Webinar:
The Coming Hydrogen Revolution in Europe

Challenges and Opportunities

12 November 2020

Agenda

1. Introduction
2. Brief hydrogen overview (by Bill Garner)
3. Legal framework and policy developments (by Martin Borning)
4. Technical state-of-the art (by Heike Bernhardt)
5. Organizational challenges for scaling up (by Frederik de Vries)

Bill Garner

- Co-Chair of GT's Global Energy Practice
- Shareholder in GT's Houston office
- Project development attorney specializing in gas-related projects---all industry segments: upstream, midstream, and downstream
- In 2019 was selected by the publication Law 360 as an "Energy MVP" which recognizes the top 5 energy lawyers in the US

GreenbergTraurig

Brief Hydrogen Overview

Bill Garner

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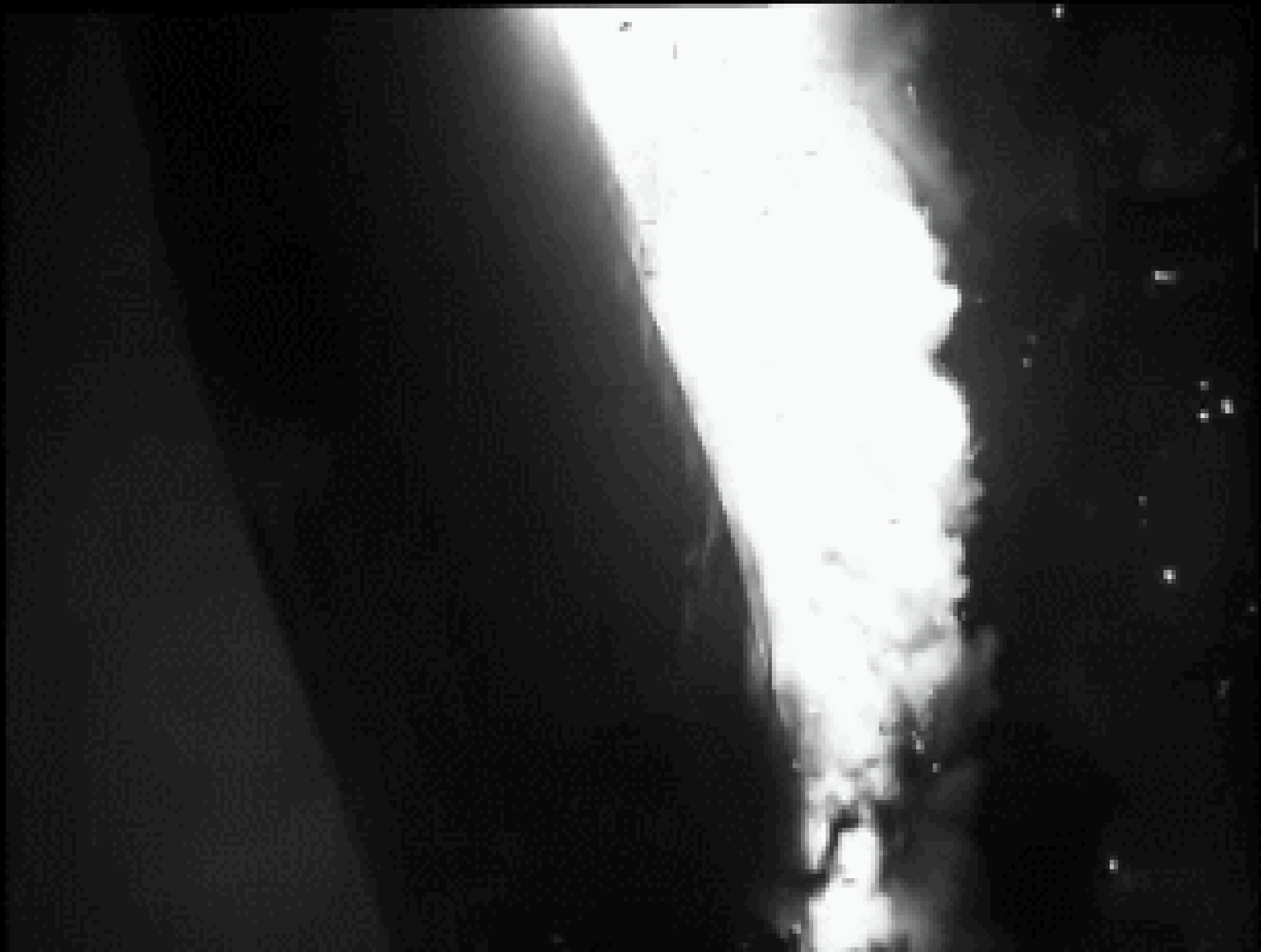
AIRBUS
ZEROe


Hindenburg



Periodic Table of the Elements

Atomic Number → 1
Symbol ← H
Name → Hydrogen
Atomic Weight ← 1.008
Electrons per shell → 1

State of matter (color of name)
GAS LIQUID SOLID UNKNOWN

Subcategory in the metal-metalloid-nonmetal trend (color of background)
- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanides
- Actinides
- Post-transition metals
- Metalloids
- Reactive nonmetals
- Noble gases
- Unknown chemical properties

