock, its nutrient value and quality of FOM varies with the substrate used as a feedstock. India has the potential to generate 370 million tonne (MT) of bio-manure every year from various feedstock.[14]; of this, municipal solid waste can provide 5.5 MT a year (estimated based on annual wet waste generation).

India is the second biggest producer and consumer of chemical fertilizers in the world. Per hectare fertilizer consumption in the country has shot up by 75 per cent over the last two decades; in 2020-21, it had reached 161 kg per hectare (ha) of gross cropped area from 92 kg/ha. More than half of the chemical fertilizers consumed in India are in the form of urea. As the cost of chemical fertilizers keeps rising continuously, the subsidy on them is growing every year. In 2020-21, the annual subsidy bill was Rs 1,31,230 crore – more than 10 times the subsidy bill in 2001-02 (Rs 12,908 crore).

> "India's foodgrain requirement to feed the estimated population of 1,400 million by 2025 will be 300 million tonne (based on rice, i.e. un-husked paddy rice). There will be a corresponding increase in requirement of other crops such as cotton, sugarcane, fruits and vegetables. The country will require about 45 million tonne of nutrients (30 million tonne for foodgrains and 15 million tonne for other crops) from various sources i.e. fertilizers, organic manures and bio-fertilizers."
>
> – Report of the Parliament's Standing Committee on Chemicals and Fertilizers, 17th Lok Sabha

While bio-fertilizers have immense scope in agriculture, horticulture and floriculture, their acceptance level is low compared to chemical fertilizers because of their relatively lower nutrient content. Bio-manure has a nutrient content of 12 kg/tonne – compared to this, urea (chemical fertilizer) has a nutrient content of 46 kg/tonne.

Marketing organic manure: A challenge

Organic manure needs to be enriched and upgraded to make it acceptable to consumers. There are cases where marketability of digestate has improved after enriching and upgrading it as per plant or crop requirements. The Union Ministry of Chemicals and Fertilizers is offering market development assistance of Rs 1,500 per tonne on the sale of FOM. The ministry has also released a set of norms and operating procedures for testing, quality verification and packaging of the manure.

Besides support from the government, the following measures are used to increase the marketability of organic manures.

- **Pelletisation of the solid component**: In a digestate, the solid fraction is considered to be the main usable fraction, as the liquid component is utilised in the next digestion cycle. The solid part can be processed by further drying and pelletisation to reduce the volume and make it more transportable for marketing and utilisation. The bulk density of loose dried digestate is 250-350 kg per cubic metre (kg/m^3), which increases to 700-750 kg/m^3 after pelletisation – this makes it easier to store and brings down the transportation costs.
- **Upgradation by adding nutrients:** The digestate can be improved and upgraded to address specific nutritional needs of crops. For instance, Govardhannathji Energies LLP, a CBG plant in Gujarat, has upgraded its biogas digestate and developed an organic fertilizer brand called UTPANN.

4 A FINANCIAL ANALYSIS

A five TPD Bio-CNG plant requires 150 tonne of segregated MSW per day, with an additional 15 per cent for impurities.

Operational costs may vary depending on whether the municipality or the project developer handles waste collection and transportation.

The majority of the capital cost is allocated to the digester, followed by the purification and pre-treatment units.

The plant remains profitable without waste collection responsibility but operates at a loss when the responsibility includes waste collection and transportation.

The presence of impurities in MSW reduces the Bio-CNG yield, requiring additional pre-treatment – which adds to the costs.

The production of Bio-CNG from municipal solid waste (MSW) represents a forward-thinking approach towards sustainable management of energy and waste. However, the implementation of such a project requires a detailed understanding of the economic, logistical and technical factors involved in it. This chapter will present an in-depth analysis of a sample Bio-CNG plant with a production capacity of five tonne per day (TPD), highlighting its benefits, costs and operational considerations (*see Table 6*).

Table 6: Details of the Bio-CNG plant

Production capacity	5 tonne per day (TPD) of CBG and 30 TPD of FOM
Segregation level of the waste received	More than 90 per cent
Feedstock requirement	150 tonne daily (considering 30 tonne of segregated MSW will yield one tonne of Bio-CNG)
Impurities accounted for (15%)	22.5 TPD
Total municipal wet waste required	172.5 TPD
Land requirement	5-7 acre
Land cost for plant installation provided by municipality	0
Estimated capital cost for installation of plant	Rs 35 crore
Monthly cost for operating the plant	Rs 0.4 crore
Per tonne collection and transportation cost of segregated MSW (assumption)	Rs 1,000

Source:

Bio-CNG production relies on the organic fraction of MSW, which can vary significantly in composition. Unlike agricultural waste which is more homogeneous, municipal organic waste includes various contaminants such as silt, sand and non-digestible materials like bagasse and tender coconut shells. These impurities can reduce the efficiency of biogas production and necessitate additional pre-treatment. The yield of Bio-CNG, therefore, depends heavily on the quality and consistency of the feedstock.

