Wasserstoff als Energiespeicher und Power to Gas

LeadIng.

THE LINDE GROUP

Uwe Würtenberger, Linde Clean Energy
Frankfurt, 27th March 2014

CLEAN
TECHNOLOGY
BY LINDE

Contents

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1. Innovation at “Linde Clean Energy”
2. Hydrogen technology a part of future energy systems
3. Hydrogen storage systems, development status and applications
4. Economics of Hydrogen storage
5. Status of pilot- & demonstration projects

The Linde Group
Headquartered in Munich, Germany

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Linde Gas

Product Range

- Oxygen, nitrogen, argon
- Acetylene and other fuel gases
- Welding / shielding gases
- Carbon oxide
- Hydrogen
- Medical gases
- Rare gases
- Ultra-high purity gases
- Gas application services

Comprised of two main divisions with 2013 revenue of € 16.7 billion

Linde Engineering

Product Range

- Petrochemical plants
- Natural gas processing plants
- Gas processing plants
- Hydrogen & synthesis gas plants
- Adsorption plants
- Cryogenic plants (e.g. ASU)
- Biotechnological plants
- CO_2 purification & liquefaction plants
- Plant components & modules

Linde has a wide portfolio of energy topics in the base business, as well as the Clean Energy arena

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Clean energy focus | Base business

Feedstock	Energy extraction		Energy conversion		Energy transport, storage and usage	
Fossil (gaseous)	Baseload LNG	Floating LNG	GTL	NG Process.	Merchant LNG	LPG
	Unconv. gas		Cogene-ration			
Fossil (liquid, solid)	N_2 EOR	NRU	Clean coal	Refinery Hydrogen	CO2 networks	
	CO_2 EOR		OxyFuel	PCC		
Renewable	Geo-thermal	Heat recovery	Biomass conv.	Photo-voltaic	Hydrogen as fuel	
	Solar-thermal		Green Hydrogen	Wind energy	Energy storage	

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Linde covers the entire hydrogen value chain with in-house technology & developments

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Production

Decentralization

Conventional
(e.g. SMR)

Green
(e.g., BtH*, Ely)

Supply / Storage

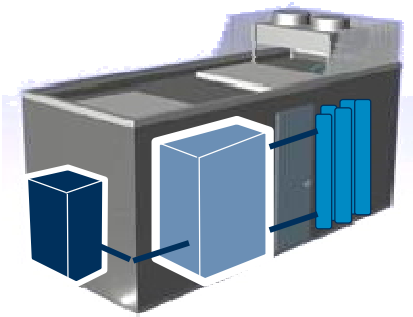
CGH_2 storage

LH_2 storage

Onsite SMR

Onsite Electrolysis

Compression / Transfer



Ionic compressor

Cryo pump

Dispenser

350 bar

700 bar

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* Biomass to Hydrogen

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Why energy storage?

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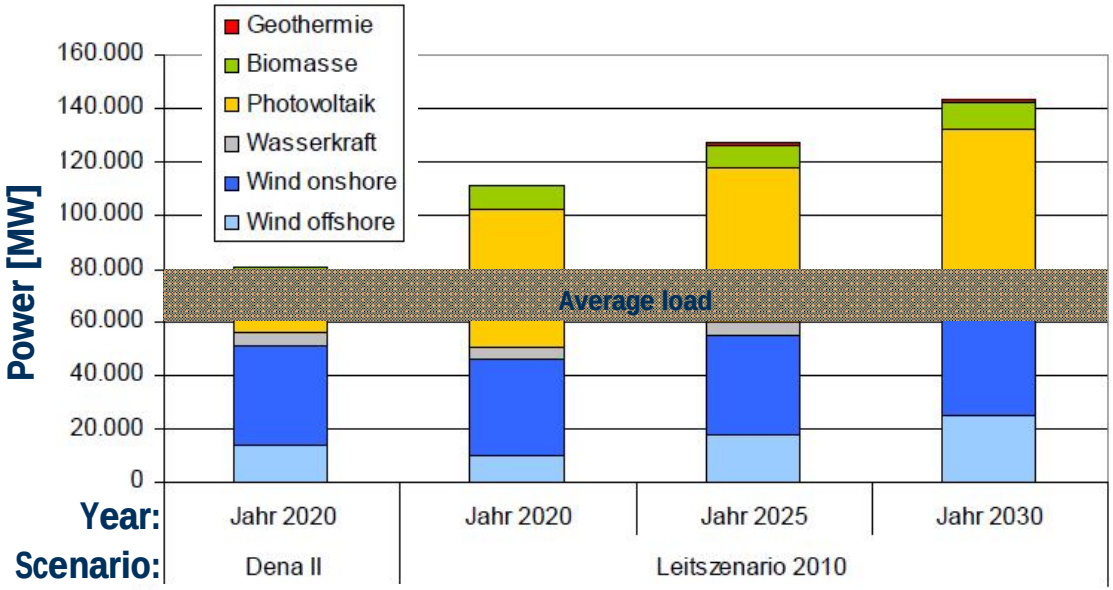
Why energy storage?

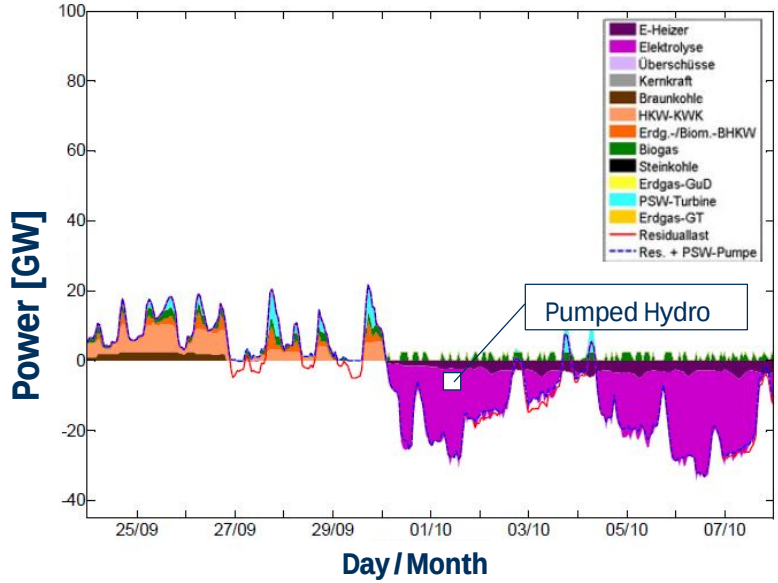
Electricity-based fluctuating renewables (Wind+PV) continue rapid growth:

- **>12% of electricity provision in Germany by 2012 (74 TWh)**
- Germany has 31 GW wind and 32 GW PV installed (+7.5 GW PV in 2012!)
- until 2020, 100-150 GW wind+PV expected; grid load is only 60-80 GW!
- High excess electricity during high-wind times; full backup capacity during low-wind times

Energy storage can shift electricity from overrun to underrun situations:

- Improved integration of renewables
- Provision of strategic energy reserves
- Lower grid extension efforts
- **Increased security of supply**





Load profile of conventional energy generation with potential for energy storage in Germany 2050 model calculation - BMU_Leitstudie 2011

No „one-fits-all“ solution to energy storage in sight!

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Requirements for storage systems:

- High efficiency (price arbitrage)
- Low power-specific costs (short-term storage)
- Low storage-specific costs, low self-discharge (long-term storage)
- Load rangeability and quick reaction (control reserve)
- High cycle / calendaric life
- Compact, safe, simple, scalable
- …

→ No technology can fulfill **all** requirements

→ Different applications will require different storage technologies

Technology class	Fossil power	Renewables	Transmission	Distribution	Customers services
Pumped hydro	🟢	🟡	🟢	🟡	🔴
Compressed air	🟢	🟡	🟢	🟡	🔴
Electrochemical	🟡	🟡	🟢	🟢	🟢
Chemical	🟡	🟡	🟡	🔴	🟡
Electro-magnetic	🔴	🟡	🟢	🟢	🔴
Thermal	🟢	🟡	🟡	🟡	🟢

Source: European Association for the storage of energy (EASE)

Strengths of hydrogen energy storage

Unlike other storage types, hydrogen can:

- store large amounts of energy at reasonable costs (~170 GWh_{LHV} in one typical salt cavern)
- facilitate seasonal storage (weeks to months)
- create cross-links from renewable electricity to other sectors (fuels, chemicals)

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Versatile usage options for hydrogen in the energy system

Highest lever in mobility and industry

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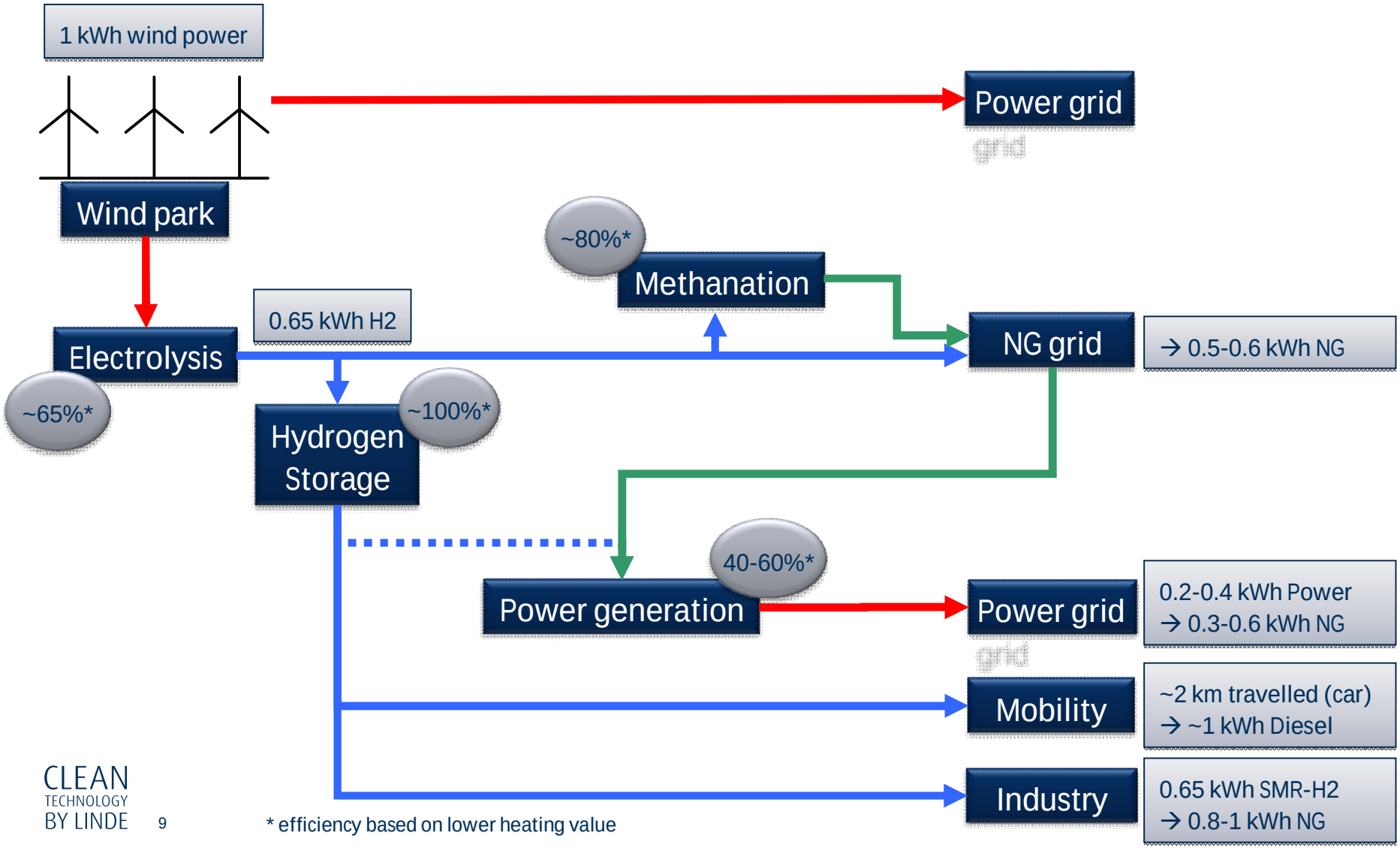

* efficiency based on lower heating value

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Hydrogen generation via electrolysis