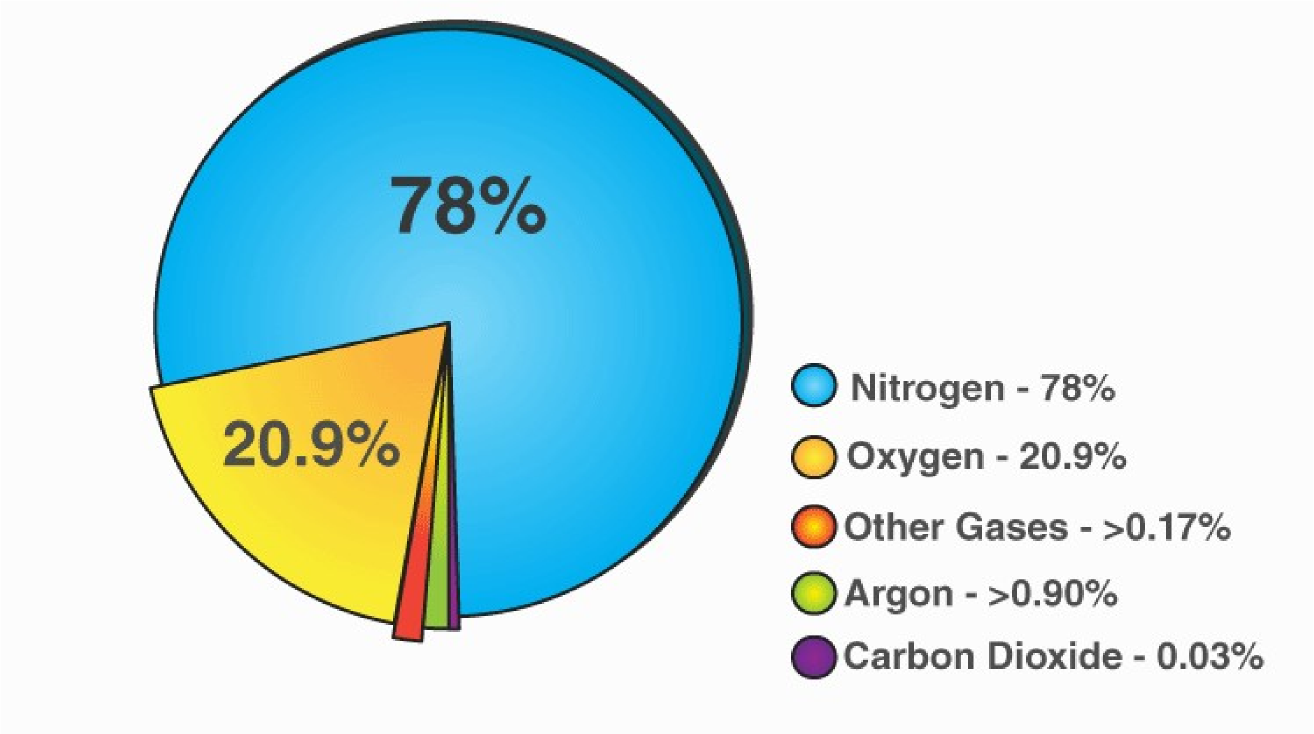
1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.008 1																	2 He Helium 4.0026 2
3 Li Lithium 6.94 2-1	4 Be Beryllium 9.0122 2-2											5 B Boron 10.81 2-3	6 C Carbon 12.011 2-4	7 N Nitrogen 14.007 2-5	8 O Oxygen 15.999 2-6	9 F Fluorine 18.998 2-7	10 Ne Neon 20.180 2-8
11 Na Sodium 22.98976928 2-8-1	12 Mg Magnesium 24.305 2-8-2											13 Al Aluminium 26.982 2-8-3	14 Si Silicon 28.085 2-8-4	15 P Phosphorus 30.974 2-8-5	16 S Sulfur 32.06 2-8-6	17 Cl Chlorine 35.45 2-8-7	18 Ar Argon 39.948 2-8-8
19 K Potassium 39.0983 2-8-8-1	20 Ca Calcium 40.078 2-8-8-2	21 Sc Scandium 44.955908 2-8-9-2	22 Ti Titanium 47.867 2-8-10-2	23 V Vanadium 50.9415 2-8-11-2	24 Cr Chromium 51.9961 2-8-13-1	25 Mn Manganese 54.938044 2-8-13-2	26 Fe Iron 55.845 2-8-14-2	27 Co Cobalt 58.933 2-8-15-2	28 Ni Nickel 58.693 2-8-16-2	29 Cu Copper 63.546 2-8-18-1	30 Zn Zinc 65.38 2-8-18-2	31 Ga Gallium 69.723 2-8-18-3	32 Ge Germanium 72.630 2-8-18-4	33 As Arsenic 74.922 2-8-18-5	34 Se Selenium 78.971 2-8-18-6	35 Br Bromine 79.904 2-8-18-7	36 Kr Krypton 83.798 2-8-18-8
37 Rb Rubidium 85.4678 2-8-18-8-1	38 Sr Strontium 87.62 2-8-18-8-2	39 Y Yttrium 88.90584 2-8-18-9-2	40 Zr Zirconium 91.224 2-8-18-10-2	41 Nb Niobium 92.90637 2-8-18-12-1	42 Mo Molybdenum 95.95 2-8-18-13-1	43 Tc Technetium (98) 2-8-18-13-2	44 Ru Ruthenium 101.07 2-8-18-15-1	45 Rh Rhodium 102.91 2-8-18-16-1	46 Pd Palladium 106.42 2-8-18-18	47 Ag Silver 107.87 2-8-18-18-1	48 Cd Cadmium 112.41 2-8-18-18-2	49 In Indium 114.82 2-8-18-18-3	50 Sn Tin 118.71 2-8-18-18-4	51 Sb Antimony 121.76 2-8-18-18-5	52 Te Tellurium 127.60 2-8-18-18-6	53 I Iodine 126.90 2-8-18-18-7	54 Xe Xenon 131.29 2-8-18-18-8
55 Cs Caesium 132.90545196 2-8-18-18-8-1	56 Ba Barium 137.327 2-8-18-18-8-2	57-71 Lanthanides	72 Hf Hafnium 178.49 2-8-18-32-10-2	73 Ta Tantalum 180.94788 2-8-18-32-11-2	74 W Tungsten 183.84 2-8-18-32-12-2	75 Re Rhenium 186.21 2-8-18-32-13-2	76 Os Osmium 190.23 2-8-18-32-14-2	77 Ir Iridium 192.22 2-8-18-32-15-2	78 Pt Platinum 195.08 2-8-18-32-17-1	79 Au Gold 196.97 2-8-18-32-18-1	80 Hg Mercury 200.59 2-8-18-32-18-2	81 Tl Thallium 204.38 2-8-18-32-18-3	82 Pb Lead 207.2 2-8-18-32-18-4	83 Bi Bismuth 208.98 2-8-18-32-18-5	84 Po Polonium (209) 2-8-18-32-18-6	85 At Astatine (210) 2-8-18-32-18-7	86 Rn Radon (222) 2-8-18-32-18-8
87 Fr Francium (223) 2-8-18-32-18-8-1	88 Ra Radium (226) 2-8-18-32-18-8-2	89-103 Actinides	104 Rf Rutherfordium (267) 2-8-18-32-32-10-2	105 Db Dubnium (268) 2-8-18-32-32-11-2	106 Sg Seaborgium (269) 2-8-18-32-32-12-2	107 Bh Bohrium (270) 2-8-18-32-32-13-2	108 Hs Hassium (277) 2-8-18-32-32-14-2	109 Mt Meitnerium (278) 2-8-18-32-32-15-2	110 Ds Darmstadtium (281) 2-8-18-32-32-17-1	111 Rg Roentgenium (282) 2-8-18-32-32-17-2	112 Cn Copernicium (285) 2-8-18-32-32-18-2	113 Nh Nihonium (286) 2-8-18-32-32-18-3	114 Fl Flerovium (289) 2-8-18-32-32-18-4	115 Mc Moscovium (290) 2-8-18-32-32-18-5	116 Lv Livermorium (293) 2-8-18-32-32-18-6	117 Ts Tennessine (294) 2-8-18-32-32-18-7	118 Og Oganesson (294) 2-8-18-32-32-18-8

57 La Lanthanum 138.91 2-8-18-18-9-2	58 Ce Cerium 140.12 2-8-18-19-9-2	59 Pr Praseodymium 140.91 2-8-18-21-8-2	60 Nd Neodymium 144.24 2-8-18-22-8-2	61 Pm Promethium (145) 2-8-18-23-8-2	62 Sm Samarium 150.36 2-8-18-24-8-2	63 Eu Europium 151.96 2-8-18-25-8-2	64 Gd Gadolinium 157.25 2-8-18-25-9-2	65 Tb Terbium 158.93 2-8-18-27-8-2	66 Dy Dysprosium 162.50 2-8-18-28-8-2	67 Ho Holmium 164.93 2-8-18-29-8-2	68 Er Erbium 167.26 2-8-18-30-8-2	69 Tm Thulium 168.93 2-8-18-31-8-2	70 Yb Ytterbium 173.05 2-8-18-32-8-2	71 Lu Lutetium 174.97 2-8-18-32-9-2
89 Ac Actinium (227) 2-8-18-32-18-9-2	90 Th Thorium 232.04 2-8-18-32-18-10-2	91 Pa Protactinium 231.04 2-8-18-32-20-9-2	92 U Uranium 238.03 2-8-18-32-21-9-2	93 Np Neptunium (237) 2-8-18-32-22-9-2	94 Pu Plutonium (244) 2-8-18-32-24-8-2	95 Am Americium (243) 2-8-18-32-25-8-2	96 Cm Curium (247) 2-8-18-32-25-9-2	97 Bk Berkelium (247) 2-8-18-32-27-8-2	98 Cf Californium (251) 2-8-18-32-28-8-2	99 Es Einsteinium (252) 2-8-18-32-29-8-2	100 Fm Fermium (257) 2-8-18-32-30-8-2	101 Md Mendelevium (258) 2-8-18-32-31-8-2	102 No Nobelium (259) 2-8-18-32-32-8-2	103 Lr Lawrencium (266) 2-8-18-32-32-8-3

Chemical Characteristics

- Colorless
- Odorless
- Tasteless
- Lightest element
- Highly combustible
- NOT a greenhouse gas
- Most common element in the universe

Composition of Air



Chemical Characteristics

- Exists mostly in compounds

Compounds:

$2H_2 + O_2$	→	Water
$2H_2O + O_2$	→	Hydrogen Peroxide
$4H_2 + CO_2$	→	Methane
$H_2 + Cl_2$	→	Hydrochloric Acid
$3H_2 + N_2$	→	Ammonia
$H_2O + CO_3$	→	Carbonic Acid
$6H_2 + 2CO_2$	→	Ethanol (Alcohol)
$14H_2O + 13CO_2$	→	Diesel
$3H_2 + CO_2$ (with catalyst)	→	Methanol
$3H_2 + CO_2$ (lab experiment)	→	High-Octane Gasoline
$12CO_2 + 11H_2O$ (photosynthesis)	→	Sugar (sucrose)
$C_5H_9ClO + C_4H_{11}NO$	→	Hydroxychloroquine

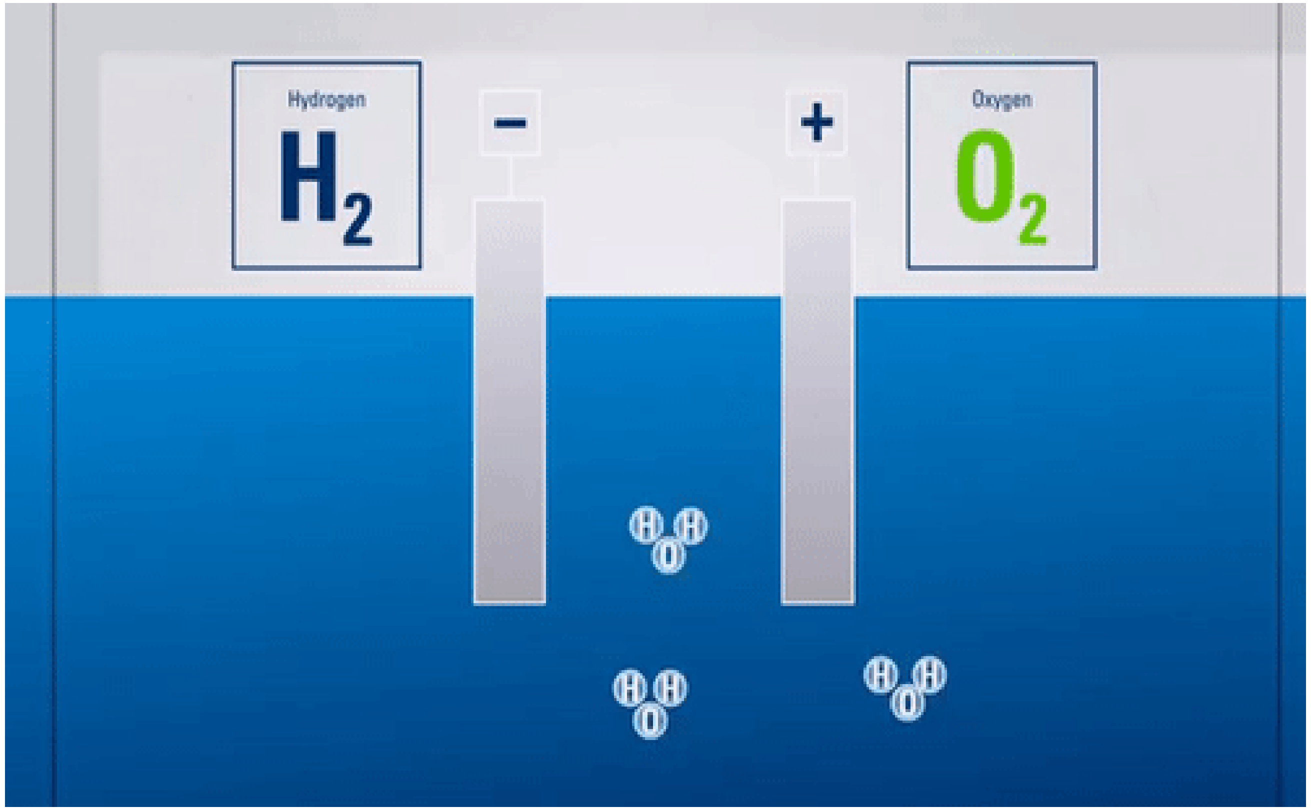
Production & Application

- <u>Production</u>

Four Types of Hydrogen Fuels:

1. Grey: steam methane reforming
2. Blue: manufacture with carbon capture
3. Turquoise: steam methane reforming with binding of carbon
4. Green: electrolysis of water

Electrolysis

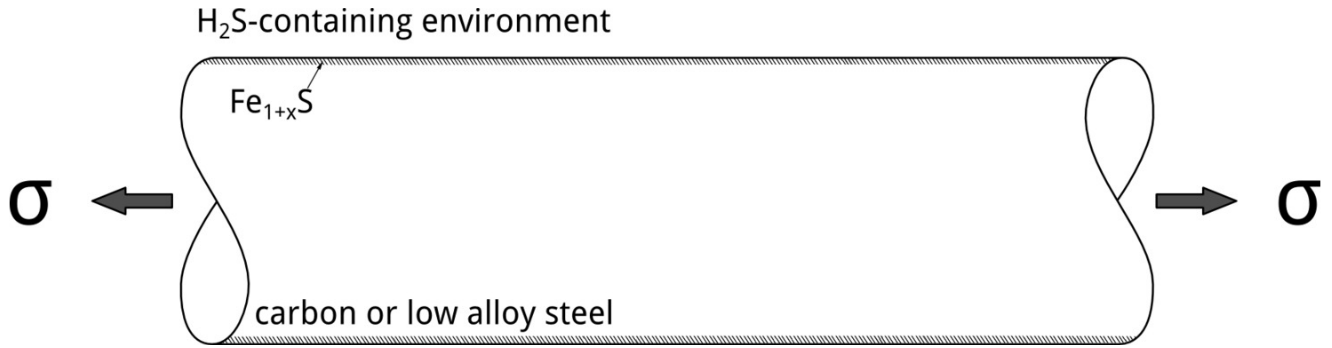


$H_2 \leftarrow H_2O \rightarrow O_2$

Ongoing Challenges & Concerns

- Current global industry is tiny
- Gas must be manufactured
- Costly
- Low energy density
- Blue flame
- Fire hazard
- Spontaneous combustion
- Steel embrittlement
- Microbial activity
- Difficult to contain/store

Steel Embrittlement



Q&A

Martin Borning

- Local partner in GT's Germany office
- Focus on advising on transactions and projects in regulated industries, mainly energy and transportation
- Frequent publisher in journals and newspapers on hydrogen

GT GreenbergTraurig

Rules for a Revolution

Creating the beneficial policy and legal framework required to boost investments in hydrogen assets

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Policy Developments

- EU Green Deal
- National climate programs
  - Dutch Climate Plan, National Energy and Climate Plan, National Climate Agreement
  - German Climate Action Plan 2050, Climate Action Programme 2030
- EU Hydrogen Strategy
- National hydrogen strategies
  - Dutch Hydrogen Strategy
    - Limburg hydrogen strategy, Port of Rotterdam hydrogen strategy
  - German Hydrogen Strategy
    - Northern German Hydrogen Strategy, Hydrogen Strategies of Bavaria, Schleswig-Holstein
- EU Energy System Integration Strategy, Sustainable and Smart Mobility Strategy
- German Steel Action Concept

Approach

- Comprehensive approach towards a veritable hydrogen economy
- Multi-phased market development
- Investment programs and funds
- Financial Incentives
- Certification
- International supply chains and trading
- Insufficient coordination regarding national roles
- Differences in promotion of different hydrogen technologies

Terminology

National Hydrogen Strategies	EU Hydrogen Strategy
	Electricity-based hydrogen
Green hydrogen	• **Renewable hydrogen / Clean hydrogen**
Grey hydrogen	Fossil-based hydrogen
Blue hydrogen	• **Fossil-based hydrogen with carbon capture**
	Low-carbon hydrogen
Turquoise hydrogen (DE)	

Existing Legal Framework

- European Level
  - Directives on Power, Gas, Renewable Energy, Energy Efficiency, TEN-E regulation
  - European Regulator: EU Commission
- State Level
  - Direct Application of EU regulations, Implementation of EU directives
  - National Laws
    - e.g. Dutch Electricity Act, German Energy Industry Act, German Renewable Energy Act
  - National Regulators
    - e.g. Dutch Authority for Consumers and Markets; German Federal Grid Agency
- Traditionally centered around Power and Gas
  - More recently Renewable Energy and Energy Efficiency
  - Hydrogen value chain enjoys no or little benefits which would promote large-scale use of hydrogen technology

