Peak Oil, Klimawandel, Energiewende – Herausforderungen für die Energieversorgung von morgen

F. Schüth

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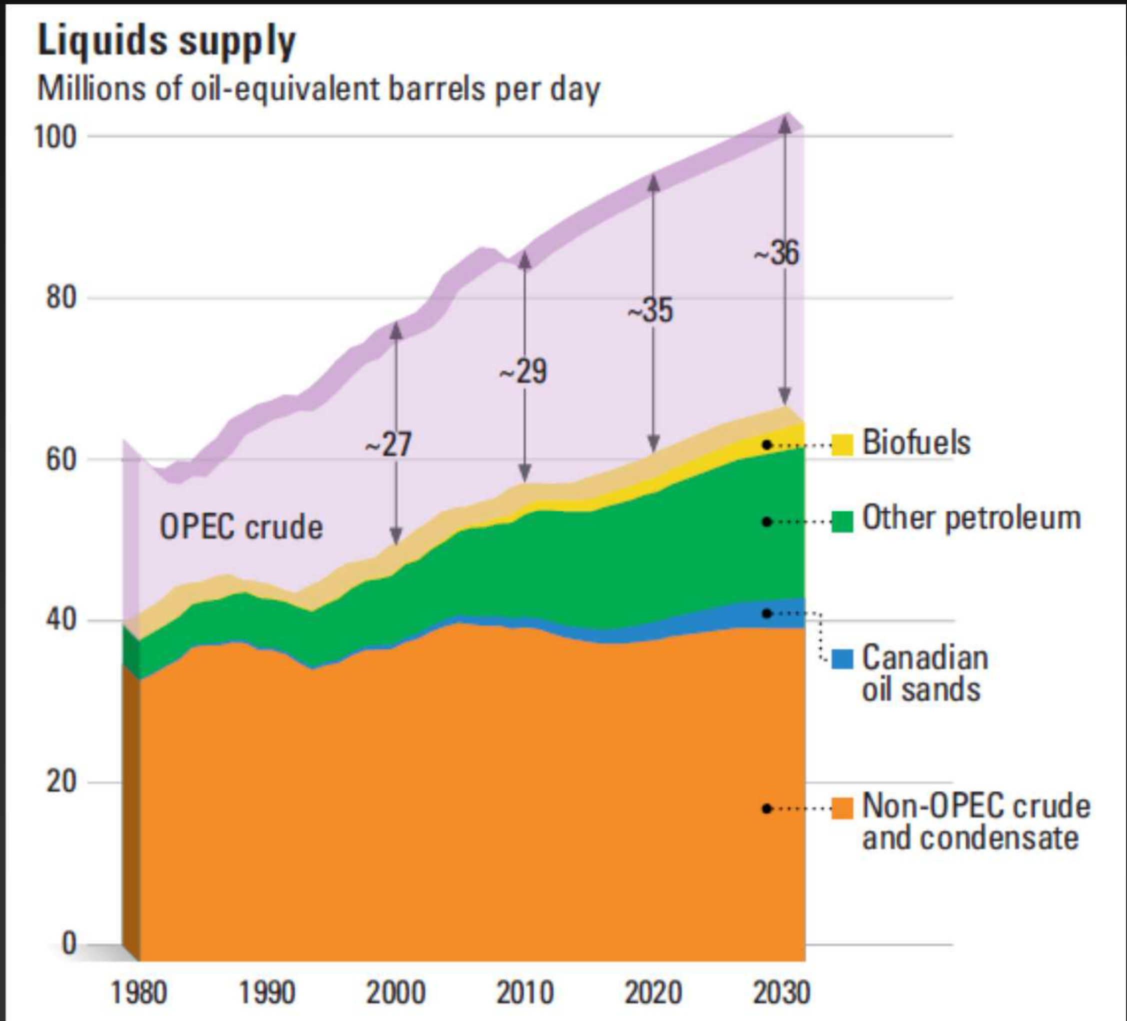
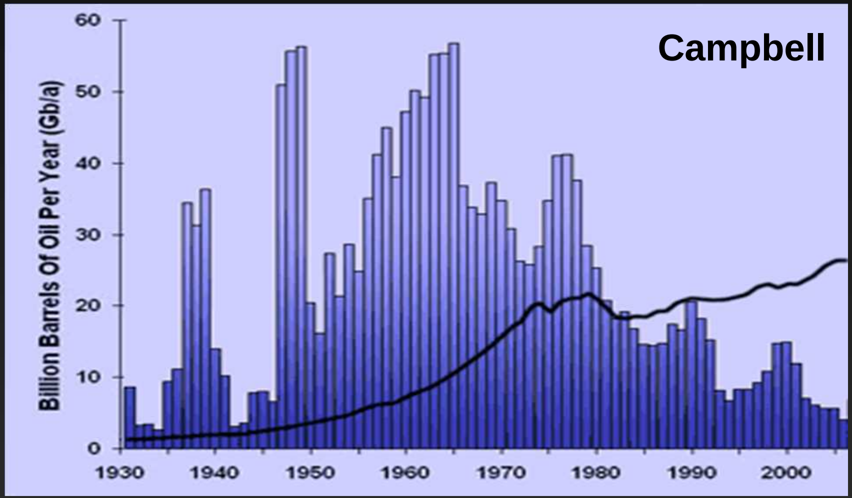
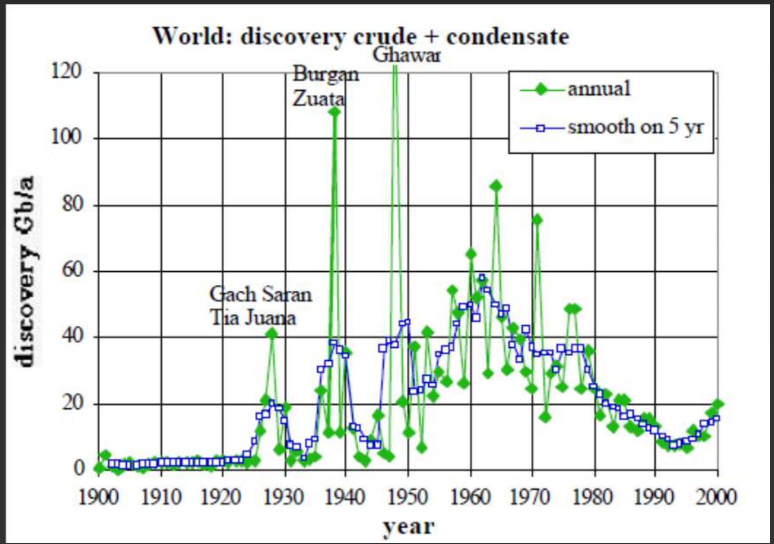
Peak Oil?



R.A. Kerr, Science 331, 1511 (2011)