Technology types, advantages and drawbacks

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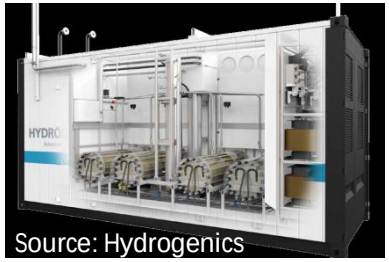
	Alkaline electrolyser AEL	**PEM electrolyser** PEMEL	**Solid oxide electrolyser** HTEL
Advantages	• Established • Long durability • No precious metal catalyst • Pressurization possible	• High current density • High pressurization Possible • Part load & peak load ability • High H2 purity • Simple system Configuration	• Low electricity consumption • Potentially high efficiency • No precious metal catalyst • Potential for high current density • Possible co-electrolysis (CO2 / H2O / H2, CO2, dual operation as fuel cell)
Drawbacks	• Relatively low current density • Corrosive electrolyte • Complex system	• Precious metal catalyst • High investment cost • Insufficient durability (catalyst degradation w. dynamic operation)	• Still R&D phase • Unproved durability • Complex heat Management



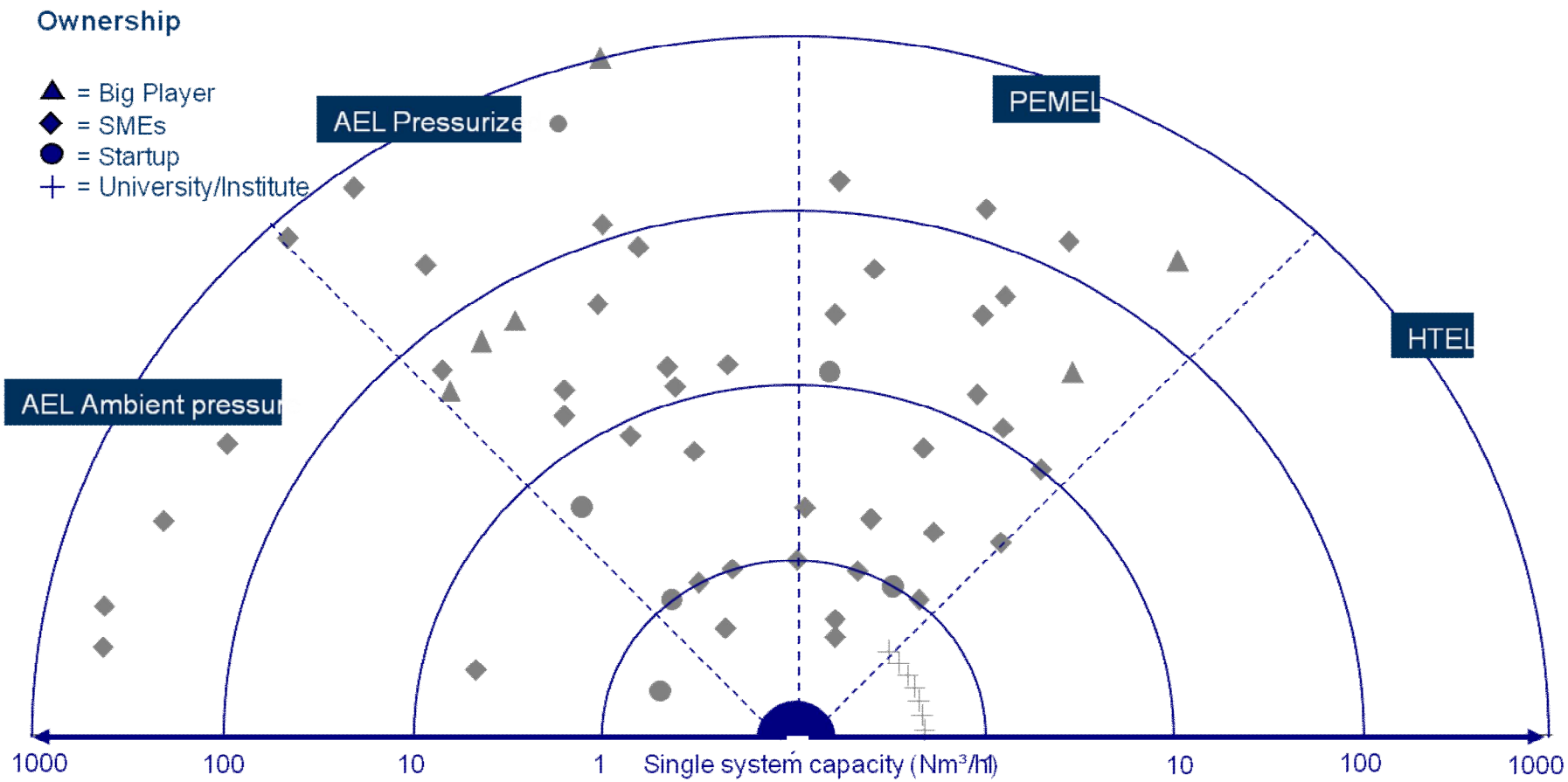
Source: Hydrogenics


PEM stack from Siemens


Solid oxide stack from Topsoe Fuel cell

Electrolysis methods, capacity [Nm³/h] on technology radar

Yet, market is dominated by few players today



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Small- and medium scale hydrogen storage