Redesigning the Energy Market

- Hydrogen Infrastructure
  - Generation, Imports, Transport, Storage, Distribution, Metering
  - Bridge Technology between the Power and Gas sector
  - Planning, Financing, Operation, Third Party Access
- Hydrogen Trading
  - Certificates of Origin
  - Supply chains
- Upstream support: Boosting power generation from renewable energy sources
  - Nationally and internationally
  - Raising the price for carbon emissions
- Downstream support: Boosting demand for hydrogen
  - Energy storage to balance fluctuations in power generation from renewable energy sources
  - Promoting hydrogen use in industrial processes, transportation, heating for industrial, commercial and residential real estate
  - Raising the price for carbon emissions

Announced Changes to the Legal Framework (I)

- Hydrogen Infrastructure
  - Review of the gas legislation as part of designing enabling market rules to the deployment of hydrogen, including removing barriers for efficient hydrogen infrastructure development
  - Introduction of a common low carbon threshold/standard for the promotion of hydrogen production installations
  - Revision of TEN-E and TEN-T regulation to fully support a more integrated energy system
  - Review of TYNDP scope and governance to better reflect cross-sectoral infrastructure planning
  - Carbon Contracts for Difference Program

Announced Changes to the Legal Framework (II)

- Hydrogen Trading
  - Comprehensive terminology and EU-wide criteria for the certification of hydrogen
- Boosting demand for hydrogen
  - Industrial Processes: Carbon prices and Carbon Contracts for Difference Program, possibly quotas of clean hydrogen
  - Transportation: Implementation of the Clean Vehicles Directive, review of the Alternative Fuels Infrastructure Directive, Carbon Contracts for Difference Program to promote alternative fuels in the aviation and maritime sector
  - Real Estate: Revision of Renewable Energies Directive and Energy Efficiency Directive to accelerate investment in smart, energy-efficient, renewable-based district heating and cooling networks

Cross-Border Opportunities

- Development of Trans-European transportation, storage, import infrastructure
- Develop production and use clusters and energy balancing across borders
- Pilot projects
  - Regional origin with European support
  - Chosen cooperation, partners handpicked to fit upstream/downstream requirements
  - Exist mostly despite missing legal framework to further boost hydrogen generation, infrastructure or use

Cross-Border Challenges

- Compatibility of the national plans to develop hydrogen economies
  - Complementary or parallel policy objectives
  - Terminology
  - Certificates of origin
  - Infrastructure standards, in particular blending
  - Use of hydrogen produced from fossil fuels
  - Use of CCS and CCU technologies

- Requires harmonization on the European level


Q&A

Heike Bernhardt

- Technical Director at DEEP.KBB (responsible for technical project realization, especially solution mining, brine production, cavern filling and flooding, re-completion and oil and gas storage operation)
- MBA in industrial engineering and management from the Technical University Braunschweig in Germany and MSc in civil engineering
- DEEP.KBB GmbH is an German engineering company specialized in subsurface technology. Worldwide planning and construction of underground storage facilities for gas, crude oil and crude oil products
- Long-term experience in subsurface storage and brine production. For over 15 years projects for storage of renewable energy via compressed air and hydrogen in salt caverns. Teams consisting of professional and experienced engineers, geologists and technicians

Future Hydrogen Network.
Basic Technical Considerations

HEIKE BERNHARDT
DR. GREGOR-SÖNKE SCHNEIDER

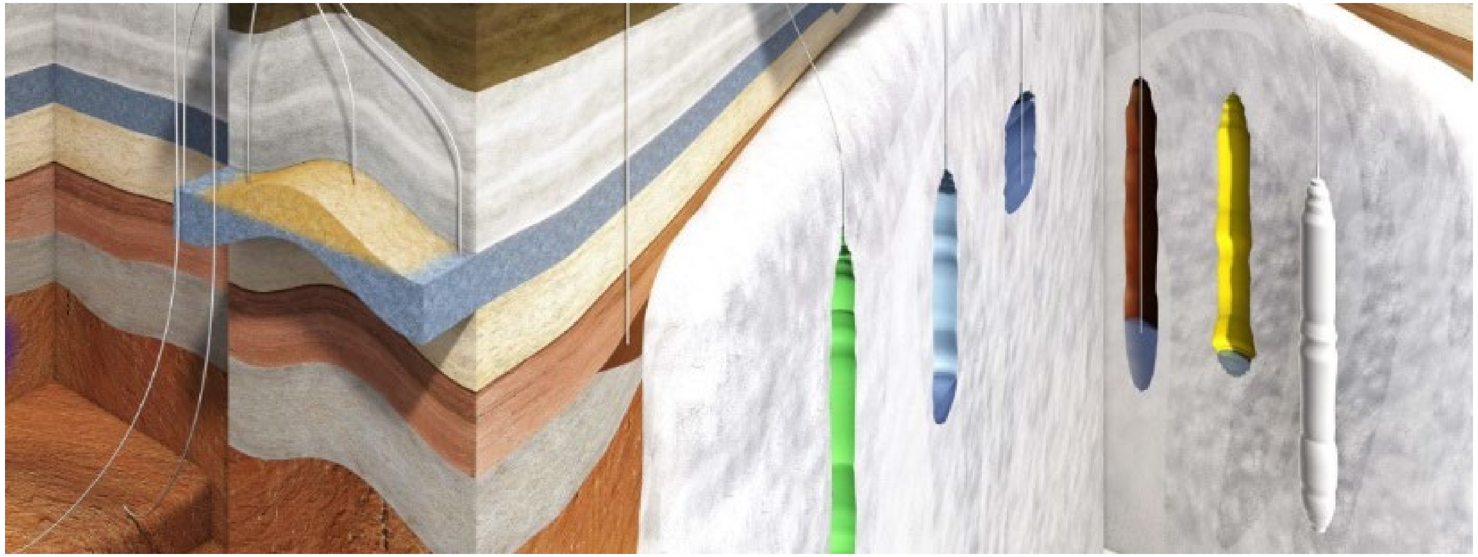
The Coming Hydrogen Revolution in Europe:
Opportunities and Challenges

