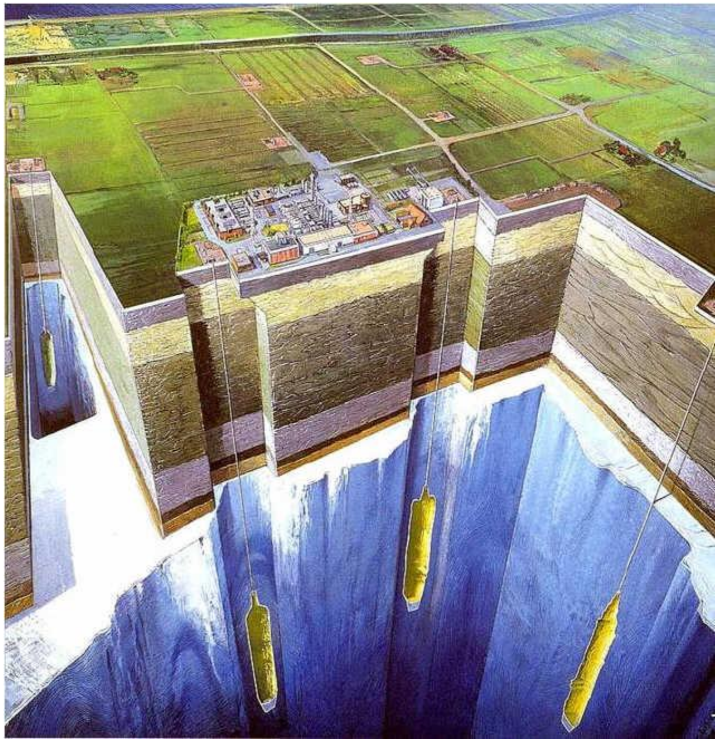
HYDROGEN PRODUCTION AND STORAGE



Achim Schaadt, Christopher Hebling

Fraunhofer Institute for Solar Energy Systems ISE

European Summer Campus 2013

Freiburg, 2nd September 2013

www.ise.fraunhofer.de

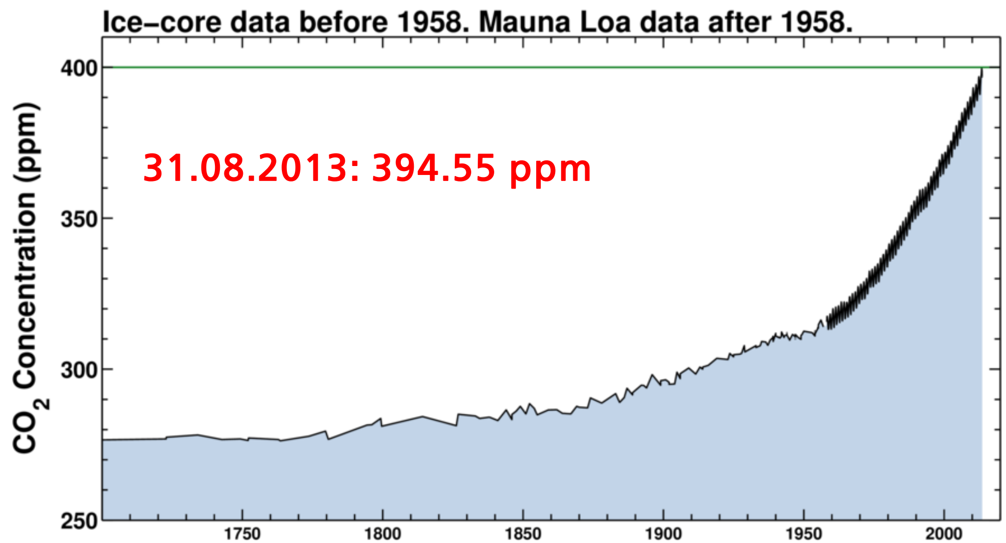
Fraunhofer ISE

AGENDA

- Why energy storage?
- Why hydrogen?
- How to produce H_2?
- How to store H_2?
- How to use H_2?
- Conclusion

Motivation

- dramatic increase of CO_2 emissions (climate change)
- shortage of fossil fuels
- regional concentration of fossil fuels
- environmental pollution by fossil energy carriers (e. g. oil spill)



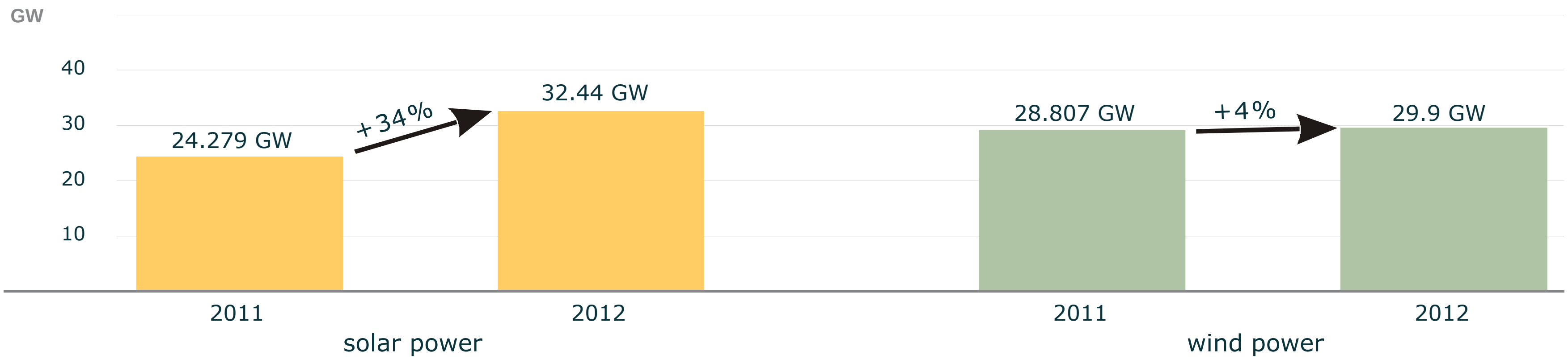
Source: http://keelingcurve.ucsd.edu/

The Energy Concept of the German Government

Aims for the year	2020	2050
Reduction green house gases	- 40 %	- 80 %
Reduction primary energy consumption	- 20 %	- 50 %
Proportion renewables on electricity consumption	35 %	80 %

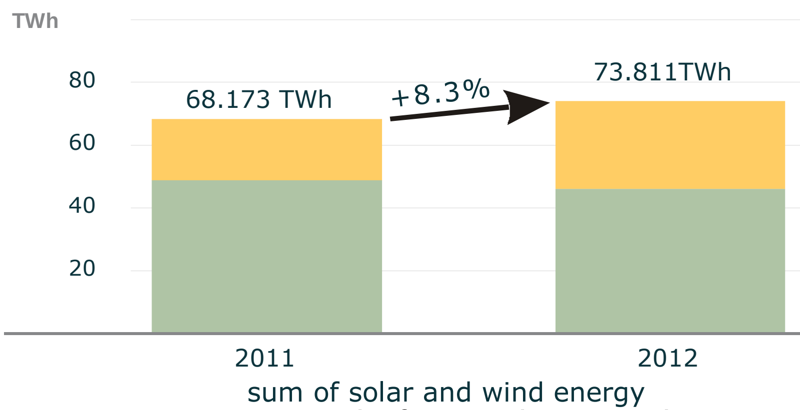
Installed solar and wind power 2011 and 2012 in Germany

