Biomethane as a source of renewable transport and thermal fuel

Dr Jerry Murphy, BioEnergy and Biofuels Research, Environmental Research Institute, UCC

ENGINEERS IRELAND - CORK REGION WINTER LECTURE SERIES

25th January 2011, Rochestown Park Hotel.
Growth in world population
Primary energy: consumption per capita

**Primary energy: Energy consumption per capita**
*Tonnes oil equivalent*

![Diagram showing energy consumption per capita for different regions and years.](image-url)
World energy supply and fossil fuel reserves

The Contribution of Fossil Fuels to the World Energy Supply

- Coal
- Oil
- Gas
- World Use
Renewable Targets 2020

- **RES** 16% – EU Target
- **RES-E** 40% – Irish Target
  - Equates to 7% RES
- **RES-H** 12% – Irish Target
- **RES-T** 10% – EU & Irish Target
Focus of Research

Research Output

2004 - 2010:

- 40 peer review journal papers
- 22 peer reviewed conference papers
- 22 invited lectures
- 3 post doctorates
- 5 PhD students
- 14 masters students

Figure 2: Energy use in Ireland by mode of application 2008

First Generation Biofuels
Ethanol (pure alcohol)
Norrköping ethanol facility
35% of thermal parasitic demand is used to dry the wet distillers grain and solubles (WDGS) to dry distillers grain and solubles (DDGS).
Liquefaction, Fermentation, Distillation
Pellets (DDGS) and pellet storage
Gross Energy of Ethanol from Wheat

| Wheat   | 8.4 t/ha | 375 l/t | 3150 l/ha | 66.5 GJ/ha/a |

Net Energy of Ethanol from Wheat

- Gross Energy: 66.5 GJ/ha/a
- Energy used in process: 41.5 GJ/ha/a
- Energy in agriculture: 21 GJ/ha/a
- Net energy: 4 GJ/ha/a
Biodiesel & Rape Seed

4 t of rape seed per hectare
30% oil return = 1.23 t oil/hectare
High energy input crop, 4/5 year rotation

<table>
<thead>
<tr>
<th>Source of oil</th>
<th>l/ha/a</th>
<th>GJ/ha/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil palm</td>
<td>3570</td>
<td>120</td>
</tr>
<tr>
<td>Coconut</td>
<td>2260</td>
<td>75</td>
</tr>
<tr>
<td>Jatropha</td>
<td>1590</td>
<td>52</td>
</tr>
<tr>
<td><strong>Rape seed</strong></td>
<td><strong>1355</strong></td>
<td><strong>46</strong></td>
</tr>
<tr>
<td>Pea nut</td>
<td>890</td>
<td>29</td>
</tr>
<tr>
<td>Sun flower</td>
<td>800</td>
<td>26</td>
</tr>
<tr>
<td>Soyabean</td>
<td>375</td>
<td>12</td>
</tr>
</tbody>
</table>
An argument for using biomethane generated from grass as a biofuel in Ireland

Jerry D. Murphy\textsuperscript{a,b,*}, Niamh M. Power\textsuperscript{c}

\textsuperscript{a}Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
\textsuperscript{b}Environmental Research Institute, University College Cork, Cork, Ireland
\textsuperscript{c}Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Cork, Ireland
What is the energy balance of grass biomethane in Ireland and other temperate northern European climates?

Beatrice M. Smyth\textsuperscript{a,b}, Jerry D. Murphy\textsuperscript{a,b,*}, Catherine M. O’Brien\textsuperscript{a,b}

\textsuperscript{a}Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
\textsuperscript{b}Environmental Research Institute, University College Cork, Cork, Ireland
Relative Energy Balance of Grass Biomethane

Gross and net energy comparison of various crop systems

GJ/ha/a

- Rapeseed biodiesel: 46 (Gross), 25 (Net)
- Wheat ethanol: 66 (Gross), 4 (Net)
- Palm oil biodiesel: 120 (Gross), 74 (Net)
- Sugarcane ethanol: 135 (Gross), 120 (Net)
- Grass biomethane: 122 (Gross), 67 (Net)
Table 7 – Biofuels, and associated land area required, to substitute for fuel used by a typical Dublin bus (28,000 l of diesel/a, 1008 GJ/a).

