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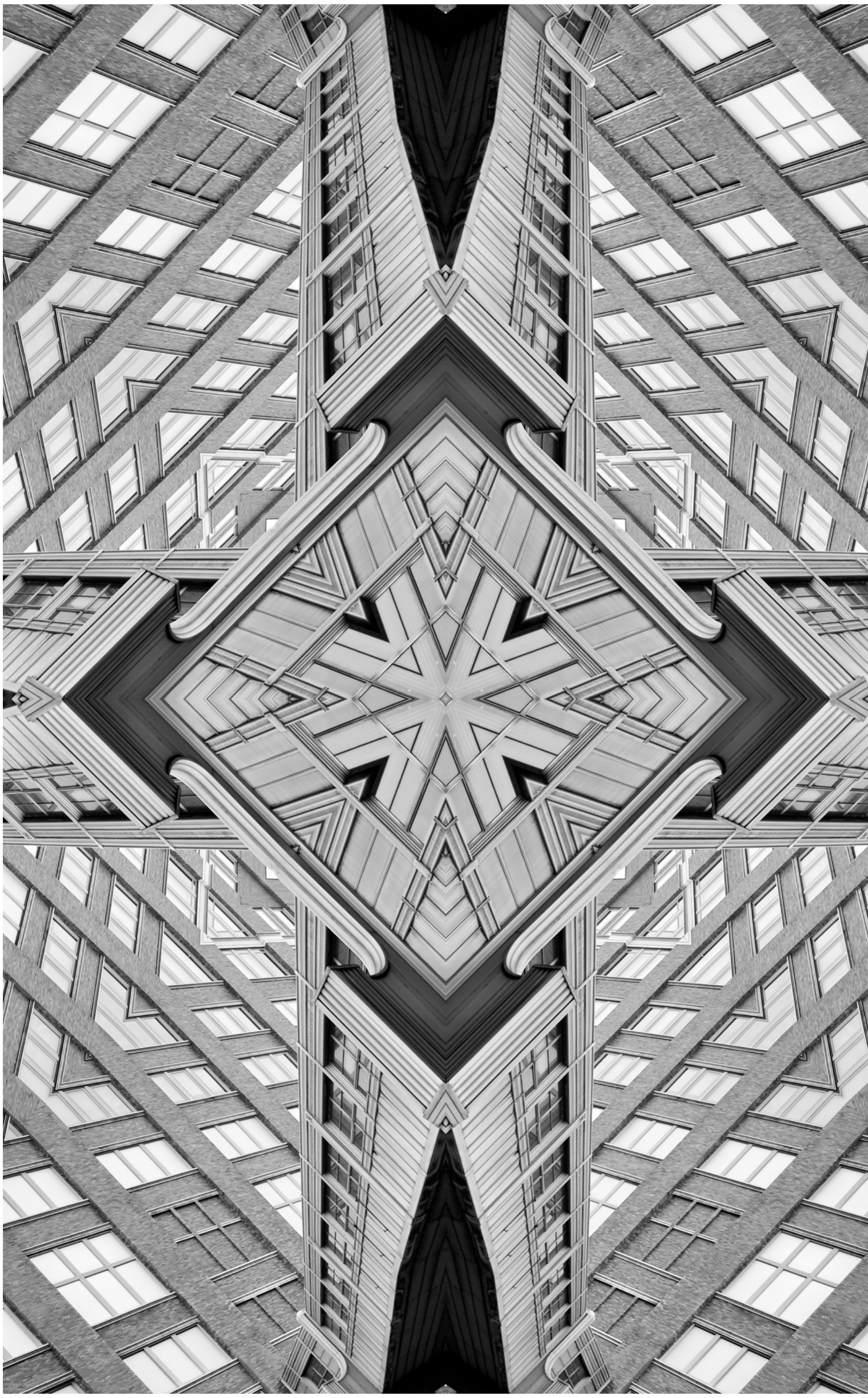

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Energy Transition Through Waste-to-Energy Projects in Peri-Urban and Rural Areas

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Abstract

Waste-to-energy projects in India have historically been city-centric. As cities are well-served by LPG and CNG distribution systems, the Bio-CNG produced has to be used for either fuelling urban public transport, or moved to rural areas at considerable cost. Distributed production and distribution of compressed biogas (CBG) from municipal organic waste in rural and peri-urban areas could be a cheaper option for local consumers. Such production and distribution of CBG would also address issues of household air pollution due to solid cooking fuels, and foreign exchange outflow on account of importing cooking fuel. This brief discusses two delivery models for CBG and argues that India is in a position to demonstrate its own model at scale to the world, towards accelerating energy transition.