Installed solar and wind power in Germany



Annual sum of solar und wind electricity production in Germany

Legend: Solar Wind



1.3 Mio Photovoltaic plants

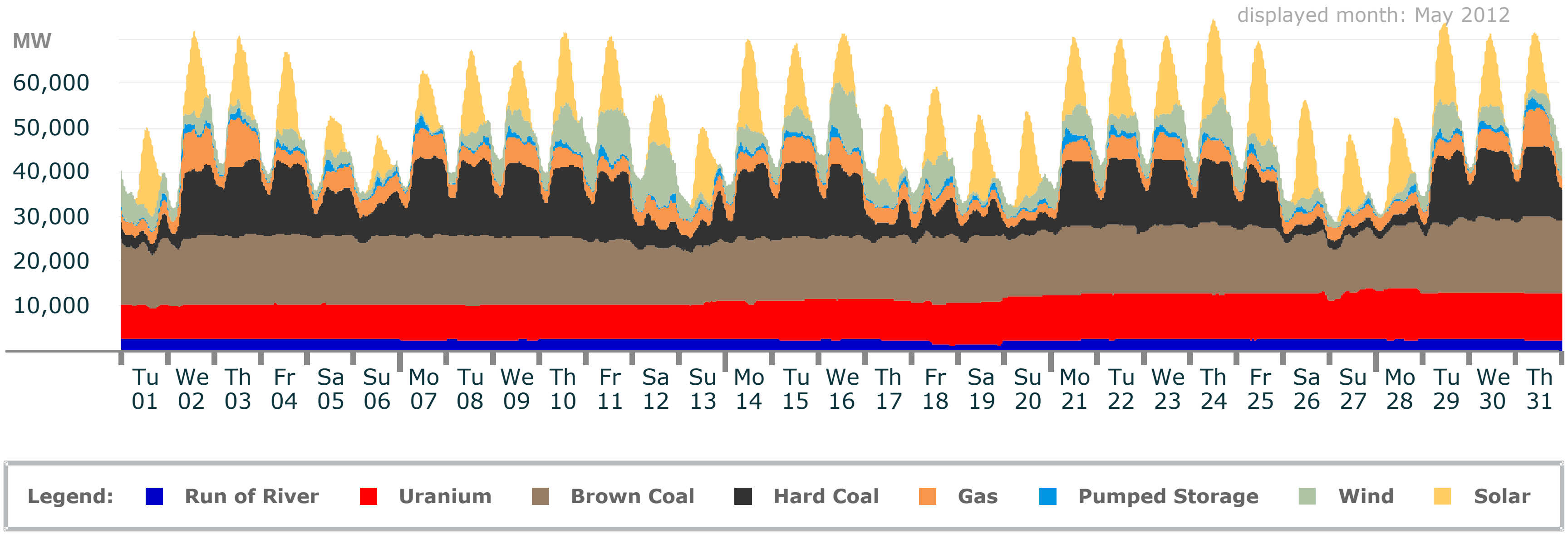
22.660 Wind power plants

Source: B. Burger, Fraunhofer ISE; data: Bundesnetzagentur

Fraunhofer ISE

Electricity Production of all Power Generators: May 2012

Electricity Generation



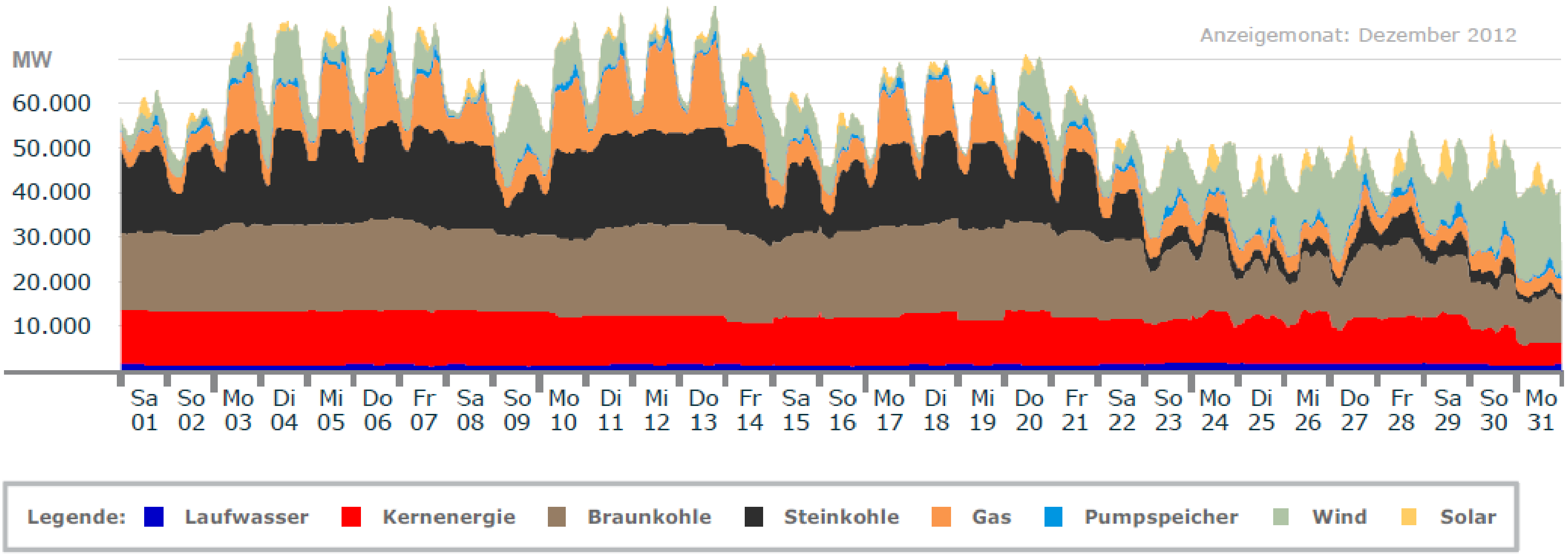
	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
min. power (GW)	1.5	6.9	11.2	1.5	1.9	0	0.26	0
max. power (GW)	3.0	11.4	17.6	17.8	11.1	4.0	14.1	22.4
monthly energy (TWh)	1.6	6,7	10.3	7.7	3.0	0.54	2.9	4.1

