Biomethane from agricultural waste: A clean vehicular biofuel.pdf

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Abstract

The food-fuel debate restricts to cultivate energy crops on the arable land and promotes the renewable energy production systems which take minimum land. The utilization of agricultural waste for biogas production is one of them that can be considered for the production of biofuels. The produced biogas can be upgraded to maximum purity (more than 97% methane) and can utilize in the gas vehicles. The production of biogas from waste not only provide energy but also minimized the emissions from land filling of these waste and also provides digestate that can replace chemical fertilizers for crop cultivation.

Keywords: Biomethane, biogas, agricultural wastes, biofuels, emissions.

Introduction

Countries across the globe currently face two major challenges: reduction in green house gas (GHG) emissions in accordance with the Kyoto Protocol; promotion and generation of sustainable biofuels. In particular a drastic increase in GHG has occurred in the transport sector and is expected to increase by three times in 2010 (Singh and Murphy, 2009). Dependence on imported oil currently stands at 98% in the transport sector. In year 2008, fossil fuels accounted for 88% of the global primary energy consumption (Brennan and Owende, 2010). The current technological progress, potential reserves, and increased exploitation leads to energy insecurity and climate change by increasing greenhouse gas (GHGs) emissions due to consumption of energy at a higher rate. The use of fossil fuels is now widely accepted as unsustainable due to depleting resources and the accumulation of GHGs in the environment that have already exceeded the “dangerously high” threshold of 450 ppm CO$_2$e (Schenk et al., 2008). With the increase in anthropogenic GHG emissions and depleting fossil reserves, mainly due to large scale use of fossil fuels for transport, electricity and thermal energy generation, it has become increasingly important to develop abatement techniques and adopt policies to promote those renewable energy sources which are capable in sequestering the atmospheric CO$_2$, to minimize the dependency on fossil reserves and also to maintain environmental and economic sustainability (Brennan and Owende, 2010; Prasad et al., 2007a,b; Singh et al., 2010a,b). Biofuels can reduce the dependency on foreign oil and play an important role in reduction of GHG’s from transport sector. Renewable bioresources are available globally in the form of residual agricultural biomass and wastes, which can be transformed into biofuels (Nigam and Singh, 2010). The production of agricultural wastes such as cattle slurry, pig slurry, poultry litter and slaughter waste per capita is relatively high. Slurry and slaughter waste are very suitable for production of

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Biomethane. Food-fuel controversy does not allow cultivating oil crops on arable land. Compressed biomethane can play a major role in reducing the fuel dependency and vehicular emissions.

Nordberg (2009) reported that utilization of compressed biogas in a bus saved 1.2 tonne NO\textsubscript{x} and 20 tonne CO\textsubscript{2} emission per year comparing to fossil fuels. The digestate / compost generated during the production of biomethane also reduce the requirement for chemical fertilizer utilization for crop cultivation, which also helps to protect the environment. The complete cycle of production and utilization of biogas as vehicular fuel is presented in Fig. 1.

![Diagram of complete cycle of biogas production from agricultural waste.](image)

**Energy production from agricultural waste**

The farming and slaughtering of cattle generates huge quantities of slurry and slaughterhouse waste, which have a very high energy potential and also suitable for biomethane production. The production of biomethane from these wastes also generates the digestate that can be used as fertilizer to cultivate crops and reduces GHG emissions during production of chemical fertilizers.

**Cattle Slurry**

Slurry refers to all types of excreta, i.e. faeces and urine from cattle. The estimation of the quantity of cattle slurry resulted in 5.08 t/a/bovine collectable slurry production, as the EPA considered only a 20 week housing period for cattle in a year. Brikmose (2000) reported the biogas potential of cattle slurry as 22 m\textsubscript{3} biogas per tonne of slurry. Assuming 55% CH\textsubscript{4} content, and allowing for energy value of CH\textsubscript{4} of 37.78 MJ/m\textsubscript{3} (Murphy et al., 2006), this yields an energy potential of 2322 MJ/bovine/a, that is equivalent to 64 l diesel (Box 1).

