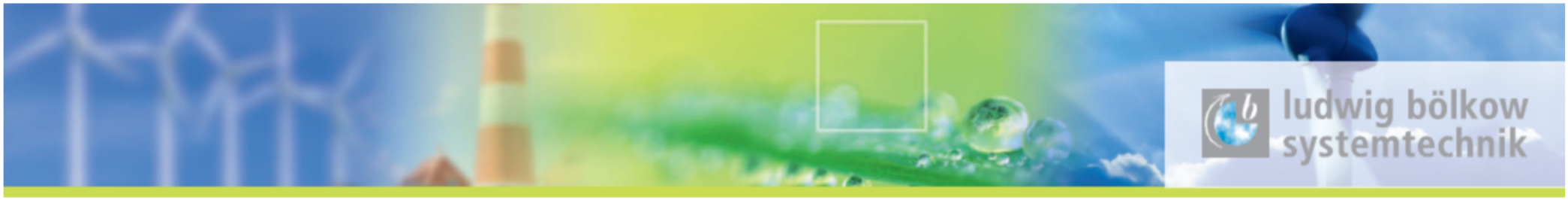

Hydrogen as energy storage medium and fuel for transport

Ulrich Bünger
Ludwig-Bölkow-Systemtechnik GmbH, Ottobrunn, Germany

Technoport Conference 2012
Trondheim, 16 April 2012

Snapshots from H2moves Scandinavia Lighthouse Project

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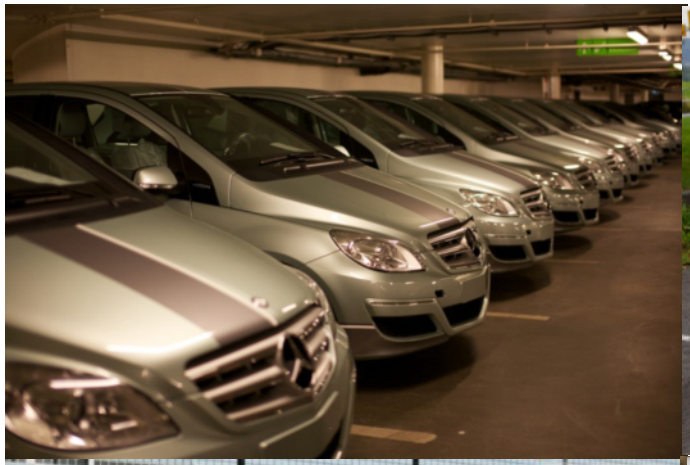

Vision of a Global „Centralized“ Energy Network

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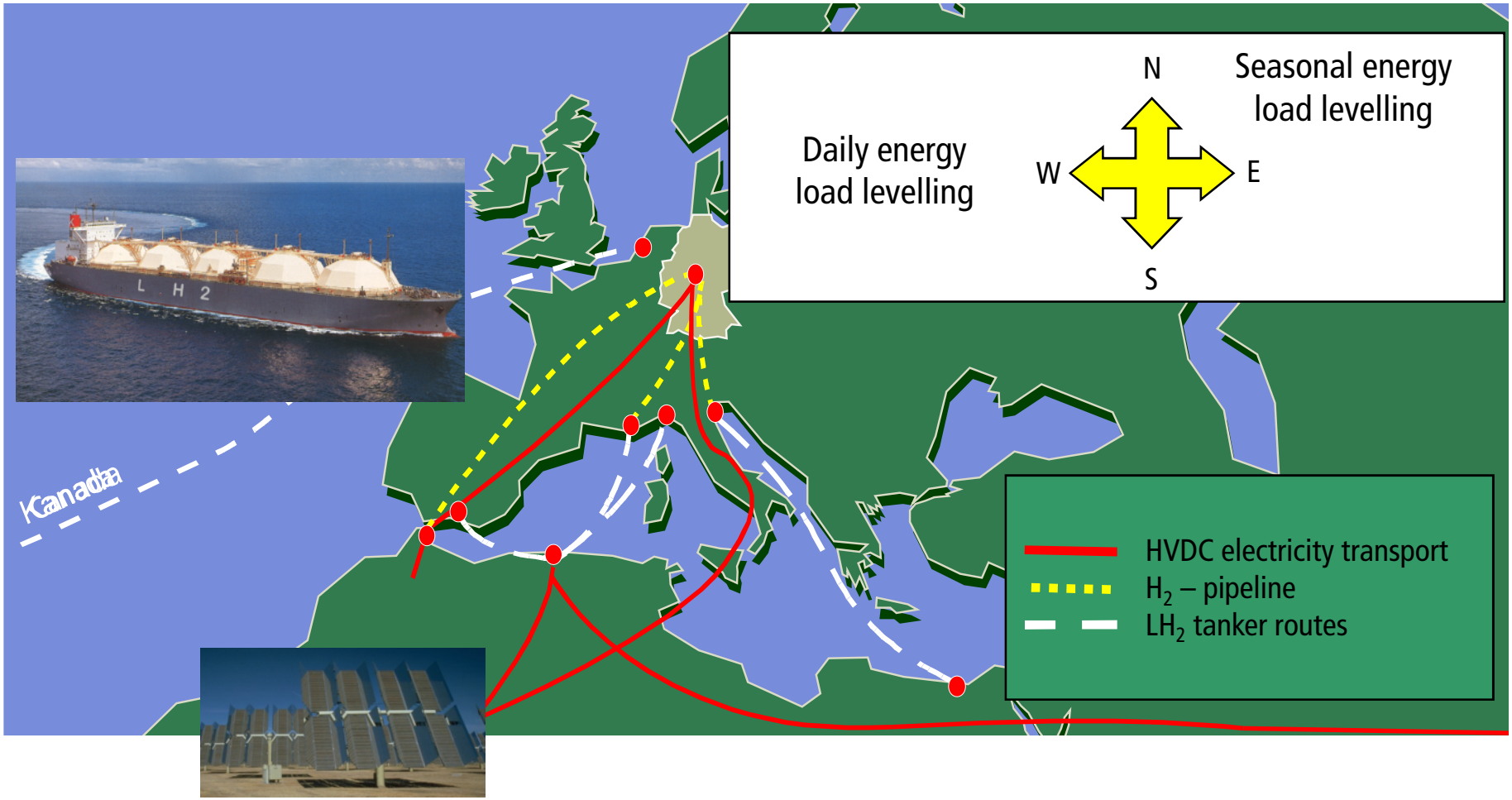
Seasonal and daily distribution of renewable forms of energy and import to the industrial world (here: Germany)



Outline

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- Global energy challenge
- Germany's approach
- Hydrogen's role in future energy
  - alternative fuel for transport
  - large-scale renewable storage
- Uncovering synergies

Global challenges in energy supply

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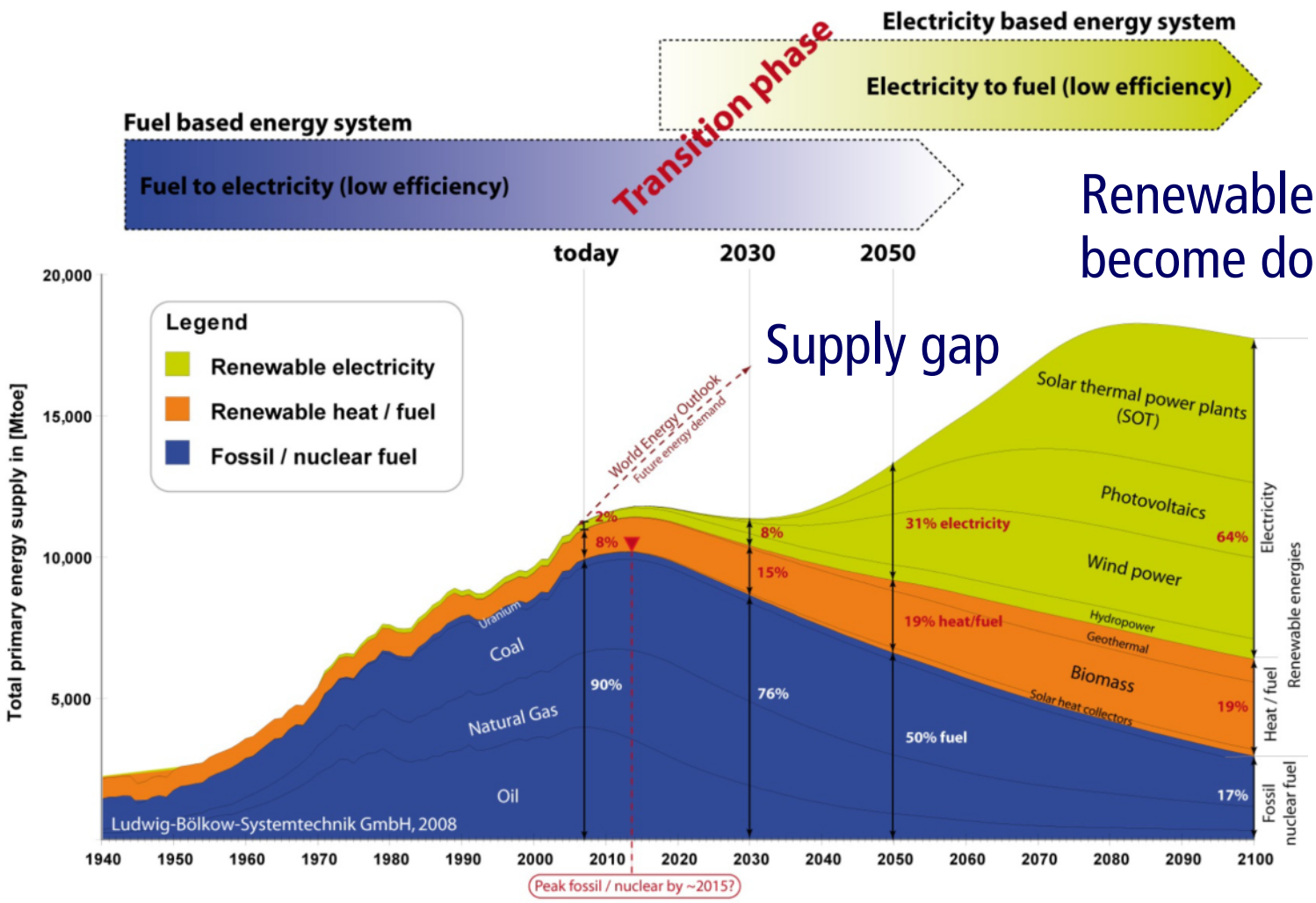

