# Biological hydrogen via fermentation

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www.biohydrogen.nl

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## Topics of Biological Hydrogen Production

- (photo)fermentative $H_2$ production
- biomass
- potential: technical and economic feasibility


*Caldicellulosiruptor saccharolyticus*

## Conversion efficiency for energy production

| **Fermentation product** | **$\Delta G_{\circ}'$ in product** kJ/mol glucose |
|---|---|
| 3 methane | -2281 |
| acetone+butanol+ethanol (ABE) | -2397 (average) |
| 2 ethanol | -2464 |
| 12 $H_2$ | -2673 |
| for comparison: $\Delta G_{\circ}'$ glucose | -2699 |

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## Hydrogen yields and production rates

| Microorganism(s) | T °C | Substrate | Observed yield $H_2$/mol monosaccharide | $H_2$ production rate mmol/L.h |
|---|---|---|---|---|
| *Thermotoga elfii* | 65 | Glucose | 3.3 | 3 |
| *Caldicellulosiruptor saccharolyticus* | 70 | Sucrose, glucose | 3.0-2.7 | 8 - 25 |
| *C. saccharolyticus* | 70 | Starch hydrolysate | 3.7 | 27 |
| *Clostridium spp.* | 36 | Glucose, xylose | 1.4 - 2.0 | 7 - 31 |
| *Enterobacter aerogenes* | 38 | Glucose | 0.6 – 1.0 | 21 - 31 |
| Sewage sludge | 35 | Glucose, sucrose | 1.7 | 26 - 30 |

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# $H_2$ Fermentation

$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 12\,H_2$ $\quad \Delta G_o' = +3.2$ kJ

$C_6H_{12}O_6 + 2H_2O \rightarrow 2CO_2 + 2CH_3COOH + 4\,H_2$ $\quad \Delta G_o' = -206$ kJ

(hyper)thermophilic bacteria

*photons*

$CH_3COOH + 2H_2O \rightarrow 2CO_2 + 4\,H_2$ $\quad \Delta G_o' = +104$ kJ

purple, non-sulfur bacteria

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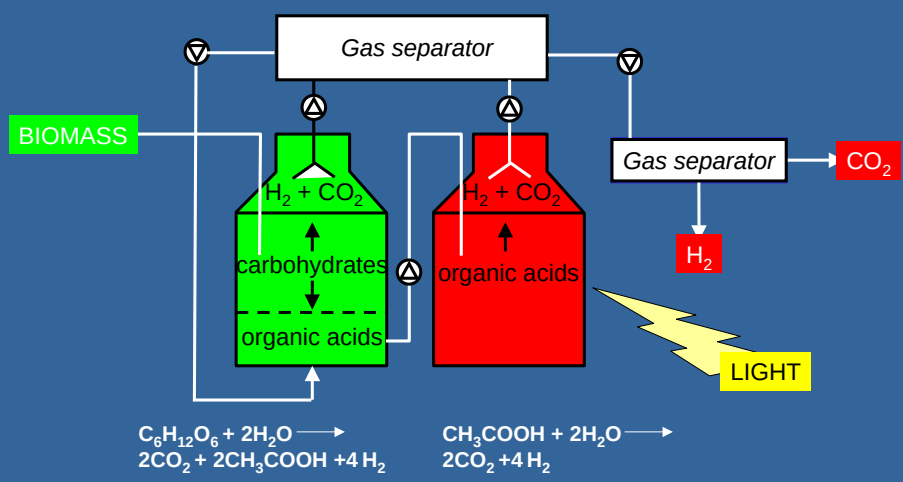
# Wageningen Bioprocess for $H_2$ production

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# Biochemistry:Typical $H_2$ Production Parameters

| | $H_2$ production efficiency (%of theoretical maximum) | Light energy conversion efficiency (%) | $H_2$ production rate (mmol/g DW.h) | Critical $H_2$ in gas phase (kPa) |
|---|---|---|---|---|
| *Caldicellulosiruptor saccharolyticus* | 74-80 | n.a. | 29 | 20-56 |
| *Rhodopseudomonas sp; Rhodobacter capsulatus* * | 26-87 | 1-2 | 0.8-1.6 | ≥90 |

n.a: not applicable; * light limitation

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# Thermophilic hydrogen fermentation

50% $H_2$ in dry gas,
10 mol $H_2$/day

*Caldicellulosiruptor saccharolyticus*
30 mL suspension to 400 L trickle bed (TNO-MEP)

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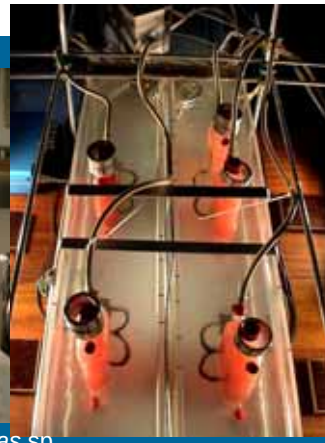
## Photo-heterotrophic $H_2$ production



