iwe
Institut für Wasserstoff- und Energietechnik der Hochschule Hof

BtX energy

Hydrogen technologies

An overview of technologies for the production and usage of hydrogen



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„water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.“

(Jules Verne, „The Mysterious Island“, 1870)

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Agenda

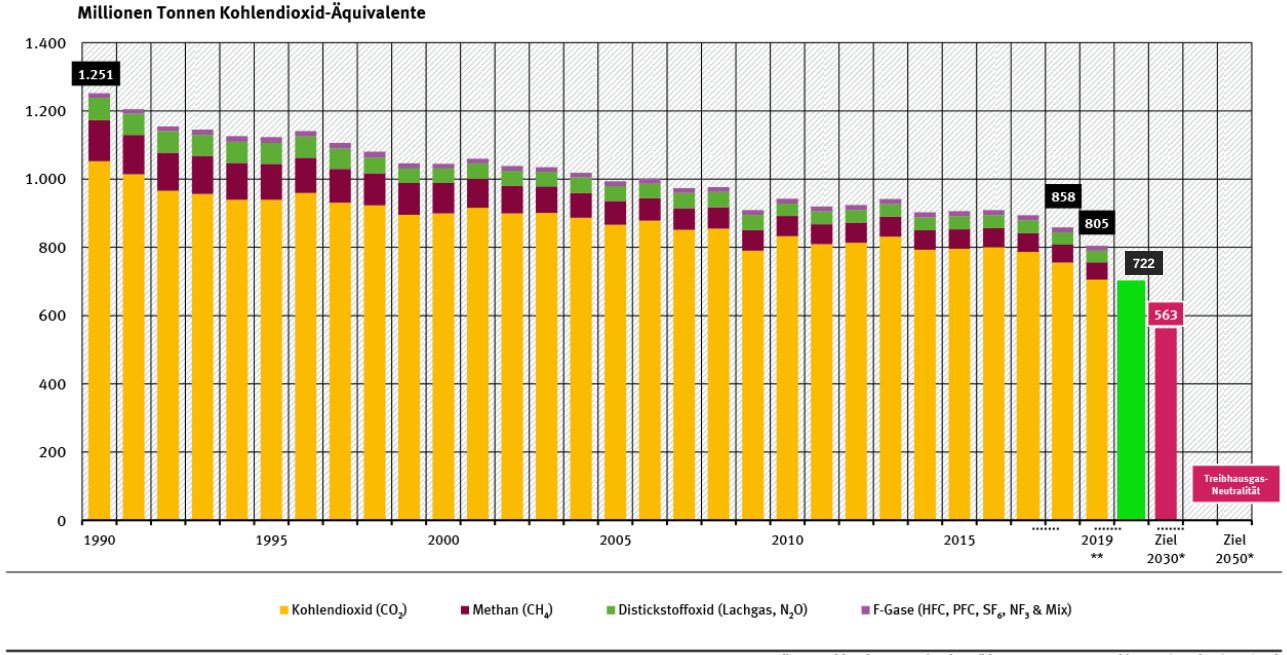
1. Motivation and general data
2. Technologies for the production of hydrogen
3. Technologies for the use of hydrogen
4. Technologies for the storage of hydrogen
5. Summary

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1 Motivation and general data

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Political goals



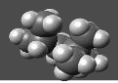
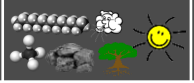
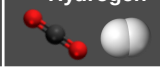
Emissionen ohne Landnutzung, Landnutzungsänderung und Forstwirtschaft
* Ziele 2030 und 2050: Bundes-Klimaschutzgesetz (KSG), Bundesgesetzblatt 219 Teil 1, Nr. 48 vom 17.12.2019
** Schätzung 2019

Quelle: Umweltbundesamt, Nationale Treibhausgas-Inventare 1990 bis 2018 (Stand 12/2019) und Vorjahresschätzung für 2019 aus UBA Presse-Mitteilung 11/2020

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1 Motivation and general data

Available energy sources / carrier

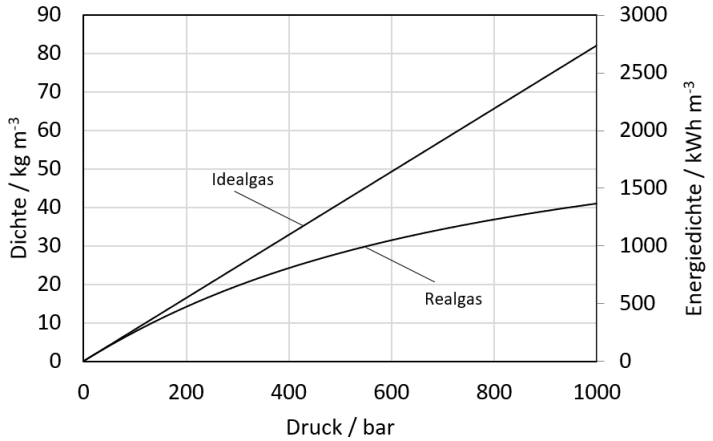
	Diesel / Oil	Petrol	Natural gas	Biomethane	Energy grid*	Renewable electricity	Fossil Hydrogen	Renewable Hydrogen
								
CO_2 footprint [kg / kWh]	0,27	0,26	0,2	-1,4 – 0,1	0,401*	0	0,3	-2,3 – 0,2
CO_2 footprint [kg / 100 km in traffic]	15,7	16,3	10,1	-63 – 4,5	7,6	0	10	-69,3 – 6
Energy densitiy [kWh / kg]	11,9	12,0	13,3	13,3	0,13 (LiPo)	0,13 (LiPo)	33,3	33,3

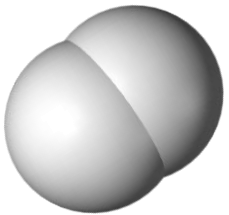
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1 Motivation and general data

What is hydrogen?