Supply gap

Renewable electricity to become dominant

Fuels replaced by electricity

Specific challenge for transport

Source: LBST, 2010

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Drivers for change

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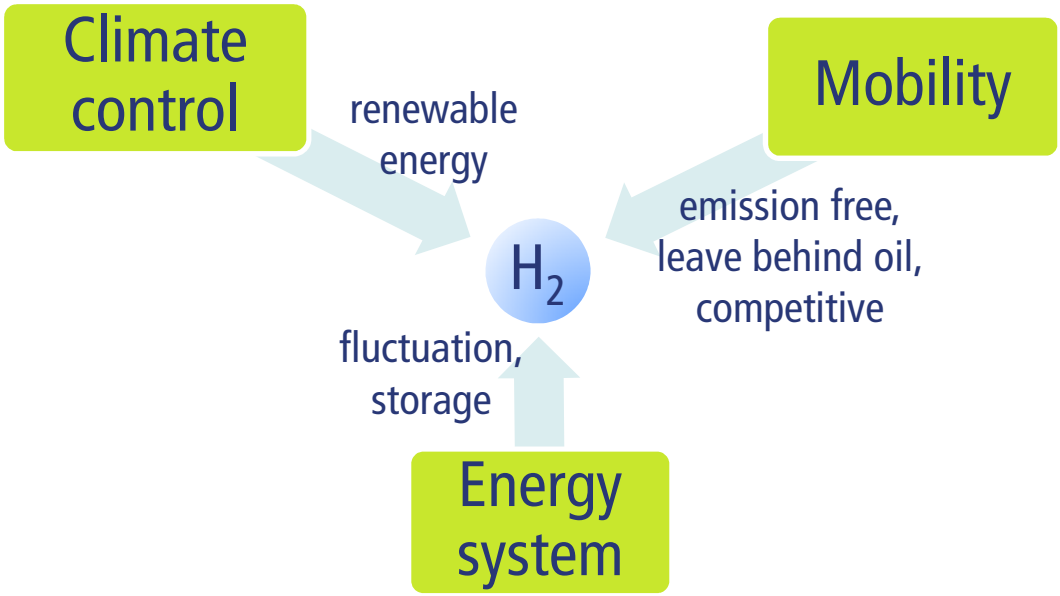
- Phase out nuclear electricity
- Reduce use of coal for electricity production without CCS
- Massively build-out renewable energy/electricity
- Growing awareness of grid extension need, smart grids & energy storage
- Substitute oil by renewable energy/electricity in transport



Renewable share in electricity generation Germany

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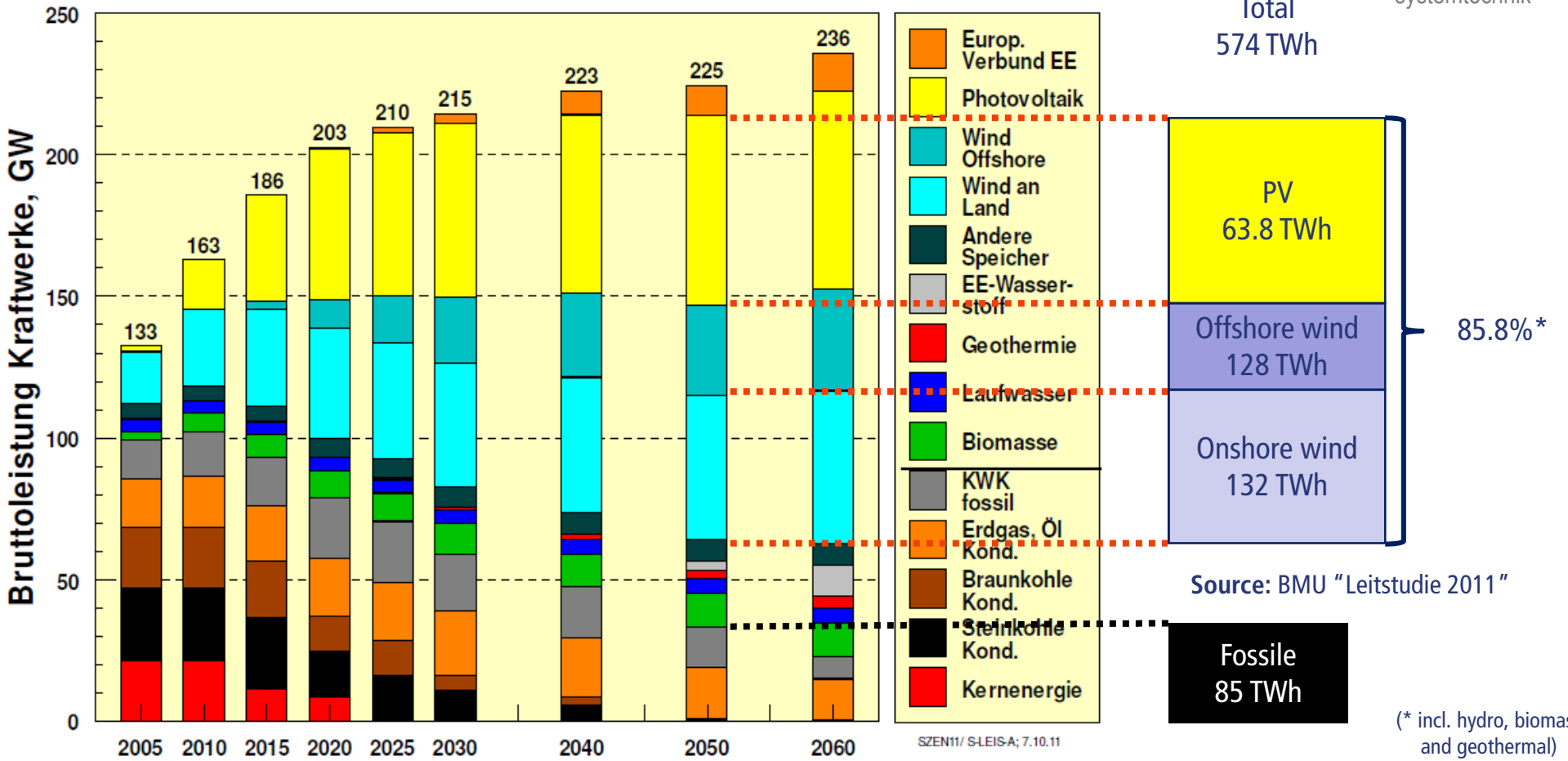
Electricity supply structure "minimum goal A"



Key data 2050: El-generation 574 TWh/a (2010: 618 TWh/a); End use electricity 393 TWh/a (2010: 516 TWh/a)
E-Mobility 2050: 44-81 TWh/a from electricity end use 393-576 TWh/a (depending on scenario)