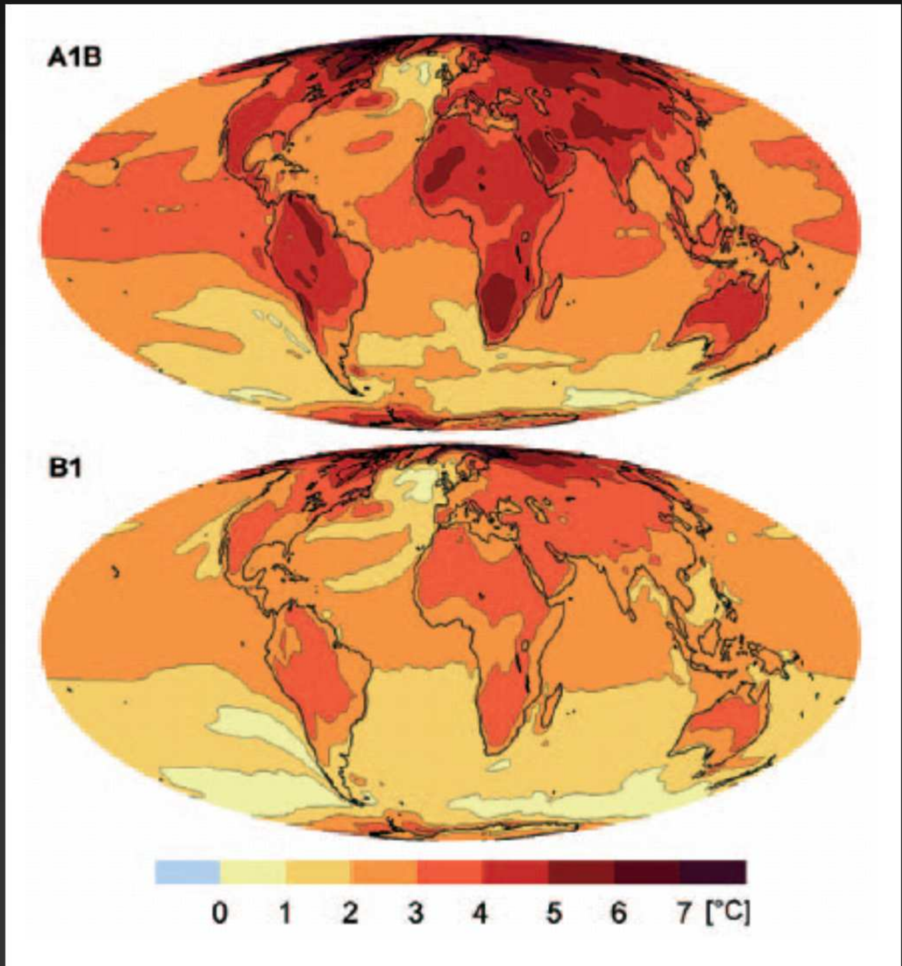
Oil discoveries are decreasing





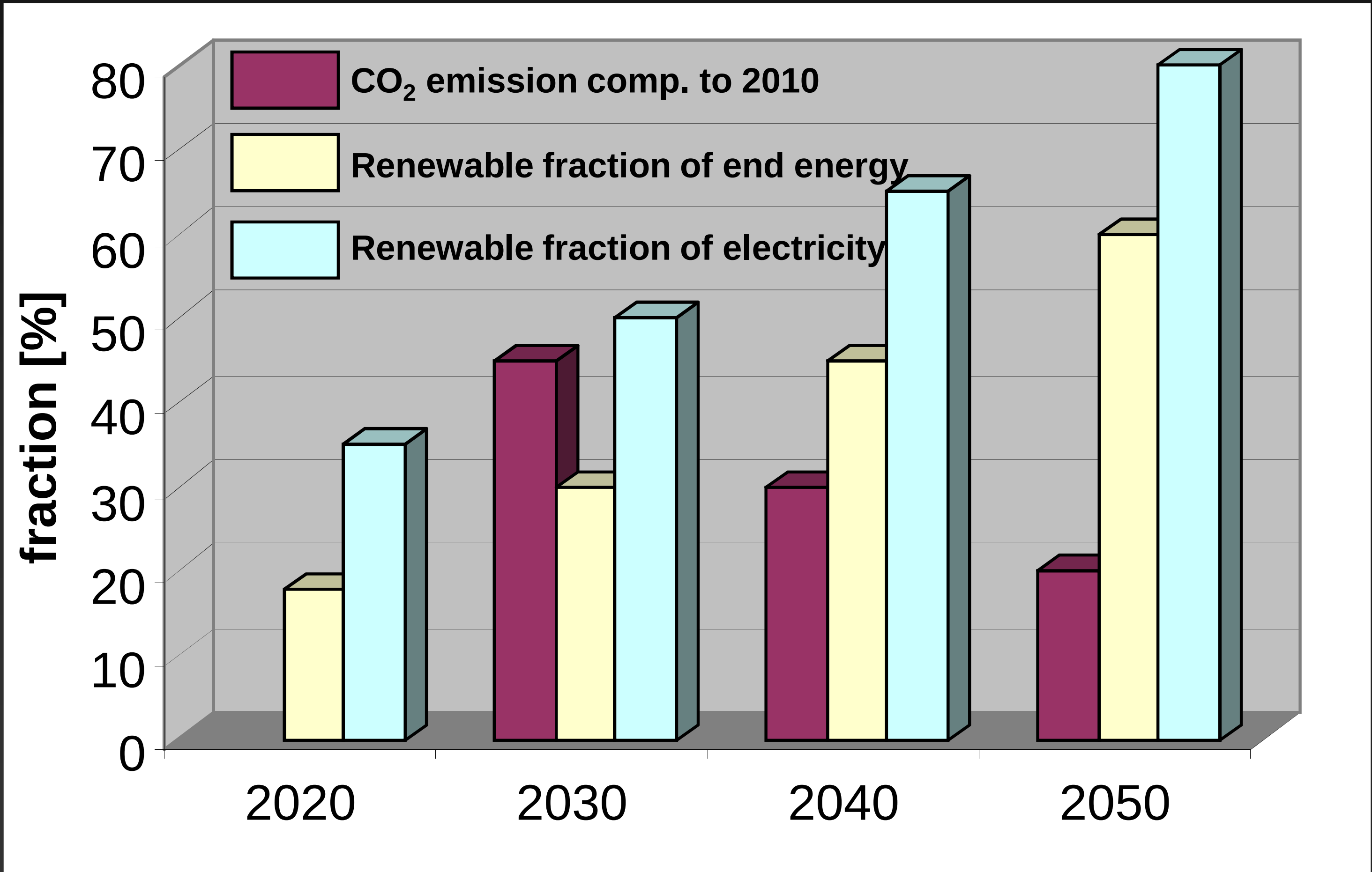
Laherrere, Petrotech 2003

Additional challenge: global warming

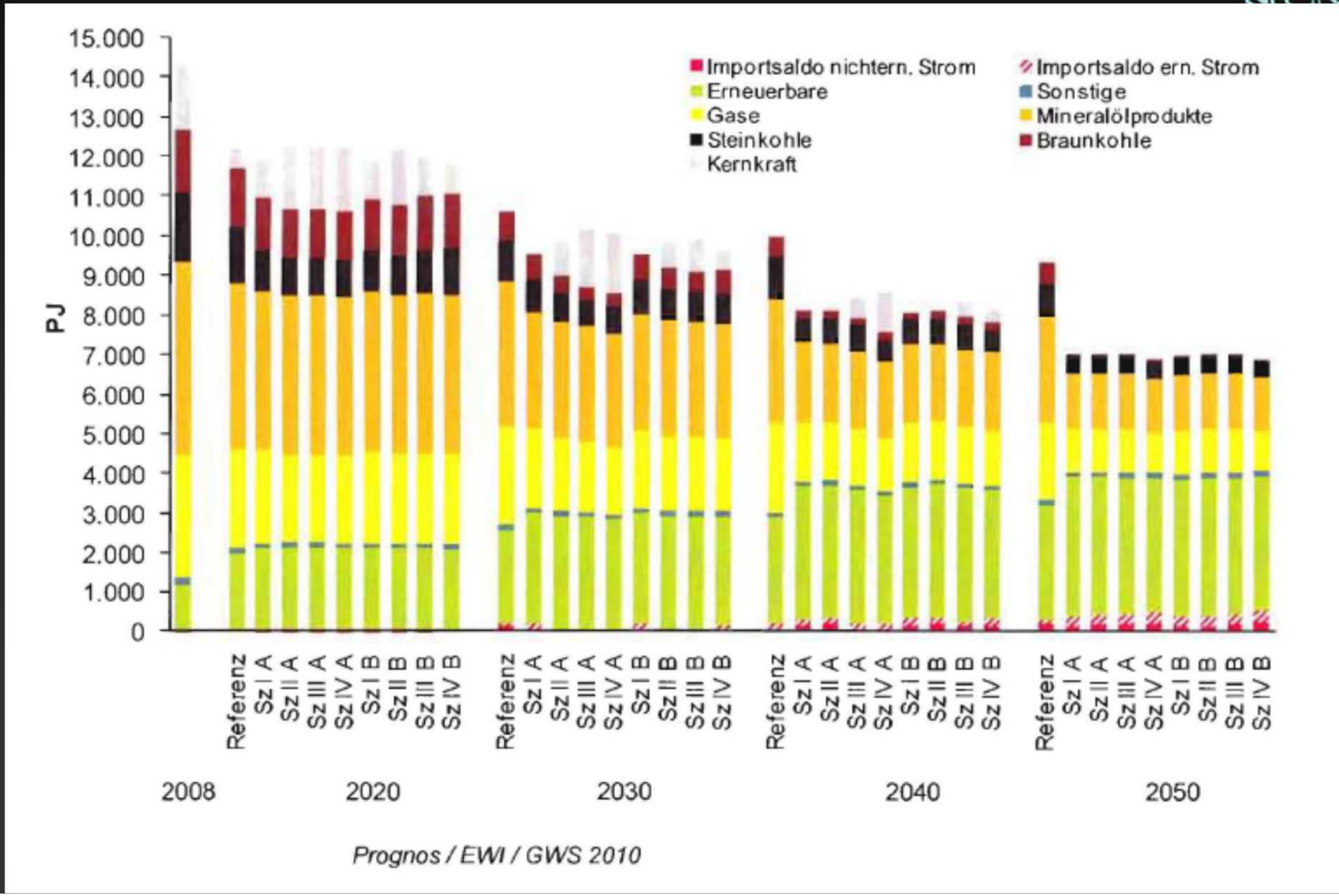


Calculated temperature differences between 2071-2100 and 1961-1990 for two different scenarios (Source: MPI für Meteorologie)

Germany's energy and climate targets



Germany's energy future

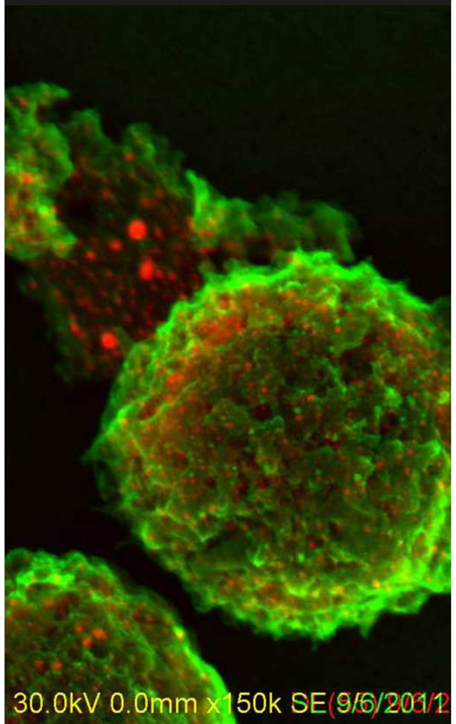


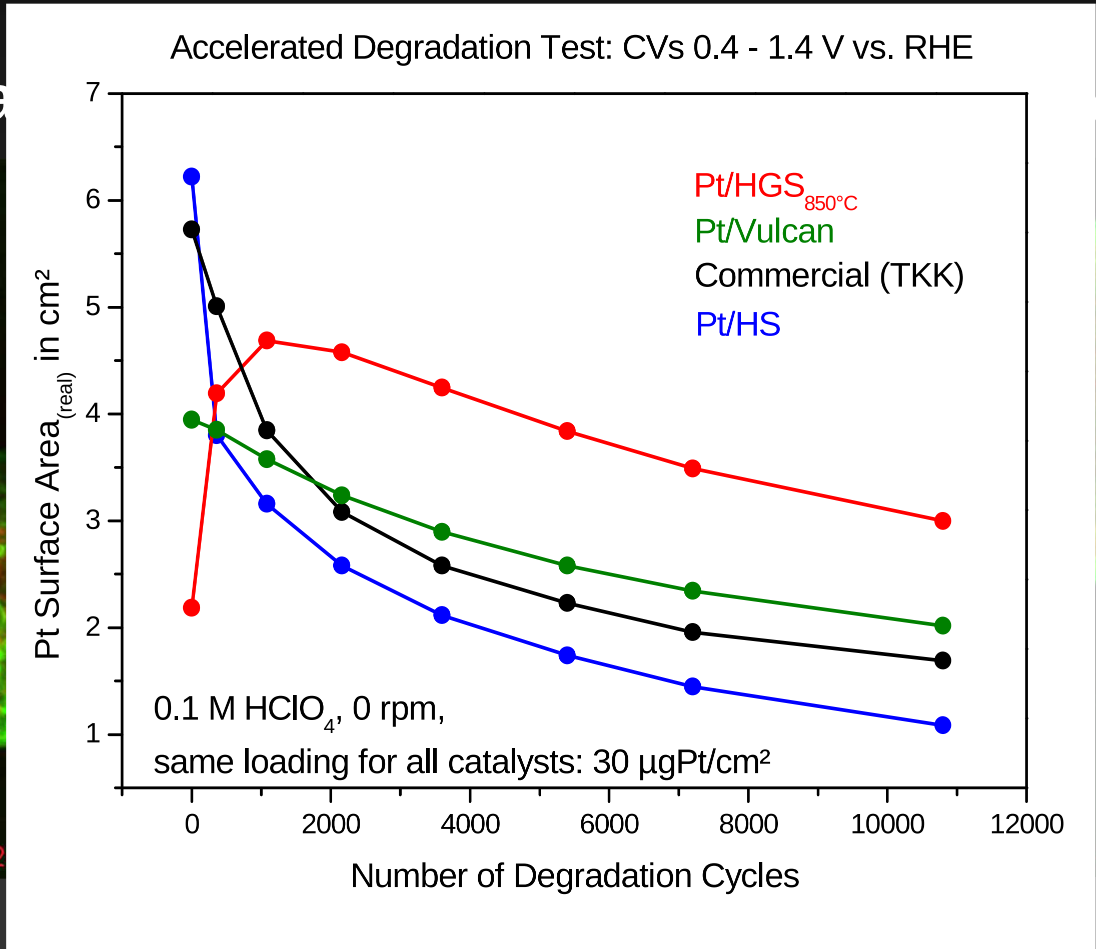
Efficiency increase in mobility: 500 km driving range with different technologies