12.11.2020

DEEP. KBB

Content

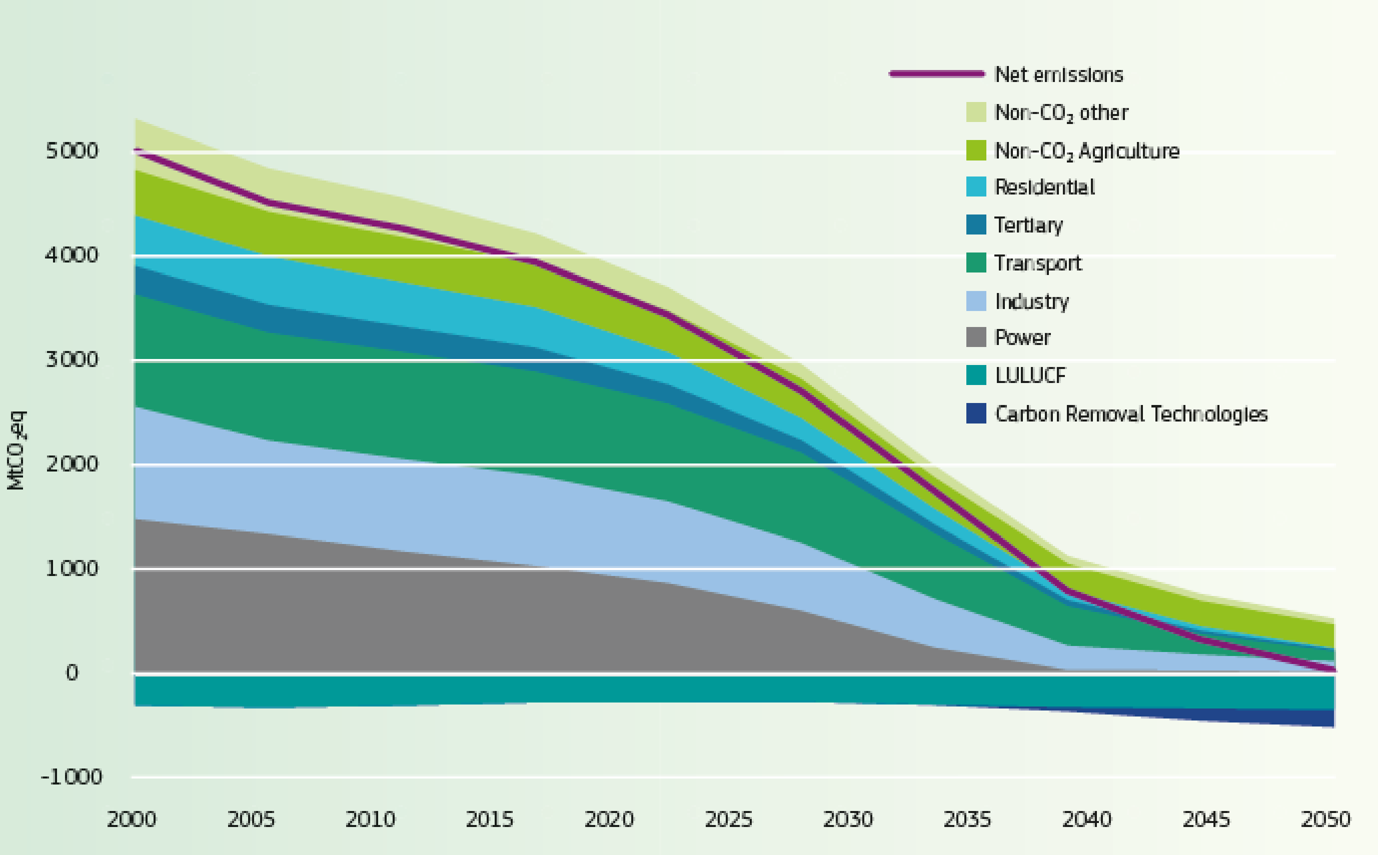
Introduction



Climate Protection: Reduction GHG Emissions…

EU Policy

Figure 5. GHG emissions trajectory in a 1.5 °C scenario

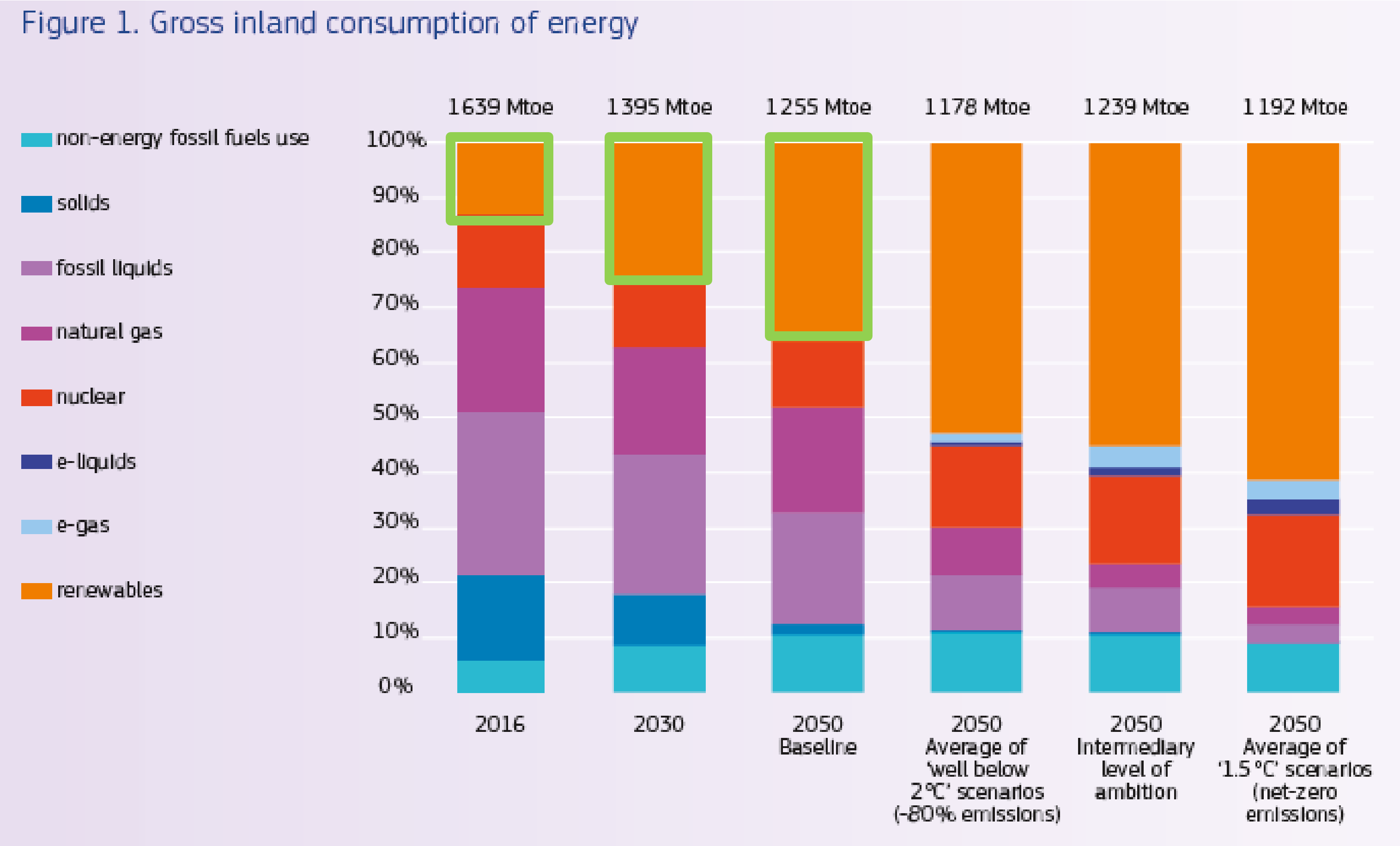


Key target for 2030:
At least 40% cuts in GHG emissions (from 1990 levels)

Source: European Commission, Going Climate Neutral by 2050. A strategic long-term vision for a prosperous, modern, competitive, and climate neutral EU economy, 2019; https://ec.europa.eu/clima/policies/strategies/2030_en