Downside: Future energy supply regionally coined

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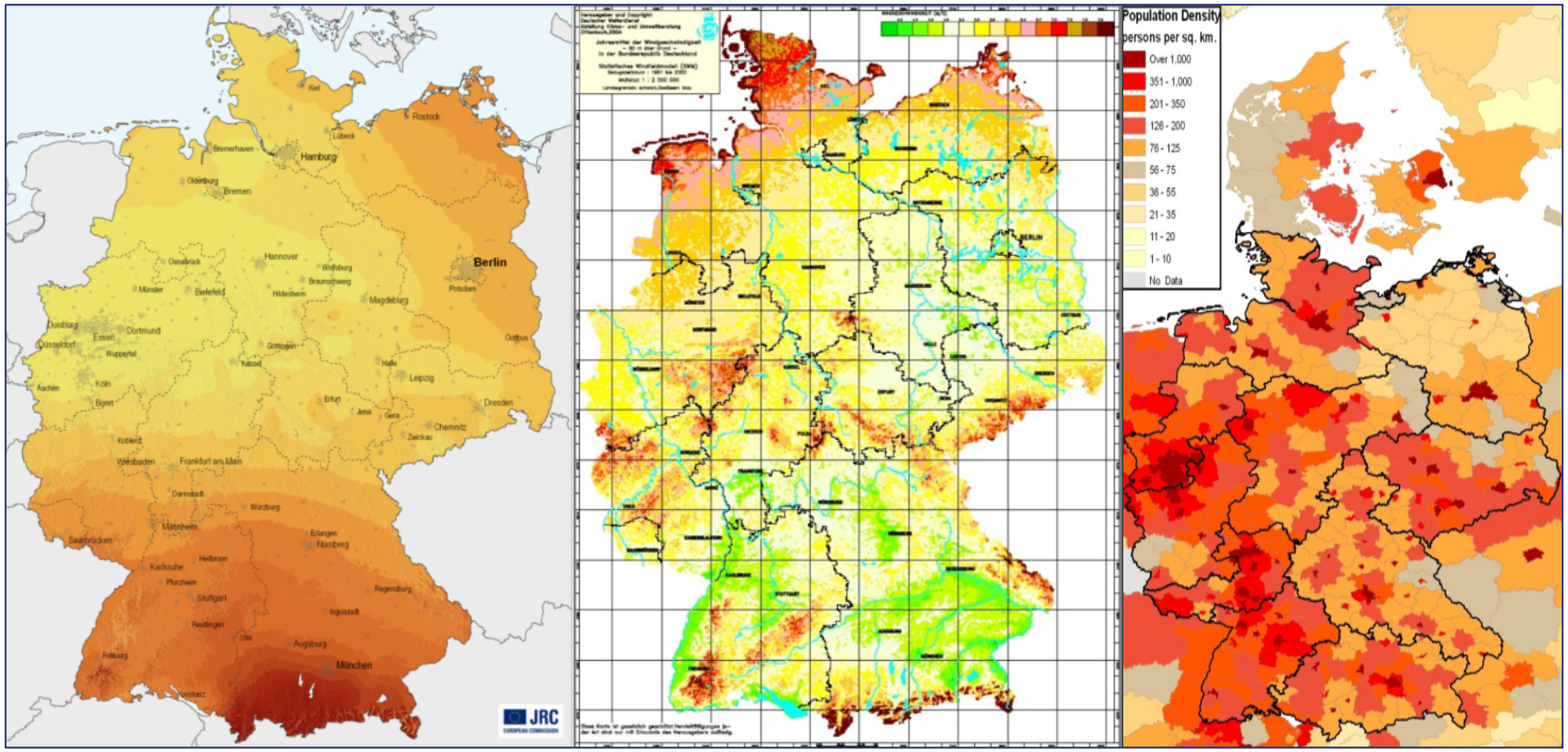
- Renewable electricity availability changes by region
- Energy end-use does not coincide with REN availability or storage sites



Solar irradiation determines use of PV energy

Wind intensity determines use of wind energy

Population density determines energy use

Upside: Electricity from wind and PV are complementary

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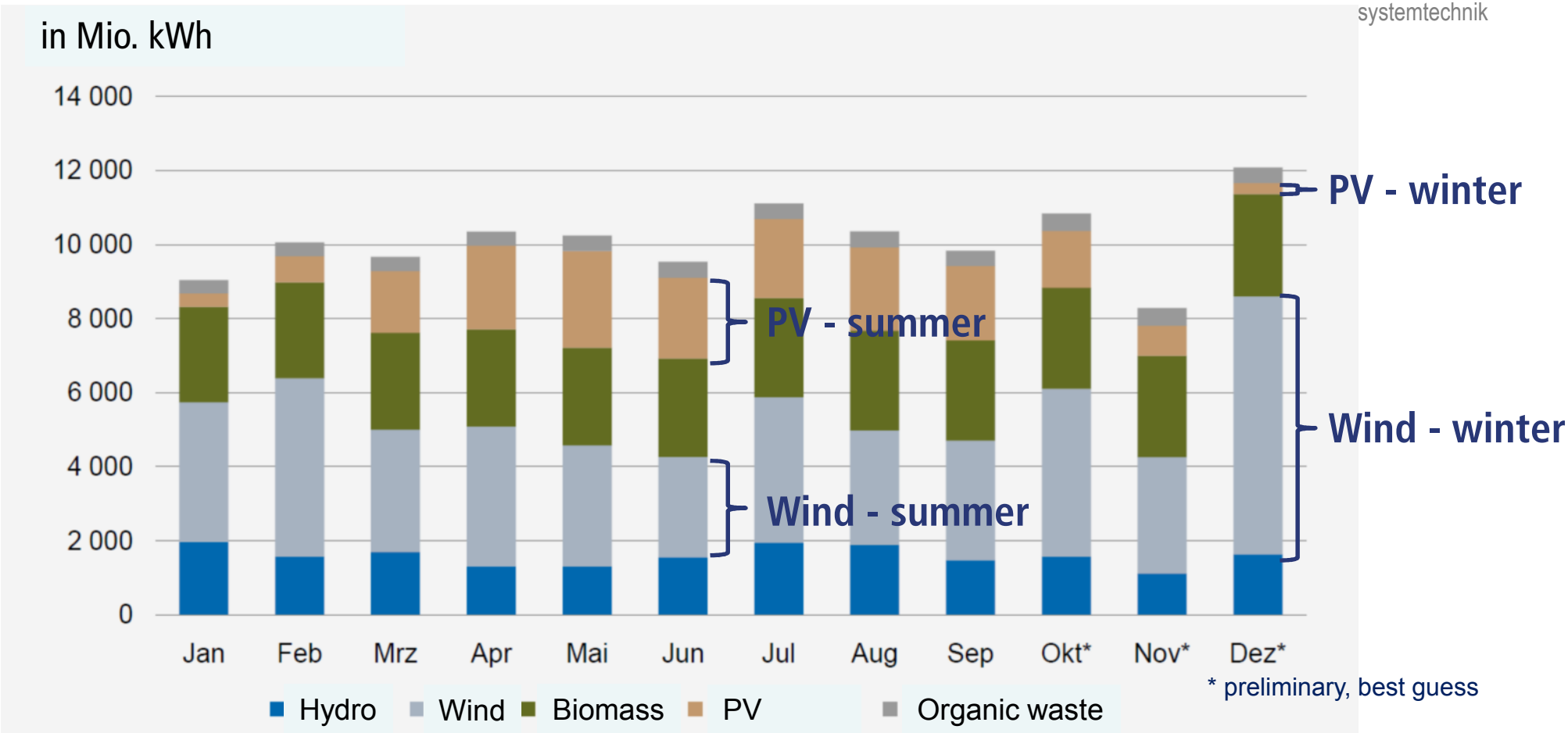

Source: BDEW, AGE 2012

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Hydrogen for transport and fuel cell vehicle

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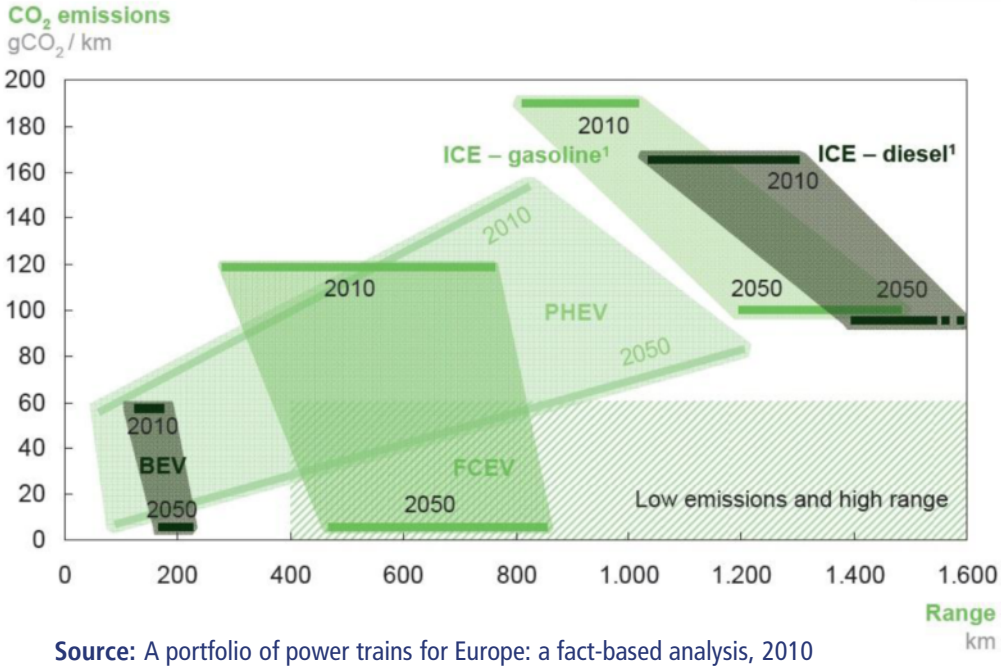
- **Multiple announcement of series production for 2014/2015 Mass market by 2020/2025**
  - Daimler, Toyota, Hyundai, Kia Motors, General Motors/Opel, Honda, Renault/Nissan, Ford
  - More than 100.000 cars in the coming 5 to 6 years
- **H_2 Mobility industry initiative prepares full hydrogen coverage for Germany**
  - Air Liquide, Air Products, Daimler, EnBW, Linde, OMV, Shell, Total, Vattenfall, NOW GmbH