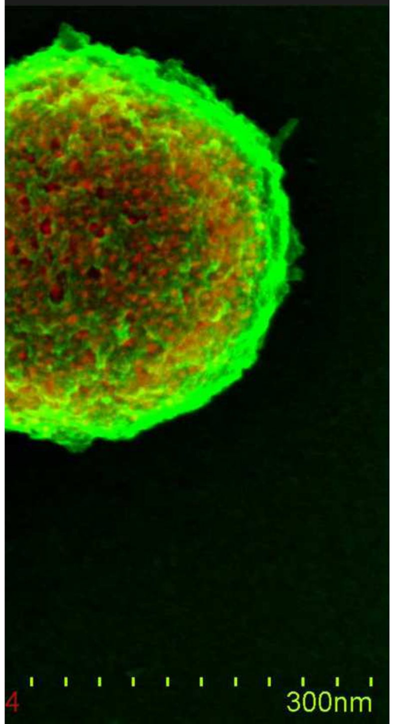
U. Eberle, M. Felderhoff, F. Schüth, Angew.Chem.Int.Ed. 48, 6608 (2009)

Durable fuel cell catalysts: SEM/STEM overlay

Before a… …cycles







C. Galeano, H. Bongard, A.H. Lu, K. Mayrhofer, J. Meier, , V. Peinecke, F. Schüth, unpublished and patent pending

Projections of a future energy mix

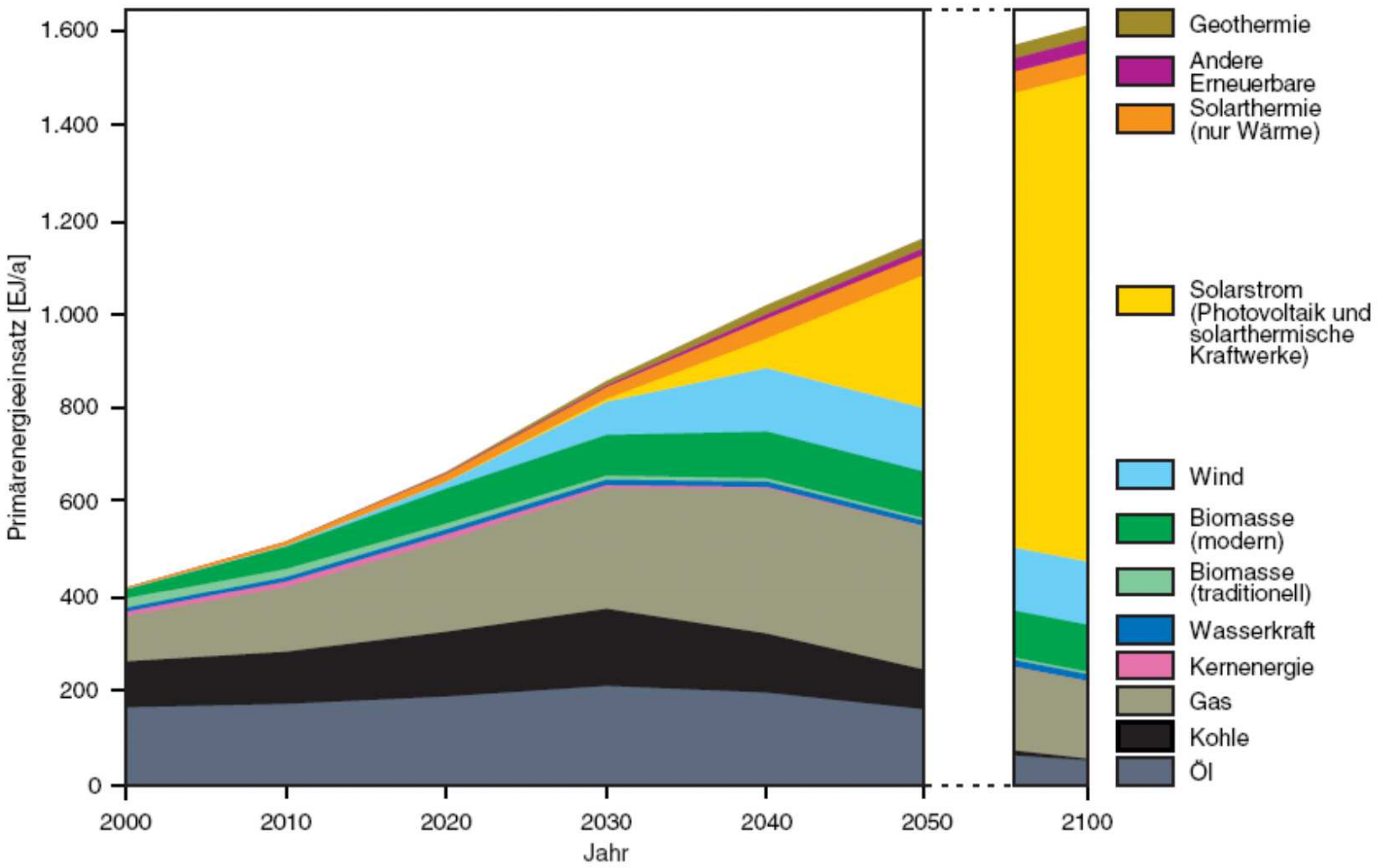
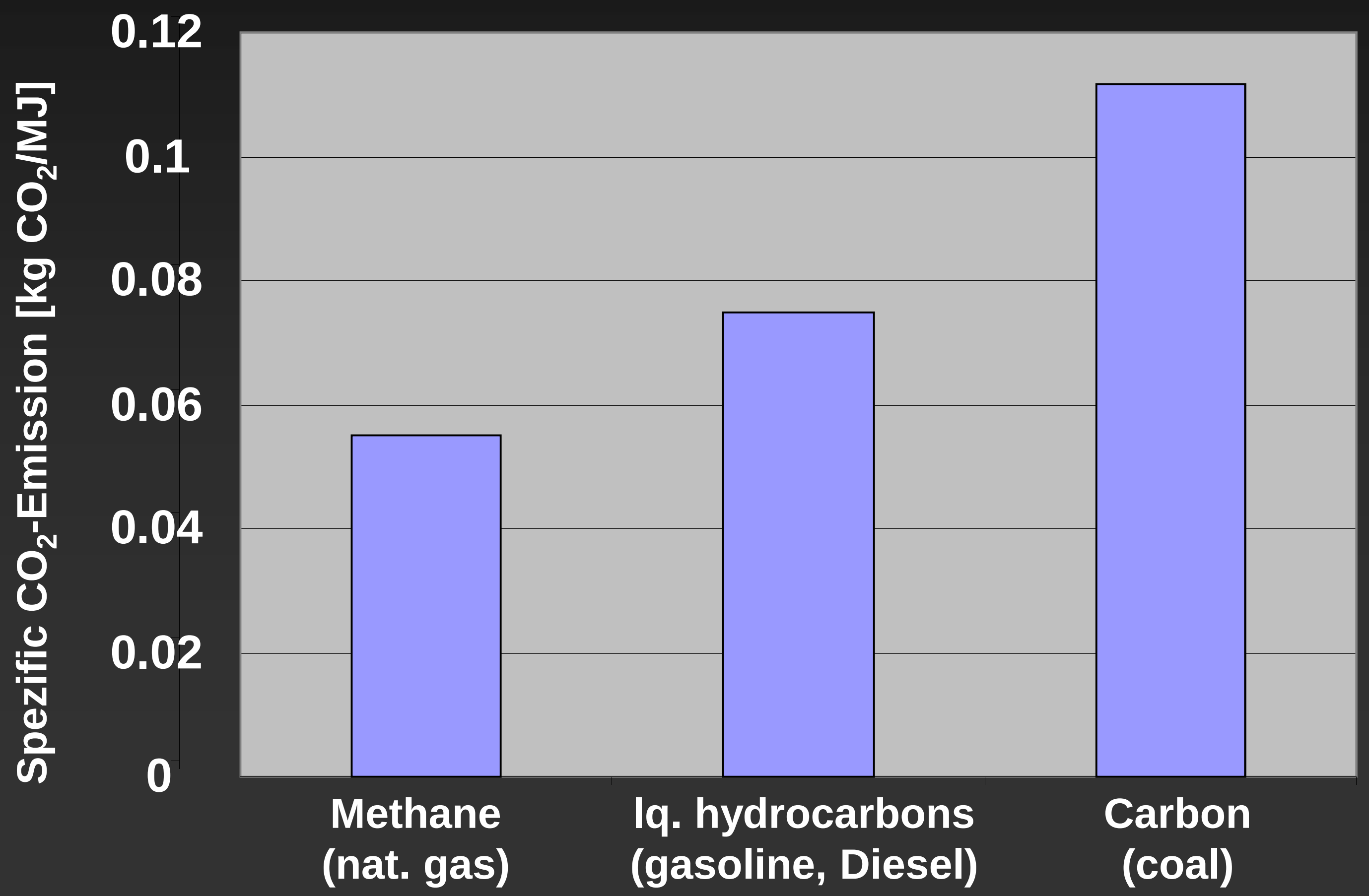