- Diatomic molecule
- Molar mass: 2.016 g/mol
- Density: 0,0899 kg/m³ (STP)
- Melting point: - 259,14 °C
- Boiling point: -252 °C
- Heating value: 33,33 kWh/kg
- Strongly non-ideal behaviour under pressure
- Joule-Thompson inversion temperature: -73,15 °C





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1 Motivation and general data

Definitions by color (practicable but not perfect)

- Grey hydrogen: Produced from fossil raw materials (natural gas, crude oil, coal) with release of CO_2
- Blue hydrogen: Produced from fossil raw materials incl. Carbon Caputre
- Turquoise hydrogen: Produced from natural gas by pyrolysis (solid carbon as residue)
- Yellow hydrogen: Produced from the general electricity mix by water electrolysis
- Green hydrogen: At least 70 % less CHG emissions than the fossile reference (mostly diesel)
  - Electrolysis from renewable energy
  - Reformation of biogenic residuals

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2 Technologies for the production of hydrogen

Steam reforming of natural gas

- Hydrogen production from natural gas*

$$CH_4 + H_2O \overset{r_{ref1}}{\longleftrightarrow} CO + 3H_2$$

$$CH_4 + 2\,H_2O \overset{r_{ref2}}{\longleftrightarrow} CO_2 + 4H_2$$

*Higher Alkanes reacting faster

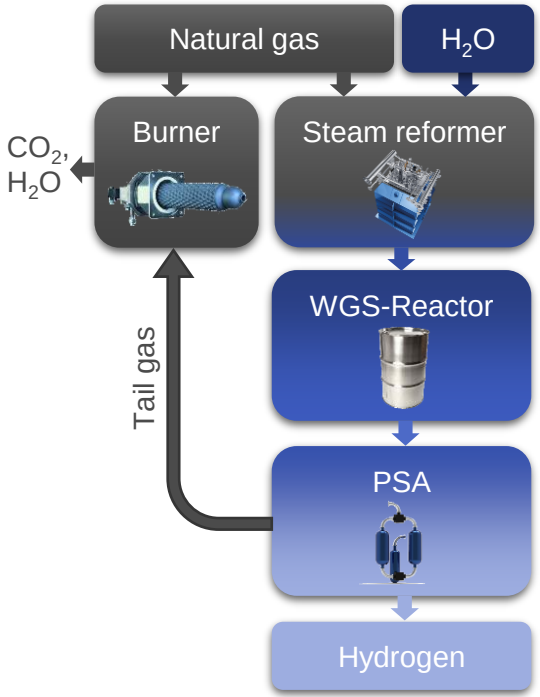
- Water gas shift for maximization of yield

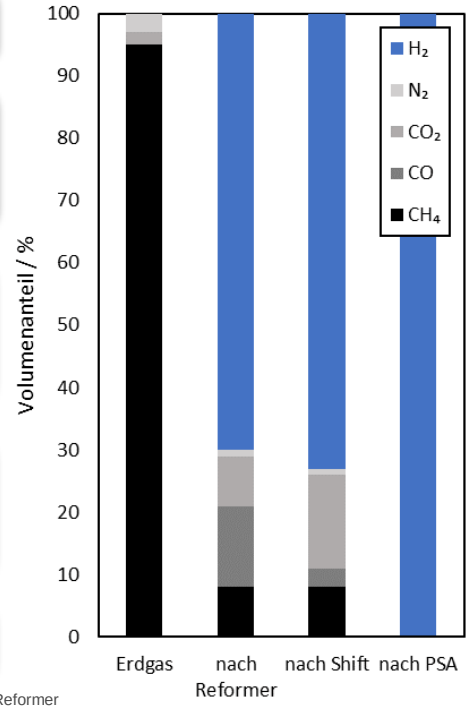
$$CO + H_2O \overset{r_{wgs}}{\longleftrightarrow} CO_2 + H_2$$

