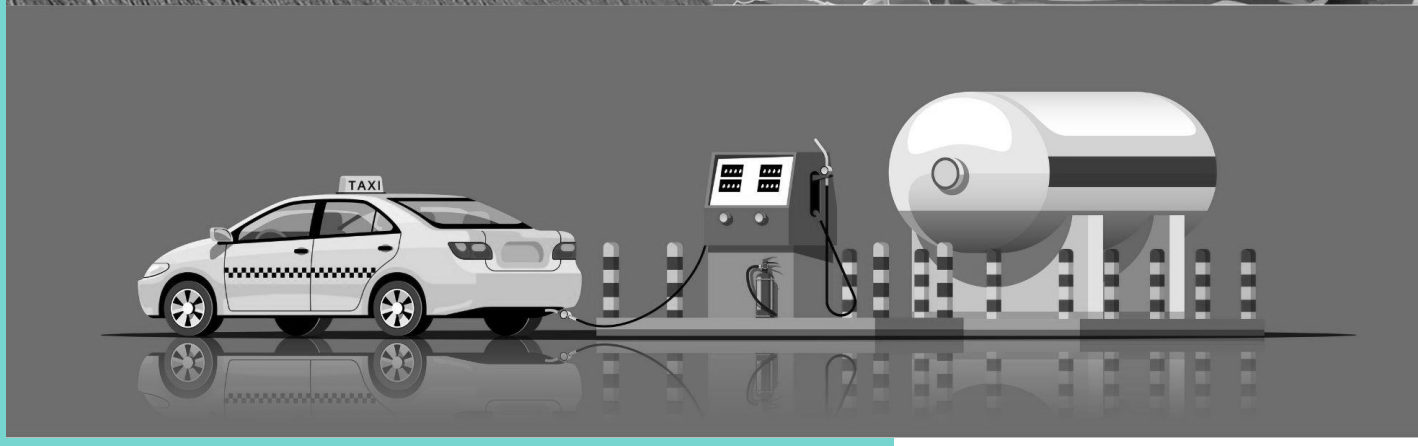


ISSUE BRIEF

WASTE TO WHEEL:
Mainstreaming bio-CNG for Mobility in Indian Cities

OLA MOBILITY INSTITUTE

Energy & Mobility | May 2022 | E&M IB 22/01

Abstract

Extracting clean energy from Municipal Solid Waste (MSW) can potentially solve the dual challenge of disposing of India's ever-growing mounds of garbage and reducing dependence on fossil fuels. The demand from energy-guzzling sectors like transportation, and commitments to decarbonising energy consumption are driving the adoption of indigenous alternative fuels like bio-CNG. With low emissions and fuel characteristics similar to those of conventional CNG, bio-CNG derived from organic waste emerges as a clean and renewable energy source. As urban India continues to generate large quantities of waste, the country's policy framework on the production and consumption of bio-CNG rightfully taps into the massive energy generation potential of waste. Only a few Indian cities have developed a sustainable supply-chain model for this fuel in a captive demand environment. Challenges such as feedstock procurement, financial support, pricing mechanism, and waste management ecosystem etc. restrict the use of bio-CNG in mobility. Situated against this backdrop, this Issue Brief explores the role of bio-CNG as an interim fuel solution towards decarbonising transportation. It advocates for a robust waste to wheel approach that can help India fill the lacunae in the supply chain and overcome institutional impediments in bringing bio-CNG into the mainstream.

Introduction

An era of rampant consumerism brings with it challenges of a growing quantum of waste. The piling up of landfills leading to uncontrolled Greenhouse Gas (GHG) emissions and soil leachate formation are posing a serious threat to the environment (Bhattacharjee & Sinha, 2015). Emissions from these open landfills constitute 50-60% methane - which traps up to 28-36 times more heat than carbon dioxide (CO_2) over a period of 100 years (Gupta et al., 1998, p. 149, 150; Environmental Protection Agency, 2021). Being a rapidly growing climate problem, cutting down on methane emissions became an international priority under the COP26 held in Glasgow, supported by over 110 countries (European University Institute, 2021).

On the other hand, open incineration of waste raises the concentration of carbon dioxide, methane and nitrous oxide in the air (Guendehou et al., 2006, p. 5.5). While the waste problem can ideally be resolved through the "Reduce" component of the Reduce-Reuse-Recycle trio, waste-to-energy models are currently the most preferred option for efficient resource utilisation. As transportation continues to be both an energy and emission-intensive sector, the use of clean fuel from waste must be explored and scaled. Fitting into the equation, bio-CNG, produced from organic waste feedstock, presents an excellent waste-to-value proposition. It burns cleaner than conventional automotive fuel, helps effectively dispose of organic waste, and yields bio-manure as a byproduct (Trivedi & Srivastava, 2021). However, despite the massive growth potential in Indian cities, bio-CNG has not generated enough traction as an automotive fuel.