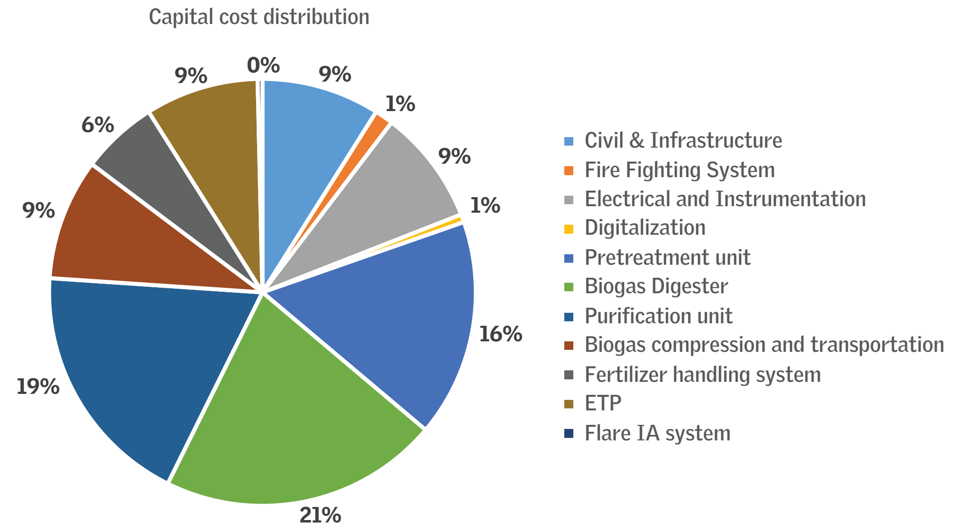
For generation of five TPD of Bio-CNG, the plant will need 150 tonne of segregated MSW. Additionally, one will also have to consider impurities of 15 per cent – the total feedstock requirement, thus, becomes 172.5 TPD.

Capex cost requirement

Capital expenditure (CapEx) is required for setting up a Bio-CNG plant. The cost of a Bio-CNG plant that works on processing municipal solid waste (MSW) will differ from plants that use other kinds of feedstock. In the latter, feedstock storage

Graph 6: Capital cost breakdown

The major chunk of the costs goes into the digester



Source: Based on analysis done by CSE

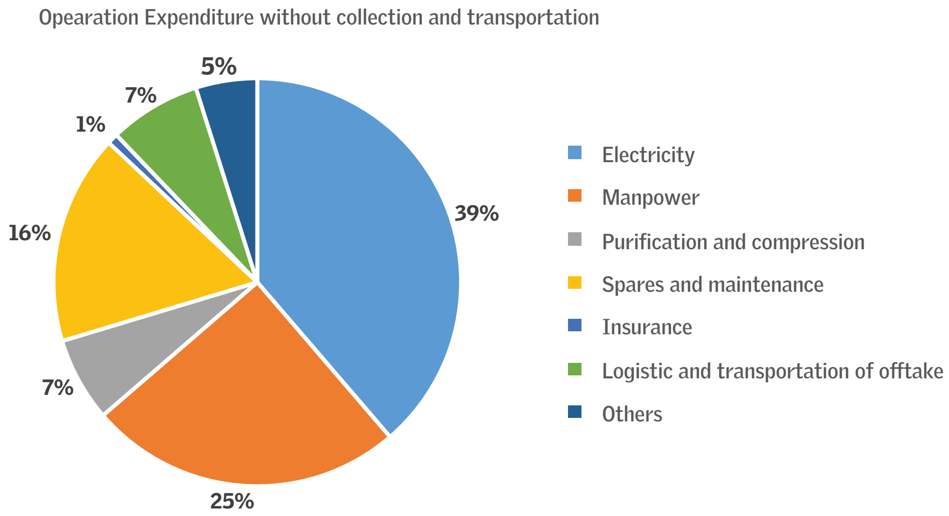
spaces are needed to ensure a consistent supply; an MSW-based plant receives daily wet waste through regular collection systems, eliminating the need for additional storage space. On the flip side, an MSW-based plant requires extra infrastructure for secondary segregation, which impacts both the capital and operational costs.

Considering all these factors, the initial investment required can be between Rs 6-8 crore per tonne of CBG capacity – which totals to Rs 35 crore for a five-tonne capacity plant. The cost may vary depending on the company, location of the installation and the technology adopted. For instance, the cost of installation in a hilly region or an area which has low temperatures may increase to 20 per cent compared to an installation in the plains. The majority of the cost is allocated to the digester, followed by the purification unit, pre-treatment unit, and other components (*see Graph 6*).

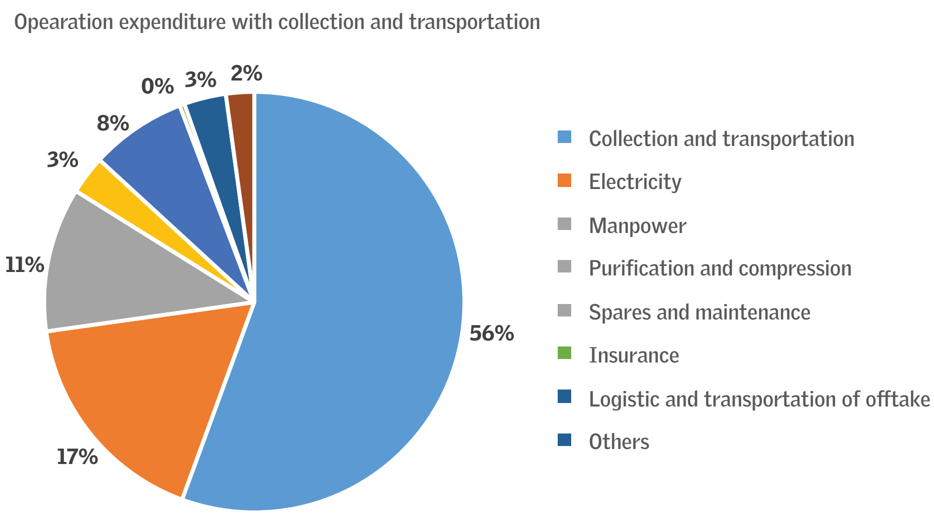
Monthly operational expenses

A Bio-CNG plant requires an operational expenditure of around Rs 0.4 crore per month, provided the plant receives segregated waste. As per the CSE research team's interactions with officials of currently operational plants, about 39 per cent of the expenses are on electricity; salaries of skilled and unskilled humanpower may take up another 25 per cent. If collection and transportation are considered as part of the daily operational costs, 56 per cent of the total is taken up by these heads; 17 per cent goes on electricity, and 11 per cent on humanpower. Mechanised plants require less human or manual labour (see Graph 7a and b).