- Tail gas removal and combustion

$$CH_4 + 2\,O_2 \overset{r_{CH_4,ox}}{\longrightarrow} CO_2 + 2H_2O$$

$$CO + 0{,}5\,O_2 \overset{r_{CO,ox}}{\longrightarrow} CO_2 + H_2$$





Source: Nitzsche (DBI) 2020

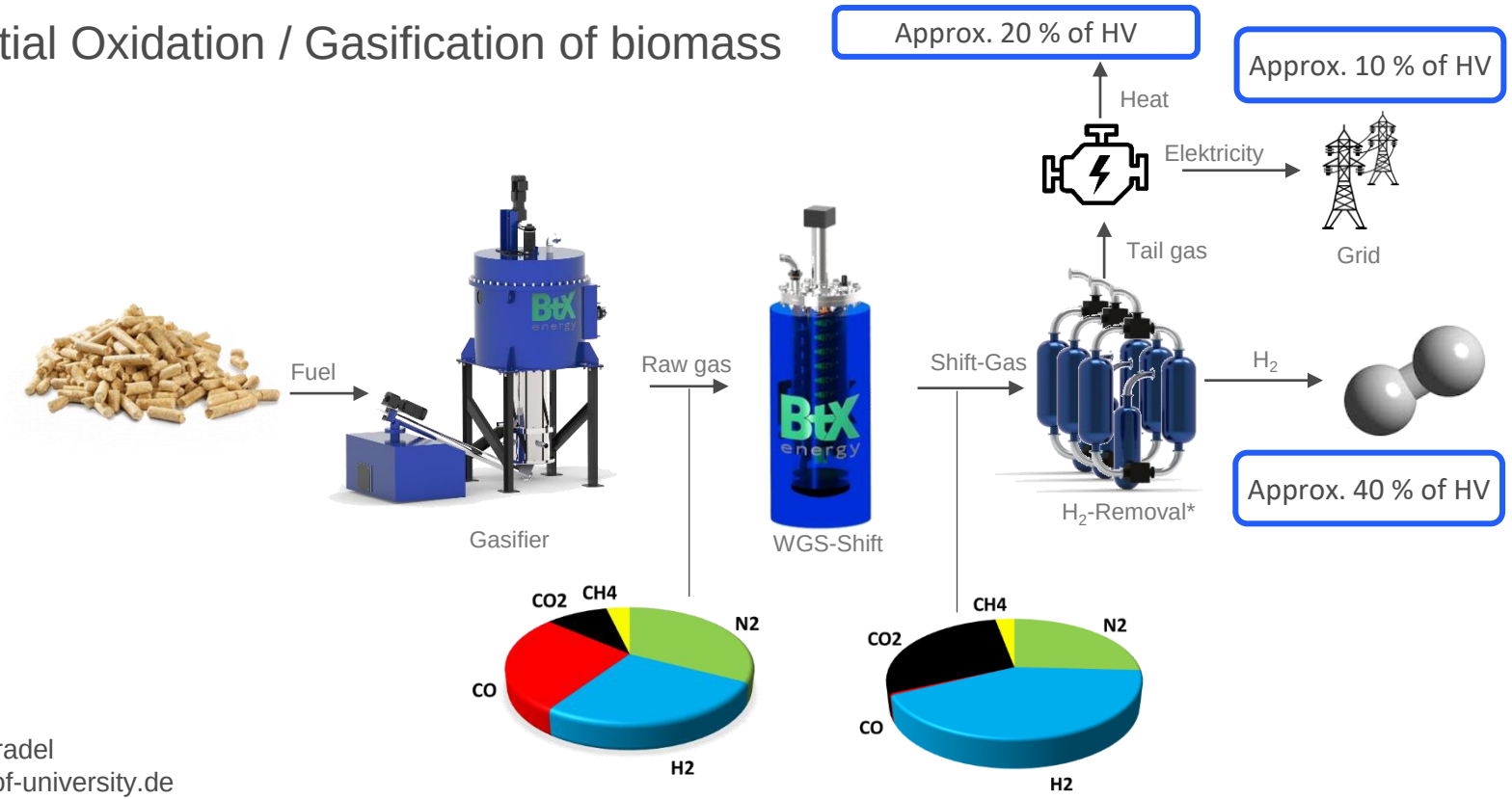
Sources: WS Wärmeprozesstechnik, WS Reformer

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2 Technologies for the production of hydrogen

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Partial Oxidation / Gasification of biomass



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Partial Oxidation / Gasification

- Pyrolysis of Biomass / Coking of Lignite

$$CH_mO_n \xrightarrow{r_{pyr}} CH_xO_y \qquad \text{mit} \quad m,n > x,y$$

- Partial Oxidation* / Gasification

$$CH_xO_y + (0{,}5 - \frac{y}{2})O_2 \xrightarrow{r_{ox}} CO + \frac{x}{2}H_2$$

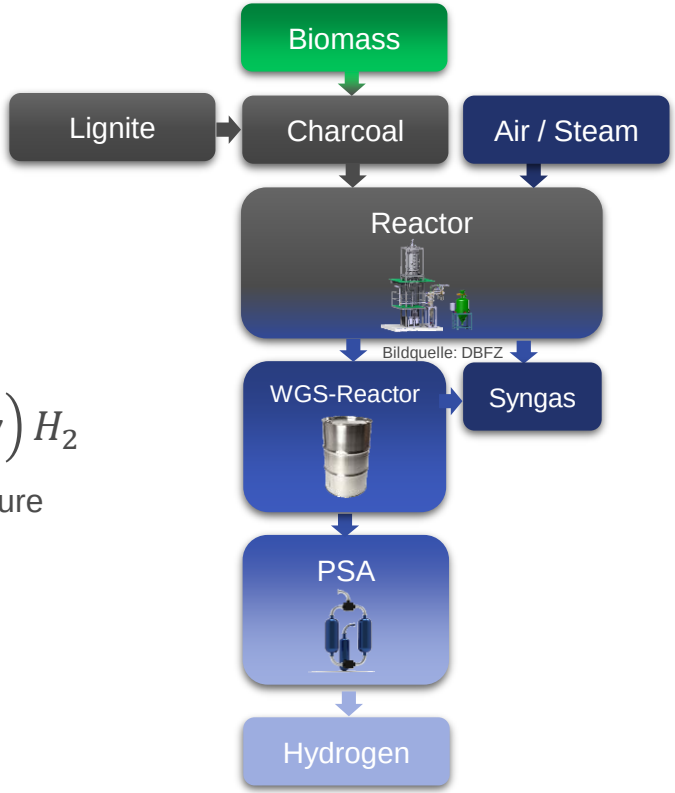
*also possible wirh natural gas / oil

$$CH_xO_y + (1-y)\,H_2O \xrightarrow{r_{gas}} CO + \left(1 + \frac{x}{2} - y\right)H_2$$

- Water gas shift to maximize hydrogen output / set mixture

$$CO + H_2O \xleftrightarrow{r_{wgs}} CO_2 + H_2$$

- Removal of hydrogen



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2 Technologies for the production of hydrogen