India imports up to 85% of its crude and around 50% of its natural gas requirements, with a significant chunk of the demand coming from the transportation sector. India is also the world's third largest energy consumer only after China and the United States (Press Trust of India [PTI], 2022). While it reconfigures its energy policies with a conscience to realise the 2070 net-zero goal, India will require adopting multiple pathways in decarbonising its energy future. Currently, Electric Vehicles (EVs) represent the face of decarbonised transport, but bio-CNG as a

fuel is a formidable option less spoken about. Bio-CNG plants can add synergy to the mission through organic waste treatment, generating renewable fuel and bio-manure. Widescale adoption of bio-CNG is expected to reduce import dependence on fossil fuels, mitigate climate change, contribute to rural development and create livelihood opportunities at the local level. In fact, it is estimated to be one of the fastest-growing forms of bioenergy based on IEA's Stated Policy Scenario (STEPS) as well as Sustainable Development Scenario (SDS). The current global consumption of biomethane in transportation is extremely small. However, by 2040 it is expected to reach more than 25 MTOE (Million Tonnes of Oil Equivalent), representing 30% of the total biomethane consumption (International Energy Agency [IEA], 2020).

This issue brief examines the overall framework for deriving bio-CNG from Municipal Solid Waste (MSW). It recognises the role of bio-CNG plants to solve the dual problem of safe disposal of organic solid waste and generating clean energy for transportation in Indian cities. Barriers to mainstreaming it have been identified by delving into the following areas of investigation:

- MSW feedstock availability for the generation of bio-CNG;
- Growth trends in conventional vehicle fuel and potential demand for bio-CNG;
- Fuel characteristics and role in decarbonising transport, reducing air pollution;
- Existing policy framework promoting bio-CNG production and consumption;
- Financing mechanisms for prospective producers;
- Lessons from Indian cities where bio-CNG-based fleets operate;
- Overcoming challenges in mainstreaming bio-CNG.

Using waste to supply the growing CNG demand

India generates around 277.1 million tonnes of MSW per annum which is estimated to reach 543 million tonnes by 2050 according to a 2021 World Bank report. This represents over 13% of the waste generated globally and almost 83% of the waste generated in South Asia alone (World Bank Group, 2021, p. 14). Up to 70% of the waste generated gets treated, and the remaining gets dumped into landfills and unauthorised disposal sites (Ministry of Housing & Urban Affairs [MoHUA], 2021). Roughly half of the treated waste is organic which is convertible to bio-CNG through a process called "biomethanation". In contrast to CNG, which is formed by compressing a fossil fuel (natural gas), bio-CNG can be produced and scaled through renewable pathways. The organic waste biomass undergoes anaerobic digestion where bacteria break it down into simpler compounds in a four-step process. Biomethanation plants execute these steps under controlled conditions to generate biogas and organic manure (Sikora et al., 2017). The biogas is filtered and compressed to yield bio-CNG, which can be used in the existing CNG-based vehicles after meeting the minimum threshold for purity (Table 1). An estimate suggests that over 1.5 million tonnes per annum (MTPA) of automotive-grade Bio-CNG can be generated by treating MSW alone in India (Ministry of New and Renewable Energy [MNRE], 2021).

With the rise in the retail price of conventional automotive fuel, there has been a significant demand for CNG vehicles in the market. From over 41 thousand CNG-only powered vehicle registrations in 2020, the number grew to more than 1.6 lakh units in 2021, almost a four-fold increase. The registration of motor spirit/ CNG vehicles in the passenger vehicle segment also saw a rise of over 12% during the same period, thanks to the aggressive promotion by India's leading automotive manufacturers (Balachandar, 2022). Despite longer

refuelling time and the presence of fewer filling stations than conventional fuels, lower fuel cost has played a big role in attracting consumers to CNG (Dalvi, 2021). India is also ramping up its CNG infrastructure, which is expected to jump from 2700 to 4500 CNG dispensing stations by FY 2025, doubling the overall supply (International Energy Agency, 2021, p. 36).

Volatile geopolitical uncertainties continue to disrupt crude and gas supplies throughout the globe, posing energy security challenges for India. With transportation consuming half of the country's oil products, it remains vulnerable to instabilities caused by price fluctuations of crude and gas (Krishnamurthy, 2022). With low domestic production, the government targets to increase the share of Liquid Natural Gas (LNG) in its energy basket from 6.2% to 15% by 2030, expecting a rising consumption. One of India's leading natural gas corporations, GAIL, expects renewables like biogas and its processed derivatives to play an important role in catering to this demand by the year 2030 (PTI, 2021).

Bio-CNG as an automotive fuel

Bio-CNG exhibits fuel characteristics similar to those of conventional CNG. A study in Camden, UK, noted that a bio-CNG vehicle displayed a 6% better efficiency improvement in fuel consumption when compared to a conventional CNG vehicle. This study also established that bio-CNG can be used interchangeably with CNG as a road transport fuel with no apparent maintenance or operational difficulties (Ministry of Petroleum and Natural Gas [MoPNG], 2018).

