MODULAR UNITS

SEMI MOBILE SYSTEMS

CIRCULAR ECONOMY

CLIMATE PROTECTION

ENVIRONMENTAL

WASTE

RECYCLING

H₂

MIDI-THERMOLYSIS

CHECK IT

WASTE2HYDROGEN

Modis GmbH CC Leipzig
Dipl.-Ing. (FH) Dirk Gerlach VDI
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Electrolysis & nuclear power
Electrolysis & mixed power

Natural gas & steam reformation
Fossil origin
Lignite origin
Coal origin

Natural gas & steam reformation with CCS
Natural gas & steam reformation with CCS

Methane pyrolysis & green power with C-fix
Methane pyrolysis & green power with C-fix

Natural Hydrogen or fracking

Plastic waste pyrolysis with CCS
Bio based Plastic waste pyrolysis with CCS

Bio waste with CCS
Bio waste without CCS

https://www.enapter.com/hydrogen-clearing-up-the-colours
https://www.bmbf.de/de/eine-kleine-wasserstoff-farbenlehre-10879.html

6.10.2021
INTRODUCTION OF COLORS

**Electrolysis & green power**
- Biomass origin
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- Electrolysis & solar power

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- Bio based Plastic waste pyrolysis with CCS

**Bio waste with CCS**
- Bio waste without CCS

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https://www.bmbf.de/de/erneuerbare-energie-forschung.html

https://www.enapter.com/hydrogen-clearing-up-the-colours
INTRODUCTION OF FRAMES

Additional consumers:
- Water evaporation: 0.72 kWh/kg H₂O
- Oxygen production via PSA: 1.5 kWh/Nm³ O₂ (38 Nm³/h 90.0% need 55 kW) [www.inmatco.com](https://www.inmatco.com)
- Transport (100 km * 15 tons) Truck 666 kWh / Ship 125 kWh


Ask your consultants for the frames!
CHECK IT
WASTE2HYDROGEN

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Electrolysis & green power

Chemical reaction:
2 H₂O (l) -> 2 H₂ + O₂ + 572 kJ/mol

Energy consumption:
- 39.50 kWh/kg H₂

CO₂ production:
- Directly none

Possible production:
- 111 kg H₂ / t H₂O

Additional points:
- Water cleaning
- Required high amount of electric power
- If electrolysers nearby wind mills at green fields, so H₂ compression up to 500 bar for truck transport required
Chemical reaction (simplified):

CH₄ + H₂O (g) → 3 H₂ + CO + 206 kJ/mol
CH₄ + 2 H₂O (g) → 4 H₂ + CO₂ + 165 kJ/mol

Energy consumption:

- 9,48 kWh / kg H₂
- 5,69 kWh / kg H₂

COₓ production:

- 4,64 kg CO / kg H₂
- 5,47 kg CO₂ / kg H₂

Possible production:

- 154 kg H₂ / t (CH₄ + H₂O)

Additional points:

- Methane losses during fracking
- Methane losses during transport
- Water cleaning
- Water evaporation (energy)
- Oxygen production requires energy
- If not used at local (industrial) site: H₂ compression for transport.
- Using of CO₂ open …
- Large scale production

Additional points:

- Methane losses during fracking
- Methane losses during transport
- Water cleaning
- Water evaporation (energy)
- Oxygen production requires energy
- If not used at local (industrial) site: H₂ compression for transport.
- Using of CO₂ open …
- Large scale production

https://de.wikipedia.org/wiki/Dampfreformierung

https://commons.wikimedia.org/wiki/File:Haber-Bosch.svg
**Additional points:**

- Methane losses during fracking
- Methane losses during transport
- External energy required
- $H_2$ compression for transport
- Clean carbon is raw material

**Chemical reaction:**

$CH_4 \rightarrow 2H_2 + C + 75 \text{kJ/mol}$

**Energy consumption:**

- 5,15 kWh/kg $H_2$

**COx production:**

- Directly none

**Possible production:**

- 250 kg $H_2$ / t $CH_4$
Chemical reaction:

\[ \text{C}_3\text{H}_8 \rightarrow 4 \text{H}_2 + 3 \text{C} + 121 \text{kJ/mol} \]