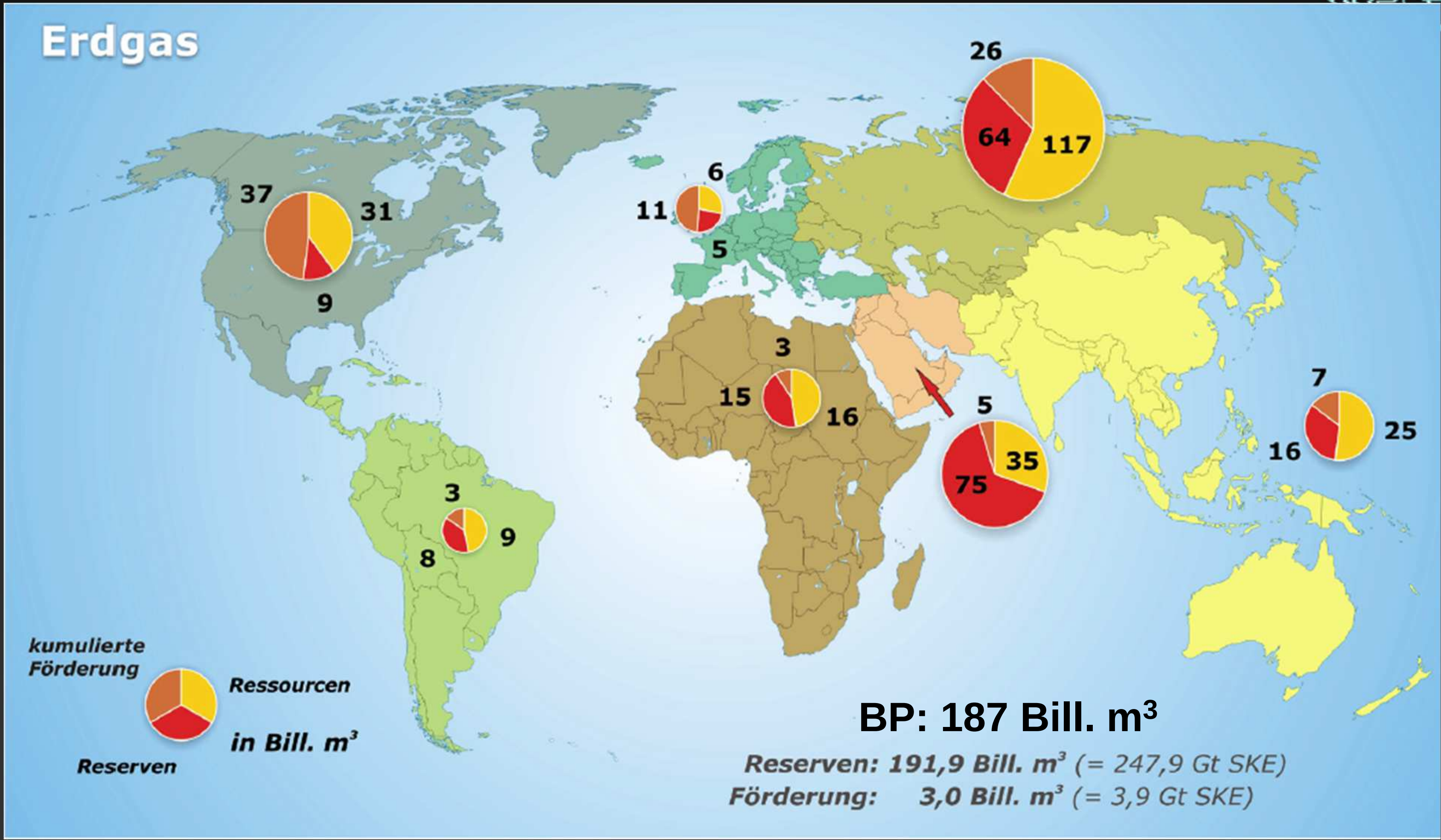
Abbildung 1
Die Veränderung des globalen Energiemix im exemplarischen Pfad bis 2050/2100.
Quelle: WBGU

Several decades still: fossils

Spezific CO_2-emission of different fossil energy carriers, lower heating value without transformation losses



Possibly most promising: Natural gas



Source: BGR, Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen (2010)

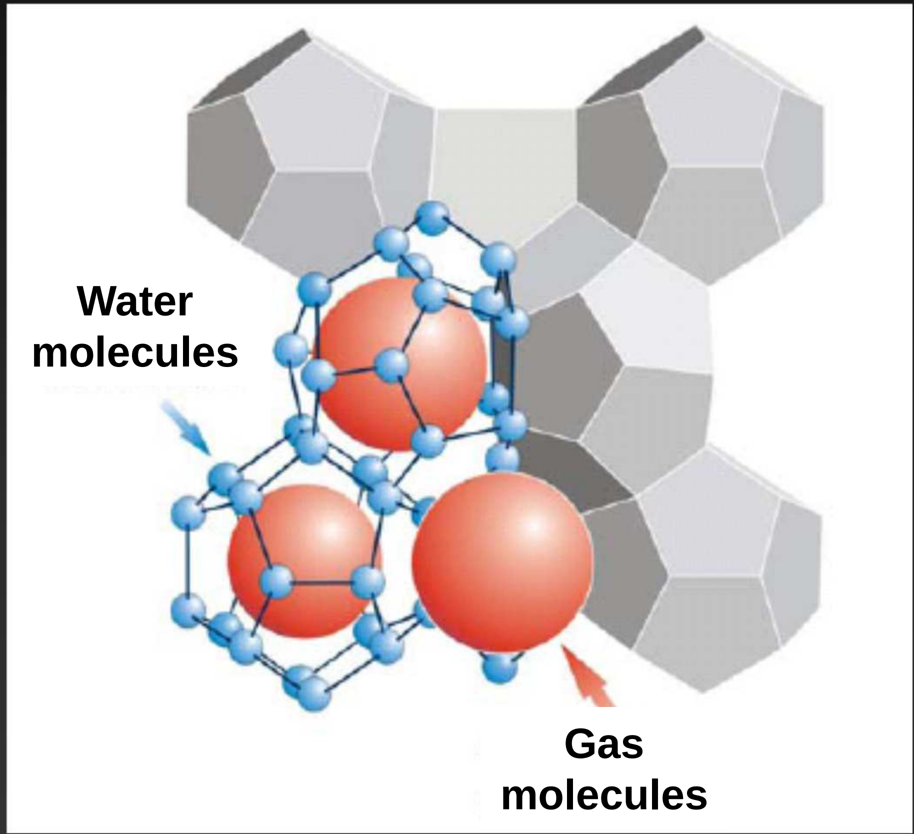
Unconventional gas

- Shale gas
- Coal bed gas
- Tight Gas (from low permeability formations)

Energieträger	Maßeinheit	Reserven (s. linke Spalte)	EJ	Ressourcen (s. linke Spalte)	EJ
Shale Gas	Bill. m³	1,7 [5)]	65 [5)]	456 [6)]	17 329 [6)]
Tight Gas	Bill. m³	1 [5)]	46 [5)]	210 [6]	7 970 [6)]
Kohleflözgas	Bill. m³	2	80	254	9 652
Erdgas in Aquiferen	Bill. m³	–	–	800	30 400
Gashydrat	Bill. m³	–	–	1 000	38 000

Source: BGR, Reserven, Ressourcen und Verfügbarkeit von Energierohstoffen (2010)