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

Fraunhofer ISE

Electricity Production of all Power Generators: December2012

Electricity Generation

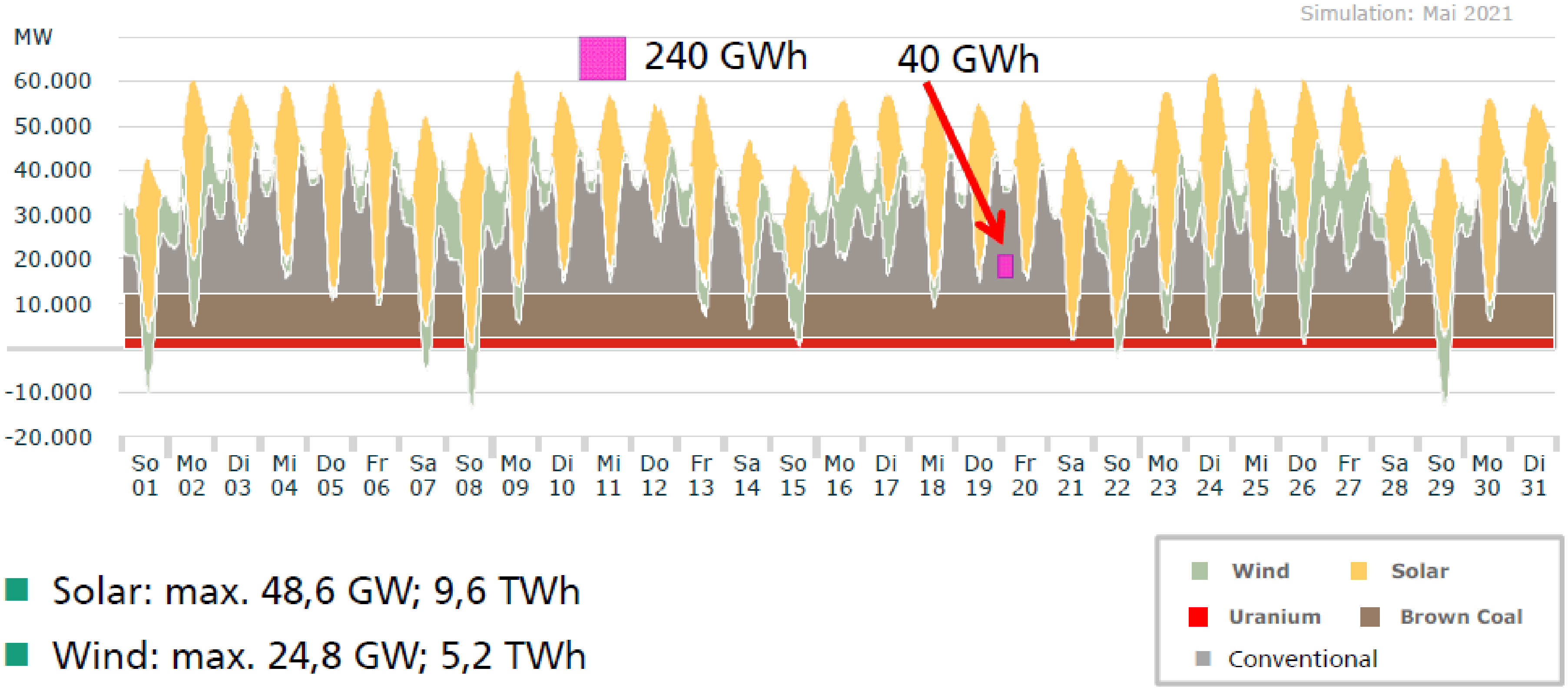


	LW	AKW	BK	SK	Gas	PSp	Wind	Solar
min. Leistung (GW)	0,9	4,4	8,9	1,2	3,2	0	0,3	0
max. Leistung (GW)	2,0	12,2	20,7	21,8	22,4	4,0	20,9	8,4
Monatsenergie (TWh)	1,1	8,0	12,8	9,4	5,0		5,6	0,4

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX, http://www.transparency.eex.com/de/

Fraunhofer ISE

Simulation: May 2021



- Solar: max. 48,6 GW; 9,6 TWh
- Wind: max. 24,8 GW; 5,2 TWh
- Conventional: min. -14,1 GW; max. 44,5 GW; 17,9 TWh

Graph: B. Burger, Fraunhofer ISE; Data: Leipziger Strombörse EEX

Fraunhofer ISE

Energy Storage Today

Pumped Hydro Storage

- State of the art
- 40 GWh/Germany
- Limited locations

< 1 GW
< 10 GWh

Compressed Air Energy St.