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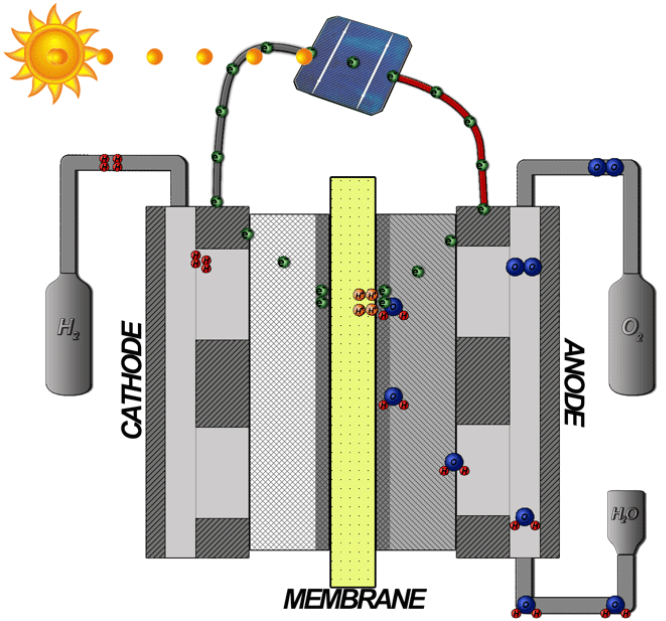
Electrolysis of water (Here: PEM-Electrolysis)

- Electrical splitting of water

$$2H_2O \rightarrow 4H^+ + 4e^- + O_2$$

- Passing through a protone exchange menbrane
- Recombination with electrons to form hydrogen molecules

$$4H^+ + 4e^- \rightarrow 2H_2$$

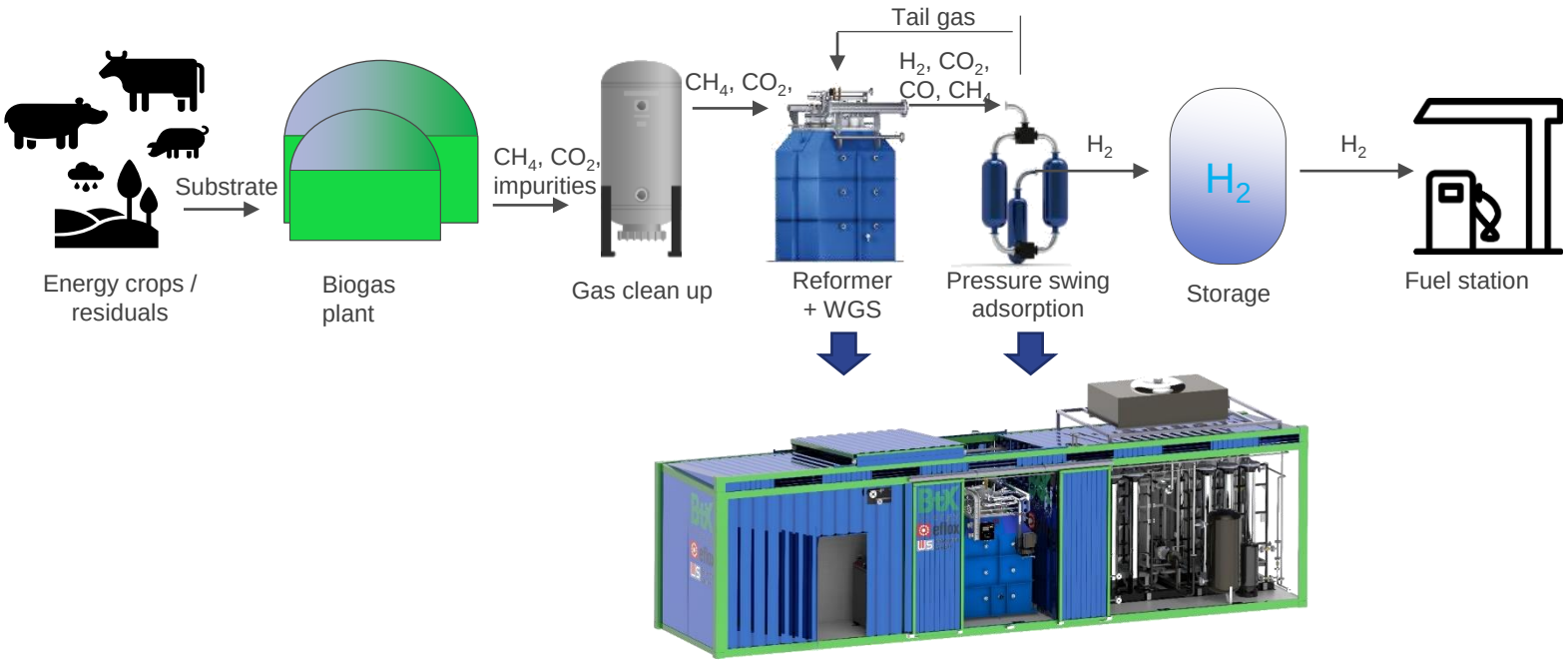


Bildquelle: Pinterest

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2 Technologies for the production of hydrogen

Steam reforming of biogas



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2 Technologies for the production of hydrogen