<table>
<thead>
<tr>
<th></th>
<th>Crop t/ha&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Fuel/t</th>
<th>Fuel/ha/a</th>
<th>Gross&lt;sup&gt;d&lt;/sup&gt; Energy GJ/ha/a</th>
<th>Land required ha/a</th>
<th>Rotation</th>
<th>Land to be contracted Ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel (rapeseed)</td>
<td>4</td>
<td>0.3 t</td>
<td>1.2 t oil</td>
<td>42</td>
<td>24</td>
<td>1 in 5</td>
<td>120</td>
</tr>
<tr>
<td>Ethanol (sugar beet)</td>
<td>50</td>
<td>100 l/t&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5000 l/ha</td>
<td>105</td>
<td>9.6</td>
<td>1 in 3</td>
<td>28.8</td>
</tr>
<tr>
<td>Ethanol (wheat)</td>
<td>8.4</td>
<td>375 l/t&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3150 l/ha</td>
<td>66</td>
<td>15.3</td>
<td>2 in 3</td>
<td>23</td>
</tr>
<tr>
<td>Biogas (sugar beet)</td>
<td>50</td>
<td>128 m³/t&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6400 m³&lt;sup&gt;c&lt;/sup&gt;</td>
<td>134</td>
<td>7.5</td>
<td>1 in 3</td>
<td>22.4</td>
</tr>
<tr>
<td>Biogas (wheat)</td>
<td>8.4</td>
<td>420 m³/t&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3528 m³&lt;sup&gt;c&lt;/sup&gt;</td>
<td>74</td>
<td>13.7</td>
<td>2 in 3</td>
<td>21</td>
</tr>
<tr>
<td>Biogas from silage</td>
<td>60</td>
<td>123 m³/t&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7380 m³&lt;sup&gt;c&lt;/sup&gt;</td>
<td>155</td>
<td>6.5</td>
<td>3 in 3</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Sustainable Biofuels

DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 23 April 2009

on the promotion of the use of energy from renewable sources and amending and
subsequently repealing Directives 2001/77/EC and 2003/30/EC

- Article 17 (2):
  - From Jan 1 2018 the greenhouse gas emissions of biofuels from new facilities are
    reduced by 60% compared to the alternative fossil fuel use;

- Article 17 (3):
  - No damage is done to sensitive or important ecosystems.

- Article 17 (4)
  - May not convert wetland, forestry or grassland to energy crop production

- Article 21 (2)
  - Biofuels from wastes, residues, non-food cellulosic material, and ligno-cellulosic
    material shall be considered to be twice that made by other biofuels
## Annex 5 of Renewable Directive

<table>
<thead>
<tr>
<th>Biofuel</th>
<th>Typical GHG savings</th>
<th>Default GHG savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat ethanol</td>
<td>32%</td>
<td>16%</td>
</tr>
<tr>
<td>Rape seed biodiesel</td>
<td>45%</td>
<td>38%</td>
</tr>
<tr>
<td>Sugar beet ethanol</td>
<td>61%</td>
<td>52%</td>
</tr>
<tr>
<td>Corn ethanol</td>
<td>56%</td>
<td>49%</td>
</tr>
<tr>
<td>Sugar cane ethanol</td>
<td>71%</td>
<td>71%</td>
</tr>
<tr>
<td>Waste oil biodiesel</td>
<td>88%</td>
<td>83%</td>
</tr>
<tr>
<td>OFMSW biomethane</td>
<td>80%</td>
<td>73%</td>
</tr>
<tr>
<td>Slurry biomethane</td>
<td>84%</td>
<td>81%</td>
</tr>
</tbody>
</table>
Energy from rubbish
Brecht II, 50,000 t/a of OFMSW to gas
Munich Waste Treatment: Dry batch digesters
Linkoping Sweden
Feed stock for Linkoping

- 7,000t/a of pig slurry
- 47,000t/a of slaughter waste
- Blood and process water pumped in
Biogas treatment

Collection over digester  Scrubbing  Compression and storage
65 buses, 10 waste collection lorries, 600 cars...
And a train
Brook an der Leitha: 60,000 t/a of out of date food with grid injection of biomethane
Biogas from grass as transport fuel in Salzburg

Source: energiewerkstatt, IEA and personal photos
Germany has 5400 digesters; Austria has 800
Biomethane: RES-T and RES-H