- 2 plants worldwide
- Some R&D activites

<< 1 GW
< 10 GWh

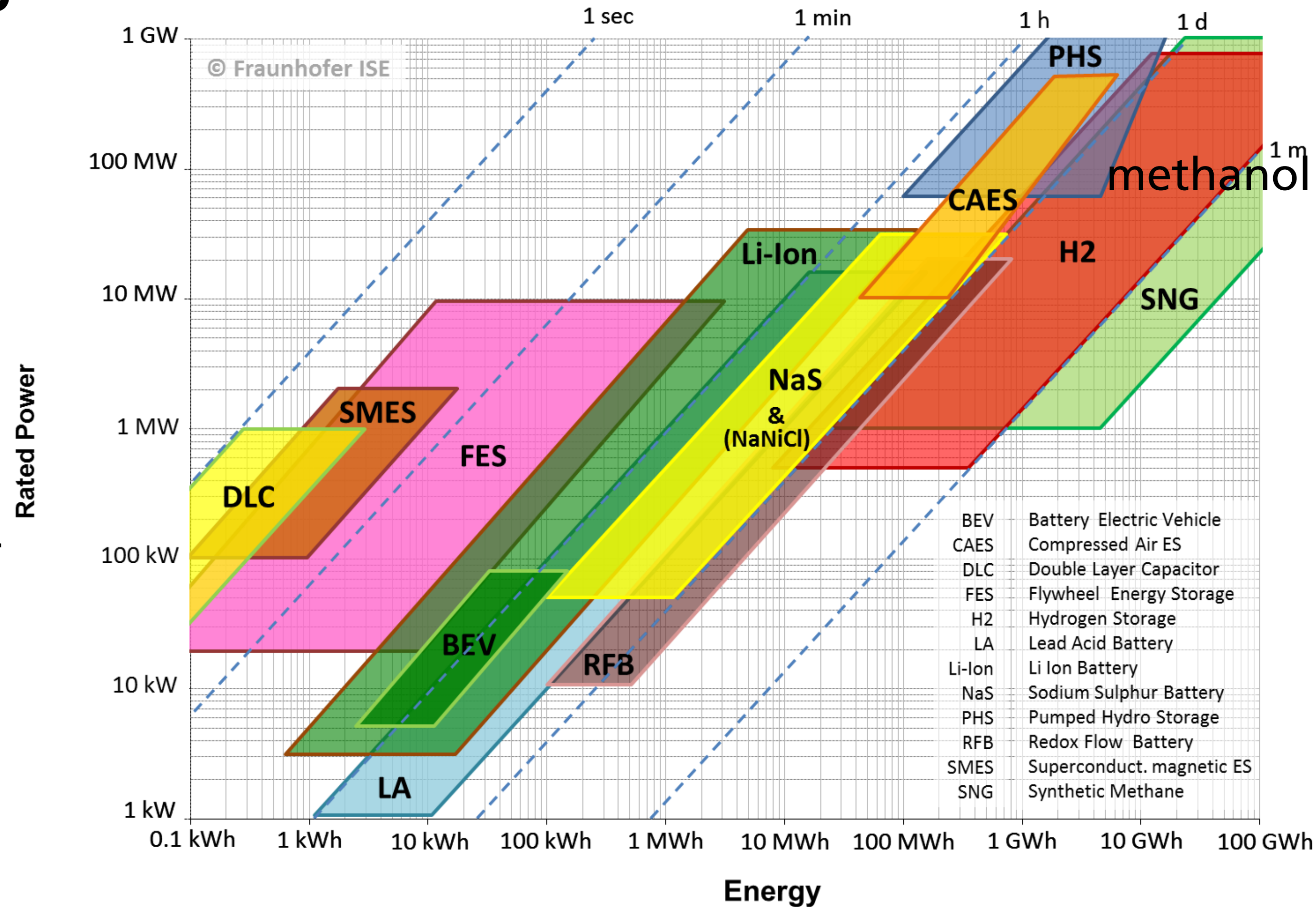
Battery Storage

- Lead Acid Batteries
- NaS Batteries
- Lithium Ion Batteries

< 10 MW
< 30 MWh

Energy Storage

- only chemical energy carriers allow storage up to the TWh range
- methanol: energy carrier



$$CO_2 + 4\,H_2 \leftrightarrows CH_4 + 2H_2O \qquad \Delta_r H^{298K} = -164{,}71\ \text{kJ/mol}$$

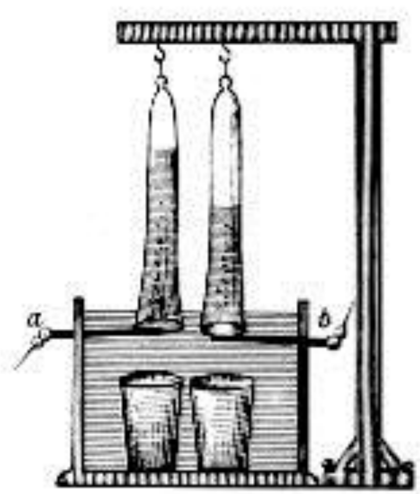
$$CO_2 + 3\,H_2 \leftrightarrows CH_3OH + H_2O \qquad \Delta_r H^{298K} = -48{,}97\ \text{kJ/mol}$$

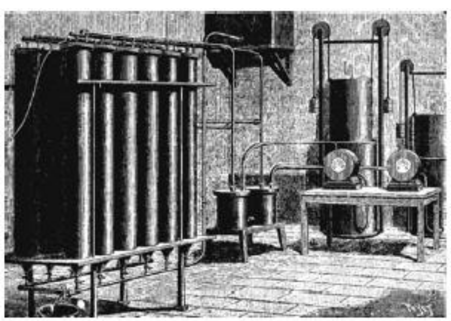
Hydrogen Energy: Main Principles

- Generation of hydrogen from
  - electric power by electrolysis
  - fossil fuels (steam reforming)
  - waste biomass (reforming)

Fraunhofer ISE

Electrolysis: Electrolytical Water Splitting
For more than 200 years


Test set-up of Ritter


Alkaline electrolyser around 1900

- Invention of voltaic pile (1799) enabled investigations of electrolytic approaches
- Main principle demonstrated around 1800 by J. W. Ritter, William Nicholson and Anthony Carlise

$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

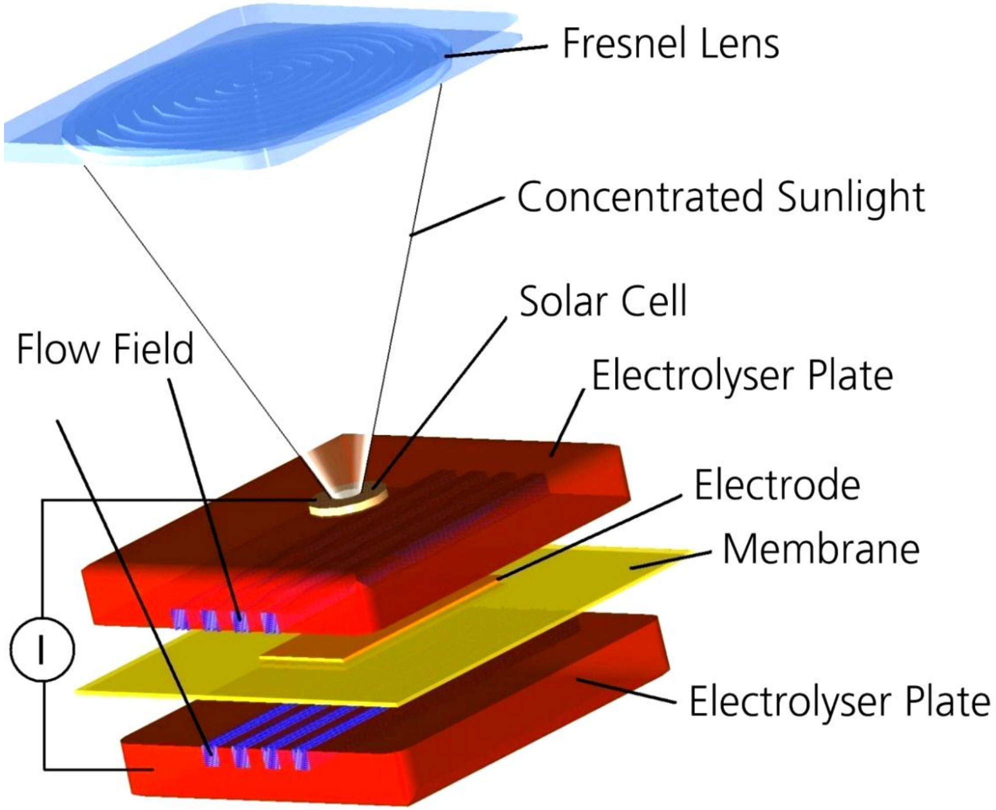

Johann Wilhelm Ritter (1776-1810)

Picture credits: all www.wikipedia.org

Fraunhofer ISE

HyCon®: Solar Hydrogen Production @ ISE

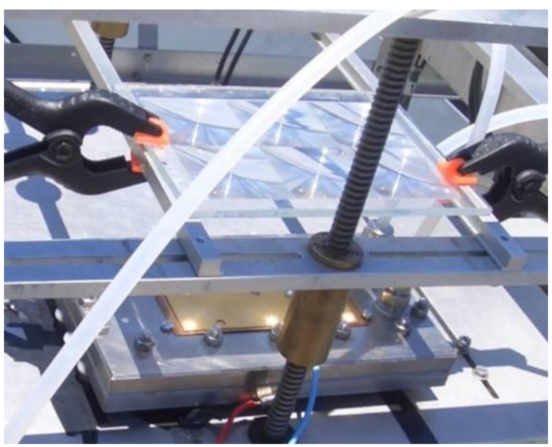
- Direct conversion from sunlight in hydrogen
- Integration of electrolysis cell in III-V multi-junction solar cell
- Highest efficiency for solar hydrogen production
- First laboratory demonstrator
- Approach patented
  - DE102004050638B3
  - WO2006/042650A2
  - US11576939

