Hydrogen as an energy carrier: production and utilisation

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Vita

⇨ Dr.-Ing. Roland Hamelmann

⇨ TU Clausthal, chemical engineering

(PhD on continous production of gas diffusion electrodes)

⇨ Manufacturing of PEMFC for Proton Motor GmbH

⇨ CoE in hydrogen and fuel cell technology

at university of applied sciences, Lübeck

⇨ eff +: start-up since 2010

(energy efficiency and hydrogen technology)

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Structure

1. **Intention of hydrogen as an energy carrier**
2. (current) Use of hydrogen in chemistry
3. (future) Production of hydrogen in the energy supply chain
4. (future) Utilisation of hydrogen in the energy supply chain
5. Summary

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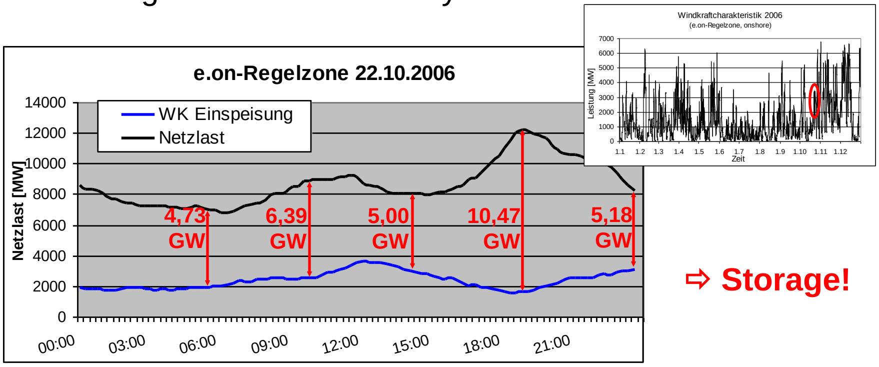
Motivation

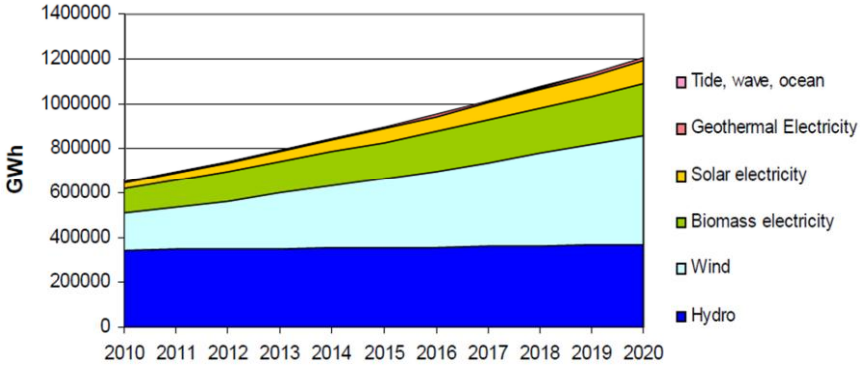
Fluctuating renewable electricity from wind