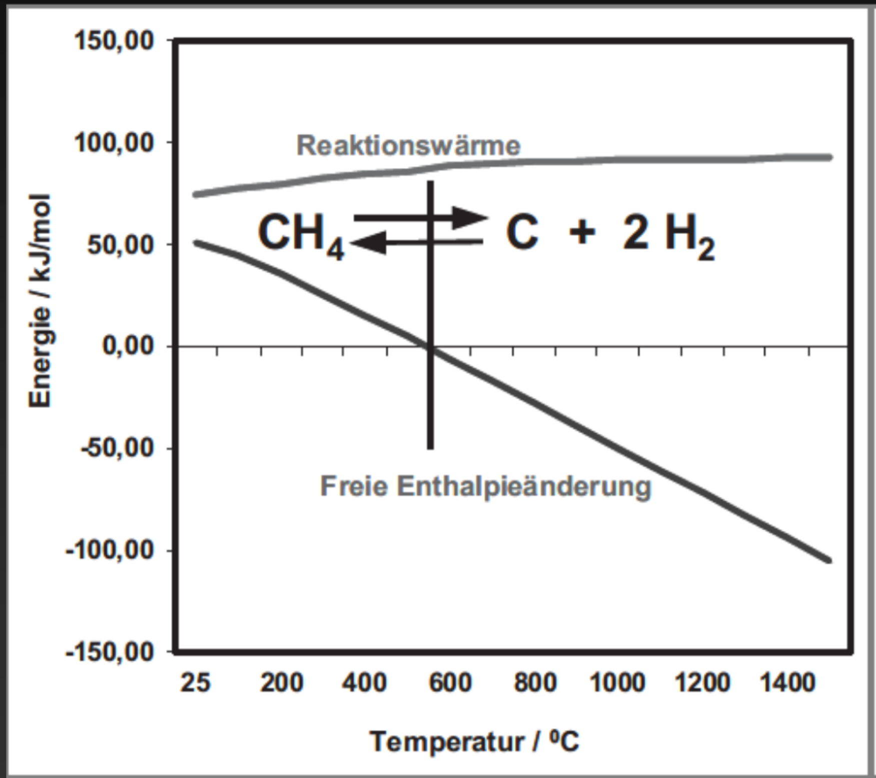
Beyond shale gas: gas hydrates



In permafrost soils and on the bottom of the ocean

Quelle: BGR, Commodity Top News No. 28, 2008

Use of methane without CO_2 emission: thermocatalytic dissociation

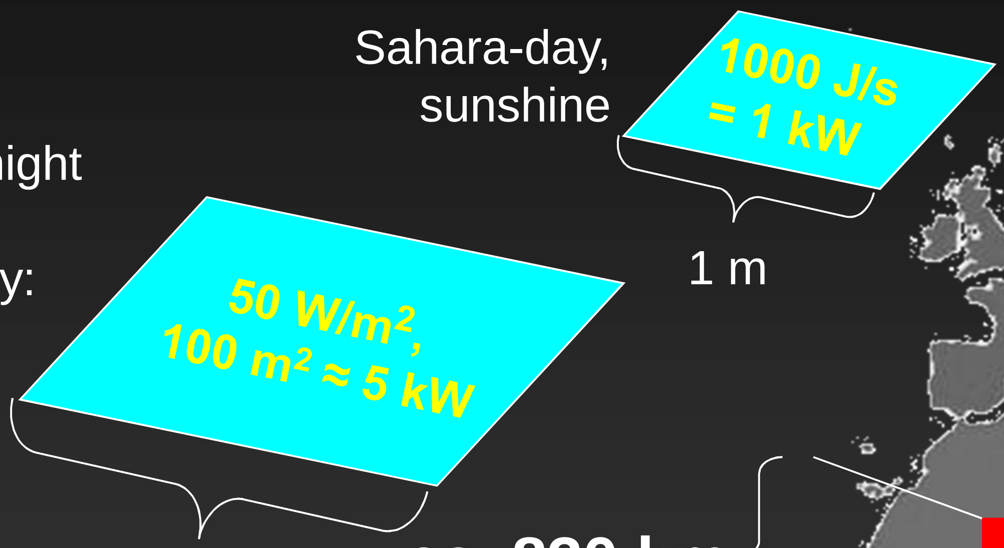


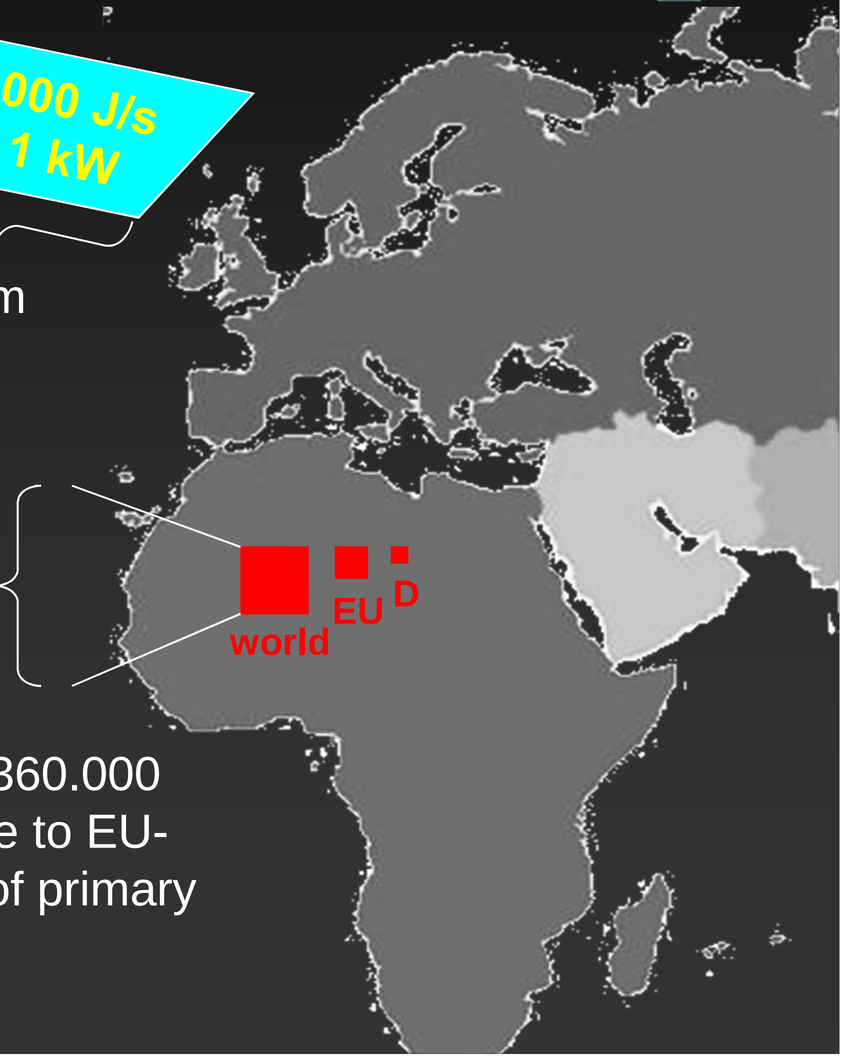
Hydrogen retains approximately 50 % of methane energy content
Resulting carbon could be stored (instead of CO_2 sequestration)

G. Kreysa, Chem.Ing.Tech. 80, 901 (2008)

In principle, the energy is there…

Sahara day&night average,
10 % efficiency:





700.000 km^2 desert area (Germany: 360.000 km^2) is sufficient, to lift 7 billion people to EU-energy standard with respect to use of primary energy

L-B-Systemtechnik
Quelle: LBST

Our most relevant renewables in the future

Foto: Georg Slickers

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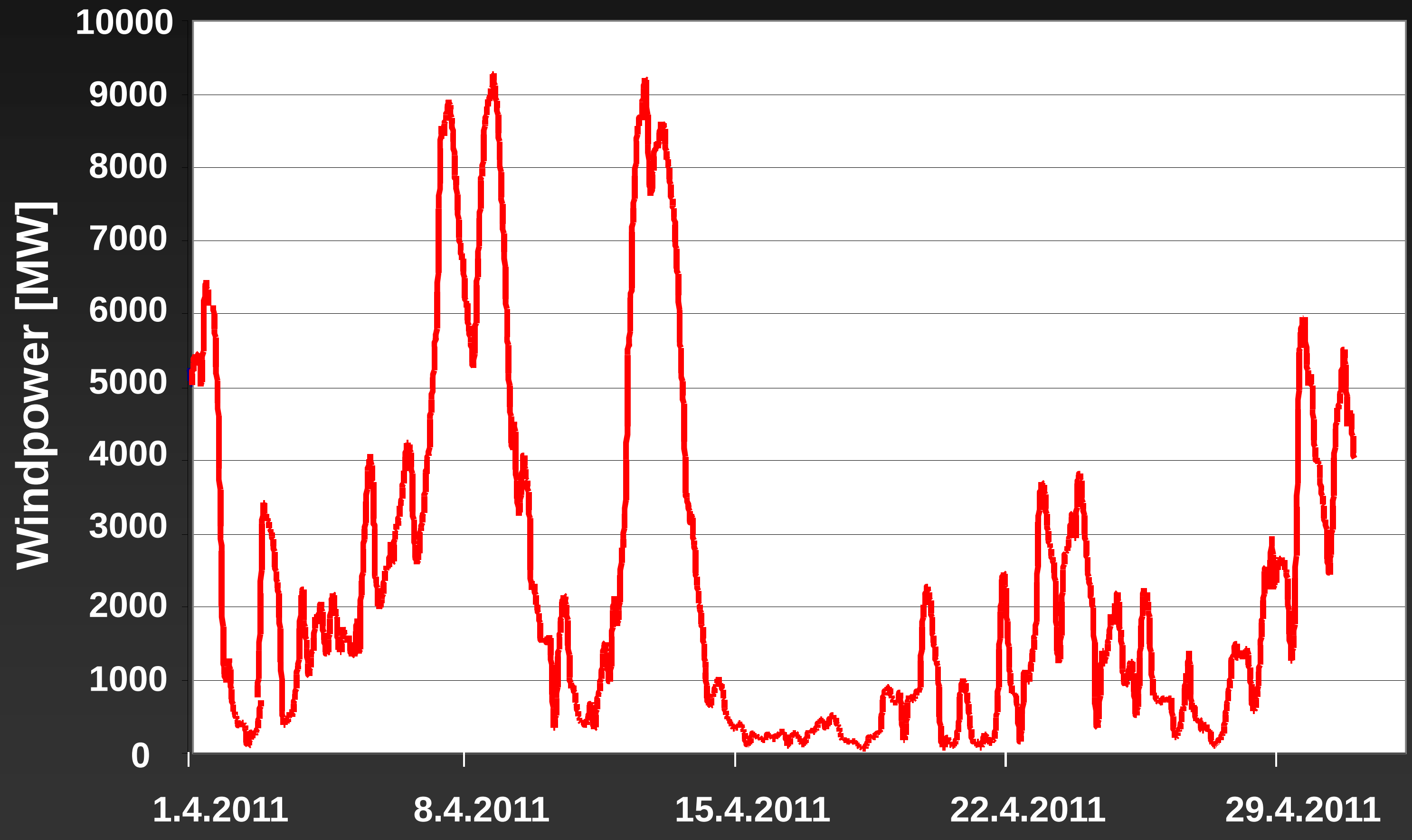
Windpower Fluctuations East Germany

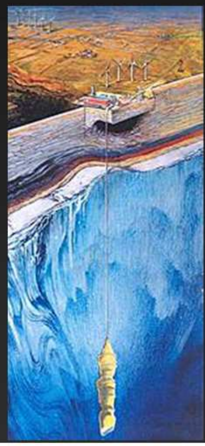


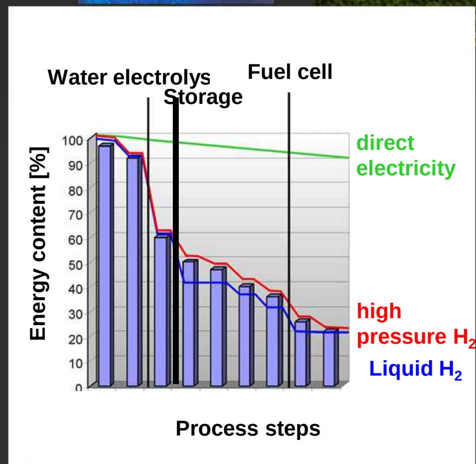
Windpower in 50 Hertz control area April 2011