Energy consumption:

- 4,18 kWh / kg \( \text{H}_2 \)

\( \text{CO}_x \) production:

- Directly none

Possible production:

- 182 kg \( \text{H}_2 \) / t \( \text{C}_3\text{H}_8 \)

Additional points:

- Propane losses during production
- Propane losses during transport
- External energy required
- \( \text{H}_2 \) compression for transport

![Propane pyrolysis & green power with C-fix](https://commons.wikimedia.org/wiki/index.php?curid=70714110)
Chemical reaction:
C<sub>3</sub>H<sub>6</sub> → 3 H<sub>2</sub> + 3 C - 20 kJ/mol (exotherm!)

Energy consumption:
- 0.92 kWh/kg H<sub>2</sub>

CO<sub>x</sub> production:
- Directly none

Possible production:
- 143 kg H<sub>2</sub> / t C<sub>3</sub>H<sub>6</sub>

Additional points:
- Collecting of waste
- Sorting of waste
- Transport of waste
- Fillers in plastic
- H<sub>2</sub> compression for transport
Chemical reaction:

\[ C_{10}H_{10}O_{4} \rightarrow 5 \text{H}_2 + 4 \text{ CO} + 6 \text{ C} + 289 \text{ kJ/mol} \]

\[ C_{10}H_{10}O_{4} \rightarrow 5 \text{H}_2 + 2 \text{ CO}_2 + 8 \text{ C} - 56 \text{ kJ/mol} \]

Energy consumption:

- 6.65 kWh/kg H\(_2\)
- -1.55 kWh/kg H\(_2\)

CO\(_x\) production:

- 9.29 kg CO/kg H\(_2\)
- 8.76 kg CO\(_2\)/kg H\(_2\)

Possible production:

- 51 kg H\(_2\)/t C\(_{10}H_{10}O_{4}\)

Additional points:

- Collecting by collecting machines
- Transporting of PET scrap
- Mostly clean fraction, direct recycling better
- H\(_2\) compression for transport
- Using of CO\(_2\) or CO open …

PET pyrolysis & green power with C-fix

Additional points:

- Collecting by collecting machines
- Transporting of PET scrap
+ Mostly clean fraction, direct recycling better
- H\(_2\) compression for transport
- Using of CO\(_2\) or CO open …
Chemical reaction:

\[ C_6H_{12}O_6 \rightarrow 6 H_2 + 6 CO + 2.142 \text{ kJ/mol} \]

\[ C_6H_{12}O_6 \rightarrow 6 H_2 + 3 CO_2 + 3 C + 1.628 \text{ kJ/mol} \]

\[ C_6H_{12}O_6 + 3 H_2O \rightarrow 9 H_2 + 6 CO_2 + 1.304 \text{ kJ/mol} \]

Energy consumption:

- 49.34 kWh/kg H2
- 37.49 kWh/kg H2
- 20.03 kWh/kg H2

CO\(_x\) production:

- 13.94 kg CO / kg H2
- 10.95 kg CO\(_2\) / kg H2
- 14.59 kg CO\(_2\) / kg H2

Possible production:

- 67 kg H\(_2\) / t Biomass
- 77 kg H\(_2\) / t Biomass + H\(_2\)O

Additional points:

- External energy required, normally from partly incineration = additional CO\(_2\)
- H\(_2\) compression for transport
- Using of CO\(_2\) or CO open ...

D-Glucose (Biomass)

Picture from: www.4teachers.de

FACT CHECK

6.10.2021
# WHY H2 -&gt; REDUCING CO2

<table>
<thead>
<tr>
<th>element</th>
<th>20 years</th>
<th>100 years</th>
<th>500 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>84 - 86</td>
<td>28 - 40</td>
</tr>
<tr>
<td>Propane / R290</td>
<td>C₃H₈</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Isobutene / 600a</td>
<td>C₄H₁₀</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>4.3</td>
<td></td>
</tr>
</tbody>
</table>

https://en.wikipedia.org/wiki/Global_warming_potential  
https://www.infraserv.com/de/standortbetrieb/facility_management/know_how/f_gase_11/gwp_rechner_1/gwp_rechner.html

## Points of interest:

- A methane leakage of 1 - 3% causes more CO₂ equivalent than incineration!
- An uncontrolled rotting of biomass with 50% methane emission causes 18 times more CO₂ equivalent than incineration.
- Compost will change over in CO₂ within 10 years. Pyrolysis-coke is stable for hundred of years.