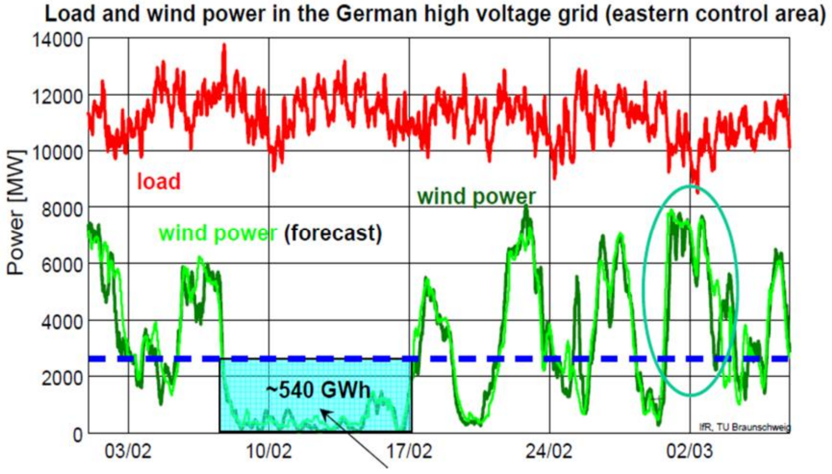
⇨ **Storage!**

Data: www.eon-netz.com

EU targets 2020



Capacity needs



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Principals

Storage ...	... type	... physics	... density [$\mathrm{kWh/m^3}$]
SMES	electrical	$E = ½*L*I^2$ $*\eta^{(w)}$	3 ...15
Condensator	electrical	$E = ½*C*U^2$ $*\eta^{(w)}$	0,1 ... 0,3
Fly Wheel	mechanical	$E = ½*J_x*\omega^2$ $*\eta^{(w)}$	50 ... 100
Battery	chemical	$E = Q*U_Z$ $*\eta^{(w)}$	30 ... 100
Pumped Hydro	mechanical	$E = V*\rho*g*h$ $*\eta^{(w)}$	0,2 ... 1,2
CAES (Air)	mechanical	$E = V*c_v*(T/v)_{NTP}*(r-r^{1/\kappa})$ $*\eta^{(w)}$	1 ... 12
Hydrogen	chemical	$E = p*V/(R*T)*H_i$ $*\eta^{(w)}$	10 ... 220

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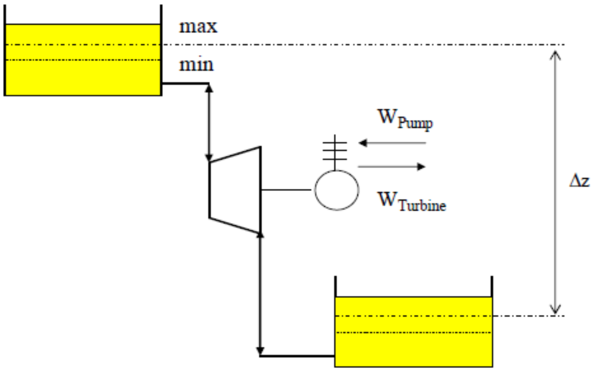
Pumped Hydro

Pumping storage power station

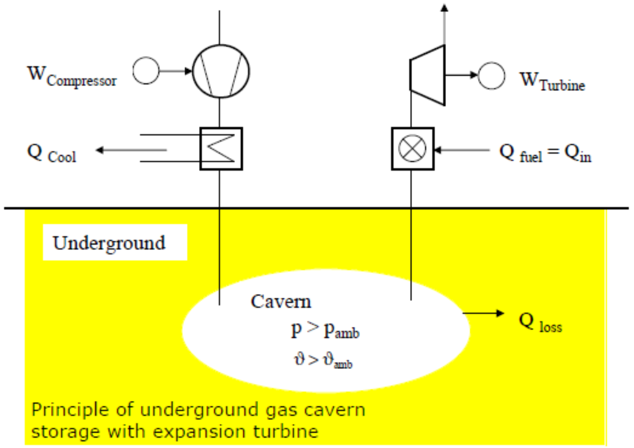


Principle of pumping storage power station

Source: http://tuuwi.wcms-file2.tu-dresden.de/download/urv/ws0809/hightech/Energiespeicherung.pdf

CAES (Air)

Gas cavern storage


$W_{Compressor}$

Q_{Cool}

$W_{Turbine}$

$Q_{fuel} = Q_{in}$

Underground

Cavern

$p > p_{amb}$

$\vartheta > \vartheta_{amb}$

Q_{loss}

Principle of underground gas cavern storage with expansion turbine

Source: http://tuuwi.wcms-file2.tu-dresden.de/download/urv/ws0809/hightech/Energiespeicherung.pdf

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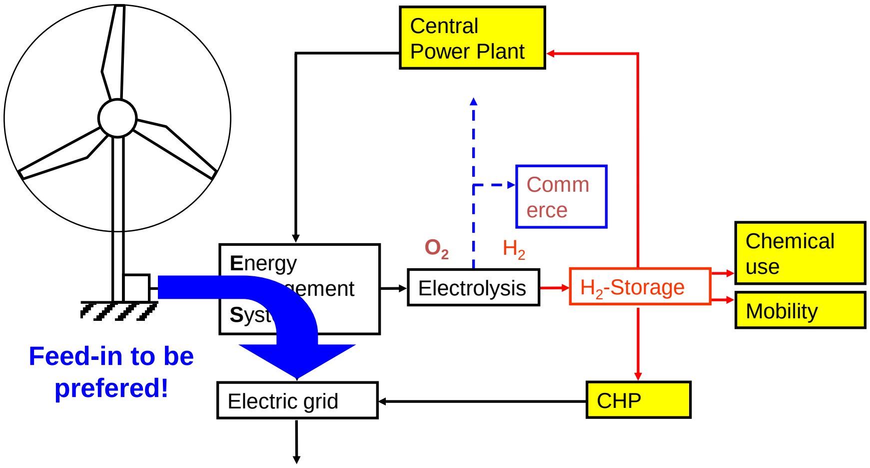
Hydrogen storage pathways