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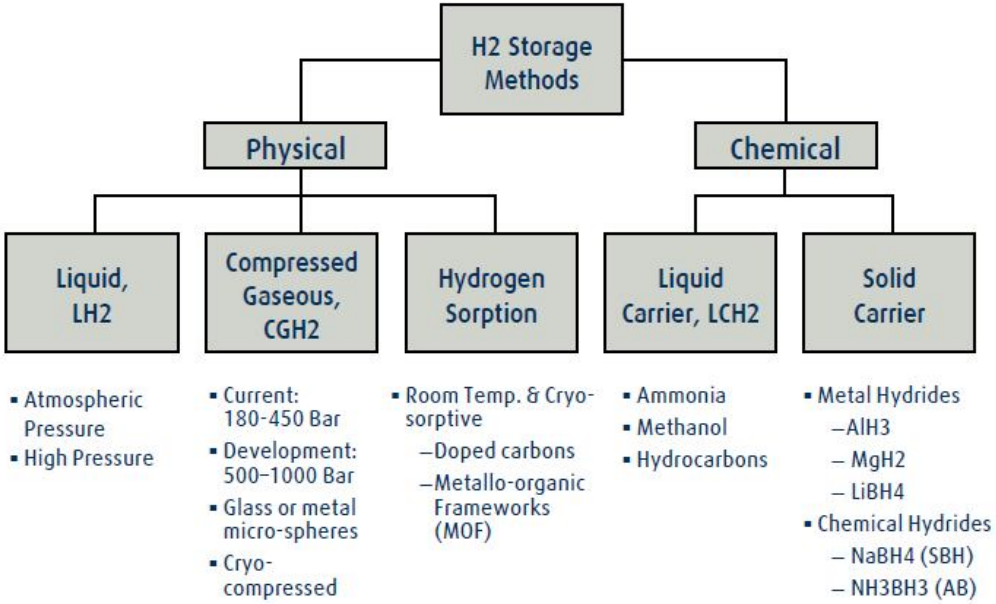

300 bar composite vessel for small-scale fuel cell

- LH_2 and CGH_2 storage state of the art
- LH_2 needs energy intensive liquefaction (-250 °C)
- Chemical storage / sorption technologies: heat release to ingest hydrogen; heat needed to release hydrogen; cycling issues
- Compressed gaseous storage: easy and reliable solution (but, hazard potential/perception)
- Volumetric density in similar range for all systems 20-50 kg/Nm³)

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Large-scale hydrogen storage
Salt caverns

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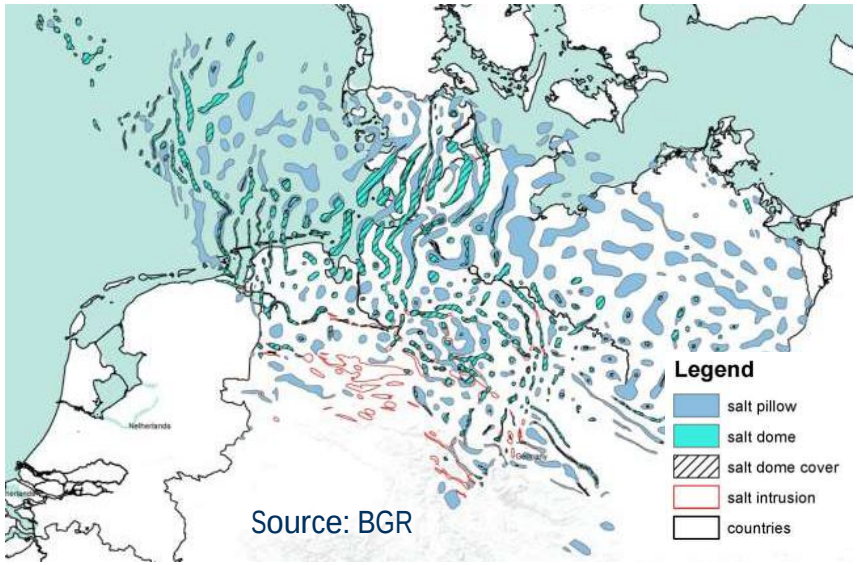
- Salt caverns are **artificial** cavities in salt domes
- Used extensively today for storage of natural gas, oil and chemicals; also hydrogen caverns exist
- Typical volume ~500,000 m³; typical pressure range 60-200 bar → filled with hydrogen, one cavern can store **about 170 GWh**
- Possible only where suitable salt structures exist (e.g. Northern Germany)
- Lead time of up to 10 years
- Well-suited for seasonal storage through low specific storage cost



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Costs of hydrogen storage
Benchmarking

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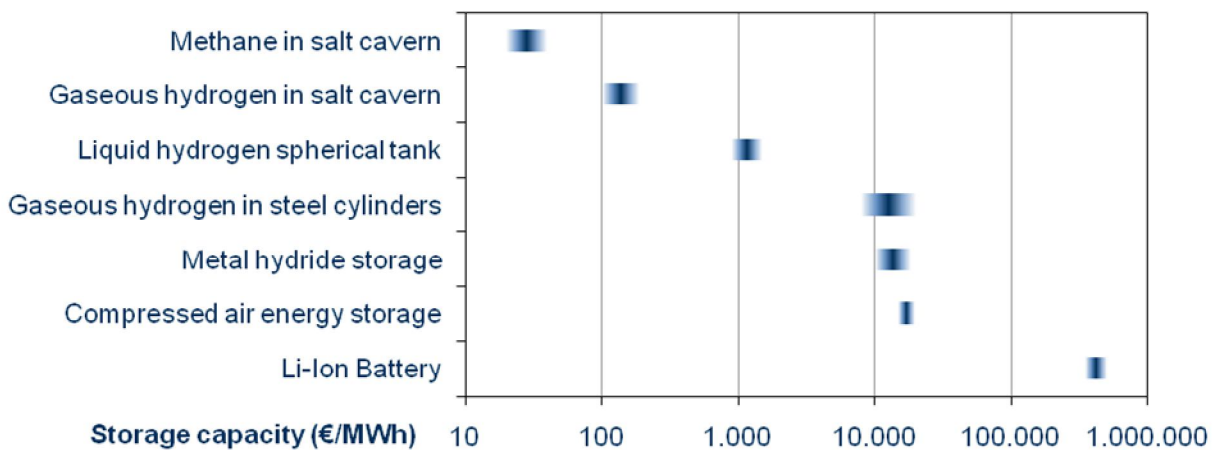
- Cavern storage is 3-4 orders of magnitude cheaper than batteries

→ Best suited for long-term storage

- Liquid hydrogen cheapest aboveground storage technology

Investment costs of hydrogen storage capacity* and comparison



* Storage system only (no electrolysers, turbines, etc.); based on lower heating value; rough estimations

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NG Grid Injection
Comparison H_2 and CH_4/SNG (Methanation)