<table>
<thead>
<tr>
<th>Feed stock</th>
<th>Potential 2020 (PJ)</th>
<th>Practical 2020 (PJ)</th>
<th>Factor for RES-T</th>
<th>Contribution to RES-T</th>
<th>% energy in transport 2020 (240 PJ)</th>
<th>% residential gas demand (34 PJ)</th>
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<tbody>
<tr>
<td>Slurry</td>
<td>15.53</td>
<td>1.88</td>
<td>X2</td>
<td>3.76</td>
<td>1.57</td>
<td>5.5</td>
</tr>
<tr>
<td>OFMSW</td>
<td>2.26</td>
<td>0.57</td>
<td>X2</td>
<td>1.14</td>
<td>0.48</td>
<td>1.7</td>
</tr>
<tr>
<td>Slaughter</td>
<td>1.37</td>
<td>0.68</td>
<td>X2</td>
<td>1.36</td>
<td>0.57</td>
<td>2.0</td>
</tr>
<tr>
<td>Grass</td>
<td>47.58</td>
<td>11.93</td>
<td>X2</td>
<td>23.86</td>
<td>9.94</td>
<td>35.1</td>
</tr>
<tr>
<td>Total</td>
<td>66.74</td>
<td>15.03</td>
<td></td>
<td>30.06</td>
<td>12.53</td>
<td>44.3</td>
</tr>
</tbody>
</table>
Number of vehicles running on GNG worldwide

- Pakistan
- Iran
- Argentina
- Brazil
- India
- Italy
- China
- Colombia
- Ukraine
- Bangladesh
- Thailand
- Egypt
- Bolivia
- Armenia
- Russia
- USA
- Peru
- Germany
- Bulgaria
- Uzbekistan

Total vehicles running on CNG

- 0
- 500,000
- 1,000,000
- 1,500,000
- 2,000,000
- 2,500,000
- 3,000,000
- 3,500,000
Italy: ratio of CNG cars to CNG service stations ca. 933:1

Germany ca. 100:1
Biomethane Buses

Number of buses running on CNG

- China
- Ukraine
- Korea
- Myanmar
- Colombia
- India
- Thailand
- USA
- Armenia
- Iran
- Bangladesh
- France
- Italy
- Australia
- Germany
- Japan
- Turkey
- Russia
- Egypt
- Sweden

12m bus

18m bus
Cost of GNG as a percentage of petrol and diesel

The graph shows the cost of GNG as a percentage of petrol and diesel for various countries, with data compared to petrol and diesel separately.
Swedish Example: First CNG then biomethane

Delivered volumes of methane gas for vehicles
(Source: Swedish Gas Association)

- **Biogas**
- **Natural gas**
- **Total**

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumes (1000 Nm³)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Irish Gas Grid

Serves:
153 towns
19 counties
619,000 houses
24,000 industrial and commercial
## Biomethane as a transport fuel

<table>
<thead>
<tr>
<th></th>
<th>OFMSW</th>
<th>Slaughter waste</th>
<th>Grass (Farm)</th>
<th>Grass (Developer)</th>
<th>Co-digest Grass &amp; slurry</th>
<th>Slurry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inject to gas grid</td>
<td>0.14</td>
<td>0.73</td>
<td>0.97</td>
<td>1.1</td>
<td>1.23</td>
<td>1.83</td>
</tr>
<tr>
<td>Compression + service station</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>Compressed biomethane</td>
<td>0.25</td>
<td>0.84</td>
<td>1.08</td>
<td>1.21</td>
<td>1.34</td>
<td>1.94</td>
</tr>
<tr>
<td>Inc. VAT @ 21%</td>
<td>0.30</td>
<td>1.02</td>
<td>1.30</td>
<td>1.46</td>
<td>1.62</td>
<td>2.34</td>
</tr>
</tbody>
</table>

Excise duty is not charged on gas used as a propellant, but VAT at 21% has to be added. Cost €/m³ biomethane = cost per litre diesel equivalent
## Biomethane as a transport fuel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Unit cost</th>
<th>Energy value</th>
<th>Cost per unit energy (€c MJ⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol</td>
<td>€1.224 L⁻¹</td>
<td>30 MJ L⁻¹</td>
<td>4.08</td>
</tr>
<tr>
<td>Diesel</td>
<td>€1.150 L⁻¹</td>
<td>37.4 MJ L⁻¹</td>
<td>3.07</td>
</tr>
<tr>
<td>Comp biomethane (Grass farmer)</td>
<td>€1.30 m⁻³</td>
<td>37 MJ m⁻³</td>
<td>3.50</td>
</tr>
<tr>
<td>CNG – Austria</td>
<td>€0.89 m⁻³</td>
<td>37 MJ m⁻³</td>
<td>2.41</td>
</tr>
<tr>
<td>CNG – UK</td>
<td>€0.71 m⁻³</td>
<td>37 MJ m⁻³</td>
<td>1.92</td>
</tr>
<tr>
<td>CNG – Germany</td>
<td>€0.70 m⁻³</td>
<td>37 MJ m⁻³</td>
<td>1.89</td>
</tr>
<tr>
<td>Bio-CNG (Grass farmer)</td>
<td>€0.76 m⁻³</td>
<td>37 MJ m⁻³</td>
<td>2.05</td>
</tr>
</tbody>
</table>

BioCNG is 10% biomethane and 90% CNG; blend allows compliance with RES-T of 10%
Bus Rapid Transport powered by Biomethane?