Steam reforming of Biogas

Hydrogen production from Biogas*

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$$CH_4 + 2\,H_2O \overset{r_{ref2}}{\longleftrightarrow} CO_2 + 4H_2$$

$$CH_4 + CO_2 \overset{r_{ref3}}{\longleftrightarrow} 2CO + 2H_2$$

* Higher Alkanes reacting faster

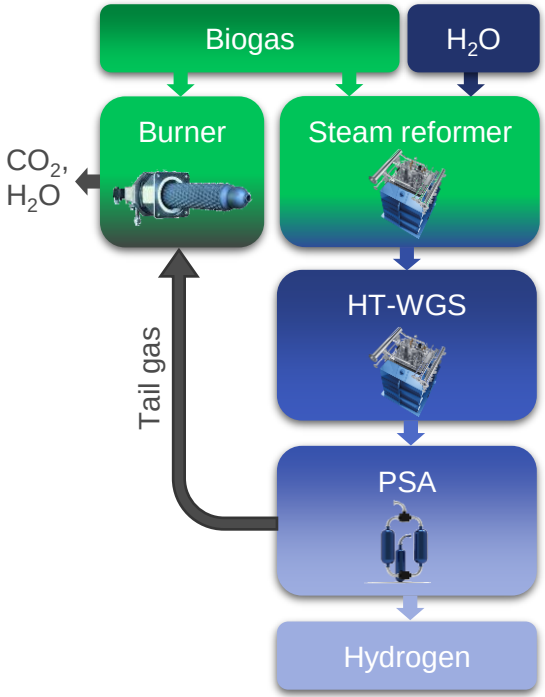
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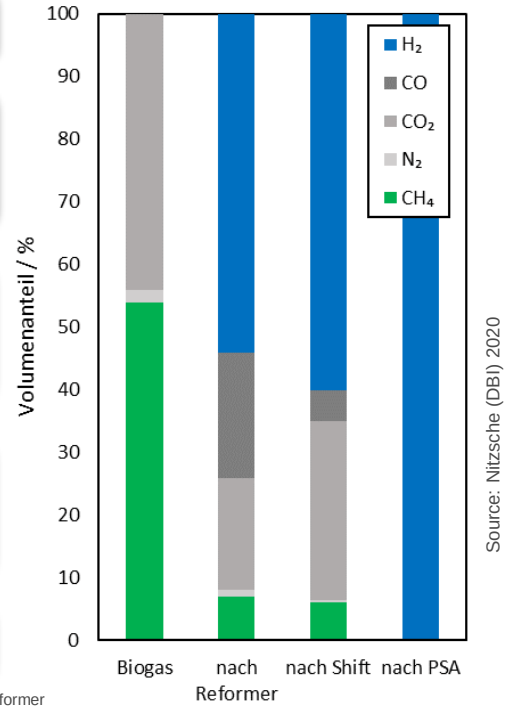
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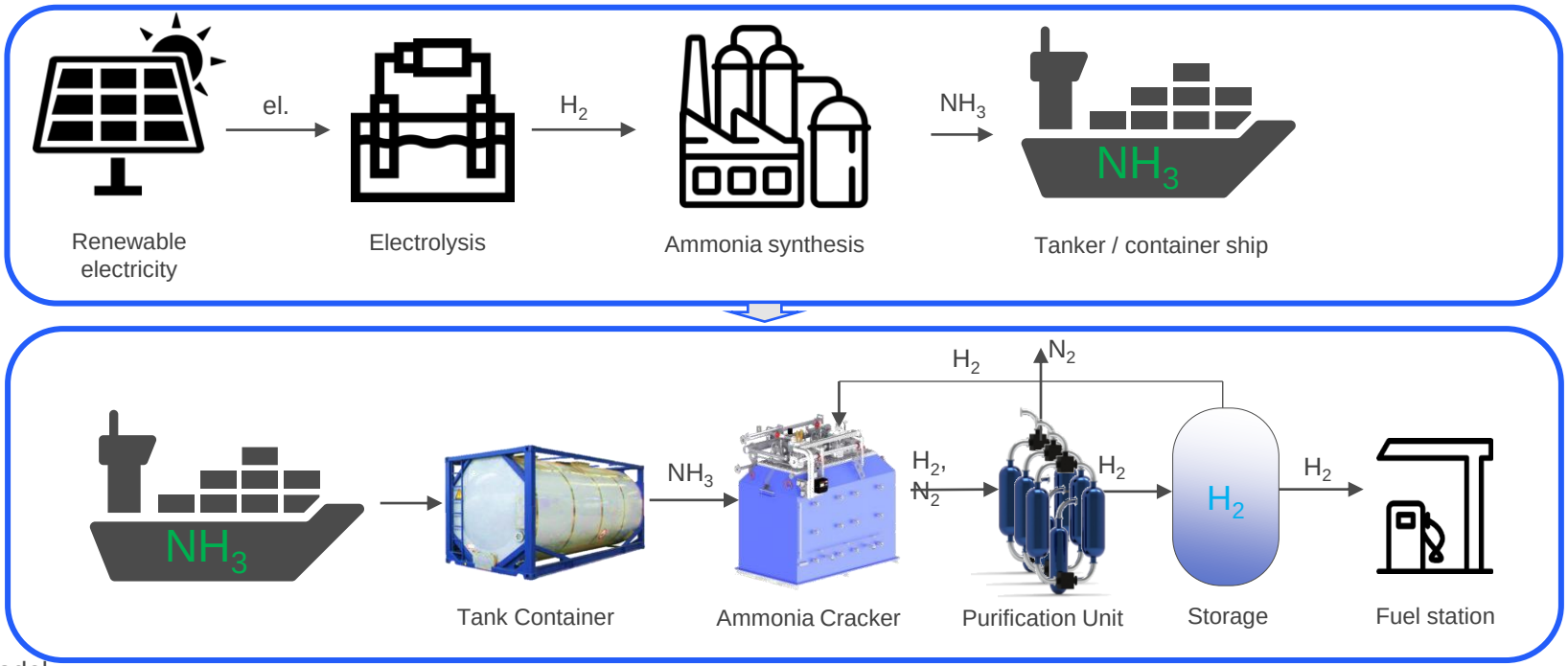


Sources: WS Wärmeprozesstechnik, WS Reformer

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2 Technologies for the production of hydrogen

Ammonia Cracking



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2 Technologies for the production of hydrogen

