Energy balances of bio-energy systems; the relative position of biogas production.

- Workshop: Energy Crops & Biogas, ’pathways to success?, Organized by Cropgen & IEA task 37, Utrecht, the Netherlands, September 22, 2005’ -

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Issues

• Development of digestion so far.
• Digestion as waste treatment option in waste treatment infrastructure.
• Some notions on energy crops.
• Final remarks on energy crops & digestion
State-of-the-art

Central digestor in Studsgard
Denmark is successful:

- 40 farm systems
- 20 centralised systems
- High market penetration
Een leercurve voor de investeringskosten van Deense biogas centrales

PR = 88% R² = 0.69
A learning curve for Danish biogas production

Based on 20 large scale grootschalige biogas plants in Denmark 1985-2001
Development of average biogas yield and income of Danish manure digestors.

![Graph showing the development of average biogas yield and income from 1988 to 2002. The graph plots average biogas yield in m³ per m³ biomass treated against the year. The average current income in 10⁶ Euro (2002) is also plotted. The years 1988, 1990, 1992, 1994, 1996, 1998, 2000, and 2002 are marked on the x-axis. The y-axis represents average biogas yield per m³ biomass treated, with values ranging from 0 to 45 m³. The y-axis for average current income ranges from 0 to 6 10⁶ Euro (2002).]
Some remarks:

• Digestion has reached sound maturity level (significant learning achieved over past decades).
• Further cost reductions hampered by scarcity of co-digestate, stalling of scale-up and market liberalisation.
• Continuity/stability of government policy very important.
More information on digestion:

Learning in renewable energy technology development
(Martin Junginger)

Strategic Niche Management for Biomass (Rob Raven)
National waste treatment infrastructure; optimalisation

- Optimalisation model; maximizing energy yield or minimizing costs.
- Performance of waste treatment and separation options in relation to scale (efficiencies, costs, heat (distribution), logistics).
- Waste supply and characteristics (moisture, contamination!).
- Boundary conditions (defaults energy system and materials).
- Analysis of different system lay outs (scenario’s).
Structure optimalisation model

Invoergegevens
o.a. afvalaanbod, technologieën, logistieke kengetallen

Vastgelegd hergebruik
niet brandbare stromen

Nieuw aanbod

Bestaande verwerkingsinstallaties
Nieuw aanbod

Optimalisatie
naar energie of kosten

t/m aanbod = 0
Nieuwe bewerkingsoptie
(hergebruik of verwerkingsinstallatie)

Afvalbewerkingsstructuur
Aantal opties (hergebruik en verwerking)
energie en kosten

Matrix model calculations:
f (scale, technology, location)
System boundaries

Biomassa- en afvalaanbod → Scheiden → Transport → Verwerking → Warmte-distributie → Herveurlijk → brandstof, elektriciteit → verlies warmte → brandstof, warmte elektriciteit → brandstof → transport brandstof → brandstof, elektriciteit → gescheiden aanbod

Warmte-distributie:
- Warmte
- Elektriciteit
- Brandstof

Uitsparing primair produktie

Copernicus Institute
Sustainable Development and Innovation Management
Waste supply for 2 scenario’s (kton)
Waste supply for 2 scenario’s in PJ

Avalaanbod in PJ (stookwaarde)
Gasification technologies: BIG/CC...

- Now: ACFB ~3500 US$/kWe, 30% eff., ~10 MWe
- M.T.: ACFB ~1500 US$/kWe, 50% eff., >100 MWe
- L.T.: PCFB + HT, ~1000 US$/kWe, 55% eff., >200 MWe

and Fischer-Tropsch/DME...)