Climate Protection: …via Increase of Renewables

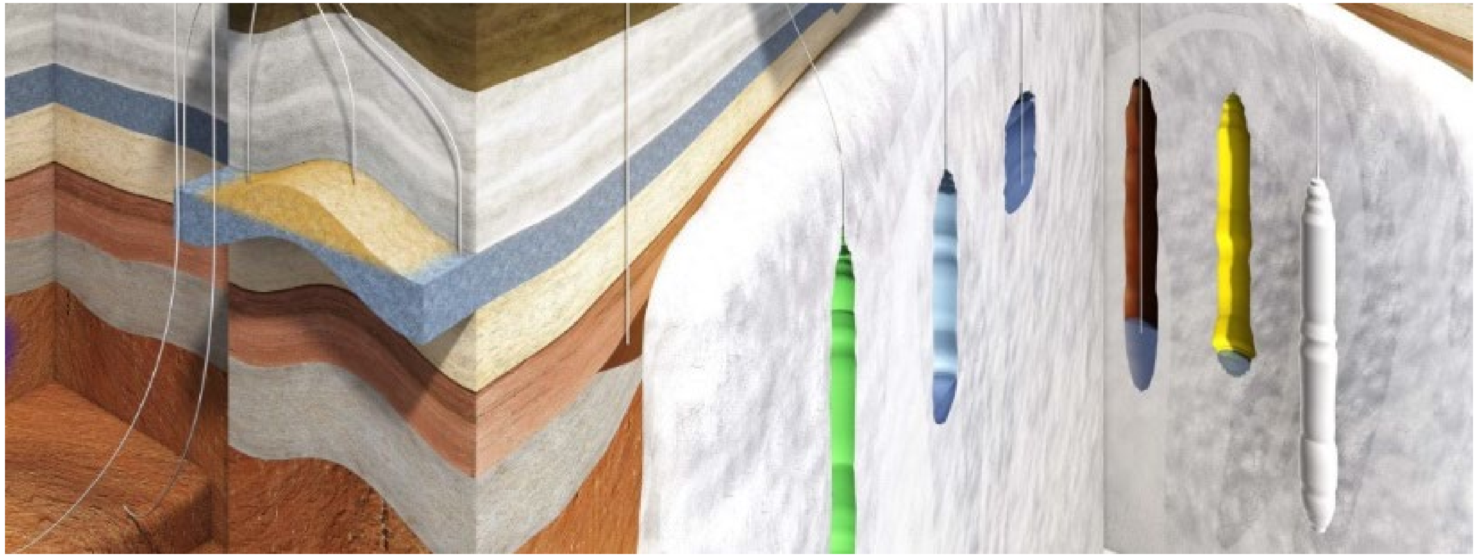
EU Policy



Key target for 2030: At least 32% share for renewable energies

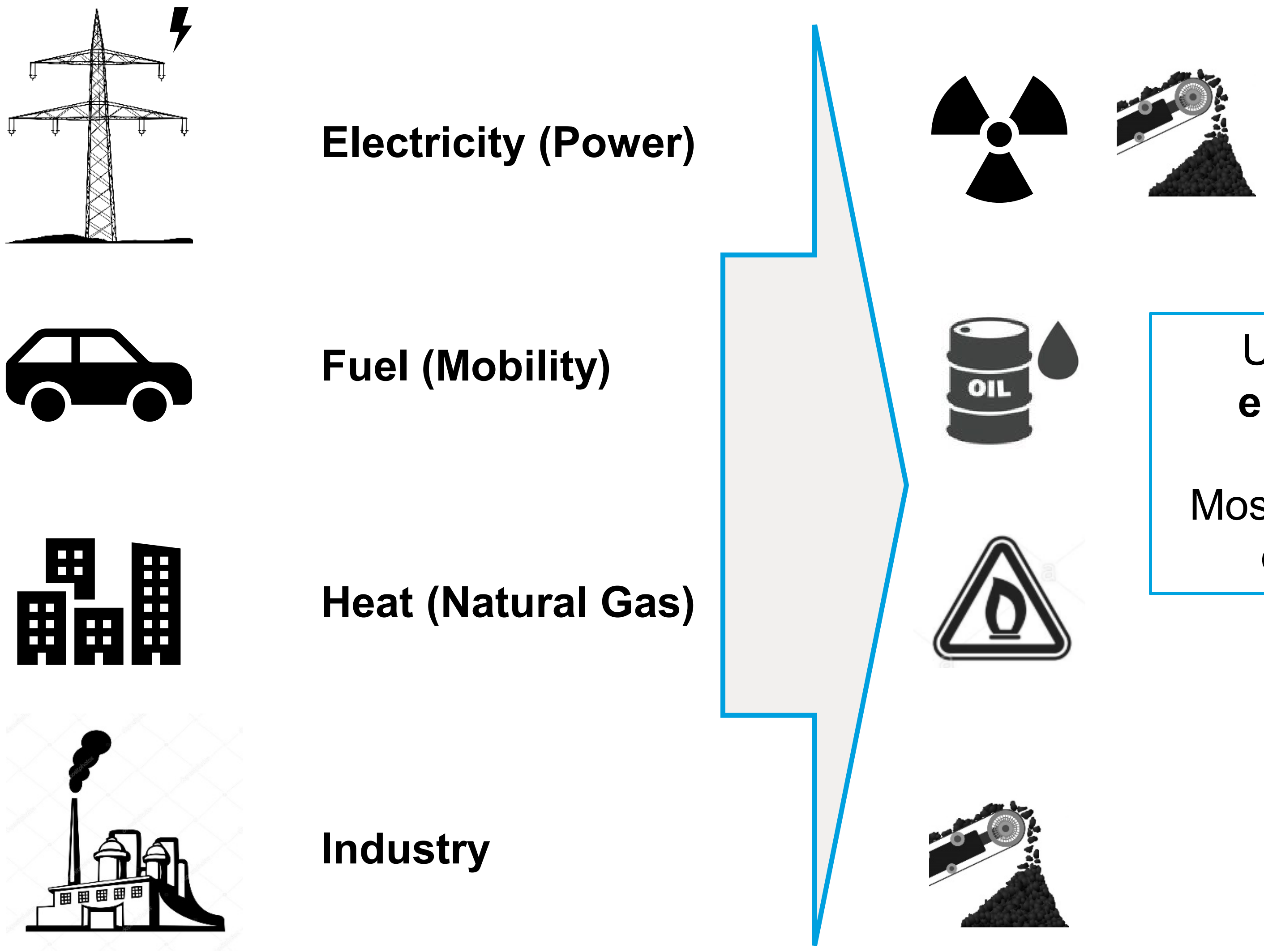
Source: European Commission, Going Climate Neutral by 2050. A strategic long-term vision for a prosperous, modern, competitive, and climate neutral EU economy, 2019; https://ec.europa.eu/clima/policies/strategies/2030_en