Central Power Plant

Commerce

Energy gement Syst

O_2

H_2

Electrolysis

H_2-Storage

Chemical use

Mobility

Electric grid

CHP

Feed-in to be prefered!

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H_2 in chemistry

Current situation

- production of appr. 600 x 10^9 Nm^3 hydrogen per year by
  - steam reforming of natural gas
  - partial oxidation of heavy oil feedstocks
  - coal gasification
  - byproduct (NaCl-electrolysis, refinery et al.)
  - alternative technologies < 1%
- usage mainly in chemichal industry (metals, glas, semiconductors, MeOH, NH_3, refinery)
- excellent knowledge about materials and handling
- yet no notable usage in energy supply

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Principles

Conventional feedstocks	Renewable feedstocks
CH_4 (steam reforming)	H_2 (wind & solar fed electrolysis)
C_nH_{2n} (partial oxidation)	Bio - CH_4 (steam reforming)
$C_{135}H_{96}O_9NS$ (coal gasification)	Bio – CH_4O (methanol reforming)
H_2 (nuclear fed electrolysis)	Bio - C_2H_6O (ethanol reforming)
	$C_{12}H_{22}O_{11}$ (wood / BtH)

Electrolysis: Basics (1/3)

Half cell reactions

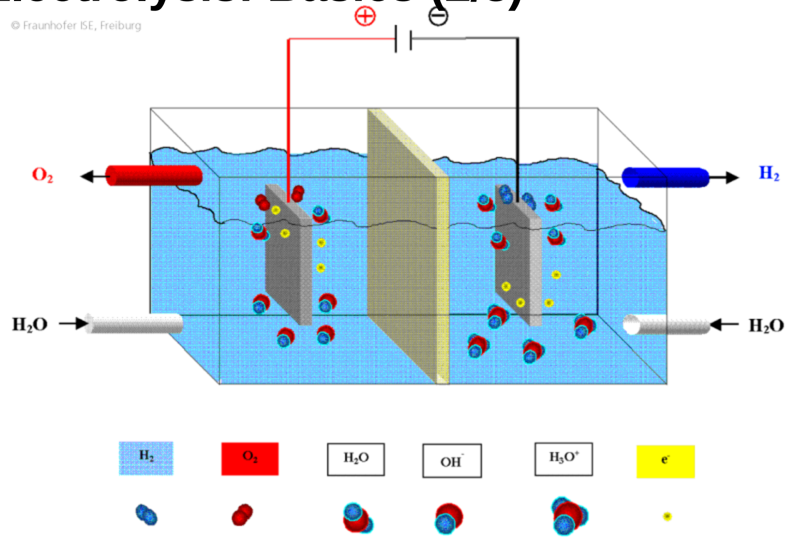
Cathode (+)	$\frac{1}{2}O_2 + 2H^+ + 2e^- \leftrightarrow H_2O$	$E_0 = 1{,}23\ V$
Anode (-)	$H_2 \leftrightarrow 2H^+ + 2e^-$	$E_0 = 0{,}00\ V$

Over all reaction

Fuel cell	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	$E_0 = 1{,}23\ V$
Electrolysis	$H_2 + \frac{1}{2}O_2 \leftarrow H_2O$	$E_0 = 1{,}48\ V$

Source: Energietechnik mit Wasserstoff und Brennstoffzellen, Sommerseminar an der FH Lübeck, 26.-28.09.2001

Electrolysis: Basics (2/3)