Source: A portfolio of power trains for Europe: a fact-based analysis, 2010

Hydrogen retail commercialization for Germany

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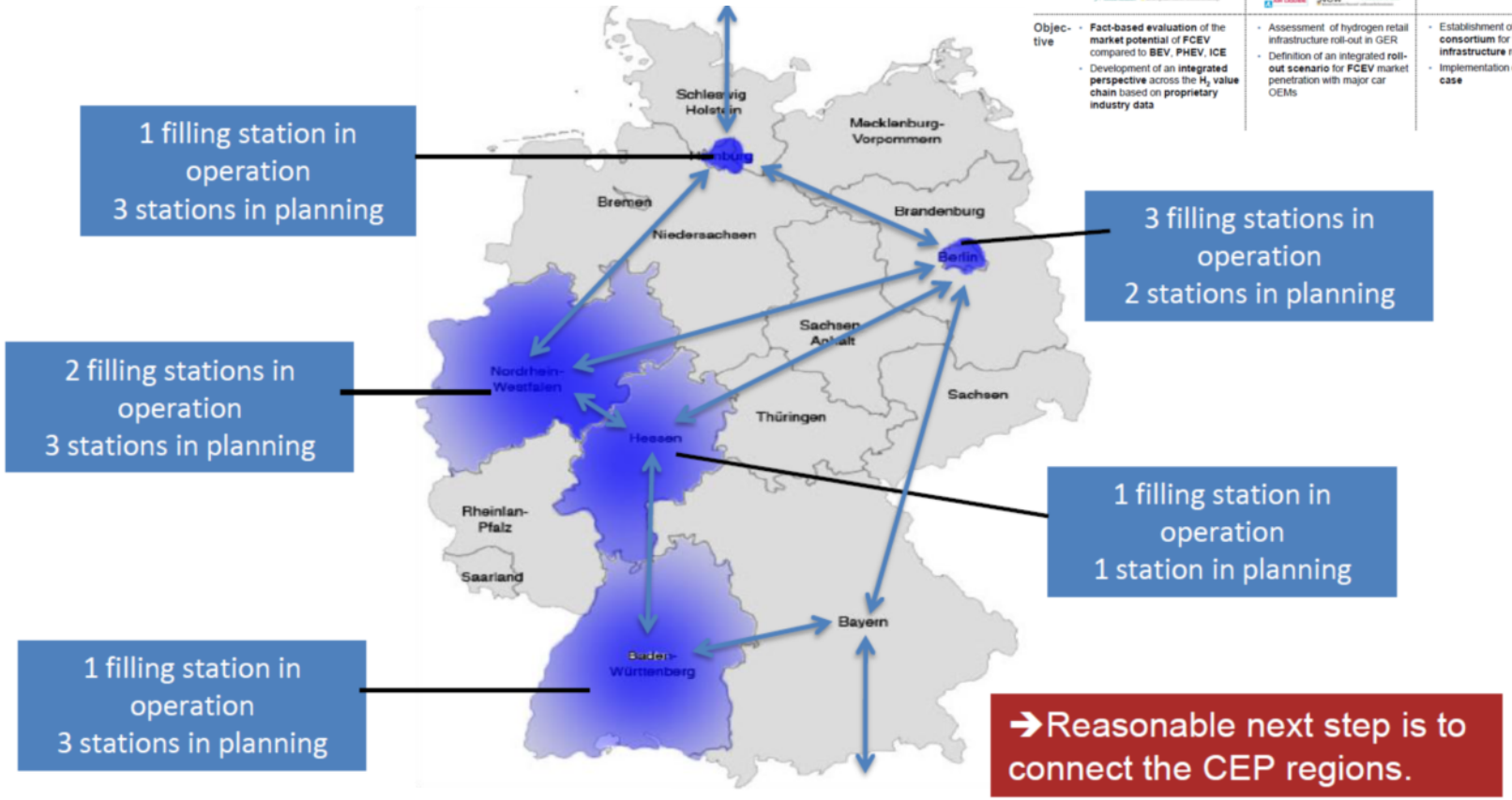
	Factual comparison of FCEV within a portfolio of power-trains	H_2 Mobility – Fact-based analysis of roll-out scenarios	H_2 Mobility infrastructure roll-out
Status	Results published Nov 2010	Ongoing	Parties to be defined (from 2011)
Objective	• **Fact-based evaluation** of the **market potential** of **FCEV** compared to **BEV**, **PHEV**, **ICE** • Development of an **integrated perspective** across the H_2 **value chain** based on **proprietary industry data**	• Assessment of hydrogen retail infrastructure roll-out in GER • Definition of an integrated **roll-out scenario** for **FCEV** market penetration with major car OEMs	• Establishment of a **future consortium** for the H_2 **infrastructure** roll-out • Implementation of a **business case**



Source: Th. Herbert, NOW, f-cell, Stuttgart, 27SEP2011

Insights 'Transport sector'

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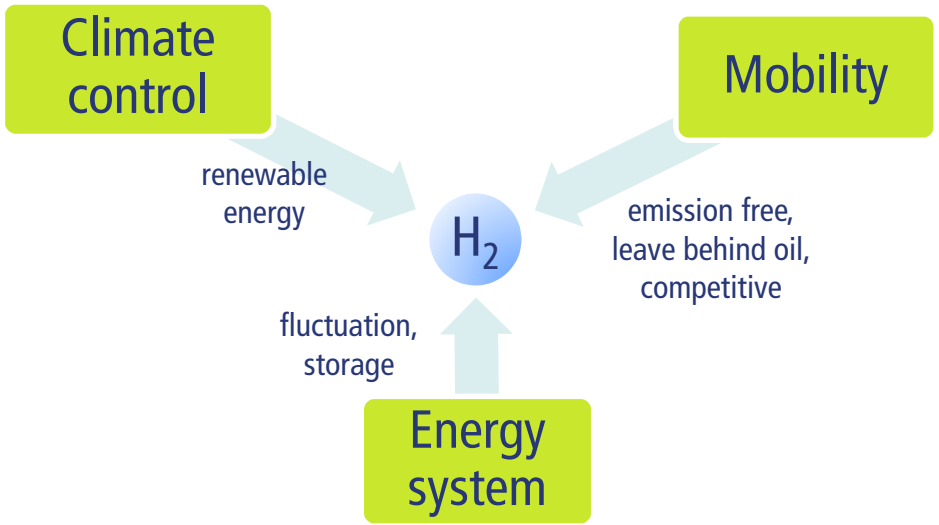
- Limited potential for use of biomass as fuel for passenger cars (competition with food sector among other) focuses ist use for heavy duty transport
- Introduction of battery electric cars slower than anticipated
- Re-invention of hydrogen as transport fuel from synergies with its use for large scale electricity storage
- Obvious principle commitment of auto industry to fuel cell technology
- No sensitivity yet of impacts on other sectors by changes in transport sector (e.g. P2G: CNG and FCEVs)
- Growing intelligence of intersectoral policy measure alignment (e.g. BDI)



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Hydrogen for electricity storage in natural gas grid

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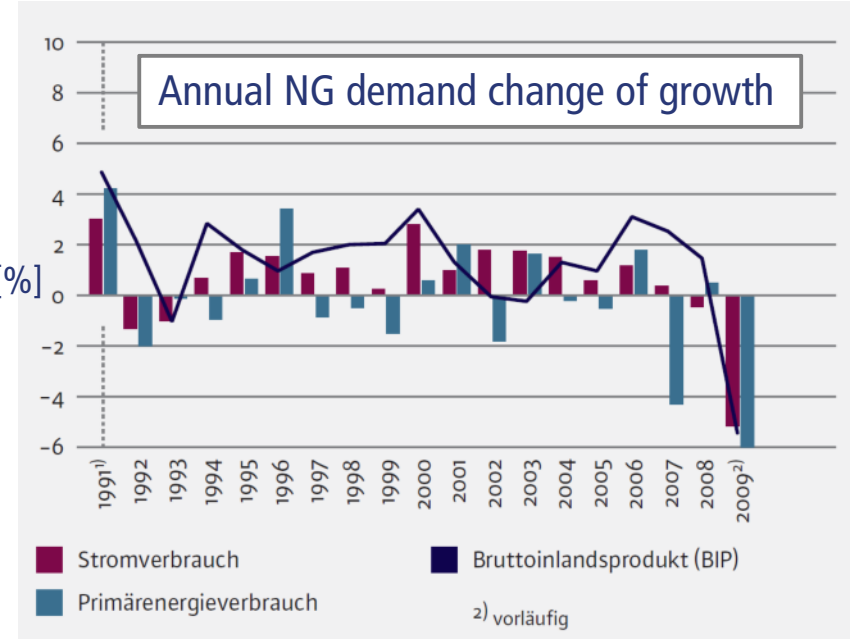
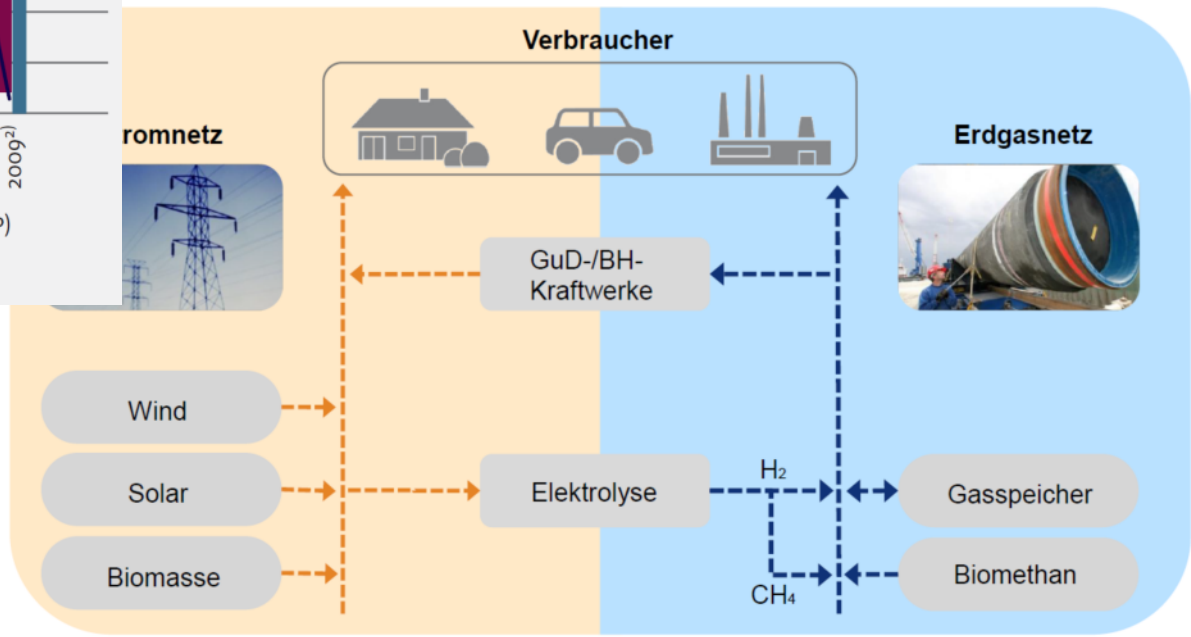