Ammonia Cracking

- Electrolysis

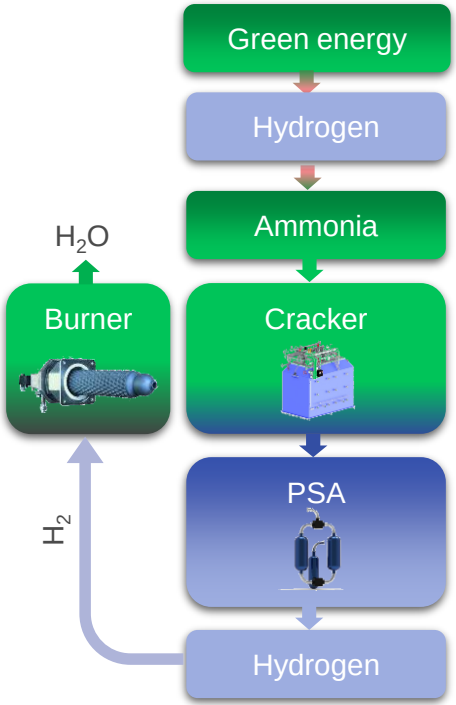
$$2\ H_2O \xrightarrow{r_{el}} 2\ H_2 + O_2 \qquad \Delta H^0 = +571.8\ kJ$$

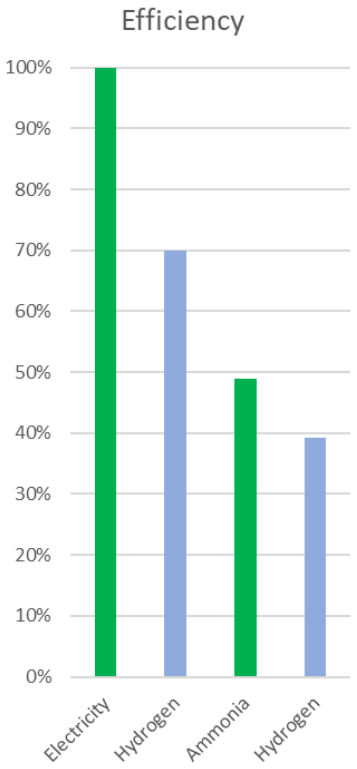
- Ammonia Synthesis (Haber-Bosch)

$$N_2 + 3H_2 \overset{r_{syn}}{\longleftrightarrow} 2\ NH_3 \qquad \Delta H^0 = -92.5\ kJ$$

- Cracking

$$2\ NH_3 \overset{r_{cr}}{\leftrightarrow} N_2 + 3H_2 \qquad \Delta H^0 = +92.5\ kJ$$





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3 Technologies for the usage of hydrogen

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Storage for non-usable surplus electricity

- Electrolysis of water
- Regeneration of electricity with fuel cells
- Available today
- Solution vor the storage of high amounts of energy
- Overall efficiency 35 – 50 %

Battery storage:

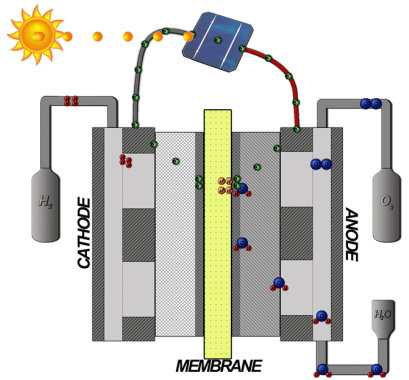
Efficiency approx. 90 %
Costs: 500 € / kWh

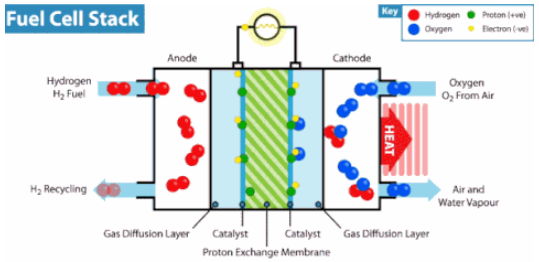
Applicable for short term storage

Hydrogen strorage:

Efficiency < 50 %
Costs: 100 € / kWh

Applicable for long term storage





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Bildquellen: Pinterest

3 Technologies for the usage of hydrogen

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Fuel for car fleets

- Currently three different vehicles available
- Costs per km mostly similar to diesel and petrol vehicles
- CAPEX comparatively high but in the range of BEVs



Bildquellen: Hyundai Motor Company, Toyota Motor Corporation, Honda Motor Corporation

Diesel vehicle

Consumption: 6 l/100 km

Fueling in 5 minutes
Approx. 25 – 60.000 €

Battery electric vehicle

Consumption: 15 kWh/100 km

Fueling in 60 minutes up to hours
Approx. 40 – 100.000 €

Fuel cell electric vehicle:

Consumption: 0,9 kg/100 km

Fueling in 5 minutes
Approx. 60 – 80.000 €

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3 Technologies for the usage of hydrogen

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Fuel for truck fleets

- First vehicles commercially available (Paul, Quantron, etc.)
- Costs per km mostly similar to diesel and petrol vehicles
- CAPEX comparatively high



Bildquellen: Nikola Motor Corporation, Daimler AG, Hyundai Motor Company

Diesel vehicle

Consumption: 6 l/100 km

Fueling in 10 minutes
Approx. 100.000 €

Battery electric vehicle

Consumption: 150 kWh/100 km

Fueling in hours
Approx. 200.000 €

Fuel cell electric vehicle:

Consumption: 8 kg/100 km

Fueling in 10 minutes
Approx. 400.000 €

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3 Technologies for the usage of hydrogen

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Fuel for bus fleets

- First vehicles commercially available (Solaris, ARTHUR, etc.)
- High ranges, even in winter
- Very low consumption
- Short fueling times