<table>
<thead>
<tr>
<th>Description</th>
<th>CH₄ emissions FOSSIL per kg fuel [g CH₄/kg_fuel]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel fuel (distillate with max. sulphur content of 10 ppm (e.g. according to DIN 51803-1 qualities) for inland water transportation according to EU directive 2009/30/EG)</td>
<td>1.80</td>
</tr>
<tr>
<td>Low Sulphur Marine Gas Oil (low sulphur distillate fuel oil similar to DMA with reduced S-content = 0.1%)</td>
<td>1.69</td>
</tr>
<tr>
<td>Heavy Fuel Oil medium quality (medium quality HFO similar to RME180 with S = 2.5 %)</td>
<td>1.56</td>
</tr>
<tr>
<td>Heavy Fuel Oil low quality (low quality HFO similar to RMK380 with S = 3.5 % and )</td>
<td>1.52</td>
</tr>
<tr>
<td>Ultra Low Sulphur Heavy Fuel Oil (ULSHFO similar to RMD80 with heavily reduced sulphur content, S = 0.1 %)</td>
<td>1.66</td>
</tr>
<tr>
<td>Methanol from steam reforming of natural gas</td>
<td>2.18</td>
</tr>
<tr>
<td>LNG2 (Liqueified Natural Gas Medium, LCA data calculated for EU import mix)</td>
<td>3.12</td>
</tr>
<tr>
<td>LNG4 (liquefied shale gas US)</td>
<td>28.70</td>
</tr>
</tbody>
</table>

Environmental impact

-5 kWh/kg H₂
0 kWh/kg H₂
5 kWh/kg H₂
10 kWh/kg H₂
15 kWh/kg H₂
20 kWh/kg H₂
25 kWh/kg H₂
30 kWh/kg H₂
35 kWh/kg H₂
40 kWh/kg H₂
45 kWh/kg H₂

-2 kg/kg H₂
0 kg/kg H₂
2 kg/kg H₂
4 kg/kg H₂
6 kg/kg H₂
8 kg/kg H₂
10 kg/kg H₂
12 kg/kg H₂
14 kg/kg H₂
16 kg/kg H₂

Chemical energy & CO₂
### ADDITIONAL ENERGY

<table>
<thead>
<tr>
<th>Stage</th>
<th>Level</th>
<th>Energy for compression</th>
<th>Cumulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td></td>
<td></td>
<td>1 – 10 bar 1,44 kWh/kg H₂</td>
</tr>
<tr>
<td>Pipeline</td>
<td>10 bar</td>
<td>1 – 10 bar 90 kg/h &amp; 130 kW 1,44 kWh/kg H₂</td>
<td>1 – 10 bar 1,44 kWh/kg H₂</td>
</tr>
<tr>
<td>LPG-Pipeline</td>
<td>20 bar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOHC-Storage</td>
<td>30 - 50 bar</td>
<td>10 – 50 bar 20 kg/h &amp; 27 kW 1,35 kWh/kg H₂</td>
<td>1 - 10 - 50 bar 2,79 kWh/kg H₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 – 50 bar 180 kg/h &amp; 123 kW 0,68 kWh/kg H₂</td>
<td></td>
</tr>
<tr>
<td>Truck (fuel)</td>
<td>350 bar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck (Transport)</td>
<td>500 bar</td>
<td>10 – 500 bar 70 kg/h &amp; 155 kW 2,21 kWh/kg H₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 – 500 bar 27 kg/h &amp; 90 kW 3,33 kWh/kg H₂</td>
<td></td>
</tr>
<tr>
<td>Car (fuel)</td>
<td>700 - 1000 bar</td>
<td>500 – 1,000 bar 75 kg/h &amp; 90 kW 1,2 kWh/kg H₂</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 -10 -500 - 1,000 bar 4,83 kWh/kg H₂</td>
<td></td>
</tr>
</tbody>
</table>
ENERGY COSTS