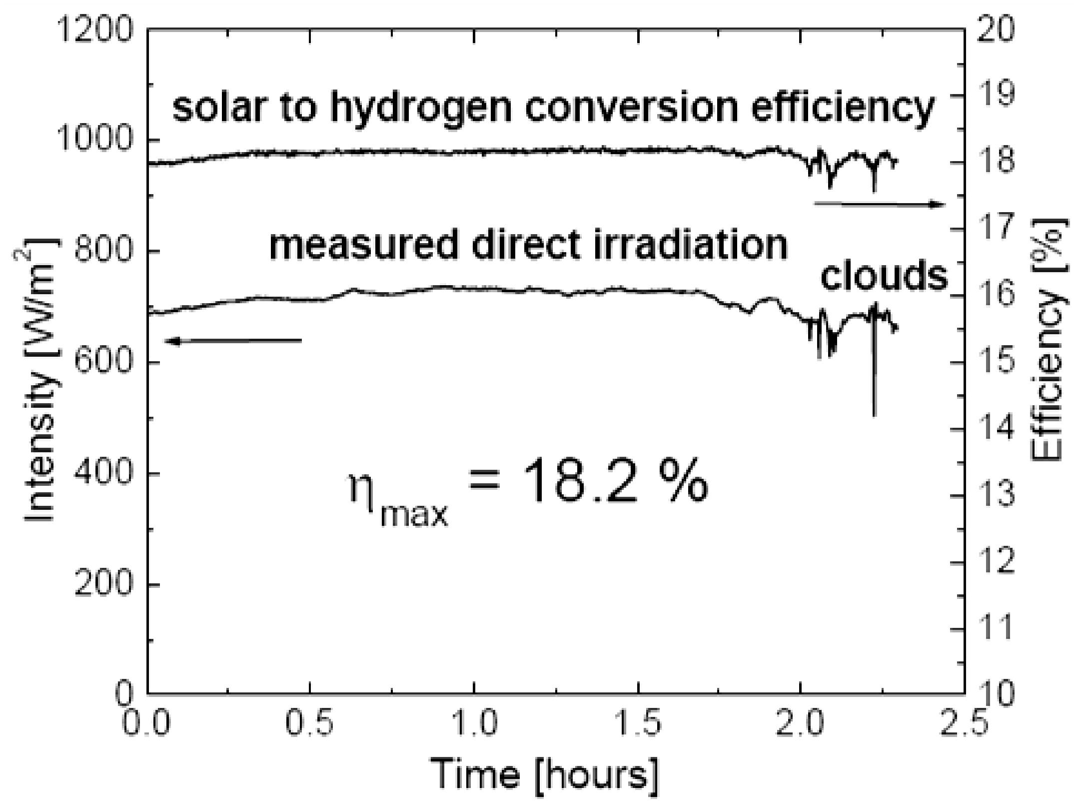


Fraunhofer ISE

HyCon®: Solar Hydrogen Production

- Outdoor test results of the first HyCon® demonstrator
- six cells in parallel
- mounted on a two axis tracking system in Freiburg/Germany





Peharz, G.; Dimroth, F.; Wittstadt, U.: Solar Hydrogen Production by Water Splitting with a Conversion Efficiency of 18%. Int. J. Hydrogen Energy, 15 (2007), pp 3248-3252

Fraunhofer ISE

Hydrogen Energy: How to Store Hydrogen?

Picture Credits:

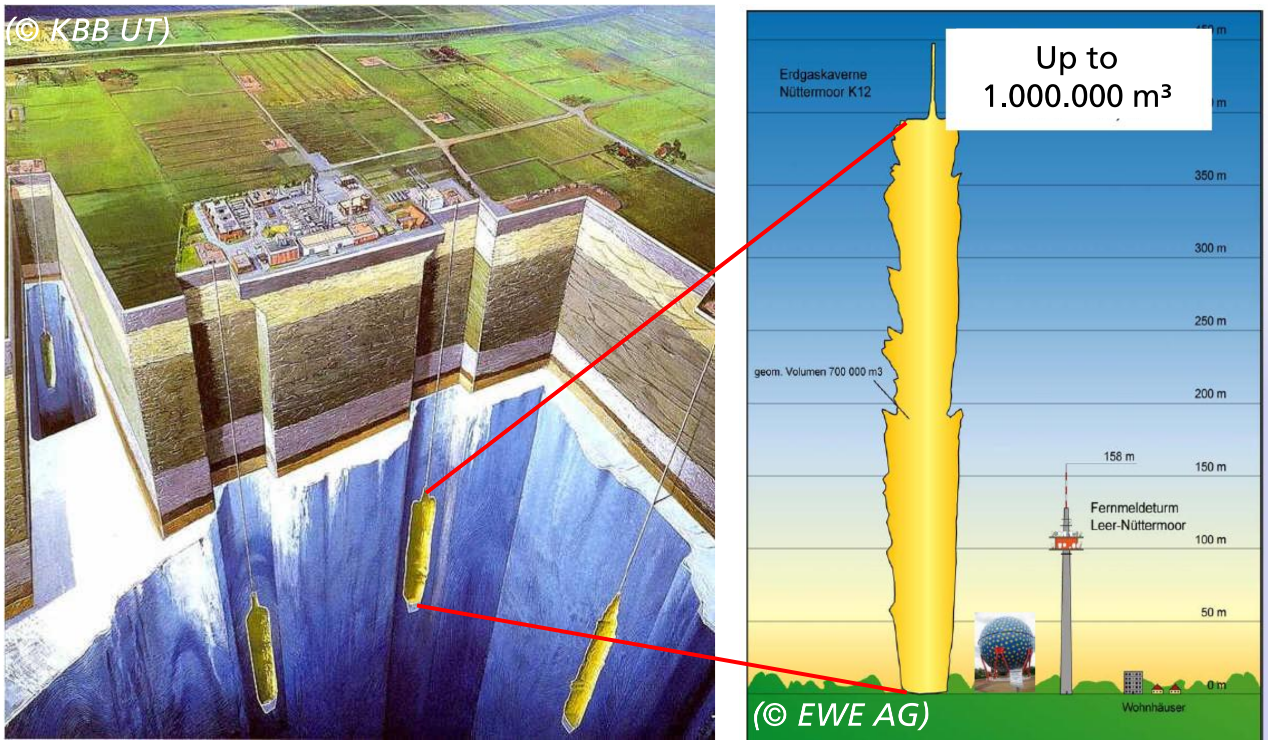
Top: Dynetek, Quantum, Linde, Magna Steyr, NASA

Bottom: Westfalen Gas, Wystrach, Dynetek, Hyfleet, NASA, KBB UT

Fraunhofer ISE

Hydrogen Energy Storage :
Underground Storage in Salt Caverns

- In the past: Storage of town gas in Germany
- Today: Natural gas reserve in Germany
- Hydrogen salt cavernes in UK and US