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	Power-to-H2 (NG grid injection)	Power-to-SNG (NG grid injection)
Gasnetzeinbindung	Eingeschränkt (max. 1-10 vol.% Beimischung)	Uneingeschränkt
Hauptbetriebsmittel	Strom	Strom + CO_2
Wirkungsgrad (H_i)	~65%	~50% (+Hochtemperatur-Wärme)
Dynamische Betriebsweise	Stand der Technik	F&E-Bedarf (Methanisierungsreaktor); ggf. abh. von Speicherkapazität CO_2
Standortkriterien	Stromnetzanbindung, Gasnetzanbindung	Stromnetzanbindung, Gasnetzanbindung, CO_2-Quelle
Potenzial / Einschränkungen	Beimischquote; aktuell ca. 2-18 TWh (→ graduelle Erhöhung)	CO_2-Verfügbarkeit (2030: ~100 TWh_{el} / a aus Biogas upgrading)
Wirtschaftlichkeit	Ohne polit. Unterstützung nicht wirtschaftlich	Ohne polit. Unterstützung nicht wirtschaftlich

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Industrial usage of hydrogen

Markets and applications

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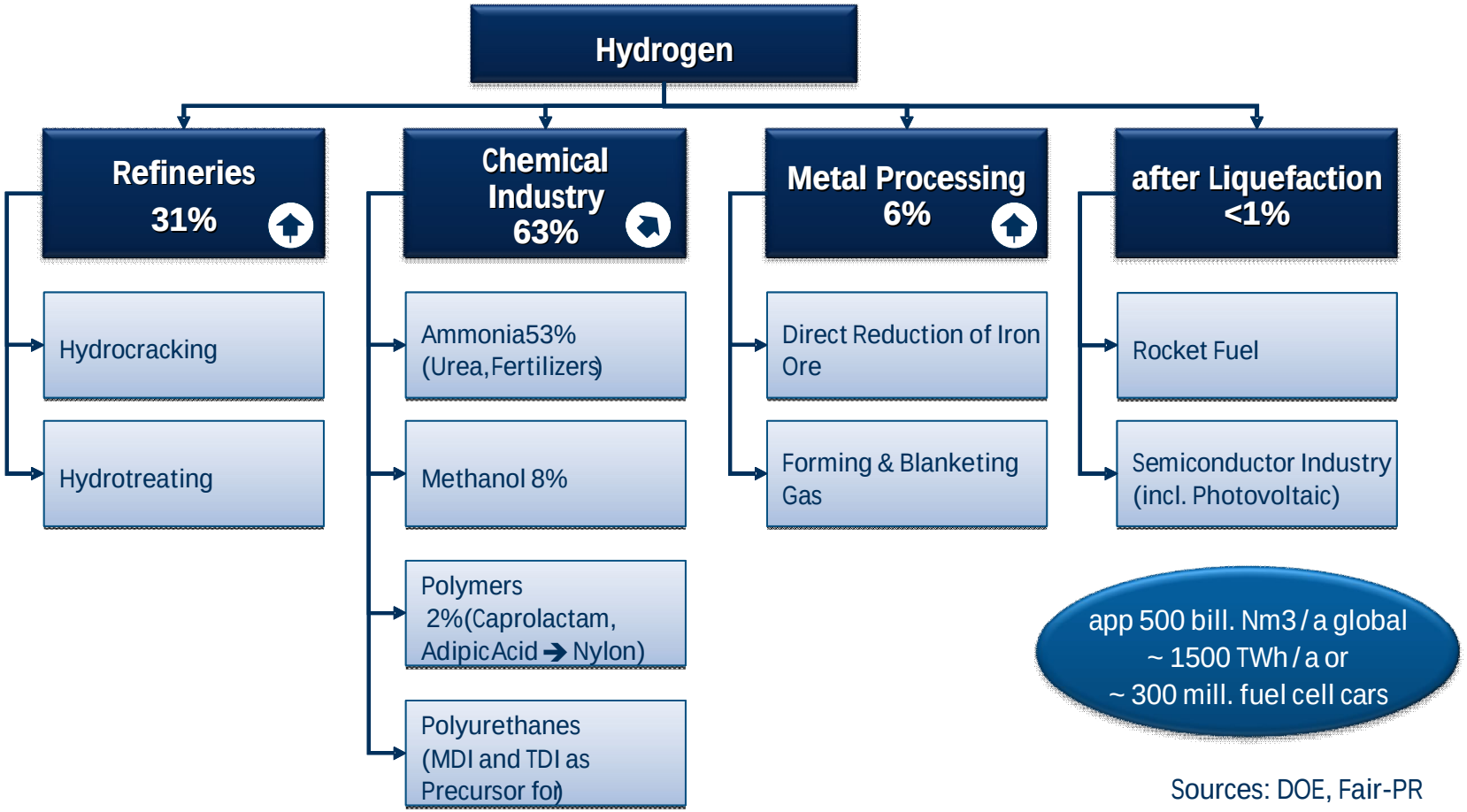

Sources: DOE, Fair-PR

- Further applications: (<1000 Nm^3 / h): Float glas, food processing, generator cooling
- Only about 5% of H2 is transported (rest produced on site)

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Why Hydrogen as fuel?

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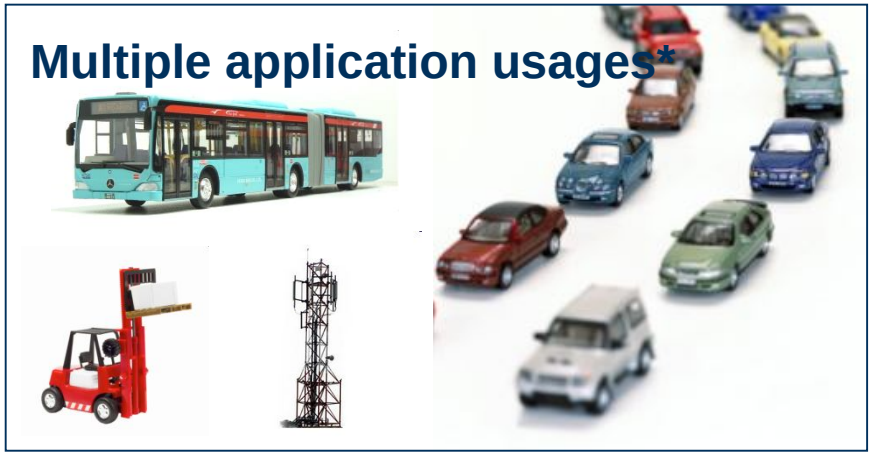
Hydrogen offers…