Source: BDEW, 2010

Natural gas industry's vision for P2G



Source: dena "Strategieplattform", APR2011

Seasonal energy storage and role of hydrogen

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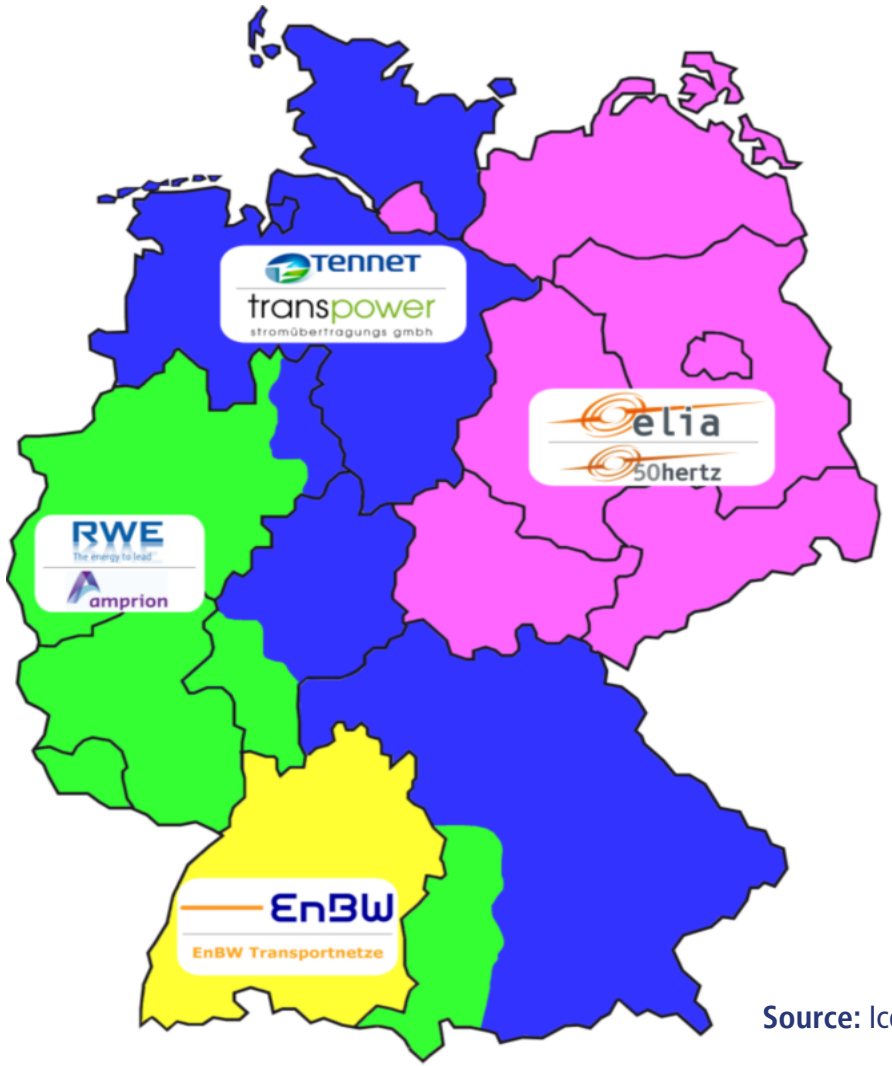

Source: Ice gixxe (Wikipedia)

Example:

- 50 Hertz grid (former Vattenfall)
- Base year: 2008
- Extrapolation: Share of REN electricity

Seasonal energy storage and role of hydrogen

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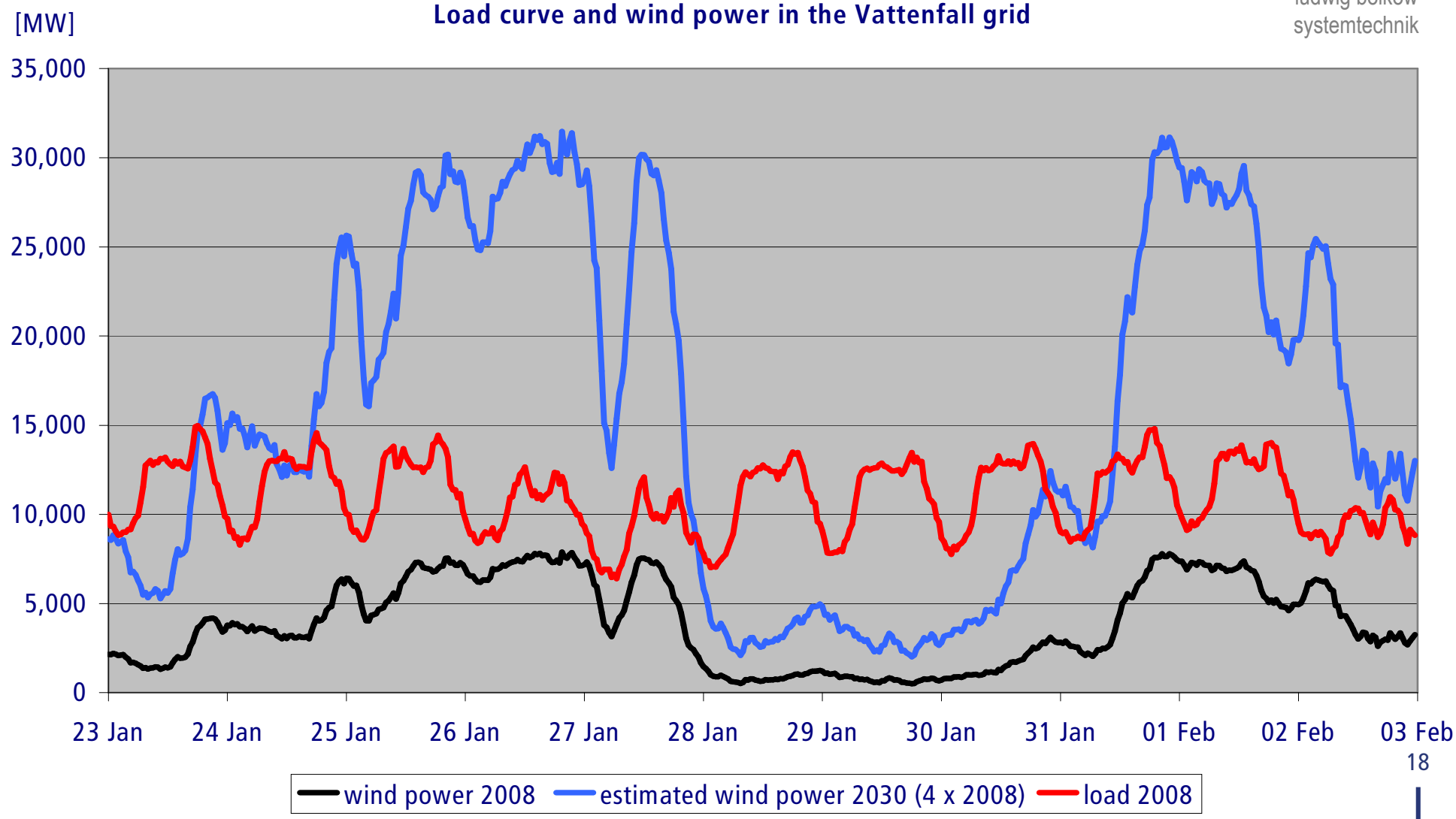