Energy costs (only chemical energy)

- Electrolysis
- NG + Steam reforming
- Methane pyrolysis
- Propane pyrolysis
- PP pyrolysis
- PET pyrolysis
- D-Glucose
- D-Glucose + Steam

Costs:
- 0.01 €/kWh
- 0.03 €/kWh
- 0.05 €/kWh
- 0.07 €/kWh
- 0.10 €/kWh

Prices:
- 0.500 €/kg H2
- 0.000 €/kg H2
- 1.000 €/kg H2
- 1.500 €/kg H2
- 2.000 €/kg H2
- 2.500 €/kg H2
- 3.000 €/kg H2

6.10.2021
Energy costs (only chemical energy)

- **Electrolysis**
- **NG + Steamreforming**
- **methane pyrolysis**
- **propane pyrolysis**
- **PP pyrolysis**
- **PET pyrolysis**
- **D-Glucose**
- **D-Glucose+Steam**

ENERGY COSTS

- 0.01 €/kWh: 0.000 €/kg H2
- 0.03 €/kWh: 0.000 €/kg H2
- 0.05 €/kWh: 0.000 €/kg H2
- 0.07 €/kWh: 0.000 €/kg H2
- 0.10 €/kWh: 0.000 €/kg H2

Slide 18 © Modis 6.10.2021
There are a lot of points have done before pure hyping hydrogen:

- Minimizing methane production by rotting of (waste) biomasses
- Minimizing direct methane leakage (pipeline / fracking / farmers)
- Change-over from composting to carbon capture & storage by pyrolysis
- Change-over from waste incineration to waste processing (recycling)
- Change-over from biomass incineration to carbon capture & storage by pyrolysis
- Change-over from biomass incineration to Waste2Product by thermolysis, ex.g. fertilizer, briquettes, activated carbon, chemical raw materials
- Change-over from fossil-fired to green-electric heating
- Reducing CO₂ production by change-over to green carbon based products.
- Change-over from carbon to hydrogen circuits
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- Reducing CO₂ production by change-over to green carbon based products.
- Change-over from carbon to hydrogen circuits
<table>
<thead>
<tr>
<th>Questions</th>
<th>Electrolyser</th>
<th>Methane pyrolysis (with biogas fermentation)</th>
<th>Waste thermolysis</th>
<th>Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>What kind of energy is available?</td>
<td>Electric energy</td>
<td>Methane (Food waste = biogas)</td>
<td>Plastic waste</td>
<td>Dry biomass</td>
</tr>
<tr>
<td>Do you have a waste problem?</td>
<td>equal</td>
<td>equal</td>
<td>Yes !</td>
<td>May be …</td>
</tr>
<tr>
<td>Is there cheap electric energy available?</td>
<td>need</td>
<td>equal / autarkic</td>
<td>equal / autarkic</td>
<td>equal / autarkic</td>
</tr>
<tr>
<td>Is there the possibility for CO2-usage?</td>
<td>equal</td>
<td>equal</td>
<td>equal, but better</td>
<td>need</td>
</tr>
<tr>
<td>Is there the possibility for methane usage?</td>
<td>equal</td>
<td>Switch over !</td>
<td>Good …</td>
<td>equal</td>
</tr>
<tr>
<td>Feeding in pipeline, cars, …</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Is there a requirement for fertilizers?</td>
<td>equal</td>
<td>equal</td>
<td>Check it …</td>
<td>Good !</td>
</tr>
<tr>
<td>(Terra preta)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Should the plant run 24h/7d</td>
<td>equal</td>
<td>need</td>
<td>need</td>
<td>need</td>
</tr>
<tr>
<td>What is the preferred H2 production capacity?</td>
<td>130 kg/h (5 MW electrolyser)</td>
<td>&gt; 1.000 kg/h</td>
<td>&lt; 600 kg/h (MIDI-Quad)</td>
<td>open</td>
</tr>
<tr>
<td>What is the required transportation?</td>
<td>In case of high pressure systems: truck tanks are ok</td>
<td>pipeline</td>
<td>Pipeline H2 station</td>
<td>pipeline</td>
</tr>
</tbody>
</table>
CHECK IT
WASTE2HYDROGEN