CO2 reduction potentials

Diversification of primary energy sources

Zero emissions at the tailpipe

Multiple application usages*



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...just like batteries

* Especially compared to electricity based transportation

Hydrogen as fuel
Rationale

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Transition to hydrogen-powered transport

driven by

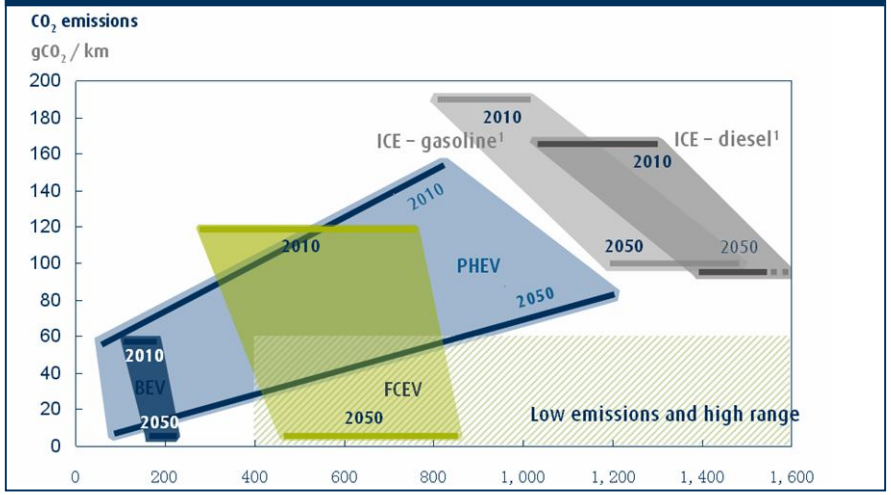
- environmental legislation,
- crude oil independency
- feedstock flexibility
- zero-emission mobility
- range and fuelling convenience

All major OEMs announced commercialization between 2014 – 2020

Key application areas

- Cars
- Buses
- Fork lift trucks
- Backup/remote power

FCEV for low emissions and high range



OEM Commercialization pipeline

Hydrogen production pathways

Intermittent power to hydrogen (power to gas)

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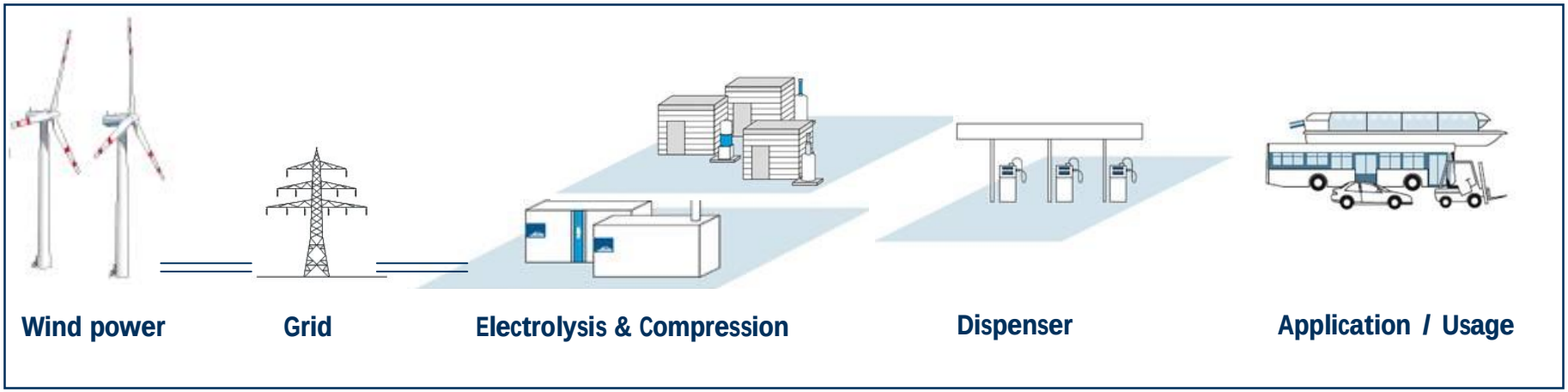
Basic flow chart: Wind to hydrogen



Linde's advanced hydrogen fuelling technologies

Key components for compression

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The Ionic Compressor

- High throughput of 35 kg / h @ 900 bar[1]
- Energy consumption reduced by 25%[2]
- Very small number of moving parts (liquid piston)
- Reduced wear and long service life
- Four times longer maintenance intervals*
- Fulfils industry standard SAE J 2601

The Cryo Pump

- Very high throughput of up to 120 kg / h @ 900 bar
- Energy consumption reduced by 70%[2]
- Hydrogen with highest purities
- No additional cooling system
- High reliability, little maintenance effort and low costs
- Fulfils industry standard SAE J 2601

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[1] For one system. Modular setup allows for higher throughputs.
[2] In comparison to a conventional piston compressor

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Use cases for electrolysis Hydrogen