Table 1: Bio-CNG Fuel Composition based on IS 16087:2016 Standards (The Global Green Growth Institute [GGGI], 2021):

S.No.	Characteristic	Requirement
1.	Methane Percentage (CH_4), minimum	90%
2.	Carbon dioxide percentage (CO_2), maximum	4%
3.	Carbon dioxide (CO_2) + Nitrogen (N_2) + Oxygen (O_2) percentage, maximum	10%
4.	Oxygen Percentage (O_2), maximum	0.50%
5.	Total sulphur content (including H_2S) mg/m3, maximum	20 mg/m3
6.	Moisture content mg/m3, maximum	5 mg/m3

CO_2 emissions for bio-CNG are 70% lower than that of motor spirit and 69% lower than that of diesel at 48 g CO_2-eq/km. Up to 73% GHG emission reduction is possible when pitched against a standard comparator for fossil fuels of 83.8 gCO_2-eq./MJ (International Renewable Energy Agency [IRENA], 2018, p. 3 & 42). An analysis published by NuGreen suggests that bio-CNG outperforms conventional CNG, biogas and as well as diesel in emissions across 4 parameters (Table 2).

Table 2: Emissions (NuGreen, 2019)				
Emissions (g/KM)	Diesel	CNG	Biogas	Bio-CNG
CO	0.2	0.4	.06	0.02
Hydrocarbons	0.4	0.6	0.35	0.12
NOX	9.73	1.11	5.44	0.48
Suspended Particles	0.1	0.22	0.5	0.1

With the inclusion of Bio-CNG as transport fuel in 2015, BIS standards (IS 16087 2016) for biogas were revised to define the quality of fuel for automotive applications. It also got a nod from the Ministry of Road Transport and Highways (MoRTH) for use in motor vehicles as an alternative to CNG (MoPNG, 2018).

Bio-CNG is thus understood as an indigenous alternative 'future fuel' to decarbonise transportation. The enabling roadmap for bio-CNG production and consumption in India falls under various support programmes listed in Tables 3 and 4.

Table 3: Policy Support		
S.No.	Policies and Schemes	Details
1.	National Policy on biofuels (MoPNG, 2018)	Lays a broad framework for the overall production and consumption of biofuels including bio-CNG using locally procured feedstock.
2.	SATAT: Sustainable Alternative Towards Affordable Transportation (MoPNG, 2018)	Promotes the setting up of bio-CNG plants to produce and supply bio-CNG to Oil Marketing Companies for automotive and industrial use at an assured rate.
3.	Auto Fuel Vision and Policy 2025 (MoPNG, 2014)	Promotes the use of alternative fuels; encourages the switch over from liquid fuel to CNG/LNG by proposing tax benefits and subsidies for vehicles using alternative fuels.
4.	Motor Vehicles Act (Ministry of Road Transport and Highways [MoRTH], 1998)	Section 52 offers provisions for use of bio-CNG in private vehicles.
5.	Solid Waste Management Rules 2016 (Central Pollution Control Board [CPCB], 2016)	Promotes segregation of waste at source and defines the roles of stakeholders to enable derivation of value from waste.

6.	Swachh Bharat Mission (SBM) and Galvanising Organic Bio-Agro Resources (GOBAR) - DHAN Scheme (Department of Drinking Water and Sanitation, 2020)	Promote the conversion of cattle dung and solid waste to Bio-CNG and compost. Aim to set up 75 bio-CNG plants across different municipalities within 2 years from FY 2022.
7.	BIS Specifications for Bio-CNG (Bureau of Indian standards, 2016)	Define the criteria for the composition of biogas for applications in engines, automotive and piped networks.
8.	BDTC: Biogas Development and Training Centre (Indian Institute of Technology Delhi, 2018)	8 institutions set up for research and development of biogas related technologies, including automotive applications of bio-CNG (Temporarily inactive).

Source: Author; compiled from multiple sources

Table 4: Financial Support

S.No.	Programme	Details
1.	Central Financial Assistance under the Programme on Waste to Energy by the Ministry of New and Renewable Energy (MNRE, 2020)	Promoted the setting up of biogas/ bio-CNG/ power plants from waste. A subsidy of INR 4 crore per 4,800 cubic metres of biogas generated per day with a funding cap of INR 10 crore per project is allocated. (Validity expired in March 2021).
2.	Priority Sector Lending - Reserve Bank of India (MoPNG, 2020)	Loans for setting up bio-CNG are under priority sector lending as per Reserve Bank of India guidelines. This is aimed at better credit penetration.
3.	Indian Renewable Energy Development Agency Ltd. (IREDA) Funds (Indian Renewable Energy Development Agency Limited, 2021)	Offers to fund up to 70% of the project cost to entrepreneurs having a contract agreement for the sale of bio-CNG with OMCs with 100% off-take guarantee.

