Grass Biomethane
European Grassland Federation Conference Kiel, Germany
30 August 2010

Dr Jerry Murphy, Dr N Korres, Dr A Singh
Environmental Research Institute,
University College Cork
12th August 2010
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

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

- Heating 41%
- Electricity 17%
- Transport 42%

An argument for using biomethane generated from grass as a biofuel in Ireland

Jerry D. Murphy\textsuperscript{a,}*, 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
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>Crop</th>
<th>Fuel/t</th>
<th>Fuel/ha/a</th>
<th>Gross 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>
</tr>
<tr>
<td>Ethanol (sugar beet)</td>
<td>50</td>
<td>100 l/t</td>
<td>5000 l/ha</td>
<td>105</td>
<td>9.6</td>
<td>1 in 3</td>
</tr>
<tr>
<td>Ethanol (wheat)</td>
<td>8.4</td>
<td>375 l/t</td>
<td>3150 l/ha</td>
<td>66</td>
<td>15.3</td>
<td>2 in 3</td>
</tr>
<tr>
<td>Biogas (sugar beet)</td>
<td>50</td>
<td>128 m³/t</td>
<td>6400 m³</td>
<td>134</td>
<td>7.5</td>
<td>1 in 3</td>
</tr>
<tr>
<td>Biogas (wheat)</td>
<td>8.4</td>
<td>420 m³/t</td>
<td>3528 m³</td>
<td>74</td>
<td>13.7</td>
<td>2 in 3</td>
</tr>
<tr>
<td>Biogas from silage</td>
<td>60</td>
<td>123 m³/t</td>
<td>7380 m³</td>
<td>155</td>
<td>6.5</td>
<td>3 in 3</td>
</tr>
</tbody>
</table>
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
Sustainable Biofuels


- 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>
Sustainability of grass biomethane

Modeling and Analysis

Is grass biomethane a sustainable transport biofuel?

Nicholas E. Korres, Anoop Singh, Abdul-Sattar Nizami and Jerry D. Murphy, * Biofuels Research Group, Environment Research Institute, University College Cork, Ireland
Sustainability of grass biomethane

<table>
<thead>
<tr>
<th>Scenario</th>
<th>% CO2 savings</th>
<th>Net energy (GJ/ha/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case scenario</td>
<td>21.5</td>
<td>64.4</td>
</tr>
<tr>
<td>Wind energy for electricity</td>
<td>42</td>
<td>64.4</td>
</tr>
<tr>
<td>Wood chips for heat demand</td>
<td>62</td>
<td>63.8</td>
</tr>
<tr>
<td>Vehicle efficiency</td>
<td></td>
<td>68.9</td>
</tr>
<tr>
<td>0.6 t/ha/a C sequestration</td>
<td></td>
<td>66.7</td>
</tr>
<tr>
<td>2.2 t/ha/a C sequestration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.8 t/ha/a C sequestration</td>
<td></td>
<td>260</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

harvest → weigh bridge → silage storage

Biogas service station ← anaerobic digester ← macerator

Source: energiewerkstatt, IEA and persona photos
A biofuel strategy for Ireland with an emphasis on production of biomethane and minimization of land-take

Anoop Singh\textsuperscript{a,b}, Beatrice M. Smyth\textsuperscript{a,b}, Jerry D. Murphy\textsuperscript{a,b,*}

\textsuperscript{a}Department of Civil and Environmental Engineering, University College Cork, Cork, Ireland
\textsuperscript{b}Biofuels Research Group, Environmental Research Institute, University College Cork, Cork, Ireland
### Table 9
Digester proposed for Ireland in 2020.

<table>
<thead>
<tr>
<th>Digester type</th>
<th>Number</th>
<th>Feedstock treated</th>
<th>Total feedstock</th>
<th>Capital Investment (M€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>183</td>
<td>50,000 t/a:</td>
<td>9.15 Mt/a:</td>
<td>183 × €7 = €1281</td>
</tr>
<tr>
<td></td>
<td></td>
<td>29,000 t/a grass (530 ha)</td>
<td>5.3 Mt/a grass (97 ha)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>21,000 t/a slurry</td>
<td>3.87 Mt/a slurry</td>
<td></td>
</tr>
<tr>
<td>Slaughter</td>
<td>4</td>
<td>52,000 t/a</td>
<td>208,000 t/a</td>
<td>4 × €15 = €60</td>
</tr>
<tr>
<td>Municipal</td>
<td>4</td>
<td>54,500 t/a</td>
<td>218,000 t/a</td>
<td>4 × €20 = €80</td>
</tr>
</tbody>
</table>

* Capital costs from Murphy and Power [41], case study of Linkoping Digester, Murphy and McCarthy [73].

7.5 – 33% substitution of natural gas
## 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>
</tr>
</thead>
<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>
Gas Grid in Ireland
Swedish biomethane use as a transport fuel

Biomethane as vehicle fuel in Sweden
30 June 2007

~ 13 500 gas-powered vehicles
(39 % increase)

~ 109 fuelling stations for CBG/CNG

~ 14 mNm³ biogas (38 % increase)

~ 12.7 mNm³ naturgas (31 % increase)

(1st half year)
GNG Vehicles

- 10 million vehicles worldwide
  - 1.75 million in Argentina
  - 580,000 in Italy
  - 70,000 in Germany

Sweden: biomethane/natural gas mix in vehicle fuel

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

Year

Sweden: biomethane/natural gas mix in vehicle fuel
## 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><strong>0.30</strong></td>
<td><strong>1.02</strong></td>
<td><strong>1.30</strong></td>
<td><strong>1.46</strong></td>
<td><strong>1.62</strong></td>
<td><strong>2.34</strong></td>
</tr>
</tbody>
</table>

Excise duty is not charged on gas used as a propellant, but VAT at 21% has to be added.

Cost €/m$^3$ 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
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
One-stage dry batch digester  (ala Munich digester)

Two-stage dry batch digesters

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

T. Thamsiriroj†,‡ and J. D. Murphy*†,‡
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
Two stage wet continuous digestion

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
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
Thank you

Funders

- Dept Agriculture Fisheries and Food (with Teagasc Grange and Queens Belfast)
- Environmental Protection Agency
- Bord Gais Eireann
- Irish Research Council for Science Engineering and Technology