<table>
<thead>
<tr>
<th>Box. 1. Energy potential of cattle slurry</th>
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<tbody>
<tr>
<td>Slurry potential</td>
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<tr>
<td>Biogas potential (@ 22 m\textsubscript{3}/t slurry)</td>
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<tr>
<td>Methane potential (55% of biogas)</td>
</tr>
<tr>
<td>Energy potential (37.78 MJ/m\textsubscript{3} CH\textsubscript{4})</td>
</tr>
<tr>
<td>Equivalent diesel (36.1 MJ/l)</td>
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</table>
Slaughterhouse waste

The slaughtering process produces large quantities of organic waste (Arvanitoyannis and Ladas, 2008) that have a huge potential for biomethane and biodiesel production. The slaughter waste generated from slaughtering one average bovine having 630 kg live weight has the potential to generate 1.25 GJ energy in the form of 32.45 m³ biogas (0.67 GJ) and 14.87 kg biodiesel (0.58 GJ) (Fig. 2; Singh et al., 2010b). The slaughtering waste of one average cattle can yield energy equivalent to 34.73 l diesel or energy equivalent to 55 l diesel can be produced from the slaughtering of one tonne live cattle.

GHG emissions/savings in biomethane production

GHG production is based on the release of CO₂ during the production of biomethane. The net GHG emissions/savings are calculated by comparing the GHG emissions during biomethane production with the GHG emissions from land spreading of cattle slurry and slaughter waste.

Notes:
Murphy et al. (2006) reported that 156 m³ biogas/t slaughter waste is generated having 55% methane content with an energy value of 37.78 MJ/m³ methane.

The biodiesel yield is 95% of the tallow input and the energy value of biodiesel is 39 GJ/t (Thamsiriroj and Murphy, 2010).

Figure 2. The mass balance and energy potential of waste generated by slaughtering of one bovine (adapted from Singh et al., 2010b)
GHG emissions/savings from one tonne of cattle slurry

The approach used to perform the GHG analysis is similar to that outlined by Murphy and co-workers (Murphy et al., 2004; Murphy and McKeogh, 2004; Murphy and McCarthy, 2005; Murphy and Power, 2007). The land application of cattle slurry results in a breakdown of organic fractions and produces GHGs. Agricultural slurry is stored for a period of time (winter months) before the land application (Murphy and McCarthy, 2005; Murphy et al., 2004). An OECD report outlined emissions of 20% of the potential biogas production by 2 months storage, with land application in moist climate emitting 10% of the remaining biogas potential (OECD, 1991). The land application of one tonne slurry emits 56.61 kg CO$_2$e (Box 2). The parasitic electrical and thermal demand for the anaerobic digestion of slurry is 10 kWh/t and 170 MJ/t, respectively. Conservatively an assumption is made that 2% of biogas production escapes as fugitive losses, losses from the gas collection system and venting, and incomplete combustion (Korres et al., 2010). The total GHG emission from slurry digestion is 22.7 kg CO$_2$e/t which saves about 34 kg CO$_2$e/t emissions when compared with land application of slurry (Box 2).

Box 2. GHG emissions/savings from one tonne of cattle slurry digestion in comparison to land application

Biogas potential of 1 tonne cattle slurry = 22 m$_3$ biogas

Maximum potential of GHG emissions (1 m$_3$ biogas is equivalent to 9.19 kg CO$_2$) = 202.18 kg CO$_2$e/t

GHG emissions in storage$^2$ (20%) = 40.44 kg CO$_2$e
GHG emissions in land spreading$^2$ (10% of remaining GHG potential) = 16.17 kg CO$_2$e

Total GHG emissions by land application of cattle slurry = 56.61 kg CO$_2$e

Parasitic electrical demand = 10 kWh/t$^2$
GHG emissions in electricity production (734 kg CO$_2$/MWh$^3$) = 7.34 kg CO$_2$e/t
Parasitic thermal demand = 170 MJ/t$^2$
GHG emissions in thermal energy production (240 kg CO$_2$/MWh$^3$) = 11.34 kg CO$_2$e
Escape of biogas during digestion (@2% of total biogas$^3$) = 0.44 m$_3$ biogas