Graphs 7a and b: Breakdown of monthly operational costs



Source: Based on analysis done by CSE



In terms of collection and transportation of the segregated waste, operations of a Bio-CNG plant can have two facets: one, in which waste collection and transportation is the responsibility of the concerned municipality and two, in which it is the responsibility of the project developer.

Revenue generation

The main sources of income for a Bio-CNG plant that produces five tonnes of Bio-CNG daily from separated municipal organic waste are the sale of Bio-CNG and

Table 7: Revenue generation of 5000 Kg CBG plant considering 90% operational efficiency

Description	CBG Generated (kg)	CBG Revenue (Rs)	FOM Generated (kg)	FOM Revenue (Rs)	Total Revenue (Rs)
Daily	4,500	2.48 lakh	30,000	0.90 lakh	3.38 lakh
Monthly (30 days)	1,35,000	74.25 lakh	9,00,000	27.00 lakh	101.25 lakh

Source: Analysis done by CSE

organic manure. Running at 90% efficiency, the plant produces 4,500 kg of Bio-CNG daily (which is about 1,35,000 kg per month) and 30,000 kg of organic manure daily (about 9,00,000 kg per month). The daily revenue from Bio-CNG sales, priced at Rs 55 per kg, is Rs 2.48 lakh, which adds up to Rs 74.25 lakh per month. The daily income from organic manure sales is Rs 0.90 lakh, totaling Rs 27 lakh per month. This price includes Rs 1.5 per kg from direct sales and another Rs 1.5 per kg from Market Development Assistance. Altogether, total plant revenue comes to Rs 3.38 lakh per day, or more than Rs 1 crore per month (*see Table 7*).

Feasibility of bio-CNG plant – two scenarios

To understand whether a Bio-CNG plant can be a good investment, two different scenarios were explored. The main difference between the two is whether the plant takes care of collection and transportation of waste. These scenarios help decision-makers understand what makes the project financially successful or difficult to sustain.

Scenario 1: Plant operation excluding collection and transportation of waste

In this scenario, the Bio-CNG plant operator only processes the waste that is already delivered to it. The responsibility for collecting and transporting the waste lies with the municipality or another agency, not the plant operator.

The financial analysis reveals that this model is highly viable:

- If Bio-CNG alone is sold, the plant earns Rs 74.25 lakh per month and spends Rs 40 lakh on operations. This means it makes a profit of Rs 34.25 lakh per month, and the initial investment can be recovered in 8.5 years.
- If both Bio-CNG and manure (FOM) are sold, the revenue goes up to Rs 101.25 lakh per month, with the cost of operations remaining the same at Rs 40 lakh. The monthly profit increases to Rs 61.75 lakh, and the payback period reduces to just five years. (*see Table 8.1*).

Table 8.1: Financial feasibility of scenario 1

Case	Operational Cost (Rs lakh)	Revenue from Bio-CNG (Rs lakh)	Revenue from FOM (Rs lakh)	Total Revenue (Rs lakh)	Net Profit (Rs lakh)	ROI (Years)	Remarks
1	2	3	4	5	6	7	
With 100 per cent bio-CNG sale	40	74.25	0	74.25	34.25	8.5	Feasible
With 100 per cent generated bio-CNG and FOM sale	40	74.25	27	101.25	61.75	5	Feasible

Source: Based on analysis done by CSE

Scenario 2: Plant operation, including collection and transportation of waste

In the second scenario, the plant's operational scope is expanded to cover the collection and transportation of segregated organic waste. This significantly increases the monthly operational costs from Rs 40 lakh to Rs 91.75 lakh.

Under these conditions, the economic feasibility declines drastically:

- If only Bio-CNG is utilised, the plant suffers a monthly loss of Rs 17.5 lakh, making the project financially unviable.
- Even with full sale of both Bio-CNG and FOM, total monthly revenues reach Rs 101.25 lakh, but with high operational costs, the net profit is only Rs 10 lakh per month. This results in an extended payback period of 29 years, rendering the project barely feasible and unattractive from an investment perspective. (*see Table 8.2*)

Table 8.2 : Financial feasibility of scenario 2

Case	Operational Cost (Rs lakh)	Revenue from Bio-CNG (Rs lakh)	Revenue from FOM (Rs lakh)	Total Revenue (Rs lakh)	Net Profit (Rs lakh)	ROI (Years)	Remarks
1	2	3	4	5	6	7	
With 100 per cent bio-CNG Sale	91.75	74.25	0	74.25	-17.5	NA	Not feasible
With 100 per cent bio-CNG and FOM Sale	91.75	74.25	27.5	101.25	10	29	Not feasible