Data downloaded from 50 Hertz webpage

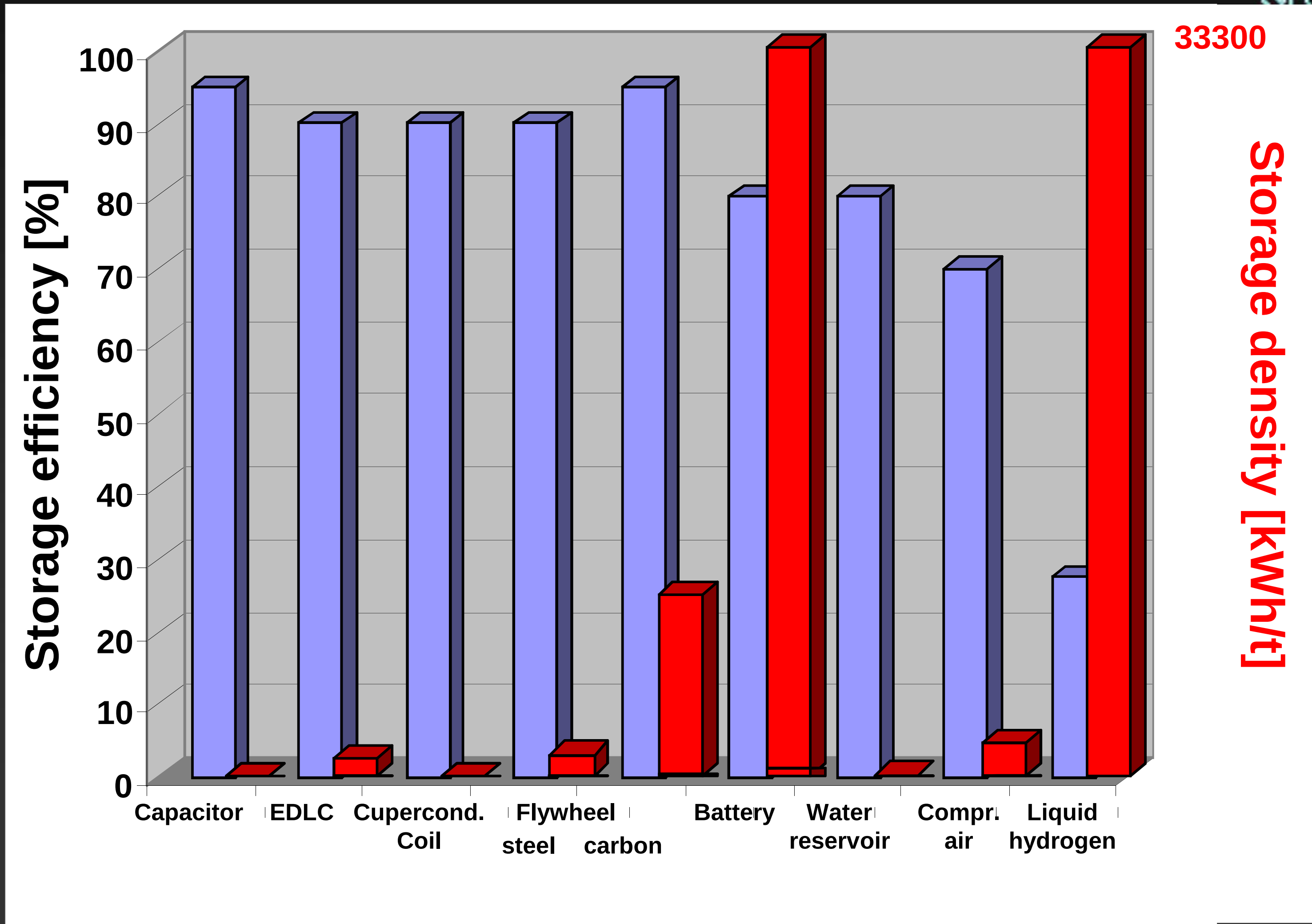
Options for energy storage

- Smart Grids
- Water reservoirs
  - » High efficiency
  - » Low costs
  - » Low capacity
- Compressed air
  - » Medium efficiency
  - » Medium costs
  - » Low capacity
- Battery
  - » High efficiency
  - » Moderate capacity
  - » costly
- Hydrogen
  - » Very high capacity
  - » Low efficiency
  - » costly





Comparison of options for electrical energy storage



Load leveling by chemical storage

- Hydrogen (120 MJ/kg)
- Methanol (23 MJ/kg)
- Liquid hydrocarbons (around 40 MJ/kg)
- Methane (50 MJ/kg)
- Ethanol (27 MJ/kg)
- solids (variable)

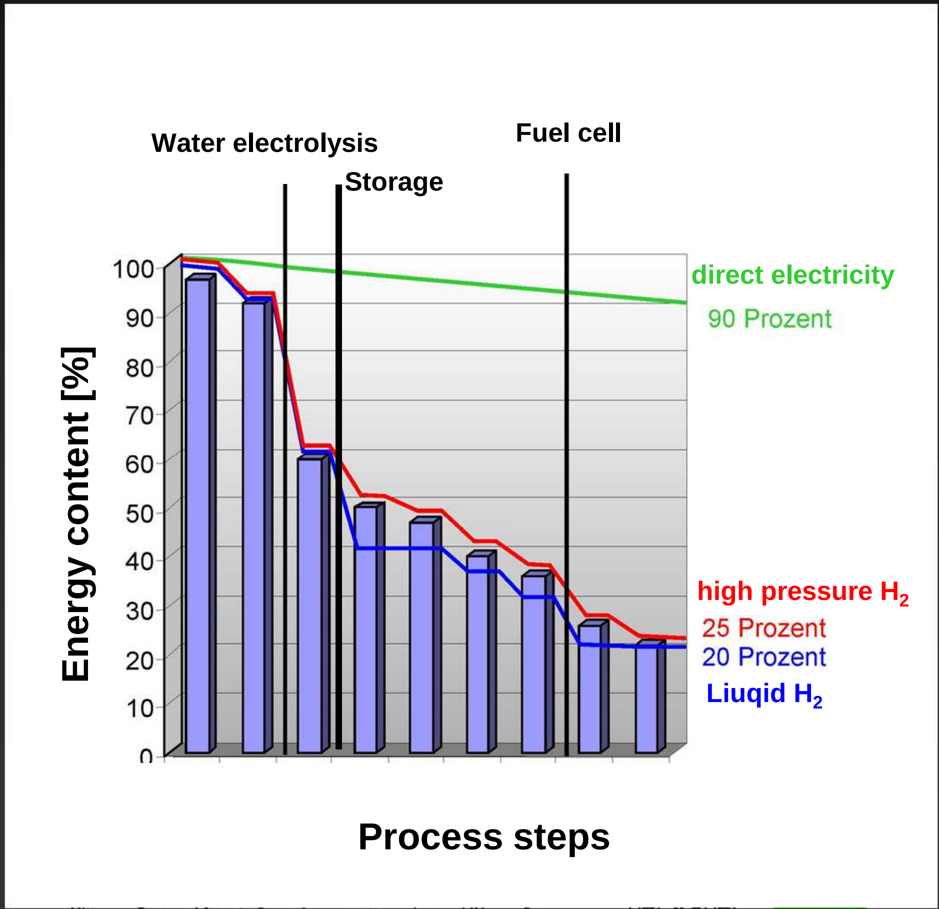
Comparison of options for chemical storage

Compound	Gravimetric storage density [MJ kg^{-1}]	Volumetric storage density [MJ L^{-1}]	Efficiency electr. – compound electr.	Efficiency shortest path to compound from regenerative energy	Comments
Hydrogen	120	0.0107 (gas) 8.52 (liq. 20.4 K)	ca. 30 %[1]	ca. 60 %[2]	requires storage facilities
Methane	50	0.0357 (gas) 21 (liq. 111 K)	ca. 25 %[1]	ca. 60 %[3]	storage and distribution infrastructure in place
Liquid Hydrocarbons	43	35	ca. 20 %	ca. 40 %[4]	storage and distribution infrastructure in place; directly useful in ICE[6]
Ethanol	27	21		controversial	regionally favorable CO_2 footprint; directly useful in ICE
Methanol	20	16	ca. 20 %	ca. 45 %[5]	directly useful in ICE

1) includes energy for compression for storage; 2) via electrolysis from electrical energy, solar-to-electricity not considered; 3) anaerobic fermentation; 4) from biomass via Fischer-Tropsch, from oil crops could be better, but depends strongly on conditions; 5) from biomass via conventional methanol synthesis; 6) ICE: internal combustion engine.

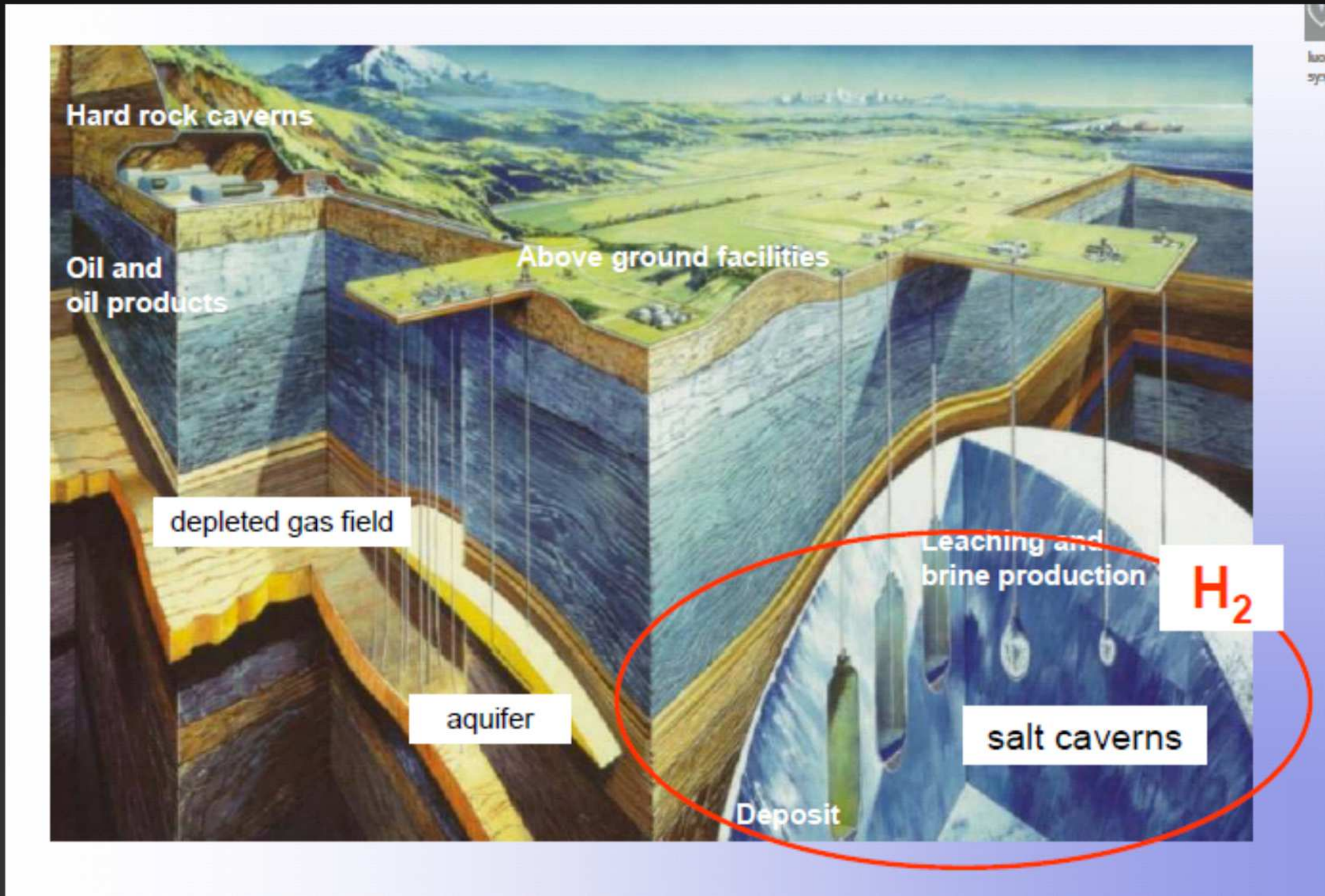
F. Schüth, Chem.Ing.Tech. 83, 1984 (2011)