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Introduction

Over the past decade, India has made significant progress in replacing the use of solid fuels such as wood, biomass, and cow dung cakes with clean cooking options, primarily liquefied petroleum gas (LPG). This transition helps address the issue of household air pollution (HAP) and associated morbidity and mortality caused by the use of solid cooking fuels.[1] HAP causes at least 800,000 premature deaths annually in the country.[2]

About 99.98 percent of Indian households had access to LPG by April 2021,[3] and domestic LPG consumption grew by over 76 percent between 2013-14 and 2021-22.[4] During FY 2021-22, India recorded 305 million active LPG subscribers of which 90 million were added following the launch in 2016 of the '*Pradhan Mantri Ujjwala Yojana*' (PMUY) scheme.[5,6] However, PMUY may be nearing saturation, as seen in the halved budgetary allocation in the current FY 2022-23, of ₹8 billion, down from ₹16 billion.[7] PMUY beneficiaries also appear to be consuming only half as much LPG as the non-PMUY consumers.[8]

To optimise the health and environmental benefits of shifting to LPG use from solid cooking fuels, significant efforts are required to bridge the gap between connection and sustained use. Suggestions such as advance subsidy instead of subsidy reimbursement, improved distribution network, and incentives for rural distributors have been made.[9] While these can help improve LPG consumption, they could perpetuate import dependence.[10]

This brief explores the potential of biogas as cooking fuel from Municipal Solid Waste (MSW), which if produced and distributed locally, could be a cheaper option for the rural and peri-urban consumers and thus simultaneously address the issues of HAP, and foreign exchange outflow on account of importing cooking fuel. The Government of India Guidelines for implementation of Waste to Energy Programme for FY 2021-22 through FY 2025-26 (Phase-I) issued on 2 November 2022, aims to do just that with financial assistance worth ₹6 billion for project developers.[11] Additionally, the approximately 108 million tonnes of organic solid waste generated annually could be put to use for production of biogas, addressing mismanagement of MSW, and avoiding methane emission that is 28 to 36 times more effective than CO_2 at trapping heat in the atmosphere over a 100-year period.[12] India ranks third among 164 countries in terms of MSW generation with at least 226 million tonnes per year. About 48 percent of MSW is composed of organic matter.[13]

The waste-to-energy model of local production and distribution could serve the developing world well, including LDCs that have high usage of solid cooking fuels. For the purpose of illustration, this brief considers the Sundarbans region in West Bengal, India. The region is among the poorest in the state, is comprised of small deltaic islands, unlikely to be ever connected to the expanding gas grid, and poses logistical challenges for material and service delivery. If local production and distribution of CBG can be demonstrated in the Sundarbans, the model would be replicable in other rural and peri-urban areas of India, and other countries in the developing world.

According to a 2014 World Bank Report,[14] one of the primary environmental health risks in the Sundarbans besides inadequate water supply, sanitation and hygiene (WSH), is household air pollution due to the use of solid cooking fuels. These risk factors contribute considerably to mortality and morbidity, particularly among women and children due to exposure to high levels of indoor air pollution from biomass-based cooking fuels.[15] Women and children are typically responsible for chores such as cooking and collecting firewood, and suffer the most grave health consequences from the use of polluting fuels in homes.[16] In 2008 alone, these risk factors caused an estimated 1,850 deaths and nearly 370,000 cases of illness such as acute lower respiratory infections, acute upper respiratory infections, and chronic obstructive pulmonary disease. The annual cost of these health effects is estimated in the range of ₹1.5 to 3.8 billion. About 80 percent of the total cost is associated with mortality and 20 percent with morbidity.[17]