Echometric cavern survey

Fraunhofer ISE

Hydrogen Storage in Salt Caverns

Town gas in Germany 1850 - 1950
(H_2-proportion > 50%) in salt caverns and pipelines

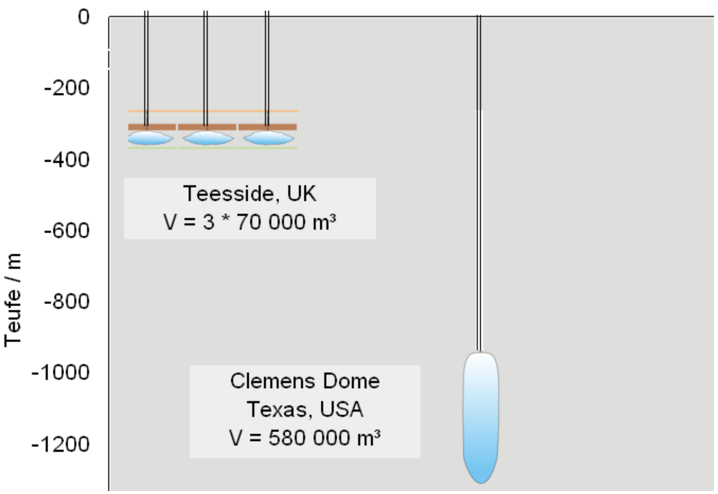
Hydrogen caverns in operation:

Teeside, UK, Operator: Sabic Petrochemicals,
3 x 70.000m3, 4.5MPa (konst.), 25 GWh,
30 years in operation

Clemens, Dome, Lake Jackson, Texas, USA,
Operator: ConocoPhillips, 580.000 m3,
7,0 – 13,5 MPa, 92 GWh, since 1986

Moss Bluff Salzdom, Liberty County, Texas,
Operator: Praxair, 566.000 m3 storage volume, 7,6 – 13,4 MPa, 80 GWh, since 2007

Outlet valve of a hydrogen caverne



(Source: KBB UT)

Fraunhofer ISE

Local Hydrogen Storage

1.5 GWh Storage Capacity (filled with hydrogen, 1.6 ha)

Source: Rosetti Marino - Italy

Hydrogen Energy: Main Principles

- Generation of hydrogen from
  - electric power by electrolysis
  - fossil fuels (steam reforming)
  - waste biomass (reforming)

© MVV

© iht

- Storage of hydrogen at
  - elevated pressure level in tanks/pipelines
  - liquified at low temperature
  - geological, underground

© Quantum

© McPhy

- Hydrogen usage in many applications
  - power generation
  - fuel for mobility
  - chemical industry (methanol, methane,..)

© Siemens

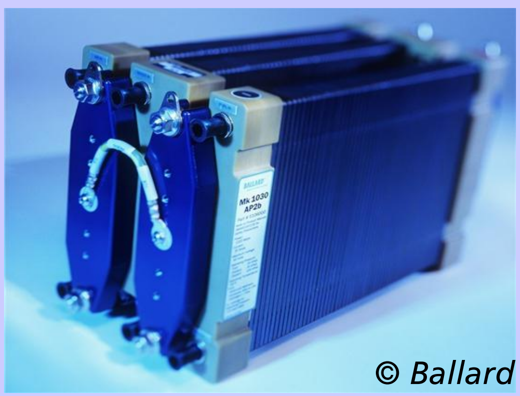
© Daimler

Fraunhofer ISE

Hydrogen Energy: Power generation

Fuel Cells

- High efficiency
- Mobile (fuel cell car)
- (Portable / stationary)
- 1 W - 100 kW