Seasonal energy storage and role of hydrogen

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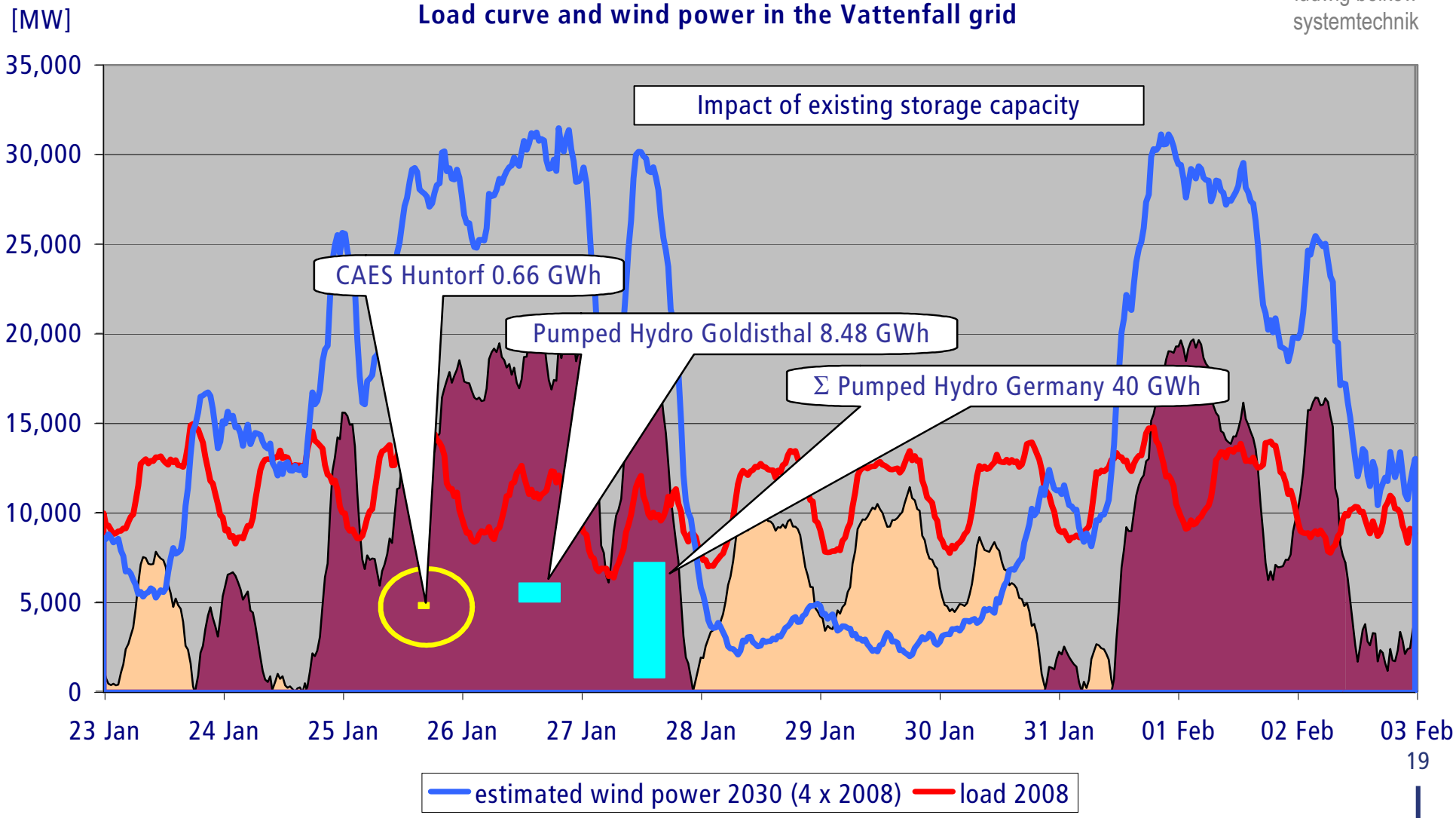

Seasonal energy storage and role of hydrogen

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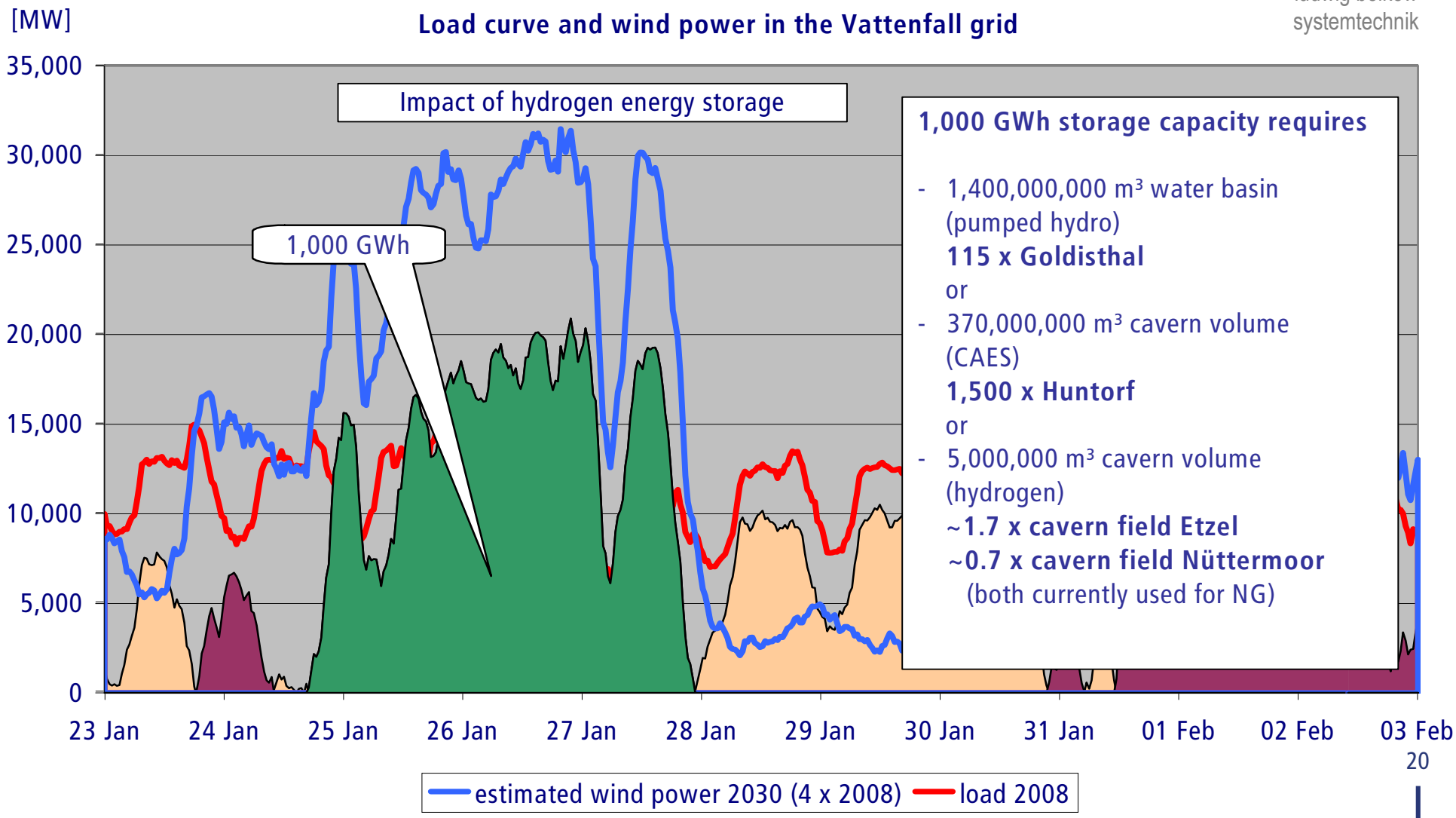

Storage characteristics

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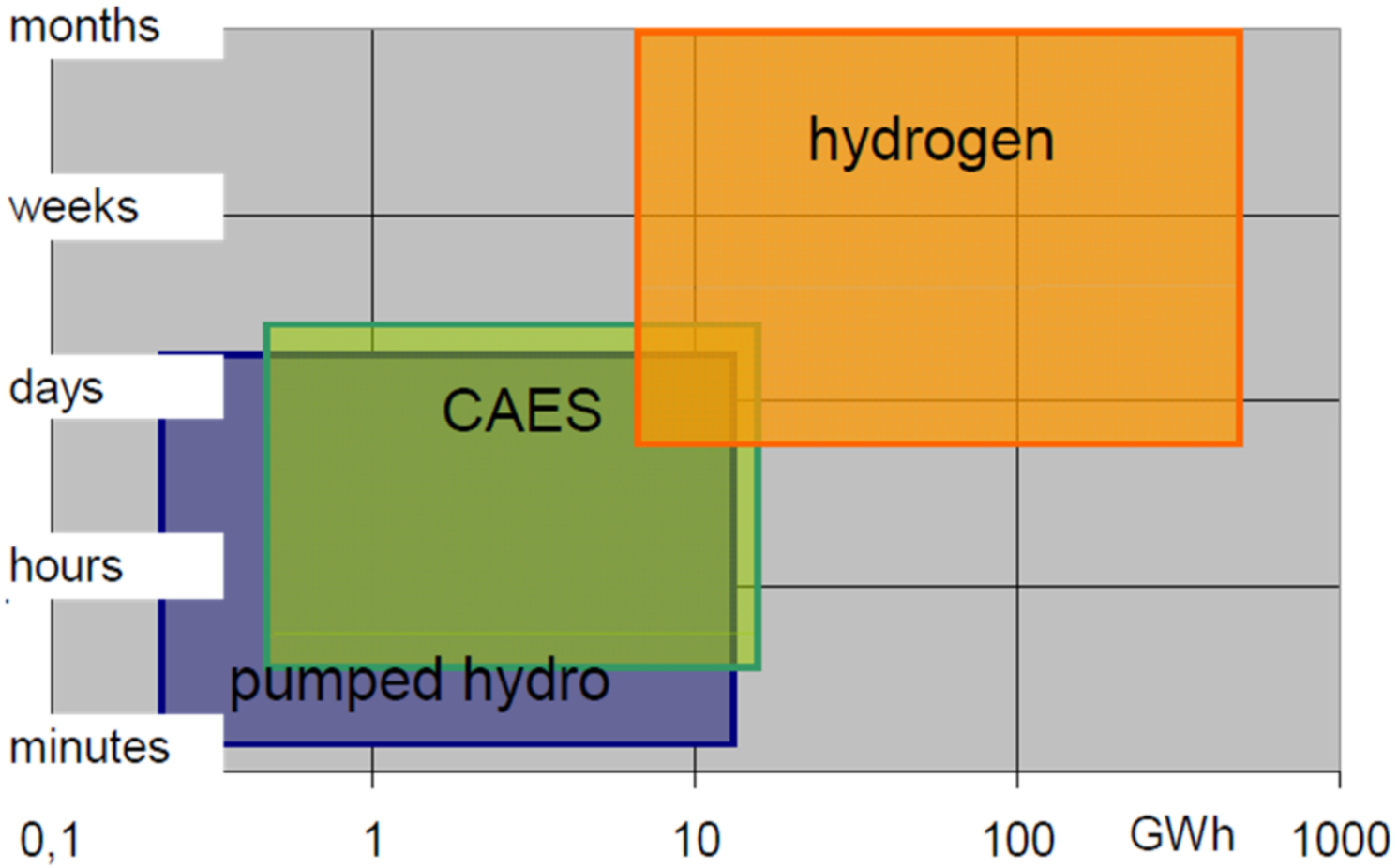