LPG as Clean Cooking Fuel

In May 2016, the Ministry of Petroleum and Natural Gas introduced the *Pradhan Mantri Ujjwala Yojana* (PMUY)—a scheme to replace traditional cooking fuels such as firewood, coal, and cow-dung cakes,[18] with LPG as a clean cooking fuel in all rural households and deprived households in urban areas. The target of the scheme was to deliver 80 million LPG connections by March 2020, and it provided financial support of ₹1,600 or ₹1,150 for a 14.2 kg cylinder and for a 5 kg cylinder, respectively. Additionally, the consumers were supported with a one-time free refill. The subsidy would be credited to the bank accounts of the beneficiaries. As of 21 May 2022, the Government announced a targeted subsidy of ₹200 per 14.2 kg cylinder for PMUY beneficiaries for up to 12 refills for the year 2022-23. However, the national average for LPG consumption has remained low at 6.25 cylinders (14.2 kg) per annum, and lower still for PMUY beneficiaries at 2.76 cylinders (14.2 kg).[19] According to the major LPG distribution companies, around 89 million connections were provided up to 2021-22 of which only 10 million consumers refilled their cylinders once; nine million did not refill even once.[20]

The following paragraphs outline the most crucial reasons for low uptake of LPG as cooking fuel.

Fuel Stacking: Historically, significant proportions of households in India have used multiple fuels for cooking, relying on wood, cow dung, or crop residue. In 1977, only 2.5 percent of all households across India were LPG consumers;[21] the proportion is now claimed by government to be 99.98 percent.[22] Despite increased LPG access, about 38 percent of Indian homes supplement LPG with solid fuels. A majority of these households are in the rural districts of India's eastern and central regions.[23]

Affordability: One of the primary reasons for the low uptake of LPG is cost of connection and of refills. Refilling requires an average rural household in India to spend 9.3 percent of their overall monthly expenditure for exclusive LPG use; the proportion is 7.1 percent in the urban areas.[24]

Receipt of Subsidy: The subsidy amount is directly credited to the consumer's account after every refill. Therefore, the consumer has to pay the entire refill amount to the retailer upfront. The inability—or unwillingness—to pay ₹1,067 upfront is a deterrent. According to a study by the Council on Energy, Environment and Water (CEEW), a not-for-profit policy research institution,[25] 13 percent of the target households did not receive the subsidy for their last LPG refill, and 23 percent were not aware if they had received it or not.

Unavailability of LPG: At present, there are around 26,000 LPG distributors in the country.[26] However, only 54 percent of all rural LPG users get their LPG refills delivered at home due to logistical constraints.[27] In rural areas, households that do not have access to home delivery have to travel an average distance of nearly 10 km to get their cylinders refilled and make their way back home.

A sustainable transition from biomass to LPG (or equivalent cooking fuels) will be achieved only when household incomes rise to sustain consumption.[28] The valuation of time savings should also increase. According to a World Bank study in the Indian Sundarbans, adoption of LPG stoves provides the lowest benefits relative to costs, unless all benefits are included (health, fuel, and time benefits).[29] The shift in emphasis of subsidy from PMUY to Waste to Energy Programme is opportune.

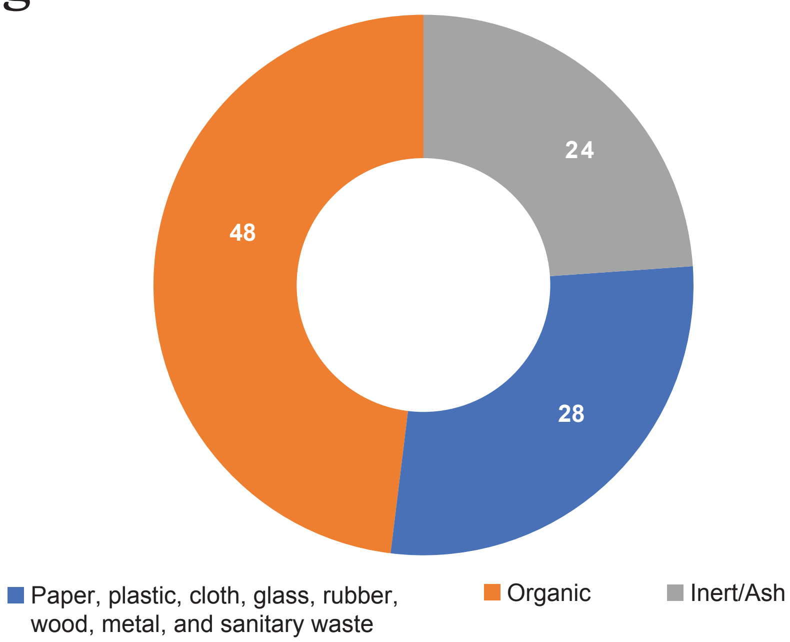
> 38% of Indian homes still supplement their LPG with solid fuels.

