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Is MSW derived DME a viable clean cooking fuel in Kolkata, India?

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ABSTRACT

An important energy poverty reduction initiative in India is aimed at replacing the use of solid cooking fuels with cleaner burning Liquefied Petroleum Gas (LPG). Projections suggest however that India will become increasingly dependent on LPG imports, the cost of which is strongly linked to the prevailing oil price and associated volatility. Dimethyl ether (DME) is a synthetic fuel which may be manufactured from domestically available carbonaceous feedstocks, and is compatible with blending with LPG. Very large quantities of Municipal Solid Waste (MSW) are generated in India's metropolitan cities, 90% of which is disposed of onto unsanitary landfills, creating major environmental and health concerns. This article investigates the techno-economic merits of reducing these impacts by using a portion of the MSW generated in Kolkata (in the form of a Refuse Derived Fuel (RDF)) to produce DME. Results suggest that the production of DME from a 50:50 blend of locally available coal and RDF (comprising 10% of the MSW placed at Kolkata's main landfill) will enable the supply of a clean cooking fuel to approximately 15% of Kolkata's population, and become cost competitive with imported LPG at an Indian basket oil price of $130 per barrel. Results also suggest that, at this blend ratio, the fossil fuel derived greenhouse gas emissions at the DME production plant will be more than offset by landfill methane emissions avoided using the RDF.

1. Introduction

In 2011, more than two-thirds of India's population relied on the use of solid cooking fuels (firewood, crop residue, cowdung cake, coal, lignite and charcoal) for cooking [1]. The use of these traditional cooking fuels may result in deforestation, higher child mortality due to respiratory illness (caused by indoor air pollution) and contribute to gender inequality [2]. In order to address these problems, the Indian government has instituted a program aimed at substituting the use of these solid fuels with liquefied petroleum gas (LPG) [3,4].

India is a net importer of LPG and its cost, which is strongly linked to the prevailing crude oil price, is high when compared with traditional fuel alternatives. The Indian government therefore uses a subsidy scheme to make LPG affordable to a greater part of the population, and to protect them against oil price volatility. At high oil prices, the cost of this may be significant and in 2012/2013 the total LPG-related subsidy was almost 2.7% of the total budget. The uptake of LPG as a cleaner cooking fuel is also dependent on the reliability of supply, and operational disruption resulting in LPG shortages have been shown to result in a return to the use of solid fuels [5].

One means of reducing the impact of these externalities may be to augment the supply of imported LPG with dimethyl ether (DME), produced from domestically available feedstock. Natural gas, coal, biomass, municipal solid waste (MSW) and CO_2 may be used for this purpose [6,7]. DME is a substance which has properties (Table 1) similar to those of propane and butane, which are the major constituents of liquefied petroleum gas (LPG). These properties allow DME to be blended with LPG and blends containing up to 20% DME may be distributed through existing infrastructure, and used in existing cooking devices, without modification [8].

The global consumption of DME in 2015 amounted to approximately 5 million tonnes [10] and occurred mostly in China. Here, the production of DME was underpinned using coal (primarily) and natural gas. Approximately 90% of the produced DME was blended with LPG [5].

The management of municipal solid waste is a critical problem in India, where it was estimated that more than eight times the amount was generated in 2011 compared with 1947 [11]. Urban cities produced in the order of 171,000 tonne per day of MSW in 2011, 25% of which came from the six metropolitan cities of Kolkata, Mumbai, Delhi, Chennai, Hyderabad and Bengaluru [12]. Various

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Table 1
Properties of DME and other common fuel types (Derived from Ref. [9]).

Property	Propane	DME	Butane
Chemical Formula	C3H8	CH3OCH3	C4H10
Boiling point (°C)	−42.0	−25.1	−0.5
Specific gravity of gas (vs air)	1.52	1.59	2.00
Saturated vapour pressure at 25 °C (atm)	9.3	6.1	2.4
Energy content (MJ/l)	22.8	19.3	26.0

studies estimate that more than 90% of this waste is disposed of onto unsanitary landfills, creating major environmental and health concerns [12,13]. This study will determine the techno-economic viability of converting a portion of this MSW into DME, with a specific focus on Kolkata.

2. Study basis

2.1. Study area

Kolkata is the capital of the state of West Bengal and was, with a population of approximately 14.1 million residents, India's third most populous metropolitan city in 2011. Kolkata's gross domestic product (GDP) was one of the largest among South Asian cities in 2008, lower than only Mumbai and Delhi [14].

