Sustainable Hydrogen Production from Biomass by Fermentation

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Sustainable H$_2$ production technologies

- Electrolysis using electricity from renewables
- Gasification/pyrolysis of biomass
- Reforming biogas methane
- Photosynthesis (algae or bacteria)
- Dark fermentation
Fermentation

- A dark anaerobic process by which bacteria and yeasts gain energy from organic matter
- Requires wet, carbohydrate-rich biomass substrates
- Produces fermentation end products - gases, acids, and alcohols
- A CO$_2$ neutral process
Fermentation of biomass to energy sources

- Ethanol
- Methane by anaerobic digestion
- Hydrogen?
Fermentative H₂ production

- property of many species of bacteria, particularly clostridia
- carbohydrates are favoured substrate
- involves hydrogenase
- H₂ yield depends on fermentation products
Fermentative H₂ yield

\[ \text{hexose} \rightarrow \text{acetic acid} + 4 \text{H}_2 \]
\[ (0.5 \text{ m}^3 \text{ H}_2 / \text{kg carbohydrate}) \]

\[ \text{hexose} \rightarrow \text{butyric acid} + 2 \text{H}_2 \]

thermodynamically unfavourable as H₂ conc rises
<table>
<thead>
<tr>
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<th>Non-sparging</th>
<th>Sparging</th>
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<tbody>
<tr>
<td><strong>H$_2$ yield</strong> (mol/mol gluc)</td>
<td>0.85</td>
<td>1.43</td>
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<tr>
<td>acetic mgl$^{-1}$</td>
<td>773</td>
<td>785</td>
</tr>
<tr>
<td>butyric mgl$^{-1}$</td>
<td>1742</td>
<td>1929</td>
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Sustainable $H_2$ production from biomass

- **Biomass** → **Acetic acid** → **H$_2$ + CO$_2$**
- **H$_2$ + CO$_2$** → **Transport or Fuel Cell**
  - **H$_2$ + CH$_4$** → **Transport**
  - **CH$_4$ + CO$_2$** → **IC engine or reformer Fuel Cell**
- **Effluent (crop irrigation)** → **Anaerobic digester**
  - **Optimised fermentative H$_2$ reactor**

Diagram:
- Biomass
- Acetic acid
- Transport or Fuel Cell
- H$_2$ + CH$_4$
- IC engine or reformer Fuel Cell
- Effluent (crop irrigation)
- Optimised fermentative H$_2$ reactor
Requirements for fermentative H$_2$ producing technology

- Non-sterile operation
- Readily-available mixed microflora
- Operating conditions optimised for H$_2$ yield
- Process stability
- Fermentable biomass substrate year-round
- Net positive energy balance
Sustainable biohydrogen production: process optimisation - EPSRC funded
Inoculum selection and start-up

- *Clostridia* spore formers selected by heating anaerobically digested sewage sludge
- Batch start-up for spore germination (1-2 days)
- Specific reactor conditions (e.g. pH, retention time) required to prevent competitive growth
Fermentation reactions lowering $H_2$ yield

Hexose $\rightarrow$ acetone/butanol/ethanol

$CO_2 + H_2 \rightarrow$ acetic acid

Hexose $+ H_2 \rightarrow$ propionic acid (non-spore formers)
Optimisation challenges for fermentative hydrogen production

- Feedstock selection
- Inoculum selection, start-up and re-start up
- Prevention of inhibition by H$_2$
- Prevention of shifts in metabolism and population
- Development of sustainable process technology (LCA)
University of Glamorgan H₂ research

• Sustainable biohydrogen production: process optimisation. EPSRC.
• A sustainable energy supply for Wales: towards the hydrogen economy. EU Objective 1.
• Feasibility of sustainable hydrogen production from wheat starch-based food industry co-products. Carbon Trust.
• Biological generation of hydrogen from renewable resources using fermentation. EPSRC SUPERGEN.
Conclusions

• Batch start-up with heat treated sewage sludge seed is successful

• Continuous operation on starch co-product is possible with $\text{H}_2$ yield of 1.9 moles $\text{H}_2$/mole hexose consumed (48% of theoretical)

• Requires $\text{H}_2$ stripping, on-line monitoring and control