Globally, rapid urbanisation, increasing population, and changes in lifestyle and food habits in the developing world are leading to increased generation of waste. Waste management is expensive and it can be the single highest budget item for many local administrations in low-income countries, where it comprises nearly 20 percent of municipal budgets, on average. In middle-income countries, solid waste management typically accounts for more than 10 percent of municipal budgets.[30] India being a lower-middle-income country, falls somewhere in between and would require a large budgetary allocation for waste management of at least 226 million tonnes of municipal solid waste (MSW) per year,[31] of which about 48 percent is composed of organic matter.[32]

Indeed, waste management has become a critical issue that India must address cost effectively on an immediate basis. Many other countries are experiencing the same, and in smaller geographies like islands, the issue is even more critical due to limited land areas and with local reefs, lagoons or inshore fisheries, and freshwater lens being particularly vulnerable to pollution.[33]

Municipal Solid Waste in West Bengal consists of organic, inorganic recyclables and inorganic non-recyclable materials, mostly heterogeneous in nature. Figure 1 shows the components.

Figure 1: Major Components of MSW in West Bengal



Source: State of Environment Report, West Bengal 2016[34]

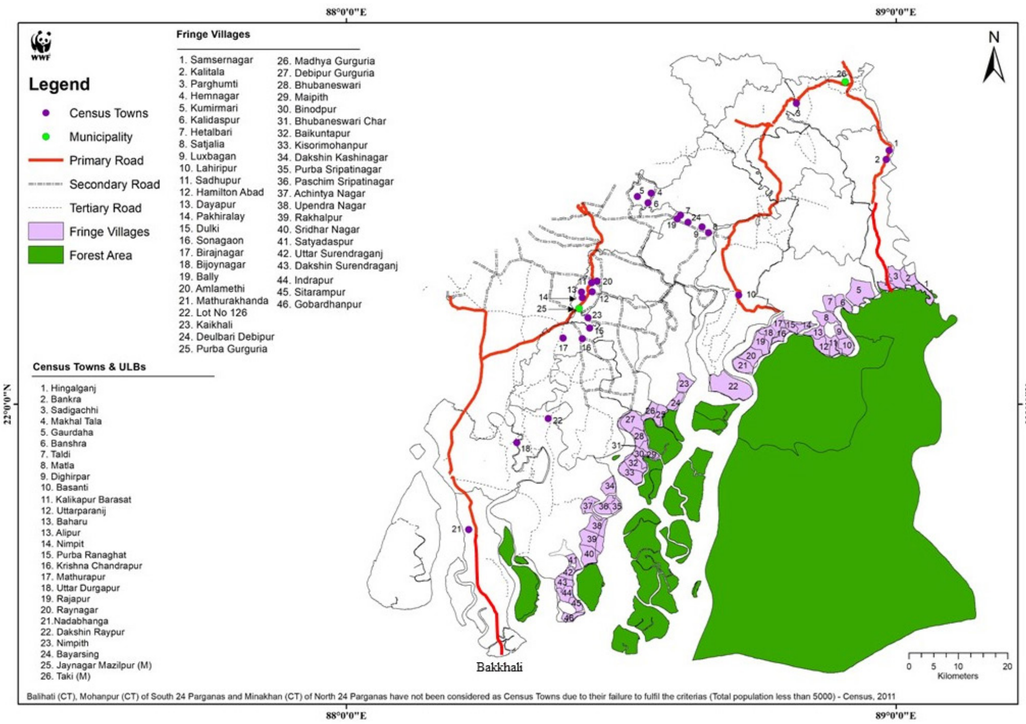
Management of Municipal Solid Waste

As per various reports[35] and articles,[36] around 90 percent of municipal waste generated in West Bengal is dumped in the open. Depending on conditions at the dump site, degradation is aerobic or anaerobic. The main degradation products are carbon dioxide (CO_2), water and heat for the aerobic process and methane (CH_4) and CO_2 for the anaerobic process.[37]