Source: KBB, 2010

European salt deposits and natural gas storage

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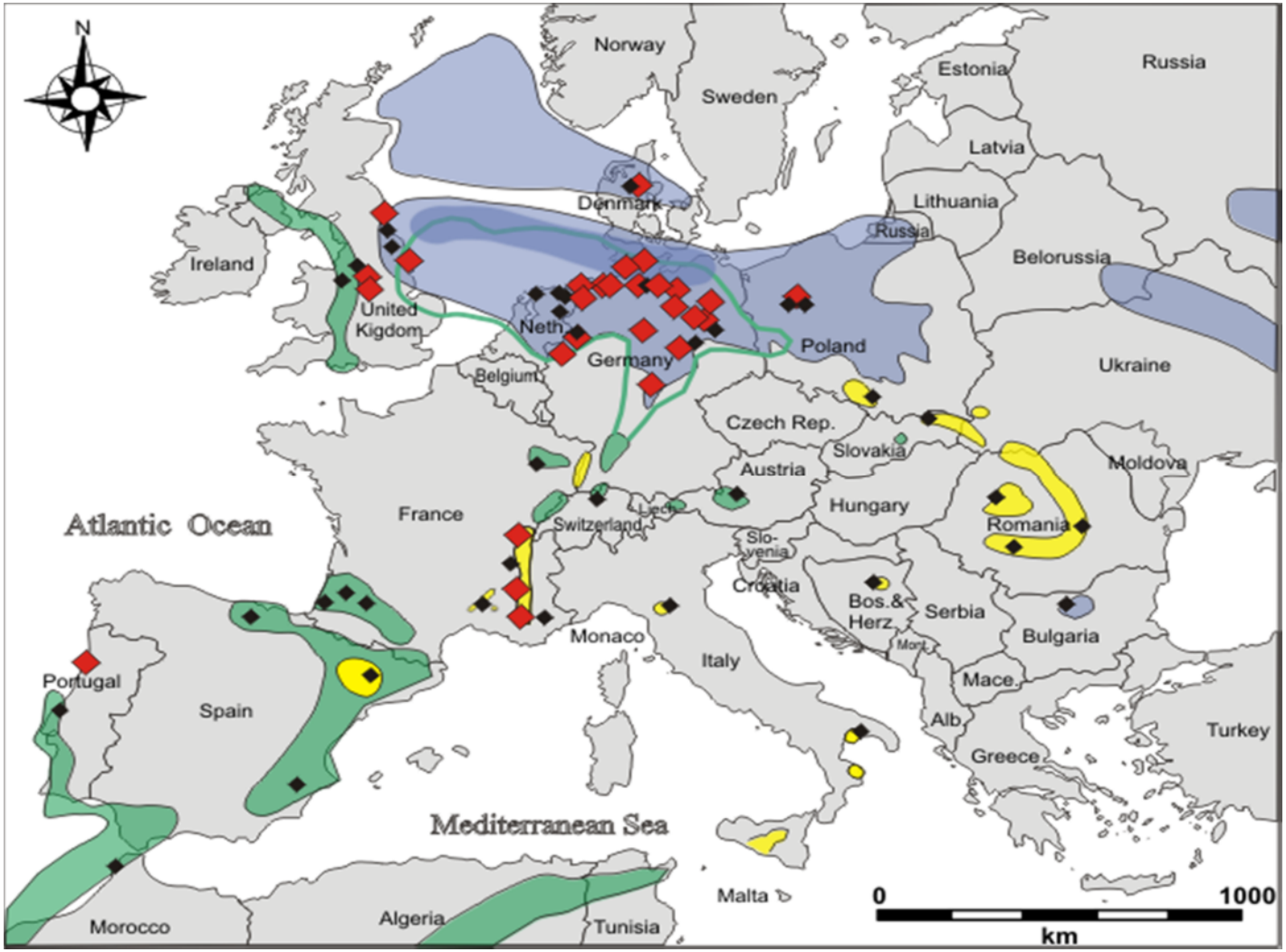

Salt cavern fields

- Gas Storage
- Storage of Crude Oil & LPG, Brine Production
- Tertiary salt deposit
- Mesozoic salt deposit
- Range of Mesozoic salt above Permian
- Paleozoic salt deposit, Permian
- Paleozoic salt deposit, Rotliegend below Permian

Source: KBB, 2009

Hands on operating experience with hydrogen caverns

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- Storage of citygas in caverns and aquifers up until the 70s
- Hydrogen salt caverns in operation:
  - **Teesside, UK**
    3 x 70,000 m³, 4.5 MPa (konst.), 25 GWh*,
    since about 30 years (Sabic)
  - **Clemens Dome, Lake Jackson TX, USA**
    580,000 m³, 7.0 – 13.5 MPa, 92 GWh*
    since 1986 (Conoco Phillips)
  - **Moss Bluff salt dome, Liberty County TX, USA**
    566,000 m³, 7.6 – 13.4 MPa, 80 GWh*
    since 2007 (Praxair)

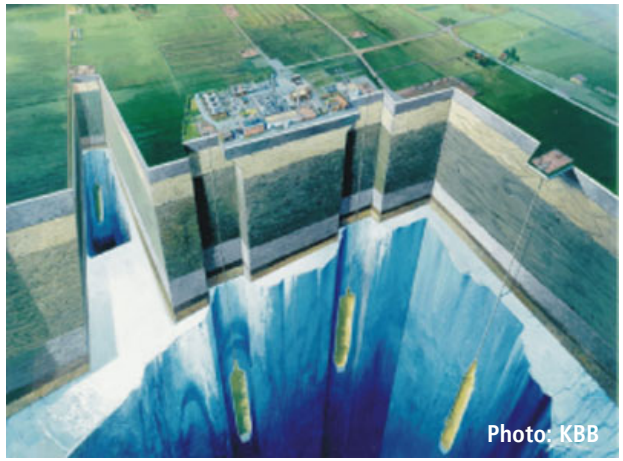
Photo: KBB


Photo: ConocoPhillips

*lower heating value H_2

Insights ‘Large scale renewable electricity storage’

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- Waining threat of Fukushima disaster is already reducing sense of urgency
- As a consequence, need for renewable electricity storage is played down (20-40 TWh) and seen long-term (>2050)
  (VDE-Study, BMU Leitstudie)

- Better test situation for higher/earlier storage demand:
  - Effect of assumption ‘real transport grid than copperplate’ and ‘delayed grid extension’ could regionally enforce demand site storage
  - Distribution grid storage in MW-class (‘district storage’) could become regionally relevant
  - Non-economic reasons for storage need such as local energy supply security and regional autonomy not reflected in economic models
  - Higher renewable energy/electricity use from transport than currently foreseen (i.e. FCEVs)
- Large scale storage needed despite grid extension, DSM and vehicle-to-grid
- Pumped hydro and compressed air storage with limited potential
- H_2- / CH_4-grid-/salt cavern storage
  - Highest ‘chemical’ storage density (only long-term storage with TWh-capacity)
  - fossile CH_4 with limited long-term potential, SNG from H_2 only with efficiency drawback
  - SNG does not contribute to efficiency increase in transport (no FCEV fuel)

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Hydrogen end-use options

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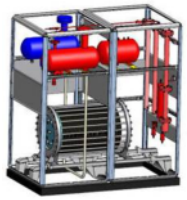
On- and offshore wind electricity