Source: Author; compiled from multiple sources

Feedstock procurement challenges

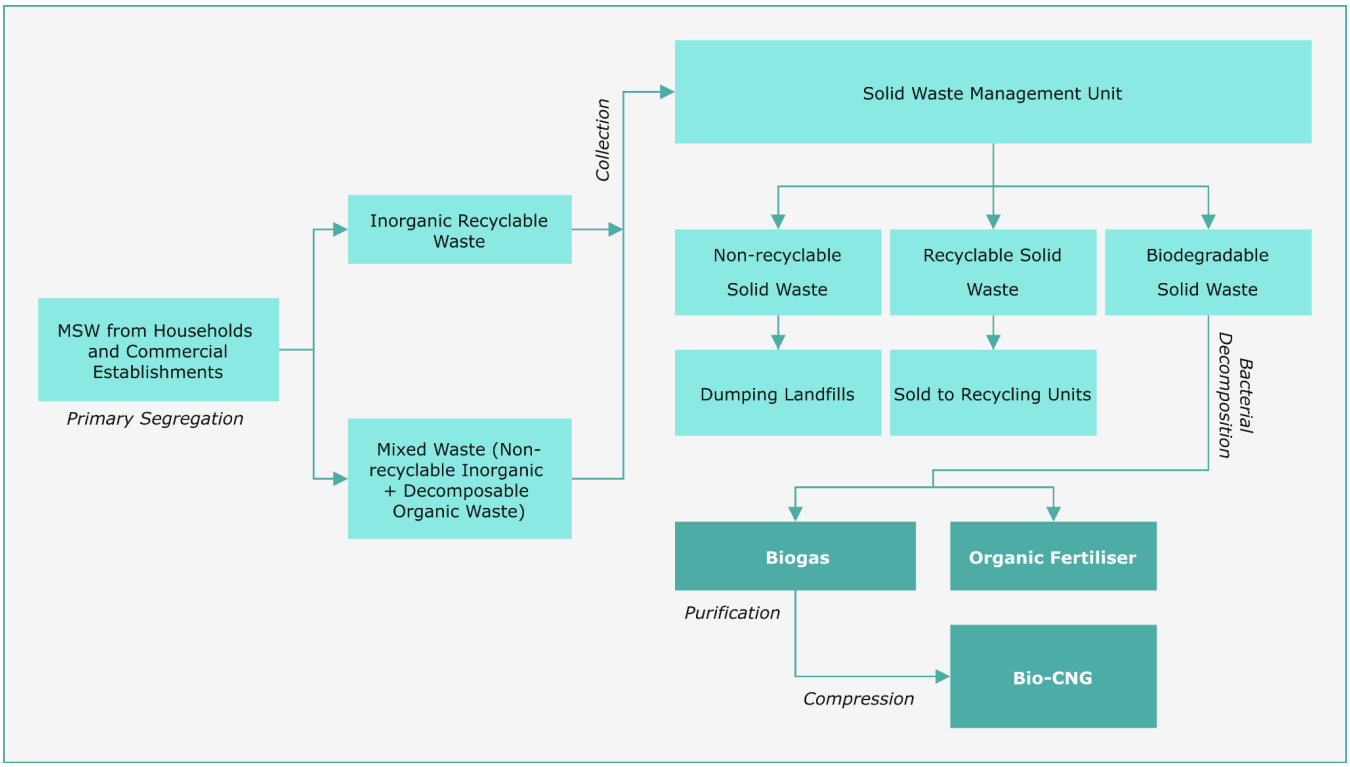
The National Policy on Biofuels 2018 categorises biofuels as 'basic' and 'advanced' based on the type of feedstock as indicated in Table 5. Bio-CNG falls under the 'Advanced biofuels' category, relying on organic waste feedstock without competing against food crops to derive energy. The feedstock can include organic MSW, agricultural waste, and sewage. For urban India, organic MSW holds weight as an important feedstock for bio-CNG plants. However, separating the organic component from the mixed MSW is often a demanding

process for most Indian municipal bodies. It requires close coordination between waste producers, collectors, transporters, processors, and governing agencies in the value chain to ensure a desirable outcome (Kumar et al., 2017).

Table 5: Classification of biofuels based on feedstock (MoPNG, 2018)

Category	Generation	Fuel	Primary Feedstock
Basic	1st generation	Bio-ethanol	Sugar rich materials like sugarcane and sugar beet. Starch-rich materials like corn, cassava and potatoes. Cellulosic materials - bagasse, wood waste, agricultural and forestry residues. Organic industrial waste.
		Bio-diesel	Non-edible vegetable oils, acid oil, used cooking oil, animal fat and bio-oil.
Advanced	2nd generation	Bio-CNG, bio-ethanol, bio-methanol, dimethyl ether (DME), bio-hydrogen, drop-in fuels	Municipal Solid Waste, lignocellulose, non-food crops, industrial waste, residue streams. Feedstock with Low CO_2 emission and high GHG reduction and doesn't compete with food crops for land use.
	3rd generation	Bio-diesel, Butanol Gasoline, Methane, Ethanol, Jet Fuel	Algae

The quality of waste feedstock is defined by the amount of organic content in it, which directly influences the quality of fuel produced, plant's operational efficiency and hence the revenue generated. It is therefore a critical parameter for the sustenance of any bio-CNG plant. This is why cities with a decent waste segregation infrastructure have had better success with bio-CNG production from MSW. For example, the Gobar-Dhan bio-CNG plant in Indore, which is marketed to be Asia's largest biomethanation plant, generates enough bio-CNG to fuel up to 400 buses per day from the 17 tonnes of bio-CNG it produces each day (Prime Minister's Office [PMO], 2022).