The Sundarbans region in West Bengal is predominantly rural with only two statutory towns (Urban Local Body), but the region is urbanising rapidly. The population in the 24 Census Towns increased from 65,684 in 2001 to 318,196 in 2011. A Census Town[38] (CT) is an urban area defined by the Registrar General and Census Commissioner of India that is not statutorily notified or administered as a town. A village is considered as a CT if it has: 1) > 5,000 population, 2) at least 75 percent of male main working population is employed in non-agricultural sectors, and 3) a minimum density of 400 persons per sq-km. The most populous CT in the region has a population of 31,000, while eight others have more than 10,000 people. The rest have a population between 5,000 and 10,000. Typically, a household in these CTs generates a kilogram of solid waste per day.[39] Overall, there are 190 self-governing village clusters (*gram panchayat*) comprising nearly one million households with a potential waste generation of one million kg per day. Considering that 90 percent of the waste is dumped in the open, the Sundarbans region is emitting around 0.6Mt CO_2 per year.[40] This will only increase with increasing urbanisation.

Figure 2 shows the location of CTs and ULBs in the Sundarbans and the villages that are difficult to cater to in the absence of decentralised production and distribution of clean cooking fuels.

Figure 2:
Census Towns and forest-fringe villages of the Sundarbans



Source: WWF-India

The Potential of Waste-to-Energy Programmes

Biomethanation is one of the most technically viable options for Indian municipal solid waste (MSW) due to the presence of high organic and moisture content, and decentralised production and distribution of clean cooking fuels. Simple small- to medium-scale systems have been developed and are being implemented in different parts of India. According to the Ministry of New and Renewable Energy (MNRE), 4.3 million family-type biogas plants have been installed across India.[41] There are some well-known examples of small-scale MSW-based biogas plants:

1. In Vijayawada, 16 tonnes of MSW and four tonnes per day (TPD) of slaughterhouse waste is used for production of biogas;

2. In Koyambedu, Chennai, a 30 TPD flower and fruit market waste-based biogas plant is in operation; and

3. Lucknow has a 500 TPD MSW-based facility.

MSW-based large biogas plants have met with limited success in India. Nevertheless, India's biggest private sector bank recently invested in the largest Bio-CNG plant in Asia.[42] The limited success of MSW-based large biogas plants is not related to the basic technology. Rather, it is more due to lack of understanding of the process, poor planning capability, and issues of quality and quantity of MSW supply. The overall performance of the biomethanation plant is greatly influenced by the input feed specification, and the plant requires segregated biodegradable MSW for optimal plant performance. It needs bearing in mind that homogeneity of the feed material is an important efficiency parameter for the plant.

Biomethanation will address the issue of mismanaged municipal solid waste, and also contribute to climate action by abating methane emission which is far more potent than carbon dioxide as a greenhouse gas.[43] However, a biomethanation plant requires a consistent source of degradable organic matter free from inert material as well as a sustainable demand for the generated biogas at appropriate economic conditions.

Although a biomethanation plant can be operated at decentralised level (up to 5 TPD), for the local authorities, biomethanation is more cost-intensive than open aerobic composting, but the process produces much less odour, requires less land, and there is no menace from the swarming of scavenger birds. For high population-density areas, all of these are advantages that are worth noting. The economic viability of the biomethanation plants can be ensured if there is a sustainable and viable market for the generated biogas in the vicinity of the plant and the sludge manure produced during the process.

The Solid Waste Management Rules, 2016[44] provides guidance on biomethanation, with Clause 15 outlining the "Duties and responsibilities of local authorities and village Panchayats of census towns and urban agglomerations." Clause 4 enumerates the "Duties of waste generators." The term "waste generator" means and includes every person or group of persons, every residential premises and non-residential establishments including Indian Railways, defence establishments, which generate solid waste.