© Ballard

Gas Engines

- Internal combustion
- Robust and reliable
- Stationary
- 10 kW - 5 MW

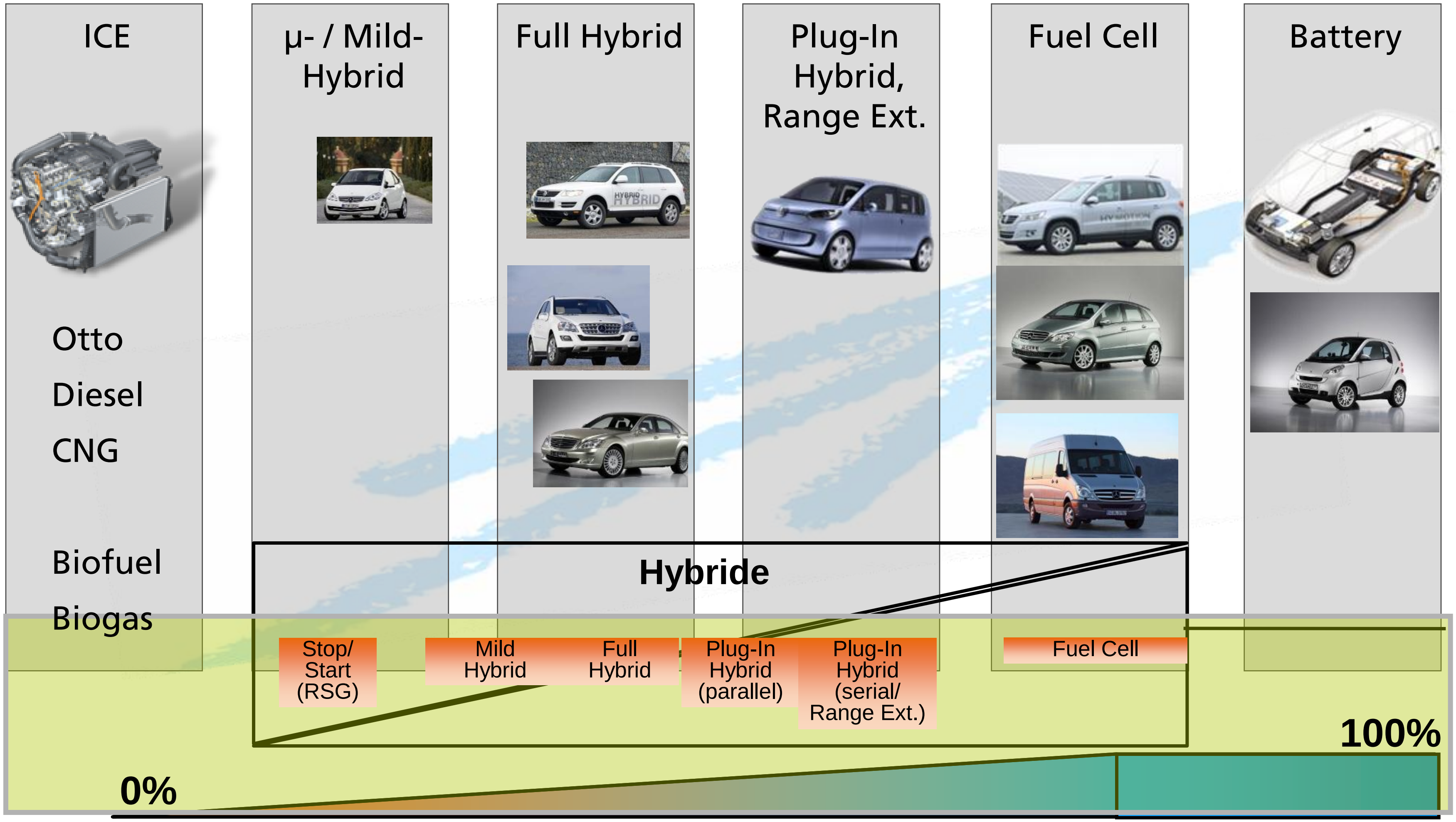
© GE Jenbacher Gasmotoren

Gas Turbines

- Power plant technology
- Moderate efficiency
- Stationary
- 1 MW - 300 MW

© Siemens

Hydrogen usage: Mobility



Fraunhofer ISE

Hydrogen Energy

Hydrogen filling Station at Fraunhofer ISE

- Hydrogen chain: from solar power to sustainable mobility
- On-site hydrogen production by PEM water electrolysis
- Medium pressure storage to enable demand side management
- Hydrogen filling station for 350 bar and 700 bar hydrogen cars
- Publicly accessible

Fraunhofer ISE

Hydrogen Filling Station at Fraunhofer ISE

Example of hydrogen filling station coupled with renewable energies (© Hydrogenics)

- Main components of the filling station:
  - (Pressure) electrolyser
  - Mechanical compressor
  - Storage tanks/vessels
  - Dispenser units
- Integrated container solution
- Publicly accessible filling station
- Located at premises of Fraunhofer ISE
- Coupled with renewable energies:
  - Photovoltaic modules (roof)
  - Certified green electricity

Hydrogen Filling Station at Fraunhofer ISE

- Save and fast hydrogen supply for:
  - Passenger cars (up to 70 MPa)
  - Cargo bikes / rickshaws
  - light-duty commercial vehicles
- Filling according to SAE J2600

- More than a hydrogen filling station:
  - Technology platform for R&D projects
  - Demonstration of hydrogen supply chain
  - Fleet tests of hydrogen vehicles
  - Monitoring of the complete supply chain

Mercedes-Benz B-Klasse F-CELL
(© Daimler AG)

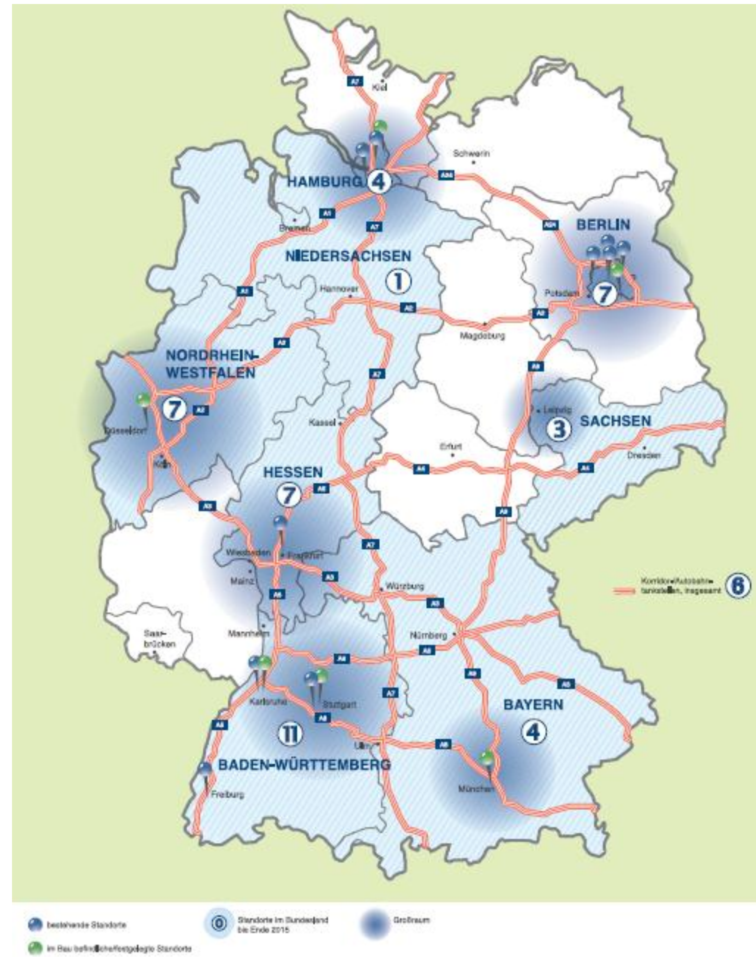
Hydrogen driven rickshaw

Fraunhofer ISE

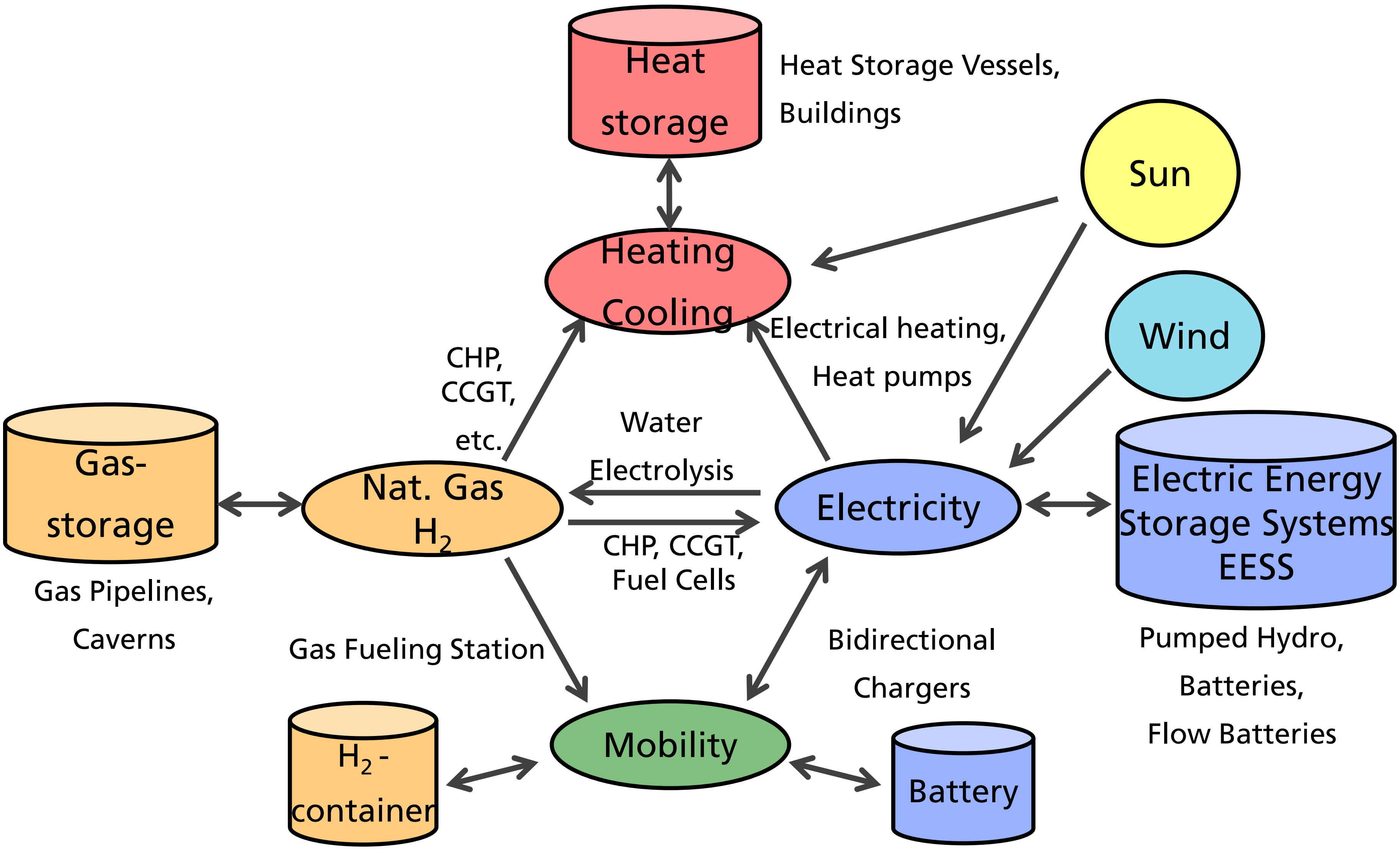
Germany to expand nationwide network of hydrogen filling stations from 15 to 50 by 2015