- Pre-treatment:
  - grinding
  - drying

- Gasification:

- Gas cleaning:
  - reforming
  - shift
  - CO₂ removal

- Gas processing:

- FT synthesis:
  - FT liquids
  - Offgas

- Gas turbine
  - Power

- Recycle loop
Performance technologies vs. capacity (costs)
Performance technologies vs. capacity (efficiency)
## Overview main characteristics waste treatment infrastructure

<table>
<thead>
<tr>
<th>naam</th>
<th>aanbod</th>
<th>achteraf scheiden</th>
<th>warmte</th>
<th>technologieën</th>
<th>Bestaande installaties</th>
<th>optimalisatie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref_energie</td>
<td>referentie</td>
<td>geen</td>
<td>referentie</td>
<td>geen beperking</td>
<td>groene wei</td>
<td>energie</td>
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<tr>
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<td>referentie</td>
<td>geen beperking</td>
<td>groene wei</td>
<td>kosten</td>
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<td>plastiek in RDF</td>
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<td>energie</td>
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<td>referentie</td>
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<td>groene wei</td>
<td>energie</td>
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<tr>
<td>Geen_WKK</td>
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<td>geen</td>
<td>warmtevraag</td>
<td>geen beperking</td>
<td>groene wei</td>
<td>energie</td>
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<td>Optimaal_WKK</td>
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<td>geen</td>
<td>onbeperkte warmtevraag</td>
<td>geen beperking</td>
<td>groene wei</td>
<td>energie</td>
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<tr>
<td>Tegenva-energie</td>
<td>referentie</td>
<td>geen</td>
<td>referentie</td>
<td>BIG/CC slechter, geen HTU</td>
<td>groene wei</td>
<td>energie</td>
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<tr>
<td>Tegenva-kosten</td>
<td>referentie</td>
<td>geen</td>
<td>referentie</td>
<td>BIG/CC slechter, geen HTU</td>
<td>groene wei</td>
<td>kosten</td>
</tr>
<tr>
<td>Max_elektr./warmte</td>
<td>referentie</td>
<td>geen</td>
<td>referentie</td>
<td>geen hergebruik en brandstofproductie</td>
<td>groene wei</td>
<td>energie</td>
</tr>
<tr>
<td>Bestaande</td>
<td>referentie</td>
<td>geen</td>
<td>referentie</td>
<td>geen beperking</td>
<td>bestaande installaties</td>
<td>energie</td>
</tr>
<tr>
<td>Marsroutes</td>
<td>Referentie, kosten verwerking</td>
<td>geen</td>
<td>referentie</td>
<td>BIG/CC slechter, bijstook additioele kosten, toepasbaarheid zoals marsroutes</td>
<td>bestaande installaties</td>
<td>energie</td>
</tr>
</tbody>
</table>
Primary energy saved in different scenario’s

![Diagram showing primary energy savings in different scenarios](image-url)
Total waste treatment costs of different scenario’s

![Bar chart showing total waste treatment costs in millions of Euros for different scenarios.](chart.png)
Results
reference scenario - energy

Saved primary energy and technology mix
Results reference scenario - costs

Costs and technology mix
Some findings

- Depending on boundary conditions, large shifts between electricity and heat, savings by recycling and transport fuels (high sensitivities).
- Key advanced technologies: 1: (B)IG/CC, 2: co-firing and gasification with NGCC, 3: Separate collection & Waste separation, 4: HTU for wet streams (possibly strong alternative for digestion).
- Large scale facilities generally more attractive.
- Increasing heat utilisation has significant potential but strongly competes with NG and possibly efficiency measures.
Biomass production performance data for various types of crops and conditions