The production and distribution of Biogas/ BioCNG from municipal solid waste can help address India's massive challenges of household air pollution due to solid cooking fuels, low uptake of LPG, and mismanaged municipal waste. Guided by this vision, the Ministry of New and Renewable Energy (MNRE) has notified the National Bioenergy Programme for the period 01.04.2021 through 31.03.2026 under Phase-I. The objective of the programme is to support the setting up of Waste-to-Energy projects for production of Biogas/ BioCNG/ Power/ producer or syngas from urban, industrial and agricultural wastes/ residues. The programme provides subsidies in the form of Central Financial Assistance (CFA) to project developers, and service charges to implementing and inspection agencies in respect of successful commissioning of Waste to Energy plants for production of Biogas, Bio-CNG/enriched Biogas/Compressed Biogas, Power/ production of producer or syngas.[45]

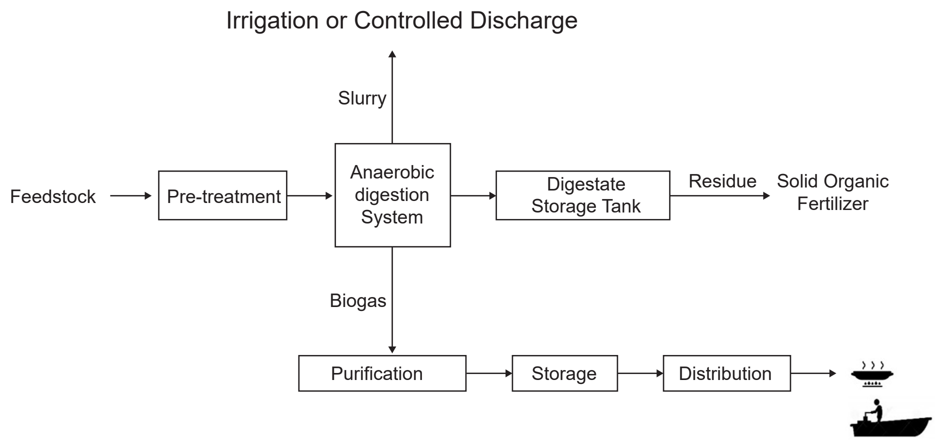
Biogas can be produced by processing municipal solid waste generated locally and converting it into compressed biogas (CBG). The generated CBG can be delivered through a pay-as-you-go model, even to remote communities either through pipelines or in bottled form.

Biogas is produced when a certain group of bacteria digest organic matter in absence of oxygen. In this process of anaerobic digestion, chemical energy is extracted from organic matter under controlled conditions in a sealed container. The general process flow of a biogas plant is presented in Figure 3. The steps involved are:

- Hydrolysis/liquefaction -- $(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6)$
- Acid Formation (acidogenesis & acetogenesis) -- $n(C_6H_{10}O_5) + \rightarrow nCH_3COOH$
- Methanogenesis - $3nCH_3COOH \rightarrow \mathbf{nCH_4} + CO_2$

A retention time of about 30 days is required to maintain the quality of the biogas (methane content and pH value). The purification process removes Sulphur, CO_2 and other impurities to upgrade it to Bio-methane (CH_4 content of >90 percent). This can be used for various heating and power delivery purposes. Per kg of organic waste can deliver around 0.035 to 0.04m^3 of gas[46] and 1m^3 of gas is equivalent to 0.42 kg of LPG.[47]

Figure 3:
The Process Flowchart of a Biogas Plant



Source: Liu et al, 2011[48]

The Waste-to-Energy Business Model

A collective enterprise in the form of Limited Liability Partnership (LLP) or a cooperative could be set up to act as the local distributor and operator of the cooking gas supply. The project developer/generator would be responsible for producing the Biogas which will be stored and transported in a container. The economic viability of the enterprise would depend on the following factors:

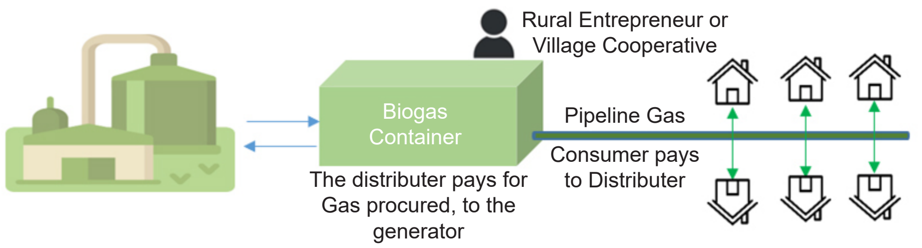
- Reliability of organic waste supply for year-round availability
- Cost of supply and segregation of waste (cost of land is not accounted for since the anaerobic digestion and purification systems would be co-located at the Gram Panchayat's waste handling unit)
- Consumer demand and willingness to pay for clean cooking fuel
- Governance and operational capacity of the village enterprise
- Local government support
- Availability of funds for capital equipment supply and installation