The hydrogen economy: hydrogen from electricity by electrolysis



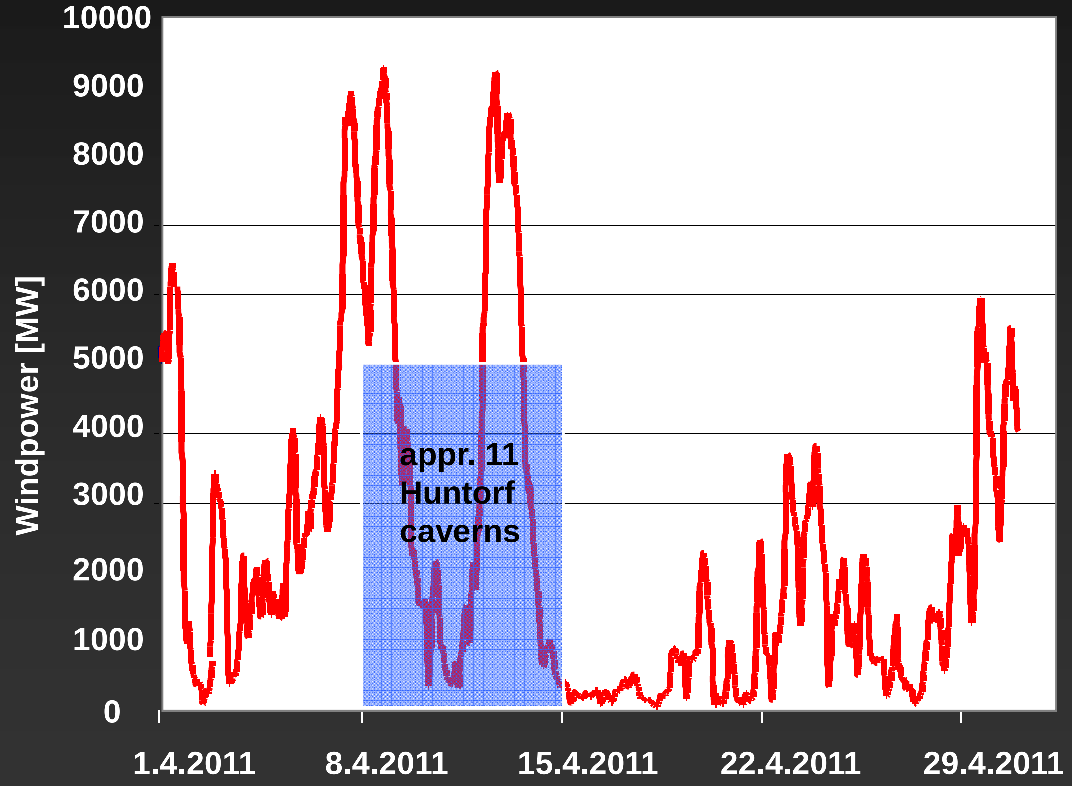
- Improve electrolysis
  - » High pressure electrolysis
  - » High temperature electrolysis
  - » Better – and cheaper – catalysts
  - » Reduced CapEx!!!
- Improve re-conversion to electricity
  - » Fuel cell
    - – Better catalysts
    - – Better systems level
  - » Turbine
    - – Materials
    - – Better control of combustion
    - – Multifuel

Storage in Salt Caverns



F. Crotogino et al., Abstracts of 18th World Hydrogen Energy Conference 2010

Buffer capacity of subterranean hydrogen



Huntorf 300 000 m^3
150 bar pressure
45 000 000 Nm^3 H_2
12 MJ/m^3 = 3.3 kWh/m^3
50 % efficiency: 74250 MWh

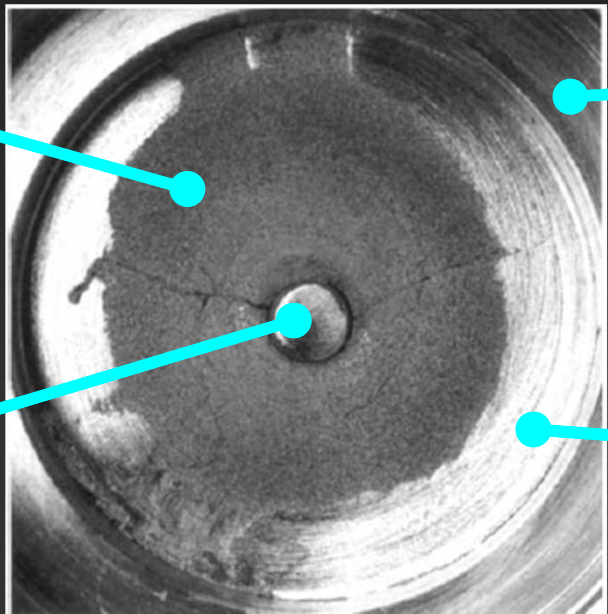
Siemens: 2012 Demonstrator Elektrolyzer 300 kW

Heat storage for base load solar thermal power

Parabolic trough solar thermal power plant Andasol I
27 500 t 60% $NaNO_3$/40% KNO_3 for heat storage between 386°C and 292°C
1010 MWh thermal, 7.5 h operation of 50 MW turbine

The Mg/MgH_2 system

- Storage density 0.9 kWh kg^{-1}_{Mg}
- Temperature range between 300 and 500°C
- Up to 1800 cycles tested
- Released hydrogen stored in different ways