June 20, 2012

- **Joint Letter of Intent to expand the network of hydrogen filling stations in Germany**
  - signed by the German Ministry of Transport, Building and Urban Development (BMVBS) and several industrial companies
  - part of the National Innovation Programme for Hydrogen and Fuel Cell Technology (NIP)
  - overall investment more than €40 million



Transition to a Solar Energy Economy

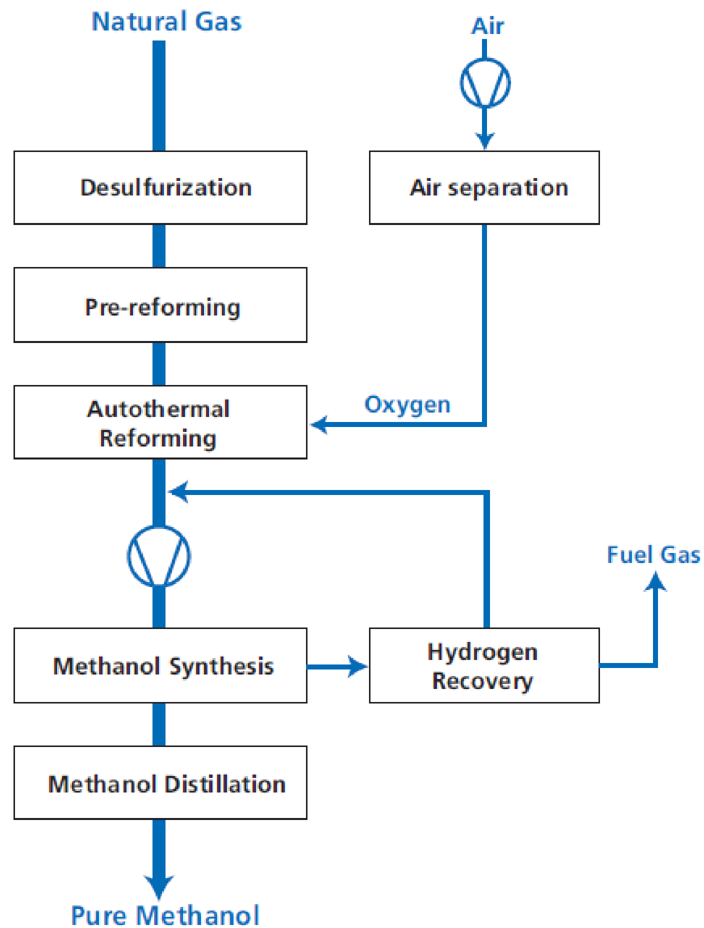


Source: Bruno Burger, Fraunhofer ISE

Hydrogen Usage: Synthesis of Chemicals from H_2 and CO_2

Methanol synthesis

- one of the most important bulk chemical in chemical industry: 60 million t in 2012
- world-scale methanol plants with capacity > 1 mio t per year
- fossil methane (natural gas) is mainly used as feedstock
- replacement of fossil methane/methanol
- methanol is used as chemical feedstock for acetic acid, formaldehyde, etc.



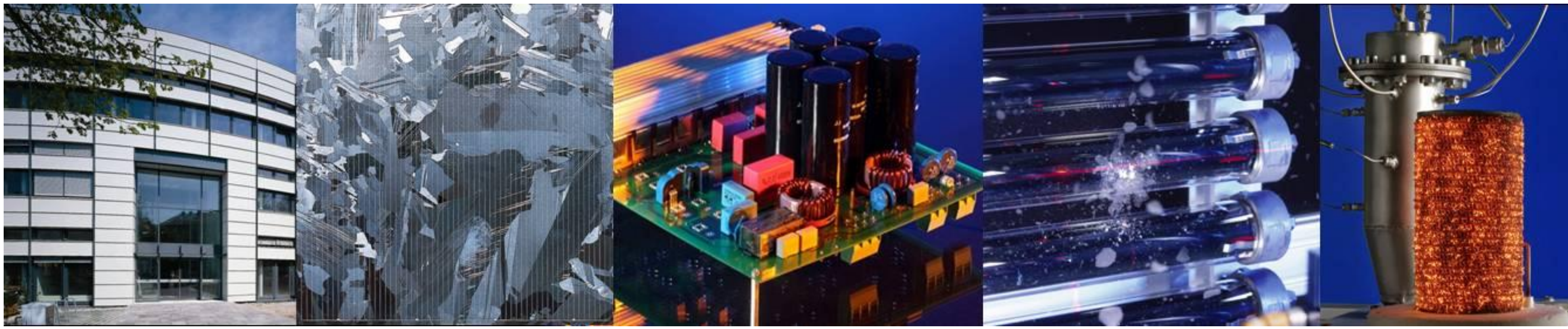
methanol production by Lurgi

Fraunhofer ISE

Conclusions

- transformation to a sustainable: 100 % renewable energy
- large amounts of fluctuating electricity sources into the energy system
- increased storage capabilities necessary
- hydrogen will play an important role as an universal energy carrier for storing energy, as a fuel in the transportation sector and a chemical component
- methanol could play a role as liquid energy carrier/chemical and as means to store CO_2
- The reward for this transformation will be long-term sustainability of the world's energy needs at lower, stable and thus predictable energy costs

Thank you



Fraunhofer Institute for Solar Energy Systems ISE

Achim Schaadt,

Deputy Head of Group Hydrogen Production

www.ise.fraunhofer.de

achim.schaadt@ise.fraunhofer.de

Fraunhofer ISE