*Rhodopseudomonas* sp.
1 L immobilised cells to 2.5 L flatpanel photoreactor;
87% efficiency on acetate; ≥90% $H_2$ in gas phase
(WUR-ATF-PE)

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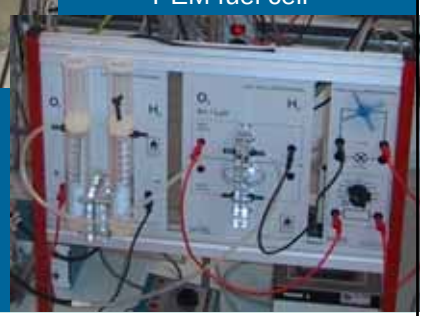
## Biochemistry: Electricity from Fermentation

*C. saccharolyticus* growing on sucrose

PEM fuel cell



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# Biomass: Applied Feedstocks


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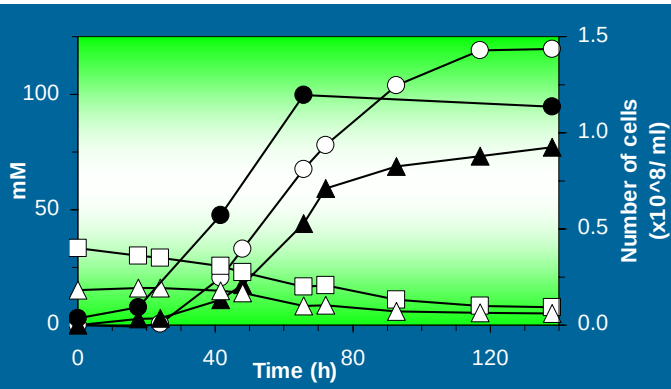
# Thermophilic $H_2$ production on organic waste




Growth of *Thermotoga elfii* on domestic organic waste hydrolysate. Cell count (●); Hydrogen (●); Acetate (▲);Glucose (■); Fructose (▲)

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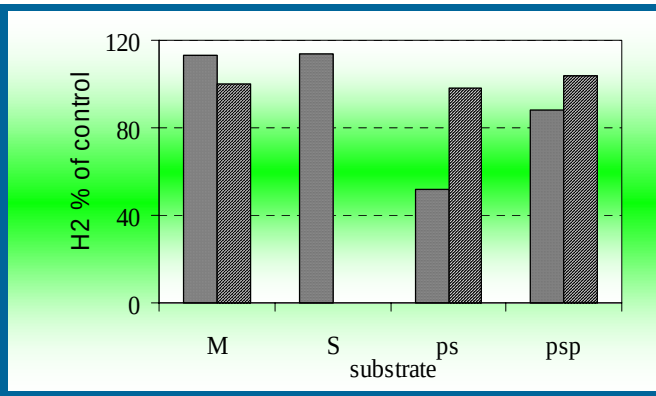
# Thermophilic $H_2$ production




$H_2$ production by *Caldicellulosiruptor saccharolyticus* and *Thermotoga elfii* on supplemented hydrolysates of *Miscanthus* (M), sweet sorghum juice (S), paper sludge (PS) and potato steam peels (PSP) and as percentage of control cultures

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# Cost of Biohydrogen

**Techno-economic evaluation for 57 kg $H_2$/h from potato steam peels**

| | EURO/kg $H_2$ |
|---|---|
| Equipment, maintenance, insurance, overhead (450 m³ thermoreactor; 12 ha tubular photoreactor) | 2.01 |
| Personnel | 0.17 |
| Potato steam peels | 0.68 |
| Caustic etc. | 0.11 |
| Electricity kW | 0.13 |
| **Total cost** [1)] | **3.10** |

Pumps, reactors
compressors
heat exchangers
containers
special equipment

[1)]Total cost = 22 EURO/GJ;

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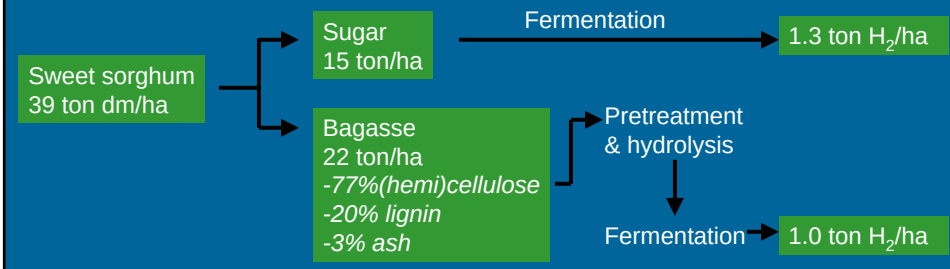
# Potential of Sweet sorghum for biohydrogen




Sweet sorghum production cost: 908 EURO/ha
Non-fermentable residu: 4.5 ton lignin /ha

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# Challenges

- Pretreatment of lignocellulosic feedstock
- $H_2$ removal in thermobioreactor
- Photobioreactor design
- $H_2$ production rates
- Utilisation of non-fermentable residues

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# Conclusion

- Biological hydrogen production from biomass shows great promise for small scale, decentral production of $H_2$.

- Further reading: www.biohydrogen.nl;

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