Table 2 summarises the primary cooking fuels used in households in India, the state of West Bengal and Kolkata in 2011. The data shows that 76.5% of households in West Bengal relied on the use of solid cooking fuels, and that 7.9% of households used coal, lignite and charcoal for this purpose. These figures are higher than the average for India and the amount of households that used coal, lignite and charcoal for cooking in West Bengal constituted more than 44% of the India-wide consumption for such purposes. Most of the solid fuels consumed occurred outside the main area of Kolkata. In Kolkata, approximately 64.7% of the 964,000 households had transitioned to the use of LPG. If one assumes an LPG cooking requirement of 22 kg per person per year [15], then this figure translates into a consumption of approximately 64,000 tonne of LPG per year.

Like many large cities in India, the primary collection of MSW in Kolkata involves the removal of street litter and household waste by street sweepers using hand carts, brooms and scrapers as tools. The collected waste is then temporarily stored in large masonry storage enclosures, trash bins and dumpsters located in depots, combined with waste collected from commercial and market areas, before being picked up and transported to the disposal site [16]. There is no source segregation system currently in place, but recycling occurs through an informal system whereby newspapers, bottles or metal from households are re-used or sold, or through the recovery of recyclable materials from refuse heaps or collection points by waste pickers and waste collectors [17].

The Kolkata Metropolitan City (KMC) has three disposal sites which are located at Dhapa, Garden Reach and Naopara [18]. Of these, the Dhapa site (located within 10 km of collection points) is the largest and has an overall footprint of approximately 34.2 ha, of which approximately 21.5 ha consists of waste disposal areas. A study done in 2013 estimated that various municipalities in the KMC area collected in the order of 4837 tonne per day of MSW, and projected that by 2035 the rate may be in the order of 8805 tonne per day. It was determined that the Dhapa site typically received in the order of 3500 tonne per day of waste in July 2013 [14]. Another study determined that by 2012 the Dhapa site would contain in the order of 11 million tonne of waste, at which time the height of all disposal areas would start exceeding the maximum stated limit of 40 m, if an alternative disposal site was not available [19]. A 700 ton per day mechanized compost plant was installed at Dhapa in April 2000 [16], but has not been operational since 2003 due to the high inert content in the segregated waste [17].

Table 3
MSW composition at the Dhapa site in Kolkata [19].

Waste Component	Content (wet wt%)
Food waste	45.50%
Garden waste	5.10%
Paper	4.00%
Textiles	4.00%
Wood	1.20%
Plastics	3.30%
Metals	0.20%
Glass & Crockery	0.30%
Inert	29.60%
Others	6.80%
Total	**100.00%**

The characteristics and composition of MSW varies from location to location and depends on a number of factors including food habits, cultural traditions, climate, location and a number of other socio-economic factors [20,21]. An estimate of the composition of the MSW at the Dhapa site is shown in Table 3 [19]. The large proportion of biodegradable material, inert and ash content and high moisture is typical of waste collected in India's other large metropolitan cities and is significantly higher than in developed countries [21]. The open dumping of municipal solid waste onto unsanitary landfills creates major environmental and health concerns, which are multiple and varied.

The recovery of recyclable materials is, for example, often done in a hazardous and unhygienic way and a clinical examination in Kolkata found that waste pickers had, compared with a control population (CP), a higher cardiovascular risk (8 x the CP), altered immunity (6 x the CP), breathing problems (3 x the CP), nose and throat infections (3 x the CP) and lung infections (3 x the CP) [12].

The quality of leachate from the Dhapa site showed that the solids concentration, BOD, COD and chlorides are much higher than that allowed for discharge to inland surface water, and analysis of groundwater highlighted the persistent presence of phenolic compounds at Dhapa and surrounding areas at concentrations

Table 2
Primary fuels used for cooking in India (as determined by the 2011 India Census[1]).

Geographic area	Type of Fuel used for Cooking					
	Coal, Lignite, Charcoal	Other solid fuels[a]	Kerosene	LPG/PNG	Electricity	Any other[b]
India	1.4%	65.8%	2.9%	28.5%	0.1%	1.2%
West Bengal	7.9%	68.6%	2.1%	18.0%	0.1%	3.3%
Kolkata	3.7%	5.8%	24.1%	64.7%	0.1%	1.5%

Notes.
[a] Other solid fuels include fire-wood, crop residue and cowdung cake.
[b] Any other also includes biogas as well as no fuels used for cooking.
[1] http://www.censusindia.gov.in/2011census/Hlo-series/HH10.html (Accessed 20 May 2016).

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