Bildquellen: Proton Motor Fuel Cell GmbH, Toyota Motor Corporation

Diesel vehicle	Battery electric vehicle	Fuel cell electric vehicle:
Consumption: 40 l/100 km	Consumption: 150 kWh/100 km	Consumption: 6 kg/100 km
Fueling in 10 minutes Approx. 200.000 €	Fueling in hours Approx. 550.000 €	Fueling in 10 minutes Approx. 650.000 €

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3 Technologies for the usage of hydrogen

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Fuel for garbage collection trucks

- One vehicle commercially available
- High ranges, even in winter
- Very low consumption
- Short fueling times



Bildquelle: FAUN Umwelttechnik & Co. KG

Diesel vehicle

Consumption: 70 l/day

Fueling in 10 minutes
Approx. 200.000 €

Battery electric vehicle

Consumption: 160 kWh/day

Fueling in hours
Approx. 500.000 €

Fuel cell electric vehicle:

Consumption: 12 kg/day

Fueling in 10 minutes
Approx. 750.000 €

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3 Technologies for the usage of hydrogen

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Fuel for trains

- Two vehicles commercially available
- High ranges, even in winter
- Low consumption
- Short fueling times



Source: Alstom S.A.

Fuel for forklifts

- Different vehicles commercially available
- no charging times or battery change stations
- advantage especially in shift operation due to short refueling times
- quickly economical with existing hydrogen infrastructure



Sources: Linde AG, Still GmbH, Toyota Motor Corporation

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3 Technologies for the usage of hydrogen

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Fuel for tractors

- One vehicle in development
- extends electrification to medium-duty vehicles
- Long range
- Short fueling times
- Data still remaining



Source: BR

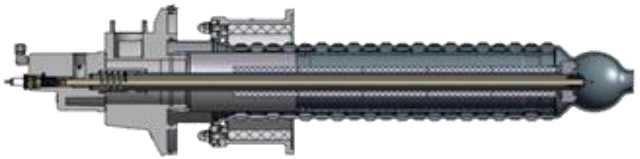
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3 Technologies for the usage of hydrogen

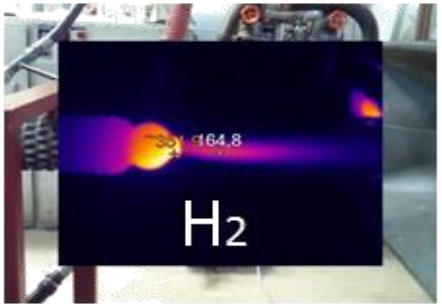
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Hydrogen Burners







Risks & Tasks
Flame Monitoring
Flashback Prevention
No_x avoidance (temperature)
Condensing technology (η > 1)

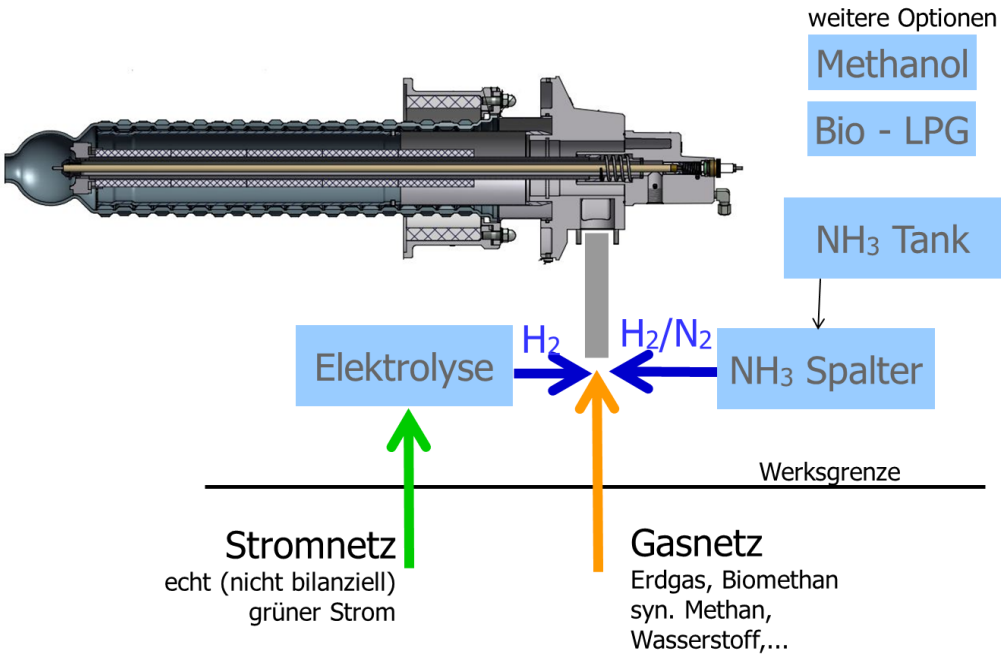
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Mixed fuel burners