Source: Based on the analysis done by CSE

5

OPERATIONAL PLANTS: SOME CASE STUDIES

Surat Agricultural Produce Market Committee (APMC) Bio-CNG plant, Surat (Gujarat)

Gobardhan Bio-CNG plant, Indore, Madhya Pradesh

Integrated Solid Waste Management Facility, Saligao, Goa

1. Surat Agricultural Produce Market Committee (APMC) Bio-CNG plant, Surat (Gujarat)

Year of commissioning:	**2017**
Land area:	**2.5 acre (about 1.01 hectare)**
Feedstock source:	**Vegetable market/s**
Feedstock required daily:	**50 tonne**
Waste collected by:	**Plant operator (Akshar Biogas Pvt Ltd)**
Capacity of CBG generation:	**2 tonne for day (TPD)**
Daily production of Bio-CNG:	**1.2 tonne**
SFOM generation:	**10 TPD**
Capital investment to set up the plant:	**Rs 8 crore**
Operational cost:	**Rs 6 lakh per month**
Revenues:	**Rs 14 lakh per month**

Cities have their vegetable markets, and managing the daily waste generated in these markets is a concern that every city encounters. Surat's Sardar market was no exception – till the Bio-CNG plant was commissioned in 2017. The plant was set up on land available inside the market itself (*see Box for data*).

The plant is jointly operated by the Surat APMC and Akshar Biogas Pvt Ltd – the APMC has given Rs 8 crore to install the plant, while Akshar is taking care of the daily operations. The revenue comes from sales of Bio-CNG and FOM. Of the total monthly revenue of Rs 14 lakh, Akshar Biogas shares Rs 3 lakh per month with the APMC to compensate for the feedstock supply cost and plant capex.

Operational processes

The waste coming out from the vegetable market or the hotel associated with the APMC is shredded in a pulveriser for slurry making. On an average, the plant receives 35 tonne per day (TPD) of waste. The composition of waste varies seasonally – the yield of biogas varies accordingly.

The slurry is pumped to the main digester where it is retained for a period of 35 days for complete biomethanation and biogas generation. The produced biogas is purified and upgraded through MPSA (minor pressure swing adsorption) to convert it into Bio-CNG. The slurry coming out from the digester is further separated into solid and liquid forms. The solid part is distributed to farmers once it matures. The liquid is treated through an ETP (effluent treatment plant) for reuse in slurry making.

Offtake management

The plant produces 1.2 tonne of Bio-CNG every day. This Bio-CNG is sold to the Indian Oil Corporation Ltd (IOCL) and industries in Ankleshwar and Chickli as furnace fuel. The FOM is distributed free of cost to local farmers.

Challenges

The plant is designed to process 50 TPD of feedstock, but due to fluctuations in waste generation at the vegetable market, it receives an average of only 35 TPD, leading to lower Bio-CNG recovery. The lack of revenues from solid fermented organic manure poses an additional challenge.

2. Gobardhan Bio-CNG plant Indore, Madhya Pradesh

Year of commissioning:	**2021**
Land area:	**17 acre (about 6.9 hectare)**
Feedstock source and type:	**Segregated municipal solid waste**
Feedstock required:	**500 TPD**
Waste collected by:	**Indore Municipal Corporation**
Capacity of CBG generation:	**17 TPD**
Daily production of Bio-CNG:	**...**
SFOM generation:	**100 TPD**
Capex:	**Rs 150 crore (additional Rs 20 crore invested in machinery for desilting)**
Operational cost (estimated):	**Rs 1.78 crore per month**
Revenues:	**Data not available**

Indore Municipal Corporation generates approximately 1,115 tonne of waste every day (TPD), with 58.25 per cent of it (about 650 TPD) being wet waste. Initially, all wet waste was transported to the Devguradia centralised composting facility, with some waste processed through decentralised facilities. In February 2021, Indore Municipal Corporation installed a Bio-CNG plant with a capacity of 550 TPD to handle segregated wet organic waste.

Operational processes

The Indore Bio-CNG facility receives about 90 per cent segregated wet organic waste daily. Upon arrival, the waste undergoes a pre-treatment process involving screening and hammer-milling to convert it into slurry. This slurry is created with a 1:1 ratio of water to waste. The slurry then enters the hydrolysis stage, which has a retention time of 1.5 to two days, allowing for the acidification and breakdown of complex organic materials into simpler forms.

Subsequently, the slurry is transferred to the main digester, where it remains for 25 days to generate biogas. The biogas produced is then upgraded and purified to achieve a methane content of over 90 per cent using the VPSA (vapor pressure swing absorption) method. The digestate slurry from the digester is separated into liquid and solid forms, with 30 per cent of the water recycled and 70 per cent used to prepare the next batch of slurry. The solid fraction, as solid FOM, amounts to approximately 100 TPD.

Offtake management

The plant produces 17 tonne of Bio-CNG every day. Half of this output is sold to Indore Municipal Corporation at a discounted rate of Rs 5 per kg, while the remaining is sold to Avantika Gas Ltd, the CNG and PNG supplier of the Indore region. The solid FOM is either left lying on the site or given free to farmers.

Challenges

Despite its success, the plant faces several challenges. The presence of non-digestible materials in the waste such as tender coconut, bagasse and coconut shells can hinder the digestion process and may require additional separation, even after the initial segregation. Another significant challenge is the presence of inert materials, which reduce the efficiency of the digester and biogas yield by settling and causing blockages. To address this issue, the plant has been upgraded with a cyclone separator at a cost of Rs 20 crore. Additionally, marketing the FOM has proven difficult due to limited demand, leading to storage issues.