Source: Fraunhofer ISE

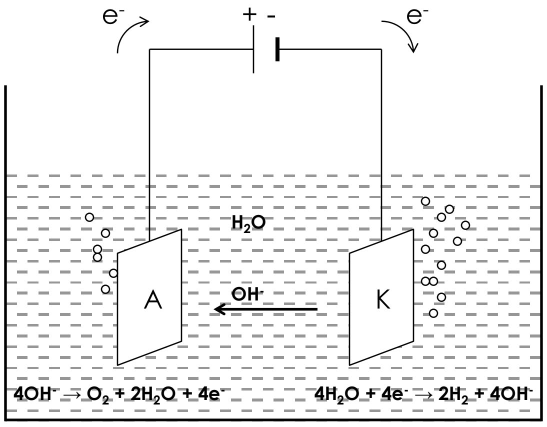
Electrolysis: Basics (3/3)

$H_2 + \frac{1}{2}O_2 \leftarrow H_2O$

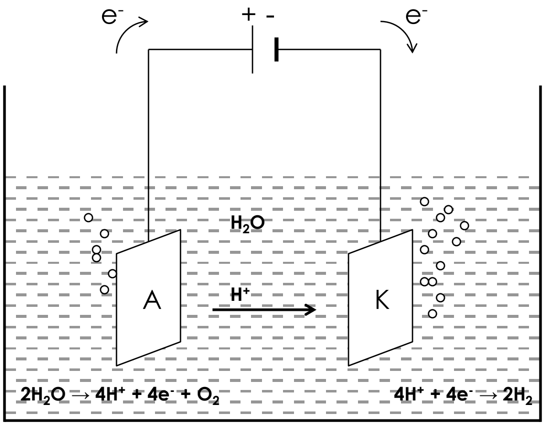
- Cell voltage U = 1,48 V @ 25 °C, 1 bar
- Heating value (H_s) E = 3,5 kWh / Nm³ H_2 = 12,6 MJ / Nm³ H_2
- Water need V = 0,805 dm³ / Nm³ H_2
- Faraday-Constant 1/F = 2,39 kAh / Nm³ H_2
- Real cell voltages are higher due to
  - Ohmic losses (electrolyte, diaphragma)
  - Wiring losses
  - Electrochemical over-voltages (cathodic, anodic), caused by mass transport and electrical field phenomena

Source: Energietechnik mit Wasserstoff und Brennstoffzellen, Sommerseminar an der FH Lübeck, 26.-28.09.2001

Alkaline Electrolysis



Acidic Electrolysis

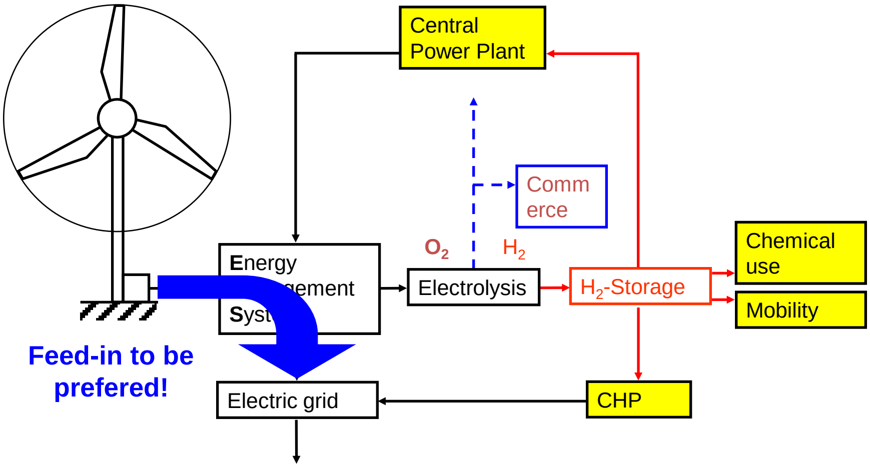


System comparison

	Acidic el.	Alcaline el.
Temperature [°C]	80 - 100	80 - 100
Pressure [Mpa]	< 30	< 30
Power range [kW]	1 – 100	1 – 125.000
Current density [kA/m ²]	< 10	2 –5
Cell voltage [V]	1,7 – 2,1	1,7 – 2,1
Spec. Energy consumption [kWh/Nm³ H_2]	4,1 – 4,9	4,1 – 4,9
Efficiency, based on Hu [%]	65 - 75	65 – 75
Catalysts	K: Pt / A: Ir	K: Stahl / A: Ni