Electricity grid

Fluctuating electricity



Electrolysis

H_2

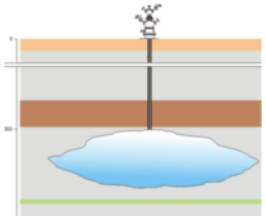
Re-electrification

Refuelling station

Compression

Industrial use

Source: LBST, 2011



H_2-storage in underground salt caverns

Injection NG grid

Achieveable H_2 prices from storage of REN electricity

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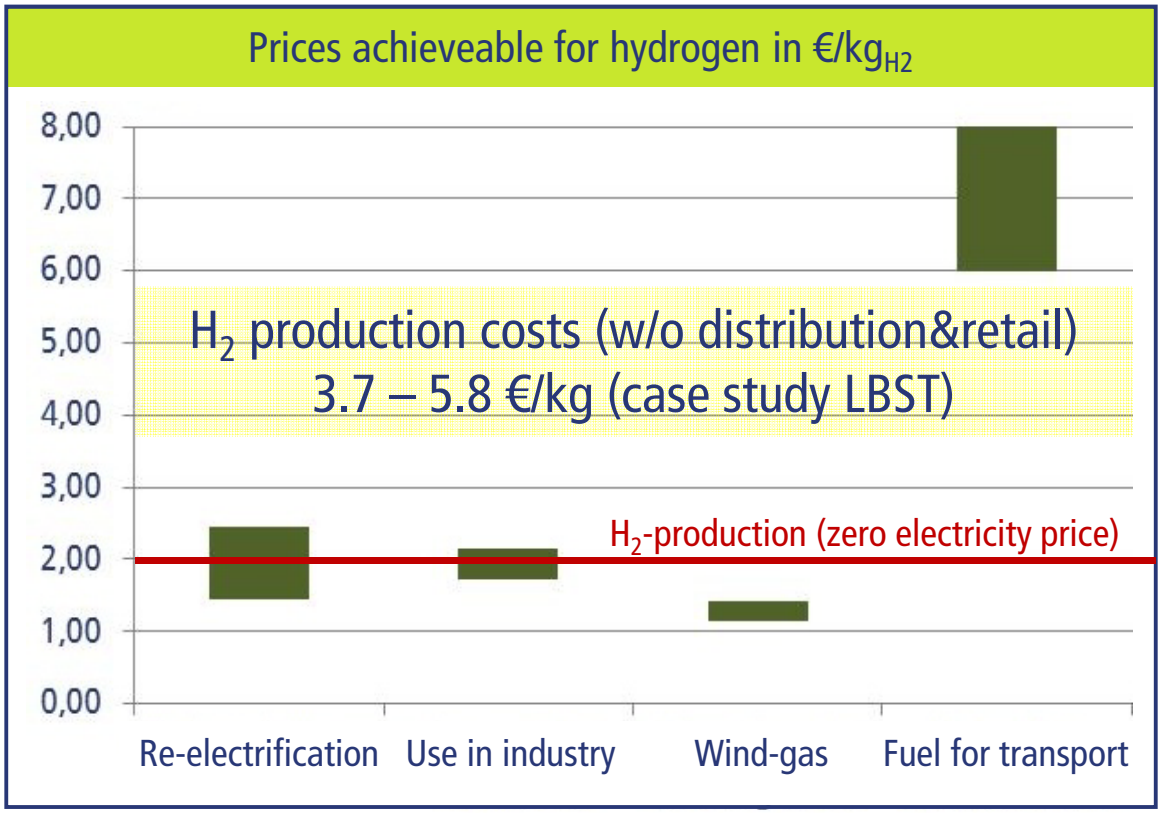
- Highest achieveable prices for H_2 as transport fuel
- 2nd priority is H_2 for industry (depending on branch and end use) and re-electrification
- Lowest priority has H_2 admixture to natural gas grid
- Change in policy targets can impact priorities, e.g. "wind-gas" or methanation can be priorised as infrastructure exists



Source: LBST, 2011

Conclusions – end-use related studies

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- OEMs in favour of possible synergies by using hydrogen as fuel and for energy storage
- 'H_2 for negative load management' uncouples H_2 from closed power-to-power loop
- Synergies of 'H_2 as vehicle fuel' and 'H_2 for large scale storage' obvious
  - dumped fluctuating electricity is used
  - dual use reduces 'H_2 from REN' provision due to economy of scale
- Strong regional differences of 'H_2 for storage concepts', depending on various factors
- Wide use of H_2 as fuel will impact its commodity prices, also of cheap O_2
- Trap of 'dirty H_2' to be avoided by only capping off cheap REN peak power
- Early policy measures required for 'H_2 from REN' to enter power market at lowest costs (~2€/kg_{H2}), e.g.
  - storage recompensation similar to 'feed in law'
  - grid access waiver at all relevant voltage levels (for onsite production also LV)

Key technology ‘electrolysis’

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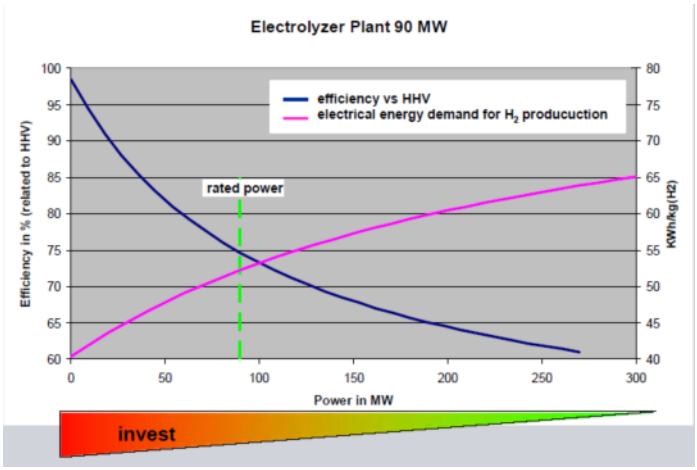
- **Requirements for adapted operation**
  - High dynamics (cold- and warmstart, load changes)
  - Excessive loads (low investment costs traded against system efficiency for reduced annual full load hours)
  - Modularity
  - High life expectancy
  - Economic synergies from series production
  - Reduction of material costs

Source: Waidhas, Siemens, SEP 2011



expected characteristics:

rated power: 90 MW

peak power: 270 MW

controllable power range: 0 – 300 %

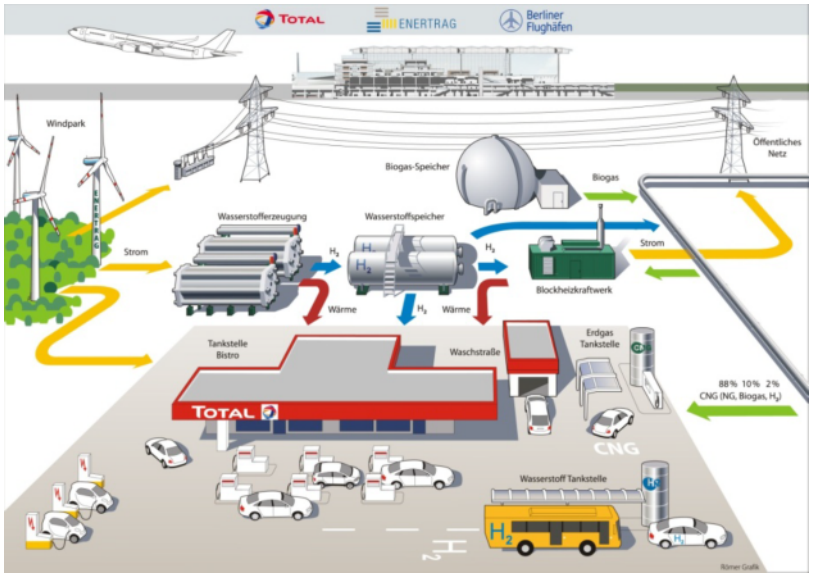
black start: < 30 min

slew rate: >> 10 MW/min

operational temperature: 70 – 90°C

outlet gas pressure: 30-50 bar (still t.b.d.)

Pilot projects (1)



- **Integrated H_2 wind project airport Berlin Brandenburg International (BBI)**
  - **Partners:** Flughafen Berlin Schönefeld, Enertrag, Total Deutschland
  - **Ambition:** hydrogen refuelling from an integrated refuelling station for cars and buses, served by renewable H_2
  - **Status:** Launch planned OCT 2011 postponed

ENERTRAG TOTAL

Source: http://www.presseportal.de/pm/25222/1571947/total_deutschland_gmbh

Pilot projects (2)

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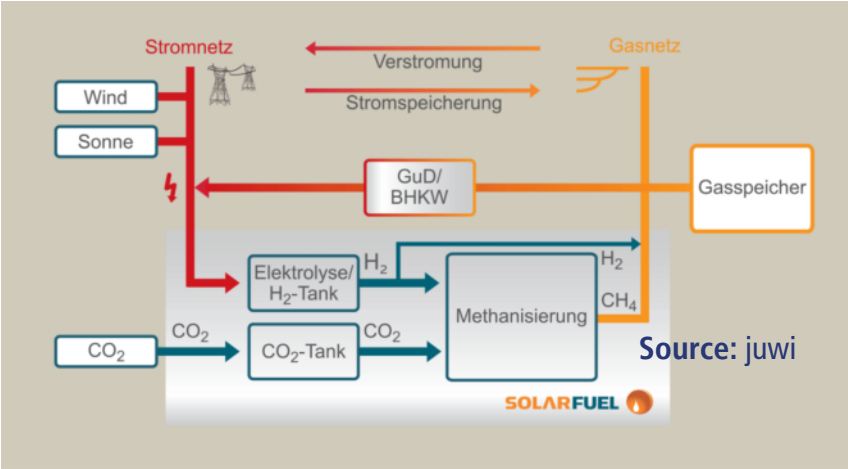

Source: juwi

- **SNG prototype plant**
  - **Partners:** (juwi), SolarFuel, ZSW, IWES
  - **Ambition:** proof of concept and demo wind H_2 methanation plant (25/250 kW) with H_2 injection to NG grid; CO_2 from biomass plant
  - **Status:** 2011-2013 plant demonstration in laboratory and at biomass plant in Morbach

juwi SOLARFUEL SMART ENERGY CONVERSION ZSW Fraunhofer IWES

- **Industrial scale SNG pilot plant**
  - **Partners:** AUDI, EWE, Solarfuel, ZSW, IWES
  - **Ambition:** to demonstrate next scale (6.3 MW) wind H_2 methanation plant with H_2 injection to NG grid and operation of CNG cars
  - **Status:** Planning phase, start of operation 2013

Audi balanced mobility SOLARFUEL SMART ENERGY CONVERSION

Conclusions

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- Hydrogen posed for commercialisation by 2015, in mass markets after 2020
- Hydrogen for energy storage need after 2025, requiring strategic planning
- Gas grid may play important role in Germany, economic case must be worked out
- Actors from all energy sectors need to synchronise their strategies to end divergence
- Most relevant synergy expected from hydrogen as vehicle fuel and energy storage
- Hydrogen for renewable electricity storage to experience different solutions (Germany: North - wind & salt cavern storage and South - PV & decentral storage)
- Hydrogen energy market to drastically outgrow hydrogen industry demand in long term

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