• Basics
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Honnuko Plant
Location: Yokohama – Dockyards
Start-up: 2000
Input: 120 kg/h
Industrial hazardous sludge
Heated by pyrolysis gas

Maizuru Plant
Location: Maizuru – Test facility
Start-up: 2001
Input: 300 kg/h
dioxin contaminated soil
Heated by LPG

Semirara Plant
Location: Semirara – Philippines
Start-up: 2005
Input: 300 kg/h
Lignite 25% WC
Heated by pyrolysis gas

Herne Plant
Location: Herne - Germany
Start-up: 1992
Input: 10.0 t/h
dioxin contaminated soil
Heated by pyrolysis gas

Spolana Plant
Location: Spolana - Czechia
Start-up: 2006
Input: 10.0 t/h
dioxin contaminated soil
Heated by natural gas

Burgau Plant
Location: Burgau - Germany
Start-up: 1984
Input: 2x 2.0 t/h
RDF up to 40% WC
Heated by pyrolysis gas

Mie Plant
Location: Mie prefecture - Japan
Start-up: 2005
Input: 4.0 t/h
Waste wood 20% WC
Heated by pyrolysis gas

Contherm Plant
Location: Hamm - Germany
Start-up: 2001
Input: 2x 6.5 t/h
RDF max 25% WC
Heated by natural gas

Photos by MPA Burgau & Werner Schütze & Dirk Gerlach
CONVENTIONAL GAS-HEATED KILNS

Please note …

• Methane pyrolysis for H₂-production needs a P3 > 800°C
• PP pyrolysis for H₂-production needs a P1 > 800°C
SAMPLE WASTE2HYDROGEN

- Refuse derived fuel (RDF): 1000 kg
- Additive: 10 kg
- Process gas: 880 kg

Thermolysis
- Rotary kiln auger funnel

Condensation
- 4 Step

Gas washer
- Process gas: 100 kg
- Hydrogen: 20 kg
- Methane: 20 kg
- CO2: 18 kg
- Sulphur: 2 kg

Condensate:
- 180 kg
- 340 kg
- 80 kg

Solvic:
- 230 kg

Acetic acid
- 120 kg

Coke
- 230 kg
High variability in …
- inputs
- temperatures (450 up to 1,200°C)
- processes (horrification - pyrolysis – gasification)
- output based operation (liquid to methane to H₂)

according to
- high energy efficiency (electric heated)
- zero emission (no burning chamber, no burners)
- safety continuous operation for > 100,000 hours
- autarkic system for green field operation
- containerized layout for easy replacement

Usable as a platform technology with option of
- catalytic processes to increase propane or butane (LPG)
- side stream liquid treatment

SGP goals
- Reducing transport, empty streets
- Local & qualified jobs
- Global energy thinking (waste heat for cooling stores)
- Processing waste instead of micro plastic in the oceans

https://www.ectaveo.ch/a-baby-chick-2/
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- Basics
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- Modis’ Vision
Modis services:
- Consulting
- Feasibility Study
- Tests
- Business plan
- Basic engineering
- Detail engineering

Production: H₂

Segregation: Turquoise + blue hydrogen By MIDI-Thermolyis

Turquoise + blue hydrogen By MIDI-Thermolyis

Solid + liquid Raw material

Farming, Carbon Capture & Storage

Thermal treatment

Loading stations
H₂ filling stations
Electric power production
H₂ for heating
Brick oven, iron reducing
H₂ + COₓ
Chemical industry

Waste
Be part of a WORLD WIDE WEB of WASTE2HYDROGEN operators!

Fixed interest
- Contract
- Offers / Pre-Contract
- MOU / LOI

Attention
- Governmental cooperation
- Project description
- Governmental suggestion