Total GHG emissions during the production of biogas = 22.72 kg CO$_2$e/t

GHG saving = 33.89 kg CO$_2$e/t cattle slurry

$^1$Murphy and McKeogh, 2004; $^2$Murphy et al., 2004; $^3$Gilligan, 2002

GHG emissions/savings from one tonne of slaughterhouse waste

The land application of slaughterhouse waste emits huge quantities of methane and carbon dioxide from the degradation of carbon containing products by microbial activities. Murphy et al. (2006) reported that slaughter waste has 23% dry solids (DS) content and 80% of DS are volatile dry solids (VDS). The maximum biogas potential for land application is taken as
65% destruction of VDS (Hobson et al., 1996). The total GHG emissions potential of slaughterhouse waste is calculated as 1099.12 kg CO$_2$e/t slaughterhouse waste applied to land (Box 3).

For the anaerobic digestion of slaughterhouse waste, the parasitic electrical and thermal energy demand is 10 kWh/t and 245 MJ/t, respectively (Murphy et al., 2006). Again conservatively it is assumed that 2% of biogas escapes during various production processes. The total GHG emission from slaughter waste digestion is estimated at 52.35 kg CO$_2$e/t of slaughterhouse waste digested (Box 3). The anaerobic digestion of slaughterhouse waste can save about 1047 kg CO$_2$e/t slaughterhouse waste in comparison to land application (Box 3).

**GHG EMISSIONS/SAVINGS IN BIOMETHANE UTILIZATION IN TRANSPORT**

Biomethane is compressed to 200 bar for use as a transport fuel (Wellinger and Lindberg, 1999). One method of scrubbing biogas from about 55% CH$_4$ to biomethane (97% CH$_4$) involves pressurising the biogas to 10 bar and dissolving the CO$_2$ in water. H$_2$S may be removed by air dosing (reduces volumetric energy density) or by addition of Fe to form precipitate (preferable when producing transport fuel) (Murphy and Power, 2009).

<table>
<thead>
<tr>
<th>Box 3. GHG emissions/savings from one tonne of slaughterhouse waste in comparison to land application</th>
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<tr>
<td>Dry solids (DS) content $^1$ @ 23% = 230 kg/t&lt;br&gt;Volatile dry solids (VDS) content $^1$ @ 80% of DS = 184 kg/t&lt;br&gt;Destruction of VDS $^2$ @ 65% = 119.6 kg/t&lt;br&gt;Biogas yield from 1 tonne slaughterhouse waste $^3$: $1 \text{m}^3$ biogas/kg VDS destruction $^3$ = 119.6 $\text{m}^3$ biogas/t&lt;br&gt;<strong>Total GHG emissions by land application of slaughterhouse waste</strong>&lt;br&gt;(1 $\text{m}^3$ biogas is equivalent to 9.19 kg CO$_2^3$) = 1099.12 kg CO$_2$e/t&lt;br&gt;Parasitic electrical demand = 10 kWh/t $^1$&lt;br&gt;GHG emissions in electricity production (734 kg CO$_2$/MWh $^4$) = 7.34 kg CO$_2$e&lt;br&gt;Parasitic thermal demand = 245 MJ/t $^1$&lt;br&gt;GHG emissions in thermal energy production allowing for pasteurisation (240 kg CO$_2$/MWh$^3$) = 16.34 kg CO$_2$e&lt;br&gt;Escape of biogas during digestion (@ 2% of total biogas $^5$ @ 156 $\text{m}^3$ biogas/t $^1$) = 3.12 $\text{m}^3$ biogas = 28.67 kg CO$_2$e&lt;br&gt;**Total GHG emissions during the production of biogas = 52.35 kg CO$_2$e&lt;br&gt;<strong>Saving of GHG = 1046.77 kg CO$_2$e/t slaughterhouse waste</strong>&lt;br&gt;$^1$Murphy et al., 2006; $^2$Hobson et al., 1996; $^3$Murphy and McKeogh, 2004; $^4$Gilligan, 2002; $^5$Murphy et al., 2004</td>
</tr>
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</table>
GHG emissions during the upgrading and compression processes are 0.66 kg CO₂e/m³ production of enriched biomethane (Box 4).