Source: Author, Ideas for India (Bhattacharjee, 2015)

The feedstock quality is also subject to temperature and seasonal variations, leading to heterogeneity in waste. Fluctuations in temperature disturb the biomethanation process in the digester, resulting in lower product yield. Therefore, the business model around the bio-CNG supply chain has so far relied on a captive demand ecosystem, where the Urban Local Bodies (ULBs) and private waste management agencies collaborate to secure feedstock supply for plants. For example, the Indore Municipal Corporation (IMC) has established an agreement with a private company that runs the plant to purchase at least 50% of the bio-CNG from it. The company would pay INR 2.5 crore to the IMC to ensure a constant supply of organic waste feedstock. The bio-CNG produced from the plant is expected to be sold to IMC at INR 5 less than the market rate (Kidwai, 2020). The plant also produces bio-manure as a byproduct. Similar bio-CNG plants are expected in 75 more municipalities in India (PMO, 2022). Bhopal, Nagpur, and Pune are also adopting a similar approach for fuelling their city buses by entering into innovative contracts (Jsnewstimes, 2021; Express Drives Desk, 2019; Abidi, 2020). However, adequate success rates in partnerships with ULBs may not hold true for all cities. A consultation with an industry expert revealed that waste management agencies have often found negotiating with ULBs difficult in setting up mutually agreeable pricing terms in feedstock supply.

The role of enabling entities

In 2018, the Ministry of Petroleum and Natural Gas launched the SATAT Scheme to help entrepreneurs set up plants utilising local feedstock for bio-CNG production. The scheme promotes bio-CNG generation in the country by encouraging Oil Marketing Companies (OMCs) to procure bio-CNG from producers at an assured rate of INR 46/kg + applicable taxes. The commercial agreement between the plant owner and an OMC is valid for 15 years, where bio-CNG is delivered to the retail outlets of the OMC (MoPNG, 2018). While the fixed rate

assures plant owners of a captive demand for their produce, a stakeholder consultation with a plant owner revealed it to be inadequate. The procurement rates for bio-CNG have not increased since 2018, despite the cost to consumers having risen significantly. While the low procurement prices and high retail margin may benefit the OMCs, it translates into an impediment for the existing and aspiring plant owners. The absence of a consistent biomass feedstock pricing mechanism has further slowed down the implementation of the scheme. Out of the set target of 5,000 bio-CNG plants by 2023, only 28 are commissioned as of April 2022 (MoPNG, 2022).

An important source of revenue for a bio-CNG plant owner is organic fertiliser. With extremely low penetration of less than 1% of the total fertiliser consumption in India, the market potential of organic fertiliser is largely untapped (MoPNG, 2018). Organic fertilisers are subject to Fertiliser Control Order (FCO) regulations, which restrict them to be sold via the same retail channels as chemical fertilisers. With no incentive to sell organic fertilisers, paired with subsidies and promotion meant for chemical fertilisers, the demand for organic fertilisers is stunted. India allocated over INR 1 (One) lakh crore for the chemical fertiliser subsidy in the 2022-23 budget session, despite the proven degradation caused to soil health (Ministry of Chemicals and Fertilisers, 2022; Tiwari, 2021). The lack of awareness among the farmers also persists regarding its benefits in crop yield, health, and the environment.

The waste to energy programme from the Ministry of New and Renewable Energy (MNRE) has been one of the key financial enablers for aspiring bio-CNG plant owners. Under the provision, a backend subsidy of INR 4 crore was provided to set up a 4.8 TPD bio-CNG plant with a cap of INR 10 crore per project. The financial support, however, expired on 31st March, 2021 and its extension is awaited from the Ministry (PTI, 2021). While the old projects would continue to get financial support, the withdrawal could prevent new entrepreneurs from setting up plants (MNRE, 2022).

Recommendations

Segregating the organic fraction of the MSW is a very resource-intensive process that slows down the efficiency of feedstock procurement in the supply chain. A strong political will to implement Solid Waste Management (SWM) Rules 2016 is required, thereby enforcing penalties for unsegregated household waste and providing incentives for segregation. Urban Local Bodies (ULBs) across cities could replicate Indore's waste management model by studying its rise to become the cleanest city in India. Educational campaigns on source segregation of waste, strengthening institutional networks of ULBs, capacity building, compensating the sanitation staff well, and establishing partnerships with the private sector have been Indore's effective enablers (Das, 2021).

The quality of biogas and bio-CNG is strongly influenced by the quality of feedstock and the homogeneity of its composition. Since temperature plays an important role in defining the yield, seasonal change can influence the bacterial growth in the digesters. This affects the pace of methane production and the final quality of bio-CNG produced. Obtaining consistent fuel quality, therefore, requires shifting to newer technologies and processes that are optimised to benefit the application of bio-CNG in automotive engines.