MgH_2

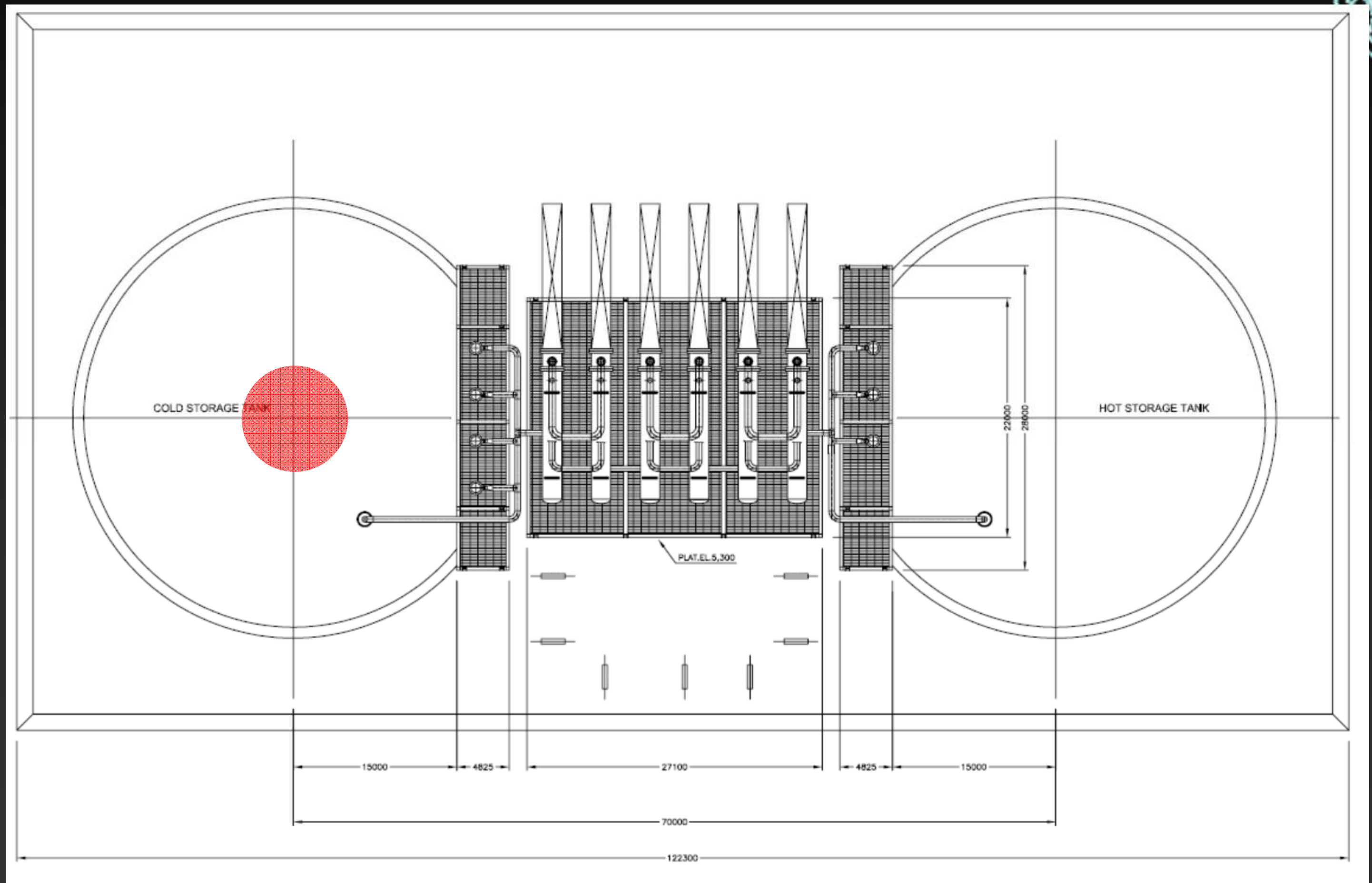
Container wall

Sinter metal tube for hydrogen admission and removal

Mg

B. Bogdanovic et al., Angew.Chem.Int.Ed. 29, 223 (1990)

Heat storage in CSP



Solar power plant Andasol I

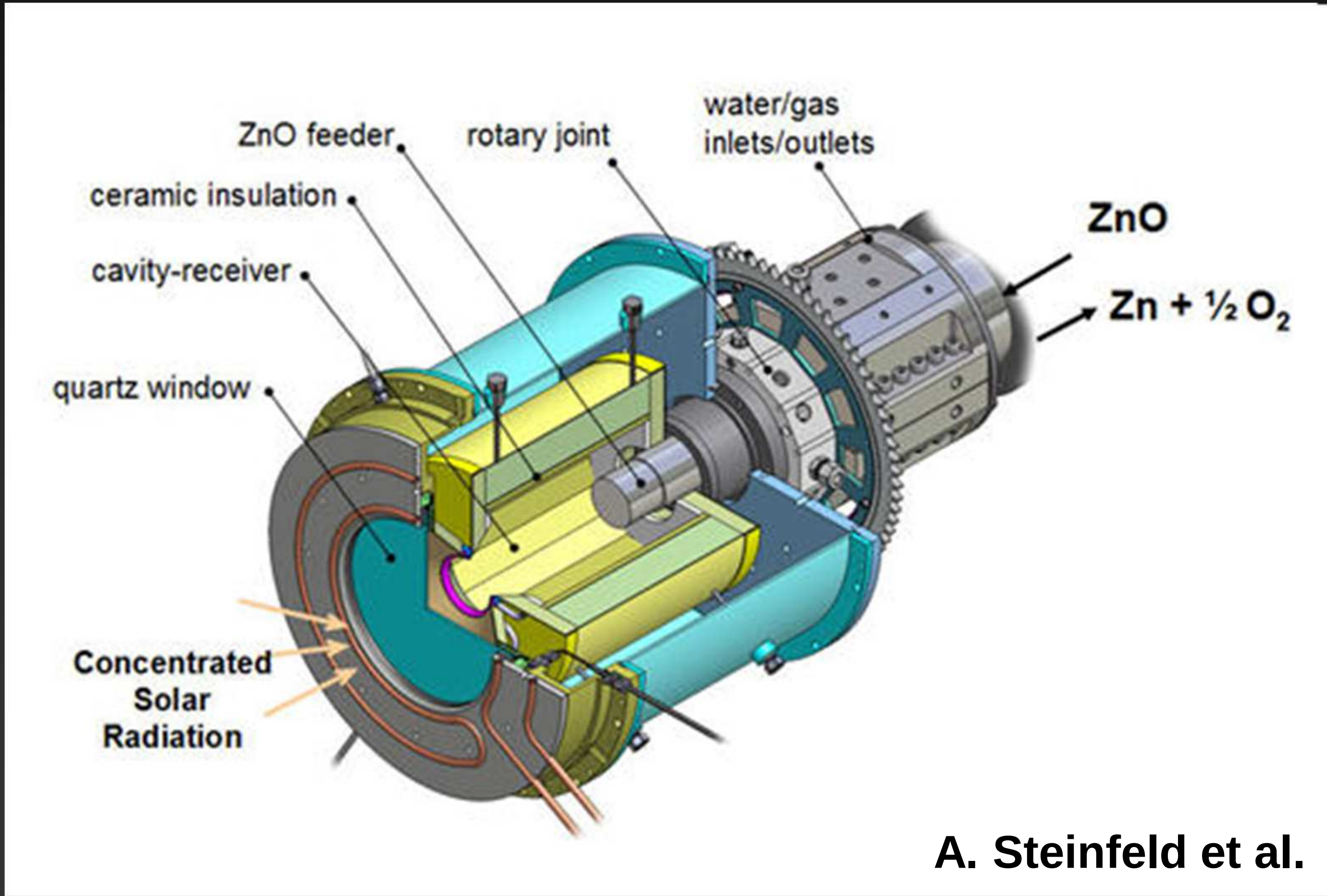
27 500 t 60% $NaNO_3$/40% KNO_3 for heat storage between 386°C and 292°C

1010 MWh thermal, 7.5 h operation of 50 MW turbine

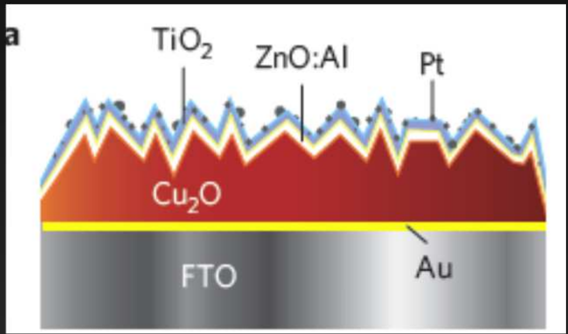
Solar power plant Andasol I

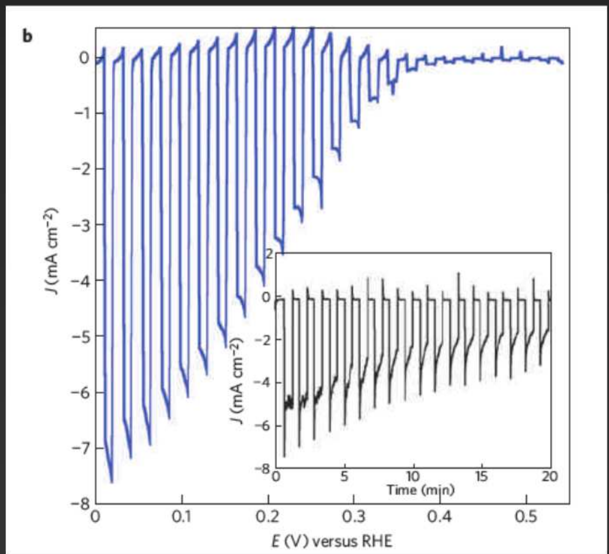
27 500 t 60% $NaNO_3$/40% KNO_3 can be replaced by 1100 t Mg

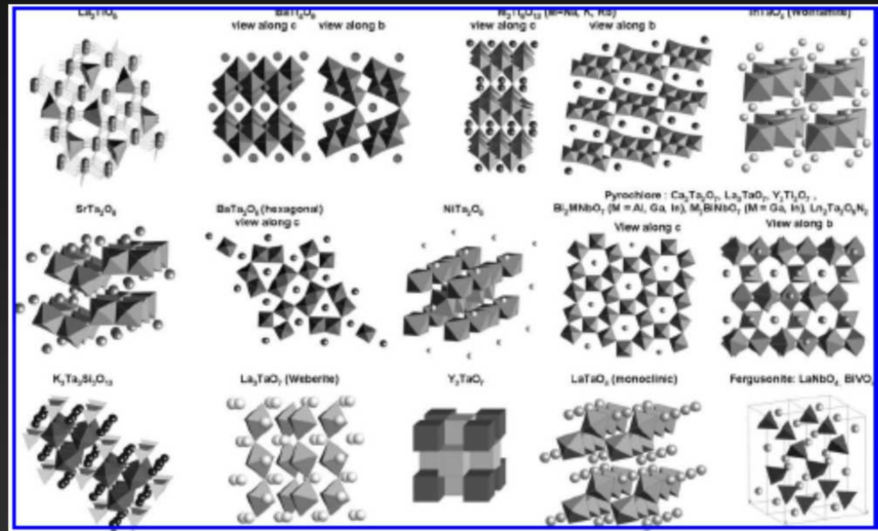
Thermal cycles for hydrogen generation



…and there is direct photolytic water splitting





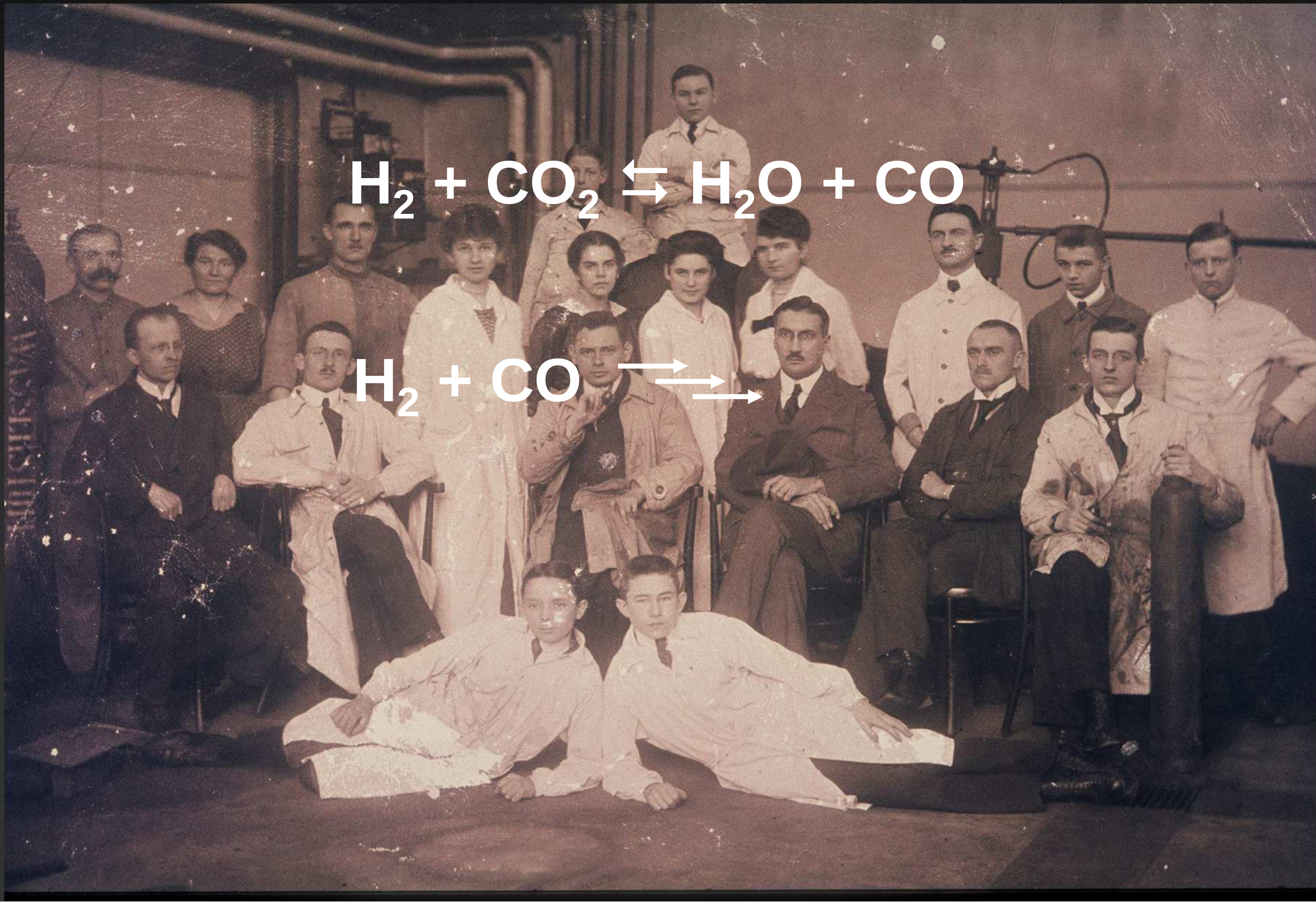


Some of the materials used for photocatalytic water splitting

A. Paracchino et al., Nat.Mater. 20, 456 (2011)

F.E. Osterloh, Chem.Mater. 20, 35 (2008)

Synthesis gas based chemistry



Hydrogen in future energy systems

- In order to minimize losses: stay electric as much as possible
- Hydrogen could be an important element in future energy system
  - » For grid scale energy storage
  - » As the product of solar thermal processes
  - » As part of the driving train of cars
  - » As entry point into chemical production
- Key issue: cost reduction and efficiency increase