The capital expenditure of a typical 15TPD plant is around ₹70 million (excluding land and bottling cost) and an average annual operational cost of ₹9.6 million. The initial expenditure of such a plant could be co-financed through blended financing options. The ratio would depend on the schemes available (Central Financial Assistance is capped at ₹50 million for Biogas and ₹100 million for Compressed Biogas) and the rest of the capital infusion particularly for the distribution enterprise could come through CSR-based funding or debts from financial institutions. A working capital grant through philanthropic organisations to the community-based village enterprise (distributor) would ensure delivery of the cooking fuel at a price point that the community would be willing to pay. A CEEW study[49] in 2020, found that if per household per LPG refill expenditure was limited to ₹450, the LPG adoption gap would be eliminated.

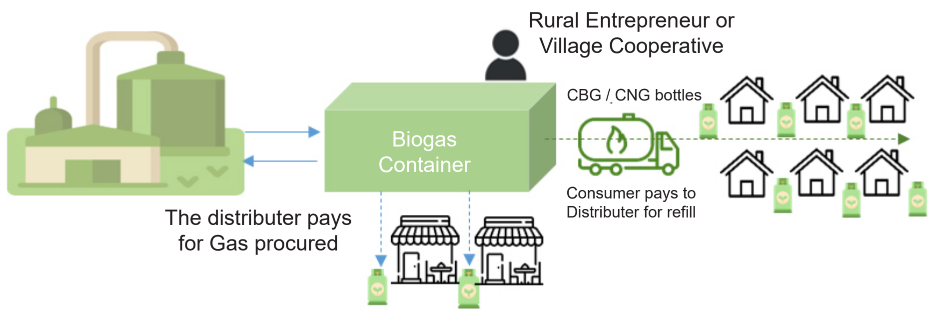
Distribution of clean cooking fuel could take one of the two routes described schematically in Figure 4.

Figure 4: Distribution of locally produced clean cooking fuel

Model 1: Gas delivered through a Pipeline



Model 2: Bottled Bio-Gas delivered



Source: Authors' own

Model 1 is a Pay-as-you-go (PAYG) model similar to electricity as a service model with Energy meters. The customer pays a subscription/connection fee before the service, and the usage is linked to the amount paid, or the amount paid is based on usage. Cooking Gas could be distributed through a pipeline with a PAYG-Gas meter. Biogas could be delivered on per unit (m^3) basis with a minimum fixed price (similar to fixed electricity tariff) and charge the rest based on consumption. Risks associated with this model include theft, safety, pressure fluctuations, low collection efficiency—which might lead to unreliability and high post-sale service cost, in turn leading to low adoption and an unviable business model.

Model 2 is similar to bottled LPG distribution but with a different form factor and refilling cost. To achieve a target consumer price of ₹450 per refill per month, cross-subsidisation might be necessary. This could be achieved by delivering biogas to local commercial establishments at a higher price point. Risks associated with this model include higher capital and operational expenditure due to high cost of bottling and transportation. A continuous infusion of working capital might be needed to keep a healthy operating margin for the community-based village enterprise (distributor).

Conclusion

The production and distribution of CBG from municipal organic waste in rural and peri-urban areas, particularly using the Pay-as-you-go model, could be a cheaper option for consumers in India's rural regions, while addressing the issues of household air pollution due to solid cooking fuels, and foreign exchange outflow on account of importing cooking fuel. Subsidised LPG for millions of rural and deprived households locks India onto a path away from green transition.

India has a long history of biogas programme, biomethanation technology, the skillset, and the financial wherewithal to demonstrate its own model at scale to the developing world. The technology and the business models discussed here, if tested and adopted, could help accelerate energy transition and demonstrate transition financing that is equitable.

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