To mitigate the challenges of high upfront project costs for setting up a bio-CNG plant, a stable financing mechanism is required. The Central Financial Assistance, being one of the main CAPEX subsidies that supports setting up new plants, has not been renewed post 31st march, 2021 (MNRE, 2022). Therefore, setting a high

assured price for bio-CNG for the first few years of establishment of new plants would help offset the CAPEX. Including bio-CNG under the Production Linked Incentive (PLI) Scheme, which provides monetary incentives based on the production capacity, can encourage further growth.

A single window facility for approvals would also be needed for aspiring plant owners to ensure smooth completion of mandatory clearances with respect to land, revenue, municipalities, pollution control board, etc. Although MoPNG is considering such a facility for the future under the SATAT scheme, the challenges arriving from the lack of it, persist.

The cost of feedstock is the direct product of the type of biomass used. A pricing mechanism linked to feedstock quality over a fixed price can potentially enable a sustainable business model and undisrupted supply of bio-CNG. Organic fertiliser, also a product of the biomethanation process, needs to be promoted and subsidised on a large scale and prioritised over chemical fertilisers. It needs to be freed from the FCO regulations and sold through diversified retail outlets to increase its market presence among the farmers. It can support the revenue stream of bio-CNG plant owners and help withstand losses caused due to fluctuations in the quality of feedstock supply.

Models of bio-CNG consumption in a captive demand environment for public transport have been effective growth enablers. They can be synergised by adopting multiple pathways for consumption. For example, while eliminating reliance on fossil fuels like LNG may currently be unfeasible, mandating GAIL to ensure a fixed percentage of biogas and its derivatives in its pipeline could help accelerate the demand. Substituting diesel with bio-CNG in tractors, Diesel Refrigeration Units (DRUs), and municipal garbage trucks can also play a major role in ensuring sustained revenues for plant owners. Both biogas and bio-CNG can be used to produce renewable electricity to power EVs as well as green hydrogen through processes like biogas reforming, water-gas-shift reaction and hydrogen separation (Minh et al., 2018, p. 111). While the current high cost of renewable electricity and green hydrogen could be a barrier, emerging low-cost technologies and processes can potentially fix it.

Exploring the aforementioned routes including removing impediments in the supply chain can thus mitigate urban India's waste problem and its dependence on fossil fuels. A robust waste to wheel approach should be integrated into policies defining the future of urban mobility and energy transitions.

References

Abidi, S. (2020, June 5). City waste to fuel 100 bio-CNG buses in Pune. *Autocar Professional.* https://www.autocarpro.in/feature/city-waste-to-fuel-100--biocng-buses-in-pune-56521

Balachandar, G. (2022, January 16). Path to clean mobility: a big surge in the sale of CNG vehicles in 2021. *The Hindu BusinessLine*. https://www.thehindubusinessline.com/companies/path-to-clean-mobility-a-big-surge-in-the-sale-of-cngvehicles-in-2021/article64880790.ece

Bhattacharjee, S., & Sinha, U. (2015, April 22). *Making the best out of waste*. Ideas for India. Retrieved March 28, 2022, from https://www.ideasforindia.in/topics/environment/making-the-best-out-of-waste.html

Bureau of Indian Standards. (2016). *Biogas (Biomethane) - Specification (First Revision)*. Bureau of Indian Standards. Retrieved March 28, 2022, from https://standardsbis.bsbedge.com/BIS_SearchStandard.aspx?Standard_Number=IS%2016087&id=27

Central Pollution Control Board. (2016). *Solid Waste Management Rules 2016*. Central Pollution Control Board. https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf

Dalvi, A. (2021, November 9). CNG car sales grow 97 percent in April-September 2021. *Autocar India*. https://www.autocarindia.com/car-news/cng-car-sales-grow-97-percent-in-april-september-2021-422554

Das, M. (2021, November 27). These are the secrets to Indore's 5-year 'cleanest city' streak. And it's not rocket science. *ThePrint*. https://theprint.in/india/these-are-the-secrets-to-indores-5-year-cleanest-city-streak-and-its-not-rocket-science/772362/

Department of Drinking Water and Sanitation. (2020). *Gobardhan*. SBM | Gobardhan. Retrieved March 28, 2022, from https://sbm.gov.in/gbdw20/

Environmental Protection Agency. (2021, June 30). *Importance of Methane | US EPA*. US Environmental Protection Agency. Retrieved March 31, 2022, from https://www.epa.gov/gmi/importance-methane

Environmental Protection Agency. (2021, October 18). *Understanding Global Warming Potentials | US EPA* . US Environmental Protection Agency. Retrieved April 26, 2022, from https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

European University Institute. (2021, November 22). *The COP26 methane moment*. Florence School of Regulation. Retrieved April 26, 2022, from https://fsr.eui.eu/the-cop26-methane-moment/

Express Drives Desk. (2019, November 27). 80 per cent of buses in Nagpur running on Bio-CNG: Nitin Gadkari. *The Financial Express*. https://www.financialexpress.com/auto/car-news/nagpur-buses-bio-cng-nitin-gadkari-air-pollution-cng-morth/1777298/