Production, distribution and use of hydrogen



Required Energy: Electricity – Fuel – Heat – Industry

Different Sectors

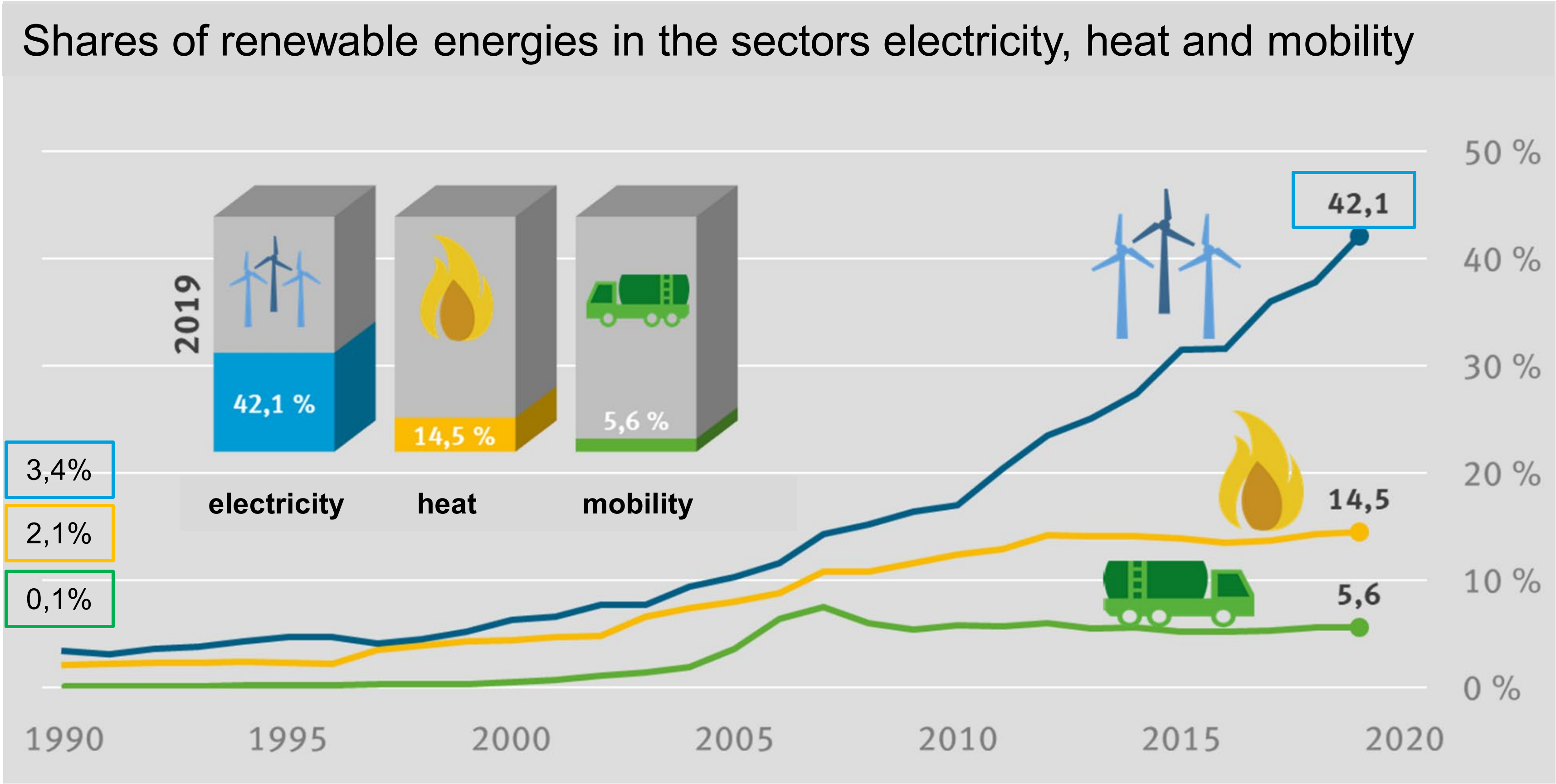


Use of **various energy** carriers

Mostly **independent** of each other

Development of Renewable Energies in the Sectors

Germany

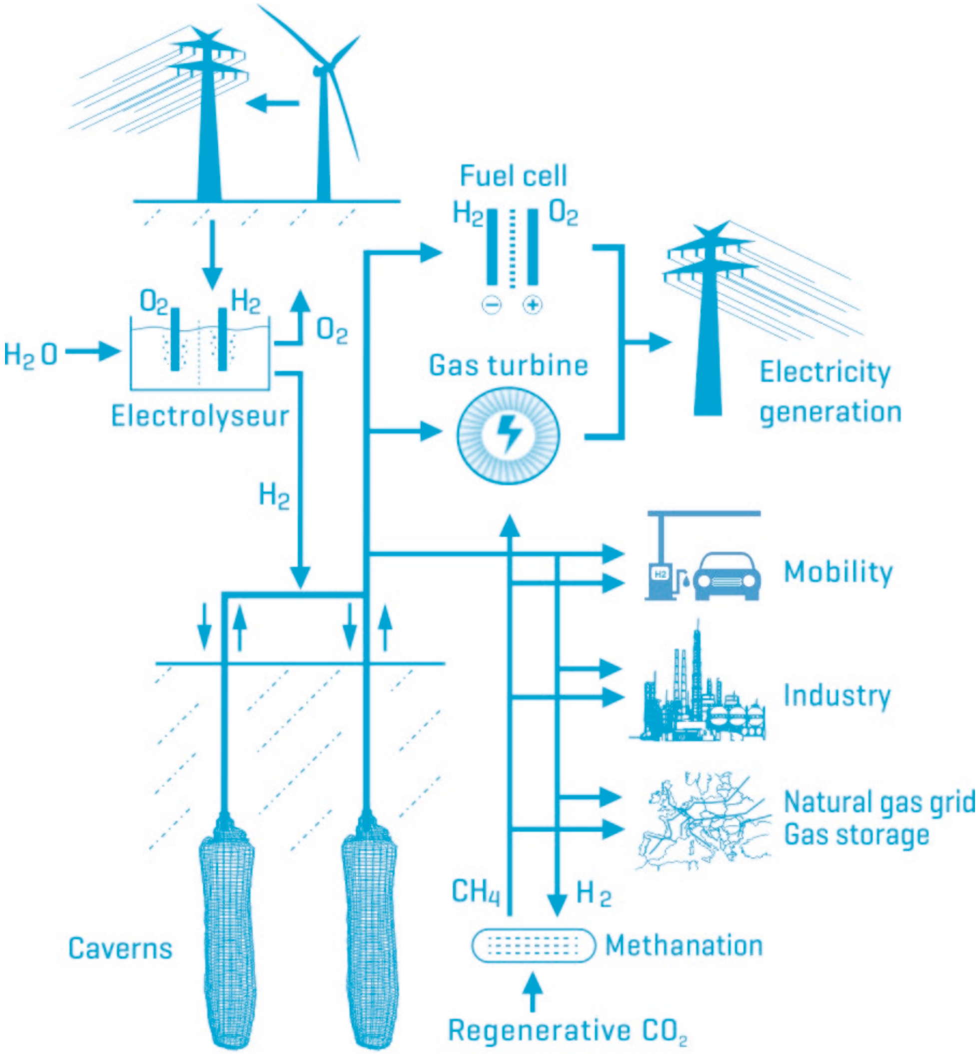


- The **focus** of energy system transition is on the **electricity sector**
- Electricity sector is **only one part** of the energy system
- **Integration** of **renewable energies** into the other sectors required

Source: Umweltbundesamt, Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), Erneuerbare Energien in Zahlen, www.umweltbundesamt.de

Production, Distribution and Use of hydrogen

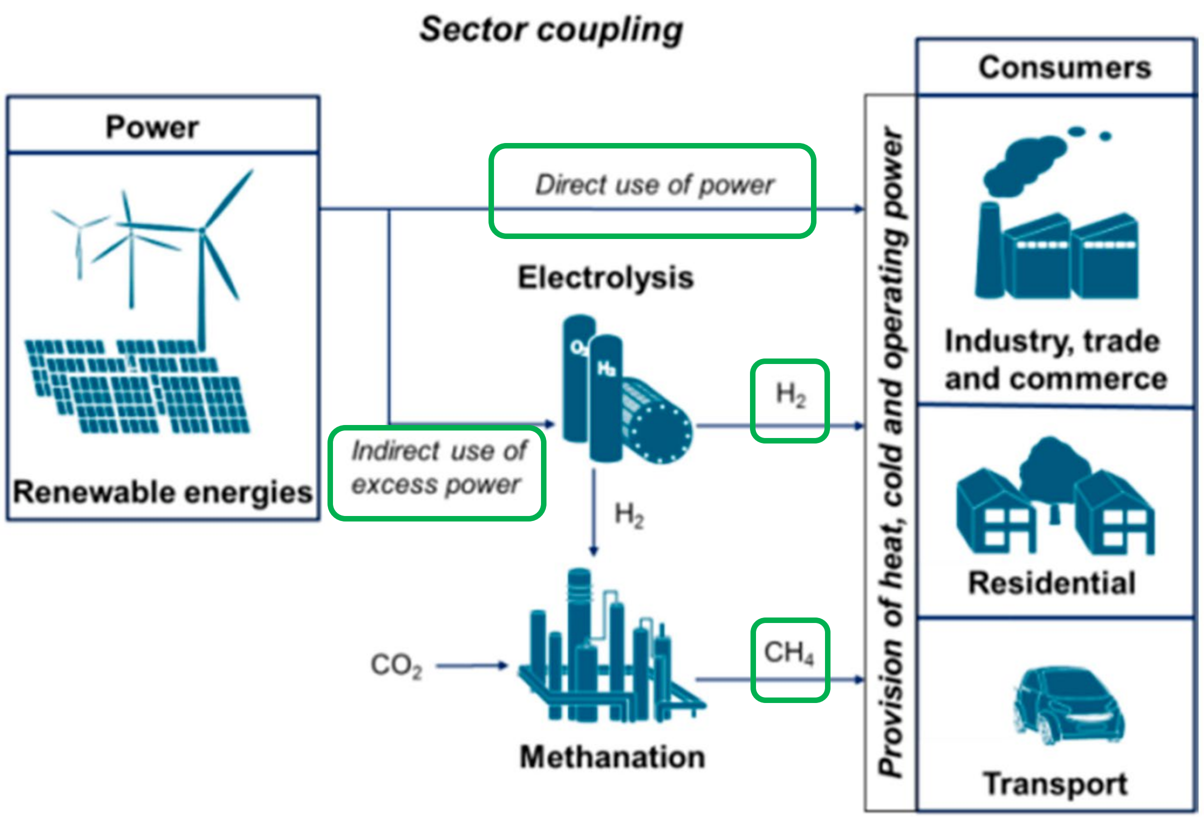
Integration of Renewable Energies



- Hydrogen **production** from renewable energies by electrolysis ("green") or natural gas coupled with carbon capture storage ("blue")
- **User**
  in sector mobility (fuel)
  in sector heat (gas grid)
  in sector electricity (reconversion to power)
  In sector industry (cooling processes, steel production, fertilizer production etc.)
- **Distribution** of hydrogen via pipelines and storage facilities
- Various **scales** of storage (e.g. tanks, geological underground)