3. Integrated Solid Waste Management Facility, Saligao, Goa

Year of commissioning:	**2016**
Land area:	**4.45 acre**
Feedstock source and type:	**Municipal solid waste**
Feedstock required:	**150 TPD**
Waste collected by:	**Goa Waste Management Corporation**
Capacity of biogas generation:	**19,500 m^3 per day (the unit is cubic metre as this is a biogas-to-electricity plant)**
SFOM generation:	**10 TPD**
Capex:	**Rs 250 crore**
Operational cost (estimated):	**Rs 1.35 crore per month**
Revenues:	**Data not available**

The Integrated Solid Waste Management Facility (SWMF) at Saligao, established in 2016 by the Goa Waste Management Corporation (GWMC), is a state-of-the-art facility that scientifically manages waste in line with the SWM rules of 2016. It effectively serves 27 local bodies along the coastal belt of North Goa and also handles beach and highway cleaning waste.

Initially designed with a capacity of 100 TPD, the plant's capacity has now been increased to 250 TPD. The facility was constructed on a remediated 20-year-old waste dump containing 73,198 tonne of waste. Operated by Hindustan Waste Treatment Pvt Ltd, the initial cost of setting up the facility was Rs 146 crore, with an additional Rs 103 crore invested during expansion. The GWMC pays Rs 2,209.6 plus 18 per cent GST to Hindustan Waste Treatment Pvt Ltd for treating one tonne of waste. Although this facility is considered expensive compared to currently operating biogas or Bio-CNG plants, the cost is justified by its continuous and effective operation.

Operational processes

The plant receives 150 tonne segregated organic waste every day. GWMC has deployed dedicated vehicles with GPS tracking and monitoring systems for collecting the segregated waste. The waste is first received at an in-feed bunker with a capacity of 10 tonne per hour (TPH), where it gets pulverised. This organic waste is then sent to a bio-press or organic extruder to separate the fibrous and indigestible materials.

Next, the pulverised waste undergoes a slurry-making process involving hammering and water addition. The slurry is then fed into a buffer tank for sedimentation, where inert and heavy materials, which are not needed for digestion, are removed before it goes into the main thermophilic digester. The facility has three digesters: one with a capacity of 1,500 m^3 and two with 2,250 m^3 each. Having multiple digesters allows continuous operation even if one digester requires maintenance.

The entire biogas generation process takes 18 days. After digestion, the slurry is separated into liquid and solid forms. The liquid part is recycled through the ETP for further slurry making, while the solid part is stabilised in a solar drying shed and used as manure.

Offtake management

The plant generates 19,500 m^3 of biogas daily, of which 16,000 m^3 is used for electricity generation through three generators – one with a capacity of 172 kW and two with capacities of 600 kW each. Any excess gas is flared off. Of the total electricity generated, 40 per cent is utilised for onsite requirements, while the remaining 60 per cent is supplied to the grid at a rate of Rs 5 per unit.

Currently, the solid digestate or manure has no established market linkage and is being distributed to farmers free of cost.

Challenges

The plant is facing several operational and offtake utilisation challenges. The presence of indigestible materials like fish bones and meat bones requires frequent maintenance of the digester, resulting in waste processing delays and a slack in biogas production. Another challenge is the lack of revenues from the solid fermented organic manure that the plant is turning out.

6 THE CHALLENGES

Lack of updated waste quantification and characterisation data

Contaminated organic waste and low segregation levels

Operational challenges due to contamination and heterogeneity of the waste being used as source

Lack of marketing access for FOM (fermented organic matter)

High capital cost of installation

Lack of clarity between municipality and project developer over roles and responsibilities

Lack of robust supply chain and market for Bio-CNG

Absence of real-time monitoring mechanisms to assess plant performance

Lack of updated waste quantification and characterisation data

The success of a Bio-CNG plant relies heavily on accurate waste quantification and characterisation. Municipal solid waste in India is highly heterogeneous, varying significantly from city to city and even seasonally within the same city. This variability complicates the prediction of biogas yields and affects the stability and efficiency of the anaerobic digestion process. Regular and thorough waste characterisation surveys are essential to tailor processes to the specific waste profile of each region.

Contaminated organic waste and low segregation levels

Effective segregation of waste at the source is critical for efficient operation of Bio-CNG plants. However, many urban local bodies struggle with enforcing strict segregation protocols. Mixed waste leads to operational inefficiencies and higher processing costs. Successful examples like Indore and Goa demonstrate the importance of comprehensive waste management infrastructure, including source segregation, compartmentalised collection vehicles, and transfer stations to ensure high-quality feedstock for Bio-CNG plants.

Operational challenges due to contamination and heterogeneity

Even after segregation, the plant faces operational challenges due to the presence of indigestible and inert materials. These can cause mechanical failures, reduce biogas production efficiency, and necessitate additional pre-treatment processes. The heterogeneity of organic waste also impacts the microbial digestion process, requiring careful monitoring and adjustment of operational parameters. For example, the Indore plant is dealing with the presence of inert materials, necessitating an additional investment of Rs 20 crore for a cyclone separator. This investment will reduce the maintenance needs of the digester, which previously was facing problems with inert materials settling into it.