The Global Green Growth Institute. (2021). *Landscape Analysis of Bio-CNG in India*. The Global Green Growth Institute. https://gggi.org/site/assets/uploads/2021/10/Landscape-Report-of-BioCNG-in-India-GGGI-1.pdf

Guendehou, G.H. S., Koch, M., Hockstad, L., Pipatti, R., & Yamada, M. (2006). *Incineration and Open Burning of Waste* (Vol. 5). Intergovernmental Panel on Climate Change. https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/5_Volume5/V5_5_Ch5_IOB.pdf

Gupta, S., Mohan, K., Prasad, R., Gupta, S., & kansal, A. (1998, November). Solid waste management in India: options and opportunities. *ScienceDirect*, *24*(2). https://doi.org/10.1016/S0921-3449(98)00033-0

Indian Institute of Technology Delhi. (2018). *BDTC - Biogas Development and Training Centre* . Biogas Research Group. Retrieved March 28, 2022, from https://web.iitd.ac.in/~vkvijay/BDTC.html

Indian Renewable Energy Development Agency Limited. (2021). *IREDA Loan Scheme for "Compressed Bio- Gas (CBG)" under SATAT Scheme*. IREDA. Retrieved March 28, 2022, from https://www.ireda.in/images/HTMLfiles/Compressed%20Biogas%20Financing.pdf

International Energy Agency. (2020). *Outlook for biogas and biomethane: Prospects for Organic Growth.* International Energy Agency. https://iea.blob.core.windows.net/assets/03aeb10c-c38c-4d10-bcec-de92e9ab815f/Outlook_for_biogas_and_biomethane.pdf

International Energy Agency. (2021). *Gas Market Report Q3-2021*. International Energy Agency. https://iea.blob.core.windows.net/assets/4fee1942-b380-43f8-bd86-671a742db18e/GasMarketReportQ32021_includingGas2021Analysisandforecastto2024.pdf

International Renewable Energy Agency. (2018). *Biogas for road vehicles: Technology brief*. International Renewable Energy Agency, Abu Dhabi. https://www.irena.org/-/media/files/irena/agency/publication/2017/mar/irena_biogas_for_road_vehicles_2017.pdf

Jsnewstimes. (2021, October 13). Initiative of Madhya Pradesh government, Bio CNG will be prepared from the waste of your homes, will be used in city buses. *Jsnewstimes*. https://jsnewstimes.com/mp/initiative-of-madhya-pradesh-government-bio-cng-will-be-prepared-from-the-waste-of-your-homes-will-be-used-in-city-buses

Kidwai, A. (2020, August 29). *Indore announces plans for one of Asia's largest biomethanation plants*. Solid Waste India. https://solidwasteindia.com/indore-announces-plans-for-one-of-asias-largest-biomethanation-plants/

Krishnamurthy, R. (2022, February 25). Russia-Ukraine war to have 'ripple effects' on India's fuel prices: Experts. *Down To Earth*. https://www.downtoearth.org.in/news/energy/russia-ukraine-war-to-have-ripple-effects-on-india-s-fuel-prices-experts-81714

Kumar, S., Smith, S., Fowler, G., Velis, C., Kumar, S., Arya, S., Rena, Kumar, R., & Cheeseman, C. (2017, March 22). Challenges and opportunities associated with waste management in India. *Royal Society of Open Science*. https://doi.org/10.1098/rsos.160764

Minh, D. P., Siang, T. J., Vo, D.-V. N., phan, T. S., Ridart, C., Nzihou, A., & Grouset, D. (2018). Chapter 4 - Hydrogen Production From Biogas Reforming: An Overview of Steam Reforming, Dry Reforming, Dual Reforming, and Tri-Reforming of Methane. *ScienceDirect*, 111-166. https://doi.org/10.1016/B978-0-12-811197-0.00004-X

Ministry of Chemicals and Fertilisers. (2022). *Notes on Demands for Grants, 2022-2023*. Ministry of Finance, Government of India. https://www.indiabudget.gov.in/doc/eb/sbe6.pdf

Ministry of Housing & Urban Affairs. (2021, December 9). 70 percent Municipal Solid Waste (MSW) processing achieved under Swachh Bharat Mission - Urban. *Press Information Bureau*. https://pib.gov.in/Pressreleaseshare.aspx?PRID=1779680

Ministry of New and Renewable Energy. (2020). *Programme on Energy from Urban, Industrial, Agricultural Wastes/Residues and Municipal Solid Waste (2019-2020) - Revised guidelines of Waste to Energy Programme - Reg.* Ministry of New and Renewable Energy, Government of India. https://mnre.gov.in/img/documents/uploads/file_s-1584425847955.pdf

Ministry of New and Renewable Energy. (2021). *Mapping the available urban and industrial organic waste in various locations in India*. Energy Potential (MW). Retrieved March 29, 2022, from https://bio-energy.isid4india.org/

Ministry of New and Renewable Energy. (2022, February 3). Establishment of Bio-Gas Plant. *Press Information Bureau*. https://pib.gov.in/PressReleseDetail.aspx?PRID=1795249