No viable economic today

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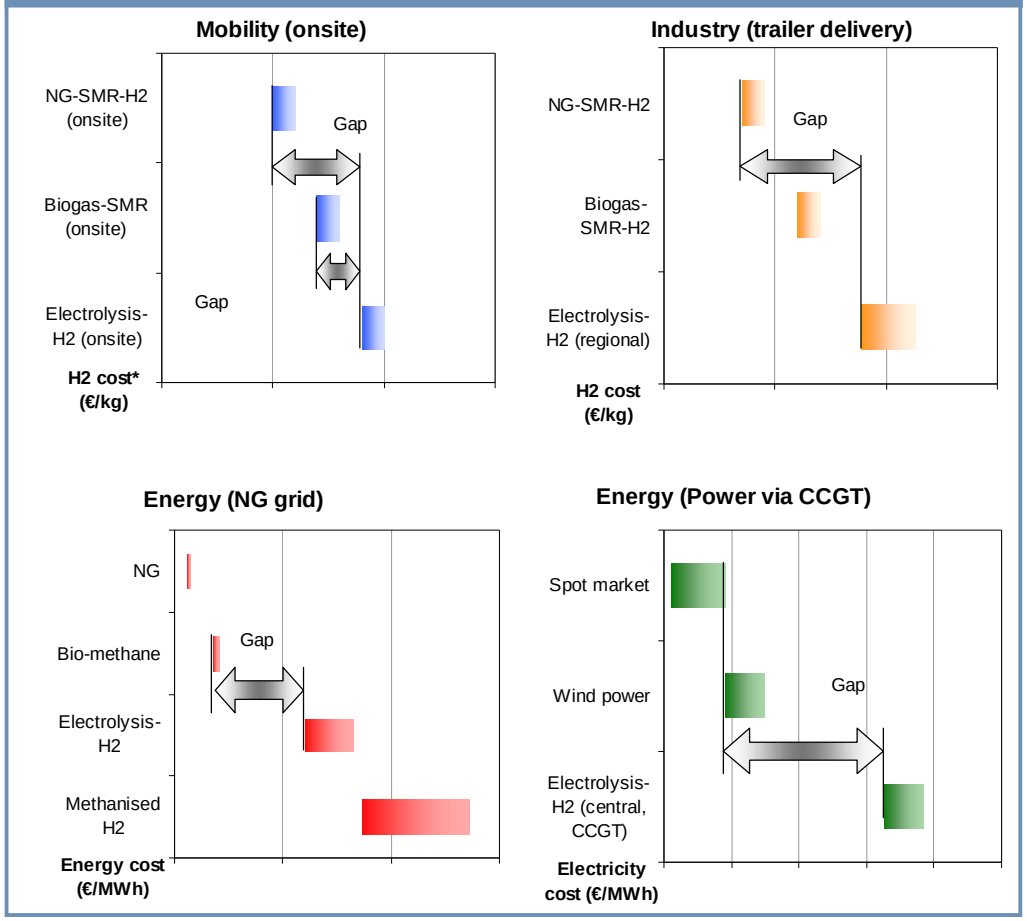
Market situation today



Economics of Electrolysis H2

- Use of electrolysis H_2 cannot compete against alternatives today
- Smallest gap in mobility (compared to Biogas-SMR)
- Largest gap in power generation

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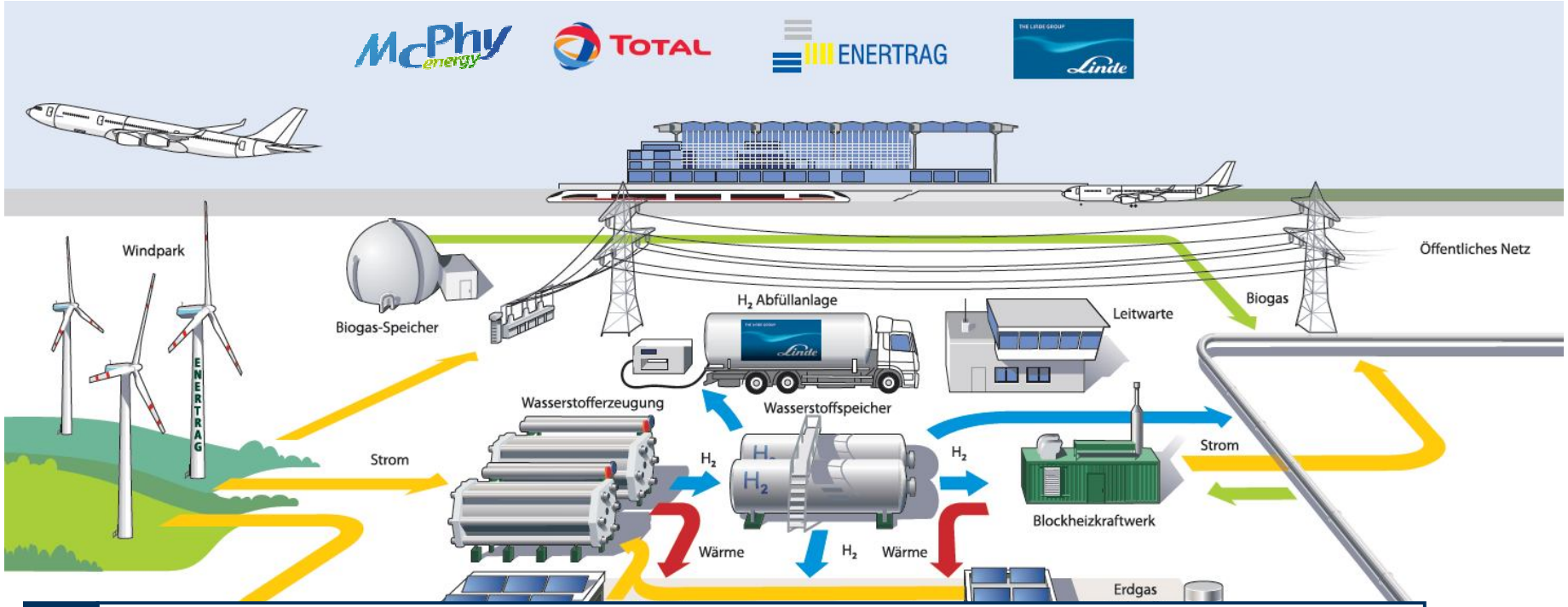
Pilot project „H2BER“ (Berlin-Brandenburg Airp

The „Swiss Army Knife“ of hydrogen energy



Key facts

- Total, Linde and McPhy erect a hydrogen refuelling station including electrolysis from windpower and a trailer filling plant at the new Berlin airport to be operated in 2014.
- Electrolysis provided by McPhy (500 kW_{el}; hydrogen output ~100 Nm^3/h or 9 kg/h)
- Hydrogen fuelling station operated by Total (350/700 bar; cars and buses)
- Linde built ionic compression, storage and trailer filling plant to take off excess hydrogen or supply additional hydrogen
- Funding via National Innovation Programme Hydrogen and Fuel Cells

Pilot project „Energiepark Mainz“

Scaling up to grid relevance

funded by:

ENERGIESPEICHER
Forschungsinitiative der Bundesregierung

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

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Key facts

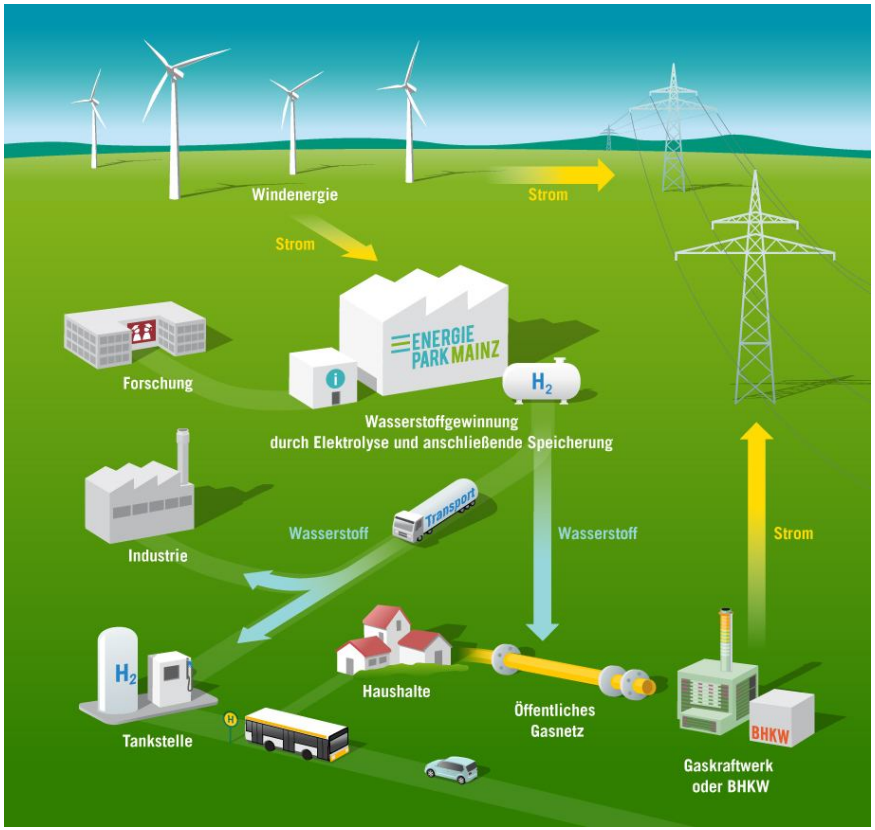
- Pilot project for hydrogen electrolysis, storage and usage in Mainz by Stadtwerke Mainz, Linde, Siemens and Hochschule RheinMain to be operated by 2015
  - Siemens PEM electrolysis with up to 6 MW peak power intake
  - Linde novel Ionic Compressor for flexible and energy-efficient operation
  - Pressurised storage ~1000 kg (~33 MWh)
  - Hydrogen trailer filling station
  - NG grid injection (CCGT power plant)
- Power from various sources (wind power, control reserve, spot markets)
- Targets:
  - Management of local grid bottleneck
  - Testing and gaining operational experience with components
  - Intelligent control and market integration

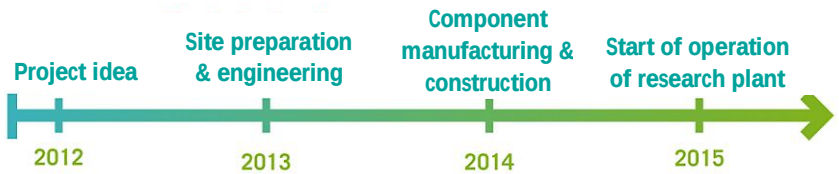
STADTWERKE MAINZ AG

THE LINDE GROUP Linde

SIEMENS

Hochschule RheinMain
University of Applied Sciences
Wiesbaden Rüsselsheim Geisenheim





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Conclusions

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— For energy system with large amount of wind and PV we need energy storage to level out the fluctuations

— Only long term energy storage can provide security of supply

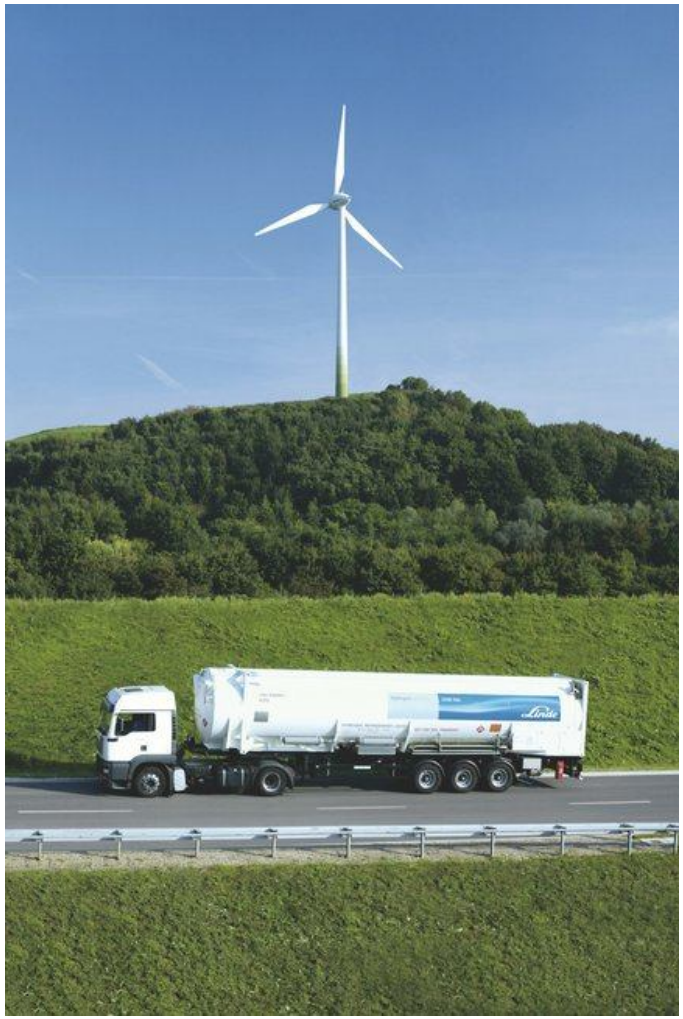
— Hydrogen storage caverns are specifically 3-4 orders of magnitude cheaper than batteries

— Hydrogen can build new bridges in the energy system (wind → mobility, industry, natural gas)

— Technology is available; cost reduction & efficiency improvement are underway

— No economic case today; favourable regulations needed to trigger market introduction

→ Linde is a strong and innovative partner on hydrogen technology and handling



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Thanks for your attention.

Uwe Würtenberger
Clean Energy Technology
Linde Innovation Management
e-mail:
uwe.wuertenberger@LINDE.com

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