Lack of FOM marketing

The digestate or fermented organic matter (FOM) from Bio-CNG plants, which can be used as organic fertilizer, often faces low market acceptance and utilisation. This is due to the lack of awareness and acceptance among farmers, inconsistent quality of the product, and competition with chemical fertilizers. Promoting the benefits of FOM and ensuring consistent quality standards are essential to improve its utilisation and sustainability of the plant – per CSE's calculations, FOM contributes about 27 per cent of a Bio-CNG plant's total revenue potential.

High capital cost of installation

The capital and operational costs of Bio-CNG plants are significant, often posing a substantial barrier to the widespread adoption and economic viability of this technology. Without government subsidies or financial incentives, the high expenses associated with setting up and maintaining these plants can deter investment and limit the scale of deployment. One of the primary reasons for these high costs is the reliance on imported components. Key equipment, such as digesters, gas storage balloons, purification units and agitators are predominantly sourced from countries like Germany, Belgium and Sweden.

Importing these components not only involves direct costs, but also attracts tariffs and import duties, further escalating the overall expense. The dependence on foreign technology and equipment not only increases the initial capital outlay but also impacts operational costs. Maintenance and repair of these sophisticated components often requires specialised knowledge and expertise, which might not be readily available locally. This leads to additional costs in terms of training or hiring foreign experts, as well as potential downtime if replacement parts need to be imported.

Lack of clarity between municipality and project developer over roles and responsibilities

The lack of clarity between municipalities and project developers in Bio-CNG projects based on Municipal Solid Waste (MSW) creates significant challenges. Ambiguities in responsibilities for waste management, infrastructure development, and financial arrangements often lead to operational delays and disputes. For instance, municipalities might fail to ensure consistent, quality feedstock, impacting plant efficiency, while unclear infrastructure roles can delay project completion. Additionally, undefined financial and regulatory duties can cause legal and sustainability issues.

Lack of robust supply chain and market for Bio-CNG

The market for Bio-CNG is still developing in India, with limited demand and distribution channels. Developing a robust supply chain and market for Bio-CNG is essential but challenging. There are pockets where vehicles are using Bio-CNG as fuel – the demand in these areas is relatively higher. Market-driven ecosystems need to be developed through a well-established supply chain in places where Bio-CNG plants are being established or are already operational.

Currently, India is dependent on petroleum companies to get it marketed through their cascade. Some progress has been made lately for injecting Bio-CNG into city gas distribution networks, but a lot more needs to be done. One critical approach to developing the supply chain should focus on a central inventory like a dashboard that provides real-time data on current and projected production capacities. Incentives must be promoted by the Ministry of New and Renewable Energy of the Government of India to attract the private sector to ensure offtake. A clear roadmap is the need of the hour to allow the Bio-CNG market to grow, so that India's energy imports climb down and the organic waste processing business gets a boost.

Absence of real-time monitoring mechanisms to assess plant performance

As municipalities across various cities increasingly adopt Bio-CNG, absence of a centralised real-time monitoring mechanism presents significant challenges. Without such a system, it is difficult to consistently track, evaluate and compare the performance of these plants across different locations. While the Gobardhan unified portal provides data on Bio-CNG plant construction and operations, it does not offer real-time insights into plant performance. This gap underscores the need for a centralised monitoring system capable of assessing key parameters such as daily plant performance, segregation levels, feedstock quantity, and byproduct utilisation.

7

THE WAY AHEAD

Implement methods for comprehensive waste quantification and characterisation

Mandate waste segregation at source and high-quality feedstock

Encourage CNG-based waste collection and transportation fleet

Adopt advanced pre-treatment solutions

Encourage million-plus population cities to adopt Bio-CNG through public-private partnerships (PPP)

Give enough teeth to the public-private partnerships (PPP)

Establish local manufacturing capacity for components of Bio-CNG plants

Recognise fermented organic matter (FOM) as a resource and establish a regulated market for it

Establish clear roles and responsibilities across stakeholders to ensure sustainability of plants

Develop and implement a centralised real-time monitoring system for Bio-CNG plants

Implement methods for comprehensive waste quantification and characterisation

The CSE assessment indicates that a number of operational plants are suffering from inconsistent feedstock supply, which eventually affects their optimum performance. This is largely because of incorrect estimation of the feedstock before the plant's designed capacity is determined. To improve the efficiency and success of the plants:

- Regular and comprehensive waste quantification and characterisation surveys should be conducted.
- Municipalities and plant operators should collaborate to develop region-specific waste profiles.
- By investing in advanced analytical tools and technologies for waste analysis, operators can predict biogas yields and tailor the anaerobic digestion process to the specific waste composition of each region.
- Creating a centralised database for waste characterisation across different cities and regions can help share the knowledge and refine the processing techniques.

Mandate waste segregation at source and high-quality feedstock

The technology for Bio-CNG production is heavily dependent on the quality of feedstock – feedstock must be free from contamination. A Bio-CNG plant cannot be conceived with mixed or contaminated waste. Therefore, strengthening waste segregation systems at source is extremely critical. Many existing biomethanation plants are suffering from contaminated feedstock, which not only affects production but also causes damage to digestors and other machines, thus adding to the operational expenditure and creating financial challenges in running the plants.

- Local governments must enforce source segregation through appropriate legal instruments and extensive engagement with waste generators through communications tools. Successful examples from Indore and Goa highlight the importance of a robust waste management infrastructure.
- Municipalities should invest in compartmentalised collection vehicles, transfer stations, and regular training programmes for their workers.
- Integrating technology such as real-time monitoring systems and AI-driven sorting mechanisms can enhance the efficiency of waste segregation.