Ministry of Petroleum and Natural Gas. (2014). *Auto Fuel Vision and Policy*. Ministry of Petroleum and Natural Gas. http://petroleum.nic.in/sites/default/files/autopol.pdf

Ministry of Petroleum and Natural Gas. (2018). *National Policy on Biofuels*. Ministry of Petroleum and Natural Gas. https://mopng.gov.in/files/uploads/NATIONAL_POLICY_ON_BIOFUELS-2018.pdf

Ministry Of Petroleum and Natural Gas. (2018). *Organic Fertilizers*. Satat. Retrieved March 31, 2022, from https://satat.co.in/satat/organic-fertilizers.html

Ministry of Petroleum and Natural Gas. (2018). *SATAT: Frequently Asked Questions*. Satat. Retrieved March 28, 2022, from https://satat.co.in/satat/faq.html

Ministry of Petroleum and Natural Gas. (2020, June 23). Financing for Compressed Bio-Gas plants to be brought under Priority Sector Lending, says Shri Dharmendra Pradhan. *Press Information Bureau*. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1633560

Ministry of Petroleum and Natural Gas. (2022). Satat : Home. Retrieved April 28, 2022, from https://satat.co.in/satat/

Ministry of Road Transport and Highways. (1988). *The Motor Vehicles Act 1988*. Ministry of Road Transport and Highways. https://legislative.gov.in/sites/default/files/A1988-59.pdf

NuGreen. (2019). *BIO-CNG*. Nugreen Energy. Retrieved March 28, 2022, from https://nugreenenergy.in/bio-cng.php

Press Trust of India. (2021, November 25). Indias gas consumption to jump more than 3 times by 2030: GAIL Directors. *Business Standard*. https://www.business-standard.com/article/current-affairs/india-s-gas-consumption-to-jump-more-than-3-times-by-2030-gail-director-121112500902_1.html

Press Trust of India. (2021, December 20). Indian Biogas Association (IBA) condemns govt for withdrawing subsidy on biogas plants. *Economic Times*. https://economictimes.indiatimes.com/industry/renewables/iba-condemns-govt-for-withdrawing-subsidy-on-biogas-plants/articleshow/88391039.cms?from=mdr

Press Trust of India. (2022, February 4). India to double down on oil, gas exploration: Hardeep Singh Puri. *The Economic Times*. https://economictimes.indiatimes.com/industry/energy/oil-gas/india-to-double-down-on-oil-gas-exploration-hardeep-singh-puri/articleshow/89345188.cms

Prime Minister's Office. (2022, February 19). PM inaugurates municipal solid waste based Gobar-Dhan plant in Indore. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1799603

Sikora, A., Detman, A., Chojnacka, A., Błaszczyk, M. K., & Cruz, S. R. (2017, February 8). *Chapter: Anaerobic Digestion: I. A Common Process Ensuring Energy Flow and the Circulation of Matter in Ecosystems. II. A Tool for the Production of Gaseous Biofuels*. IntechOpen. Retrieved March 31, 2022, from https://www.intechopen.com/chapters/51769

Tiwari, P. (2021, July 22). Creeping disaster: Over half of India's soil is degraded. *Newslaundry*. https://www.newslaundry.com/2021/07/22/creeping-disaster-over-half-of-indias-soil-is-degraded

Trivedi, V., & Srivastava, S. (2021, January 20). Clean push: Why compressed biogas has an edge over CNG. *Down To Earth*. https://www.downtoearth.org.in/news/energy/clean-push-why-compressed-biogas-has-an-edge-over-cng-74874

World Bank Group. (2021). *India: Sustainable Solid Waste Management in Mountain Areas*. The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/35499/India-Sustainable-Solid-Waste-Management-in-Mountain-Areas.pdf?sequence=1&isAllowed=y

Ola Mobility Institute (OMI) is the policy research and social innovation think-tank of Ola, focused on developing knowledge frameworks at the intersection of mobility innovation and public good. The Institute concerns itself with public research on electric mobility, energy and mobility, urban mobility, accessibility and inclusion, and future of work and platform economy. All research conducted at OMI is funded by ANI Technologies Pvt. Ltd. (the parent company of brand Ola).

www.ola.institute

mobilityinstitute@olacabs.com

https://twitter.com/OlaMobilityInst

https://medium.com/@mobilityinstitute

Author:

Adhnan Nazir Wani

Adhnan is a Research Intern at OMI. He holds a Masters in Social Design (M.Des) from the School of Design, Ambedkar University Delhi.

Editors: Roshan Toshniwal, Associate Director & Head, Urban Mobility; Aishwarya Raman, Director & Head of Research

Peer Reviewers: Kevin Houston, Owner & Co-founder, Carbon Masters; Akshay Mani, Senior Associate - Zero Emissions Transport, Evenergi

Cover Image: Photos by Pch.vector, Upklyak and jcomp on Freepik and Pixabay.

Suggested Citation: Wani, A. 2022. *Waste to Wheel: Mainstreaming Bio-CNG for Mobility in Indian Cities*. Ola Mobility Institute.