<table>
<thead>
<tr>
<th>Crop &amp; global conditions.</th>
<th>Energy ratio</th>
<th>Yield (dry tonne/ha*yr)</th>
<th>Net energy yield (GJ/ha*yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRC (US, Europe) (e.g. Willow and Hybrid Poplar)</td>
<td>10:1</td>
<td>10-12</td>
<td>180-200</td>
</tr>
<tr>
<td>- short term</td>
<td>20:1</td>
<td>12-15</td>
<td>220-260</td>
</tr>
<tr>
<td>- longer term</td>
<td>10:1</td>
<td>2-10</td>
<td>30-180</td>
</tr>
<tr>
<td>Tropical plantations (e.g. Eucalyptus): 1. No genetic improvement, fertilizer use &amp; irrigation.</td>
<td>20:1</td>
<td>6-30</td>
<td>100-550</td>
</tr>
<tr>
<td>2. Genetic improvement and fertilizer use.</td>
<td>20:1</td>
<td>20-30</td>
<td>340-550</td>
</tr>
<tr>
<td>3. Genetic improvement, fertilizer and water added.</td>
<td>12:1</td>
<td>10-12</td>
<td>180-200</td>
</tr>
<tr>
<td>Miscanthus/Switchgrass</td>
<td>20:1</td>
<td>12-15</td>
<td>220-260</td>
</tr>
<tr>
<td>- short term</td>
<td>18:1</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>- longer term</td>
<td>20/30:1</td>
<td>1-4</td>
<td>30-80</td>
</tr>
<tr>
<td>Sugar cane (Brazil)</td>
<td>10:1</td>
<td>10-16</td>
<td>30-100</td>
</tr>
<tr>
<td>- short term</td>
<td>20:1</td>
<td>16-21</td>
<td>140-200</td>
</tr>
<tr>
<td>- longer term</td>
<td>4:1</td>
<td>4-7</td>
<td>50-90</td>
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<tr>
<td>Sugar Beet (NW Europe)</td>
<td>10:1</td>
<td>10-16</td>
<td>30-100</td>
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<tr>
<td>- short term</td>
<td>4:1</td>
<td>4-7</td>
<td>50-90</td>
</tr>
<tr>
<td>- longer term</td>
<td>10:1</td>
<td>16-21</td>
<td>140-200</td>
</tr>
<tr>
<td>Rapeseed (including straw yields; NW Europe)</td>
<td>4:1</td>
<td>4-7</td>
<td>50-90</td>
</tr>
<tr>
<td>- short term</td>
<td>10:1</td>
<td>7-10</td>
<td>100-170</td>
</tr>
<tr>
<td>- longer term</td>
<td>10:1</td>
<td>16-21</td>
<td>140-200</td>
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</tbody>
</table>

\(^{a)}\) The value quoted in Moreira and Goldemberg, 1999 (1:7.9) includes energy expenditures in transportation and processing of sugarcane to ethanol. Also it is assumed the only final product is ethanol.
## Basics energy crop options (EU)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Typical yield ranges (odt/ha*yr)</th>
<th>Energy inputs (GJprim/ha*yr)</th>
<th>Typical net energy yield (GJ/ha*yr)</th>
<th>Production cost ranges European context (Euro/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rape</td>
<td>Short term 2.9 (rapeseed) 2.6 (straw)</td>
<td>11</td>
<td>110 (total)</td>
<td>20</td>
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<tr>
<td></td>
<td>Longer term 4 (rapeseed) 4.5 (straw)</td>
<td>12</td>
<td>180 (total)</td>
<td>12</td>
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<tr>
<td>Sugar Beet</td>
<td>Short term 14</td>
<td>13</td>
<td>250</td>
<td>12</td>
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<tr>
<td></td>
<td>Longer term 20</td>
<td>10</td>
<td>370</td>
<td>8</td>
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<tr>
<td>SRC-Willow</td>
<td>Shorter term 10</td>
<td>5</td>
<td>180</td>
<td>3-6</td>
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<tr>
<td></td>
<td>Longer term 15</td>
<td>5</td>
<td>280</td>
<td>&lt;2</td>
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<tr>
<td>Poplar</td>
<td>Shorter term 9</td>
<td>4</td>
<td>150</td>
<td>3-4</td>
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<td></td>
<td>Longer term 13</td>
<td>4</td>
<td>250</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>Shorter term 10</td>
<td>13-14</td>
<td>180</td>
<td>3-6</td>
</tr>
<tr>
<td></td>
<td>Longer term 20</td>
<td>13-14</td>
<td>350</td>
<td>~2</td>
</tr>
</tbody>
</table>
Final remarks

- Digestion is a sound and available conversion technology for wet(ter) biomass streams (including manure).
- Thermal conversion options strong competitors for drier and lignocellulosic biomass.
- Perennial crops (lignocell...) generally have better energy & GHG & environmental balances (and economics!) than annual crops.
- Role of digestion…?