**Box 4. GHG emissions in upgrading and compression of biomethane**

Upgrading/scrubbing = 0.35 kWhₑ/m³ enriched biogas
Compression= 0.35 kWhₑ/m³ enriched biogas
Total electricity requirement = 0.7 kWhₑ/m³ enriched biogas

**GHG emissions by consumption of electricity = 0.51 kg CO₂e/m³ enriched biogas**

Biogas losses during upgrading and compression = 1%
GHG emissions = 0.01*0.714 kg/m³*21 = 0.15 kg CO₂e/m³ enriched biomethane

**Total GHG emissions in upgrading and compression of biogas**

= 0.66 kg CO₂e/m³ enriched biogas

Density of methane is 0.714 kg/m³ and global warming potential is 21 times that of CO₂

1Murphy and Power, 2009; 2Murphy et al., 2006

The biomethane production from each tonne of slurry and slaughterhouse waste has the potential to replace 13 and 92.5 l diesel resulting in GHG emissions savings of 43 and 1111 kg CO₂e, respectively. (Table 1).

Table 1. Net GHG savings by replacement of diesel/petrol with biomethane produced from cattle slurry and slaughterhouse waste (1Beer et al., 2003; 2Murphy et al., 2006; 3Murphy and McCarthy, 2005; 4Thamsiriroj and Murphy, 2009).

<table>
<thead>
<tr>
<th></th>
<th>Slurry (t⁻¹)</th>
<th>Slaughterhouse waste (t⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas production (m³)</td>
<td>22.00</td>
<td>156.00</td>
</tr>
<tr>
<td>Biomethane after upgrading and compression (m³)</td>
<td>12.47</td>
<td>88.45</td>
</tr>
<tr>
<td>GHG emissions in biogas production (kg CO₂e)</td>
<td>-33.89</td>
<td>-1046.77</td>
</tr>
<tr>
<td>GHG emissions in upgrading and compression of biogas (kg CO₂e)</td>
<td>8.23</td>
<td>58.38</td>
</tr>
<tr>
<td>GHG emissions by biomethane consumption in transport (kg CO₂e)</td>
<td>24.45</td>
<td>173.37</td>
</tr>
<tr>
<td><strong>Total GHG emissions (kg CO₂e)</strong></td>
<td>-1.21</td>
<td>-815.02</td>
</tr>
<tr>
<td>Energy value of biomethane produced (GJ)</td>
<td>0.47</td>
<td>3.34</td>
</tr>
<tr>
<td>Equivalent diesel (l) (36.1MJ/l diesel)</td>
<td>13.05</td>
<td>92.57</td>
</tr>
<tr>
<td>GHG emissions by diesel consumption (kgCO₂e) (2.688 kg CO₂e/l diesel)</td>
<td>35.08</td>
<td>248.83</td>
</tr>
<tr>
<td>Addition of indirect emissions in diesel production (kgCO₂e) (14.2kg/GJ = 0.51 kg CO₂e/l diesel)</td>
<td>6.65</td>
<td>47.21</td>
</tr>
<tr>
<td><strong>Savings from avoided diesel (kgCO₂e)</strong></td>
<td>41.73</td>
<td>296.04</td>
</tr>
<tr>
<td><strong>Net GHG savings from diesel replacement (kg CO₂e)</strong></td>
<td>43</td>
<td>1111</td>
</tr>
</tbody>
</table>
Conclusions

Slurry and slaughter waste are very suitable for the production of biomethane. Compressed biomethane from these feedstocks can save about 33 and 1111 kg CO$_2$e GHGs. The whole life cycle GHG reduction for these feedstocks is good when compared to the whole life cycle analysis of the fossil fuel displaced. The digestate/compost generated during the production of biomethane will provide substitution for chemical fertilizer.

Acknowledgement

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