Encourage CNG-based waste collection and transportation fleet

One of the concurrent challenges identified during the course of the study has been to ensure offtake of compressed biogas. India is yet to build a grid-based ecosystem for supply and distribution of Bio-CNG. By encouraging municipalities to adopt CNG-fueled fleets, the locally produced Bio-CNG can be effectively utilised, ensuring a stable demand that supports the economic viability of Bio-CNG plants. This transition not only reduces greenhouse gas emissions and operational costs, but also aligns with circular economy principles by transforming waste into a renewable energy source that powers its own management.

- Establishing long-term fuel supply agreements between municipalities and Bio-CNG plant operators will ensure the sustainability of both the waste management system and the Bio-CNG plants, fostering broader adoption of this eco-friendly technology.

Adopt advanced pre-treatment solutions

To mitigate operational challenges, Bio-CNG plants should incorporate advanced pre-treatment technologies, such as mechanical separators and screening systems, to remove indigestible and inert materials before they enter the digestion process.

- Regular monitoring and adjustment of operational parameters should be conducted to account for the heterogeneity of organic waste.
- Investing in research and development to create more resilient microbial cultures that can better handle variations in waste composition can enhance biogas production efficiency.
- The example of the Indore plant's investment in a cyclone separator underscores the importance of such technologies in reducing maintenance costs and improving overall plant performance.

Encourage million-plus population cities to adopt Bio-CNG through public-private partnerships (PPP)

Cities with large populations generate significant amounts of waste: the daily per capita waste generation ranges between 0.5 kg to 0.6 kg[1]. To manage this waste, cities maintain a collection infrastructure that includes everything from small tippers to large compactors. Traditional composting methods often fall short due to underutilisation of the compost produced, or its inferior quality.

However, there is an opportunity to fuel these collection and transportation vehicles using the very waste that they carry. This approach can not only manage large quantities of waste effectively, but can also ensure optimal utilisation of the resulting fuel. Cities and municipalities like the Municipal Corporation of Delhi, Bruhat Bengaluru Mahanagara Palike, Ahmedabad, Pune, Greater Mumbai, Chennai, Greater Hyderabad, Lucknow, Kolkata etc have the potential to generate Bio-CNG from biodegradable waste and use it to fuel their collection and transportation fleets (see ***Annexure****: Checklist for installation of Bio-CNG plant* *from municipal solid waste*).

- While the existing schemes to propel the Bio-CNG sector provide financing and market development assistance, a policy is required to identify large cities with substantial biodegradable waste generation and introduce Bio-CNG as a mandatory technology option through public-private partnership (PPP) model – just like the Municipal Corporation Indore has done.
- Such a mandate must incorporate source segregation and segregated collection – this is absolutely non-negotiable for setting up a Bio-CNG plant.

Give enough teeth to the public-private partnerships (PPP)

- Establish innovation incubators that can bring together technology providers, municipalities, research institutions and private investors to co-develop customised Bio-CNG solutions. These incubators will focus on creating region-specific technologies that are cost-effective and suitable for local waste profiles.
- Financial incentives, such as grants and risk-sharing mechanisms, can be offered to successful pilot projects.
- Implement outcome-based financing models where private partners are incentivised based on performance metrics, such as the quantity of Bio-CNG generated, the quantum of waste processed, and the quality of the by-products. This ensures that the private sector remains focused on achieving measurable outcomes rather than just meeting contractual obligations.

Establish local manufacturing capacity for components of Bio-CNG plants

To reduce the capital and operational costs of Bio-CNG plants, efforts should be made to localise the manufacturing of key components such as digesters, gas storage balloons and purification units.

- Encouraging technology transfer and establishing joint ventures with foreign companies can help build domestic capacity.
- The government can provide financial incentives such as subsidies or tax rebates for local manufacturers to reduce dependency on imports.
- Research and development into cost-effective alternatives to imported components should also be prioritised.

Recognise fermented organic matter (FOM) as a resource and establish a regulated market for it

To increase the utilisation of digestate or fermented organic matter (FOM) as an organic fertilizer, a multi-faceted approach is needed.

- Raising awareness among farmers about the benefits of FOM through targeted education and demonstration programmes can help drive market acceptance.
- Establishing consistent quality standards for FOM in collaboration with agricultural research institutions, will ensure that the product competes effectively with chemical fertilizers.
- Government subsidies or incentives for the use of FOM can further boost its market penetration.
- Developing partnerships with agricultural cooperatives and businesses can facilitate the distribution and adoption of FOM.

Establish clear roles and responsibilities across stakeholders to ensure sustainability of plants

Clear and well-defined agreements between municipalities and project developers are essential for economic and environmental sustainability of Bio-CNG projects. These agreements should specify roles and responsibilities related to waste management, infrastructure development, financial arrangements and community engagement.

- Forming a joint task force or coordination committee with members from the Ministry of Housing and Urban Affairs, Central Pollution Control Board, State Pollution Control Board and other relevant entities can help resolve disputes and ensure smooth project implementation.
- Regular communication and progress reviews should be established to address emerging issues promptly.
- Municipalities must be made accountable for providing consistent, high-quality feedstock, while developers should adhere to agreed-upon timelines and performance standards.

Develop and implement a centralised real-time monitoring system for Bio-CNG plants

To address the lack of real-time monitoring in this sector, it is essential to establish a centralised system at the Ministry of Housing and Urban Affairs that tracks and reports on Bio-CNG plant performance across cities.