More details: http://www.now-gmbh.de/presse/now-workshop-wasserelektrolyse.html

Hydrogen storage pathways



Central Power Plant

Commerce

O_2

H_2

Energy gement Syst

Electrolysis

H_2-Storage

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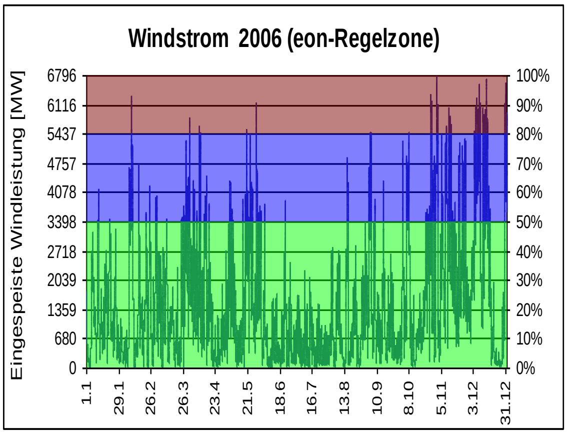
CHP

Effect



Cap
(101 GWh = 0,8 %)

Electrolysis
(1.083 GWh = 8,3 %)

Feed-in
(11.801 GWh = 90,9 %)

Data: www.eon-netz.com

Renewable potential

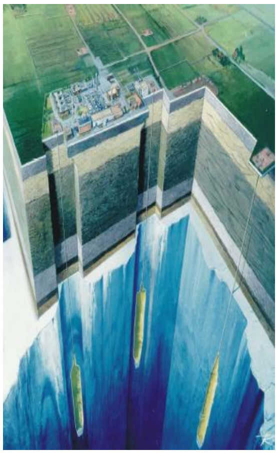
Ex. 1: eon control region 2006
1.083 GWh $\cong$ 253 Mio Nm³ H_2 $\cong$ 22.500 t H_2

Ex. 2: Vattenfall control region 2006
829 GWh $\cong$ 193 Mio Nm³ H_2 $\cong$ 17.200 t H_2

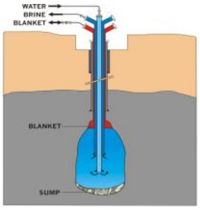
Ex. 3: Offshore-scenario Schleswig-Holstein 2015 (2,24 GW)
357 GWh $\cong$ 83 Mio Nm³ H_2 $\cong$ 7.400 t H_2

$\eta_{Electrolysis} = 70\ \%$ $H_u = 3{,}00$ kWh/Nm³ $\rho = 0{,}089$ kg/Nm³

Saline storage options



- Saline caverns with net volume
  V = 300.000 ... 750.000 m³ are creatable
- Pressure range depends on depth
  (p = 60 ... 180 bar at 1.000 m)
- Suitability of saline caverns for H_2-storage
  is proven (Teesside/UK, Texas/USA)



pics: KBB Underground Technologies GmbH

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Ex. mobile usage

GM Chevrolet Equinox

www.h2cars.de

Ex. 1: 80.000 Fahrzeuge
Ex. 2: 61.100 Fahrzeuge
Ex. 3: 26.300 Fahrzeuge

@ 20.000 km / Jahr
@ 1,4 kg H_2 / 100 km

MAN ARGEMUC

www.h2cars.de

Ex. 1: 1923 Fahrzeuge
Ex. 2: 1.470 Fahrzeuge
Ex. 3: 632 Fahrzeuge

@ 90.000 km / Jahr
@ 13 kg H_2 / 100 km

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Ex. stationary usage

option co-firing

www.sps-magazin .de

Ex. 1: 75,9 MW
Ex. 2: 57,9 MW
Ex. 3: 24,9 MW

@ 4.000 h / Jahr
@ η_{el}= 40 %

option CHP

www.sokratherm.de

Ex. 1: 265 x 200 kW
Ex. 2: 202 x 200 kW
Ex. 3: 87 x 200 kW

@ 5.000 h / Jahr
@ η_{el}= 35 %

option micro-CHP

www.otag.de

Ex. 1: 15.800 x 2 kW
Ex. 2: 12.000 x 2 kW
Ex. 3: 5.200 x 2 kW

@ 6.000 h / Jahr
@ η_{el}= 25 %

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eff +

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Summary

1. Energy markets tend to be more renewable and more electrical
2. Fluctuations in renewable power generations require large capacities for load leveling
3. Hydrogen technology offers high storage capacities as well as sustainable supply options for mobile and stationary power needs