Cork Bus (89 buses): 600 ha of grass biomethane
Biomethane as a source of Renewable Heat
### Biomethane: RES-T and RES-H

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Basic Research in Reactor Design and Operation
What type of digester configurations should be employed to produce biomethane from grass silage?

Abdul-Sattar Nizami a,b, Jerry D. Murphy a,b,*

a Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
b Environmental Research Institute, University College Cork, Ireland
One-stage and two-stage wet digesters

One-stage dry continuous digesters

DRANCO

Valorga
One-stage dry batch digester (ala Munich digester)

Two-stage dry batch digesters

Batch with UASB

Two-stage / Sequential-batch

Hybrid batch-UASB
Difficulties Associated with Monodigestion of Grass as Exemplified by Commissioning a Pilot-Scale Digester

T. Thamsiriroj†,‡ and J. D. Murphy*,†,‡
Modelling mono-digestion of grass silage in a 2-stage CSTR anaerobic digester using ADM1

T. Thamsiriroj\textsuperscript{a,b}, J.D. Murphy\textsuperscript{a,b,*}

\textsuperscript{a} Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
\textsuperscript{b} Environmental Research Institute, University College Cork, Cork, Ireland
Continuously Stirred Tank Reactor
Gas production from grass

Energy content of grass ~ 19 MJ/kg Volatile Solid (VS)

Energy content of CH$_4$ ~ 38 MJ/m$^3$

1 kg VS destroyed = 19MJ = 0.5 m$^3$ CH$_4$

Max production of gas is 500 L CH$_4$/kg VS added
Continuously Stirred Tank Reactor

440 L CH4/kg VS added; 88% destruction
@ 40 days retention time @2 kg VS/m3/d
Role of Leaching and Hydrolysis in a Two-Phase Grass Digestion System

A. S. Nizami, †,‡,§ T. Thamsiriroj, †,‡,§ A. Singh, ‡,§ and J. D. Murphy*, †,‡,§
70% destruction of volatiles in 30 days when sprinkling 100 L/d over bale silage

Should be equivalent to 350 L CH4/kg VS added in 30 days
Design, Commissioning, and Start-Up of a Sequentially Fed Leach Bed Reactor Complete with an Upflow Anaerobic Sludge Blanket Digesting Grass Silage

Abdul-Sattar Nizami,†,‡ Anoop Singh,†,‡ and Jerry D. Murphy*,†,‡

†Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland, and ‡Biofuels Research Group, Environmental Research Institute, University College Cork, Cork, Ireland

Received December 22, 2010
SLBR-UASB

Figure 1. Sequencing Leach Bed Reactors reactor complete with UASB (SLBR-UASB)
SLBR-UASB
Sequencing fed Leach Bed Reactors coupled with Upflow Anaerobic Sludge Blanket, (SLBR-UASB)

310 L CH4/kg VS added
62% destruction
@ 42 days retention time

Sprinkle rate dictated by UASB (upflow velocity < 1m/d) at 17 L/d

Improvement proposed: separate leaching and UASB flows
100 L/d for sprinkling; 17 L/d for UASB
2 pumps; one at 17 L/d for UASB; the second at 600 L/d (100 l/d over each batch)

341 L CH₄/kg VS added at a retention time of 30 days

Second pump allowed increase of 10% in gas production with a 28% decrease in reactor size

Compare to a dry batch system! Ability to double capacity of existing systems by adding UASB
New products require:

- **Market:**
  - potential for up to €2 billion industry

- **Sustainable**
  - Environmental (> 60% GHG savings)
  - Financial (as a transport fuel)

- **Potential for IP**
  - SLBR-UASB
  - 2 stage wet continuous digester with mixing system
Biofuel and Bioenergy Research Group
Funded by:

- Bord Gais Eireann
- EPA
- SEAI
- HEA PRTLI
- IRCSET
- DAFF