- This system should capture real-time data on key parameters like feedstock quantity, segregation efficiency, gas production rates, and by-product utilisation.
- Such a platform will ensure optimal plant operation, quick issue resolution, and sharing of best practices. For example, the Goa Waste Management Corporation at Salegaon uses a robust monitoring system, publicly updating monthly performance reports to assess concessionaire performance.

Annexure

Checklist for installation of Bio-CNG plant from municipal solid waste

This section provides a comprehensive and step-by-step guide to Urban Local Bodies (ULBs) planning and installation of Bio-CNG plant with a Bio-CNG generation capacity of 5 TPD from segregated organic municipal solid waste.

Step-by-Step Checklist

Step 1: Waste Assessment and Feedstock Availability
- Conduct a detailed municipal waste audit to quantify daily organic waste generation.
- Ensure the availability of a minimum of 150 TPD segregated organic waste(Bio-CNG production will be affected and reduced if the quantum of segregated organic waste is less than 150 TPD).
- Identify major Bulk Waste Generators (BWGs) such as hotels, institutions, and markets.
- Analyse seasonal and daily variations in organic waste generation.

Step 2: Strengthening Source Segregation
- Evaluate the current status of waste segregation; target over 90 per cent segregation at source.
- Design and implement Information, Education, and Communication (IEC) campaigns.
- Deploy dedicated collection infrastructure for organic waste, including vehicles and bins.

Step 3: Site Selection and Suitability
- Select a site with a minimum area of 5–7 acres within or near the city limits.
- Ensure the site meets the following criteria:
  - o Road connectivity and transport accessibility
  - o Availability of utilities (electricity and water supply)
  - o Adequate buffer from residential areas
  - o Free from legal disputes and encumbrances

Step 4: Technology Selection
- Choose a technology provider approved by MNRE or MoPNG.
- Ensure the technology solution includes:
  - o Pre-treatment and shredding units
  - o Anaerobic digestion system
  - o Biogas purification, compression, and bottling units
- Prefer modular and scalable technology designs for future expansion.

Step 5: Financial Feasibility and DPR Preparation
- Prepare a Detailed Project Report (DPR) incorporating:
  - o Capital and operational expenditure estimates
  - o Revenue projections from Bio-CNG, organic manure, MDA, and carbon credits
  - o Break-even analysis and Internal Rate of Return (IRR)
- Identify and secure funding sources: SBM 2.0, 15th Finance Commission, PPP, or other financial source.

Step 6: Statutory Approvals and Regulatory Compliance
- Obtain mandatory clearances and approvals from:
  - o State Pollution Control Board (SPCB)
  - o Petroleum and Explosives Safety Organisation (PESO)

- o Chief Electrical Inspectorate (as applicable)
  - o Fire and Town Planning Departments
- Ensure adherence to SWM Rules, 2016, and applicable technical standards of MNRE/MoPNG.

Step 7: Project Development and Tendering

- Finalize the mode of project implementation (DBO/DBOT/PPP).
- Draft and float a Request for Proposal (RFP) including:
  - o Performance-based output criteria
  - o Penalty clauses for underperformance
  - o Key Performance Indicators (KPIs) linked payment milestones
- Conduct bid evaluation based on technical capability, O&M experience, and financial proposal.

Step 8: Construction and Commissioning

- Consult a qualified Project Management Consultant (PMC) or in-house technical oversight team.
- Supervise construction progress, machinery commissioning, and trial runs.
- Ensure the plant operator(s) are trained and follows operational SOPs.

Step 9: Revenue Assurance and Market Linkage

- Execute long-term purchase agreements with:
  - o Oil Marketing Companies (OMCs) for Bio-CNG
  - o Agricultural stakeholders for organic manure
- Apply for Market Development Assistance (MDA).
- Explore opportunities for carbon credit certification and green financing.

Step 10: Performance Monitoring and Continuous Improvement

- Establish an institutional monitoring mechanism to oversee Bio-CNG plant performance.
- Regularly monitor the following KPIs:
  - o Plant uptime and operational efficiency
  - o Gas production vs. design capacity
  - o Waste volume processed
  - o Revenue streams (Bio-CNG, manure, MDA)
- Conduct:
  - o Monthly internal performance reviews
  - o Bi-annual third-party audits

Risk Mitigation Matrix

Potential Risk	Mitigation Strategy
Low segregation at source	Strengthen IEC activities; enforce source segregation; incentivize compliance
Inconsistent waste quality	Define input standards; introduce quality control at intake
Poor offtake for Bio-CNG/manure	Intital MoUs with buyers; promote local market linkage
Technical downtime or failure	Include AMC clause; maintain spare parts inventory
Delays in regulatory approvals	Designate a nodal officer to fast-track clearances and permissions

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Municipal Solid Waste (MSW) in India comprises approximately 40–60% organic waste. When left untreated or improperly managed, this organic fraction significantly contributes to greenhouse gas (GHG) emissions, particularly methane—a potent climate pollutant. While composting has been the primary method for managing organic waste, the resulting compost is often underutilized due to weak market linkages and limited demand.

In contrast, Bio-CNG offers a promising alternative by converting segregated organic waste into a clean, renewable energy source that can replace fossil fuels in transportation and industry. This report explores the untapped potential of Bio-CNG generation from municipal organic waste, presenting an overview of current operational facilities, their challenges, and the necessary prerequisites for setting up new plants. It further outlines strategic recommendations to ensure effective implementation and scalability of Bio-CNG plants, ultimately contributing to circular economy goals and reducing the carbon footprint of urban waste management systems.

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