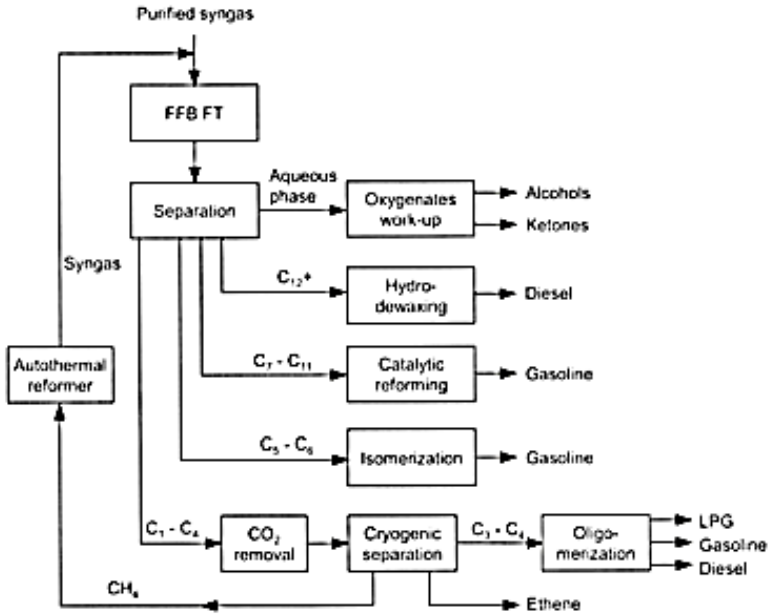
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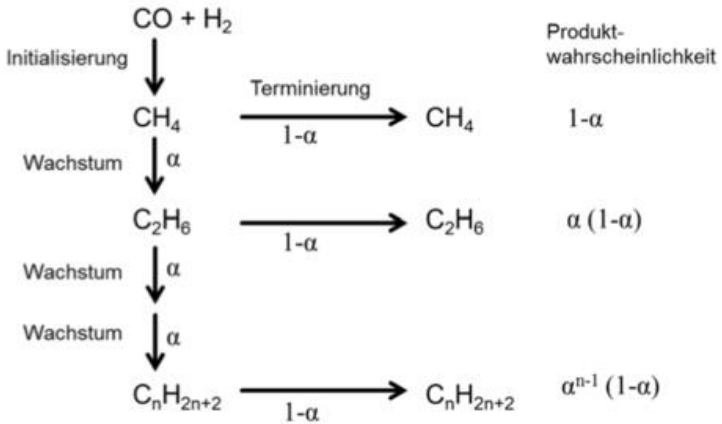
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Synfuels – Fischer Tropsch Synthesis





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3 Technologies for the storage of hydrogen

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Pressurized Storages

- Large strorages (e.g. fueling stations) – up to 100 bar
  -> 133 kWh/m³ at 20°C



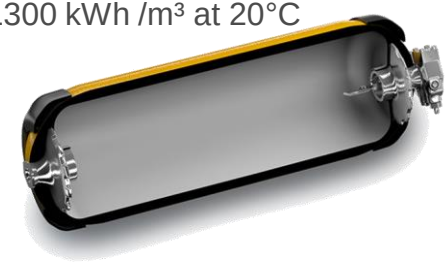
Source: Reiner Lemoine Institut gGmbH

- Bottle bundles (transport, fueling stations) – up to 500 bar
  -> 930 kWh /m³ at 20°C

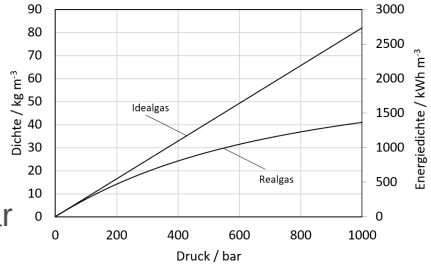


Source: Wystrach GmbH

- High pressure storages (vehicles, dispenser buffer) - up to 900 bar
  -> 1300 kWh /m³ at 20°C



Source: Toyota Motor Corporation



For comparison: Energy denisity of diesel fuel = 9800 kWh / m³

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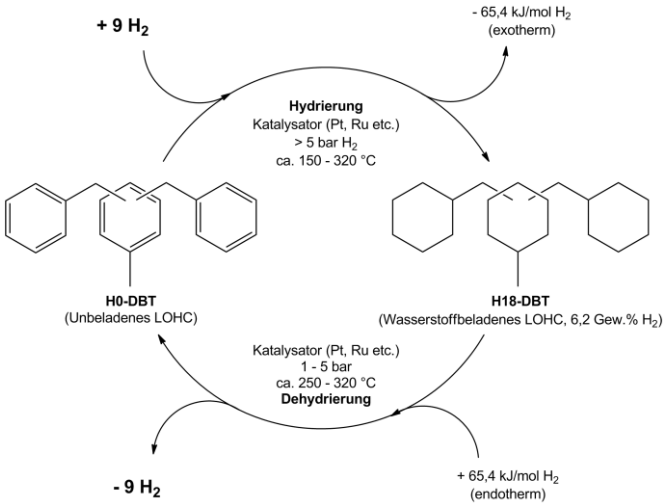
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Storage of hydrogen – LOHC

- Storage by hydrating Dibenzyltoluene to perhydro-dibenzyltoluene
- Liquid and hardly flammable transport medium
- Approx. 2000 kWh/m³



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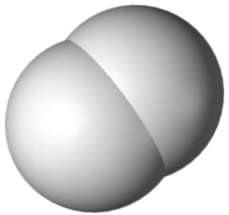
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Liquid storages

- Liquification via compression and cooling
- Approx. 30 – 40 % of HV for liquification
- Boil-Off-Losses because of non-adiabatic conditions
- Approx. 2400 kWh/m³



Comparison:

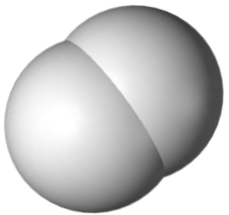
	300 bar	600 bar	LOHC	Liquid
Mass capacity per trailer	500 kg	1000 kg	2000 kg	4000 kg
Energy capacity per trailer	16,66 MWh	33,33 MWh	66,66 MWh	133,33 MWh
Energy demand for storage	8 %	12 %	30 %	35 %

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5 Summary

- Hydrogen is a climate-friendly energy carrier if produced and handled correctly
- Everybody can produce and use hydrogen by himself
- Not every project makes sense, just because H2 is now in fashion

  ->hydrogen can be quickly economical in self-production, if the project planning is right



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Kontakt



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