Sector Coupling with Hydrogen

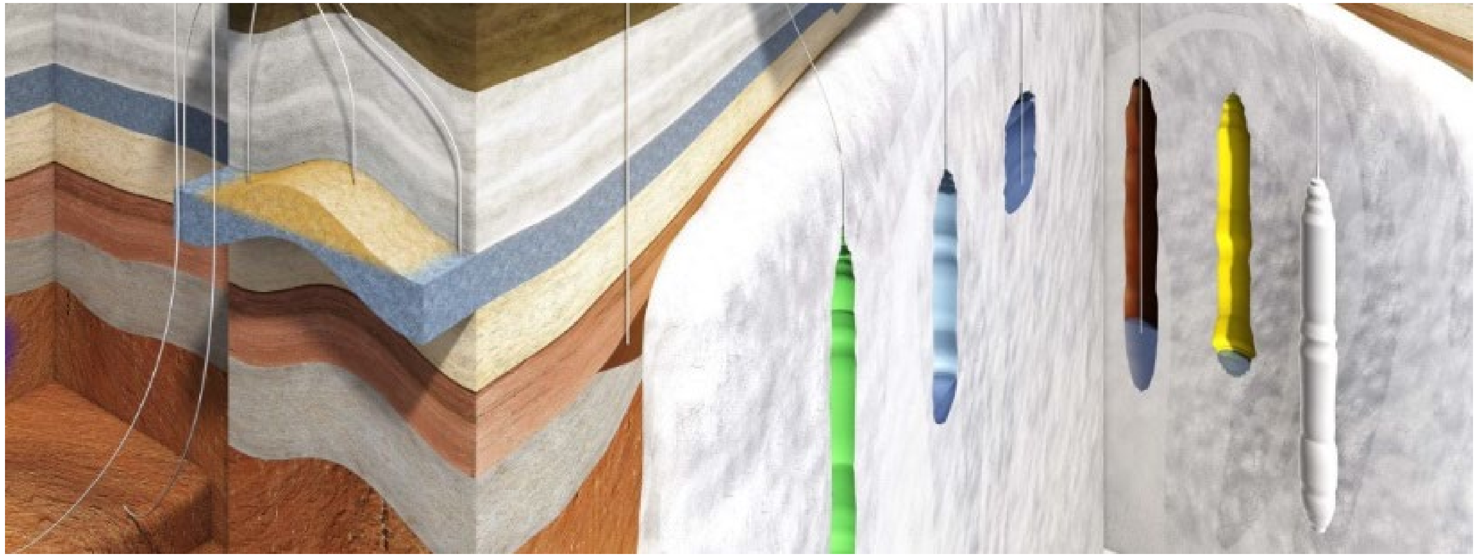
Connecting Heat, Electricity, Mobility and Industry



- **Feed-in fluctuations** of wind and solar power
- **Use of excess power** for hydrogen production
- **Balancing** the energy **demand** of the different sectors with hydrogen (sector coupling)
- Question of **large-scale storage** options for securing energy supply?
- **Development** of a complex **network** for production, distribution and use of hydrogen

Source: Forschungszentrum Jülich GmbH, Robinus et al, Linking the Power and Transport Sectors—Part 1: The Principle of Sector Coupling, Energies 2017, 10(7), 956

Development of hydrogen network



Development of Hydrogen Network

Scenario and Challenges

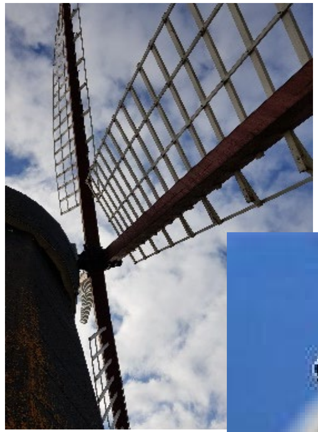
Scenario

- **Similar** development as for natural gas network, but **not identical**
- **Dynamic, successive, long-term** development of a hydrogen network
- Policy **objectives** and need to ensure **security** of supply will likely **speed up process**
- Development of a **complex technical infrastructure** on regional, national, transnational, international and global level is required

Foto: Mitteldeutsche Netzgesellschaft Gas mbH

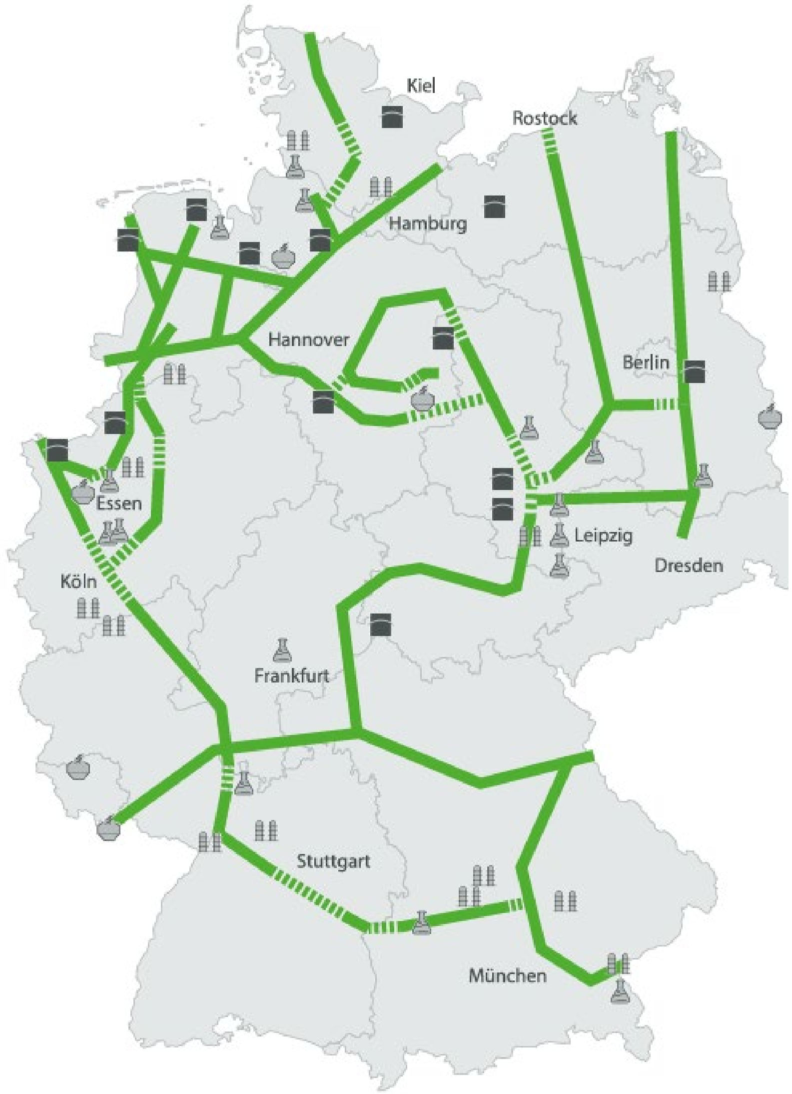
Challenges

- **Adjustment and expansion** of existing gas network to supply all sectors
  - → Scenario of transition phase?
  - → Gas blending and hydrogen content (10% → 100%)?
  - → Grey and green hydrogen?
  - → Role of natural gas?
- **Enlargement of group of end users** due to the conversion to hydrogen in all sectors
  - → Question of security of supply:
  - → Bottlenecks? Need for imports?



Development of Hydrogen Network

Vision (Germany)

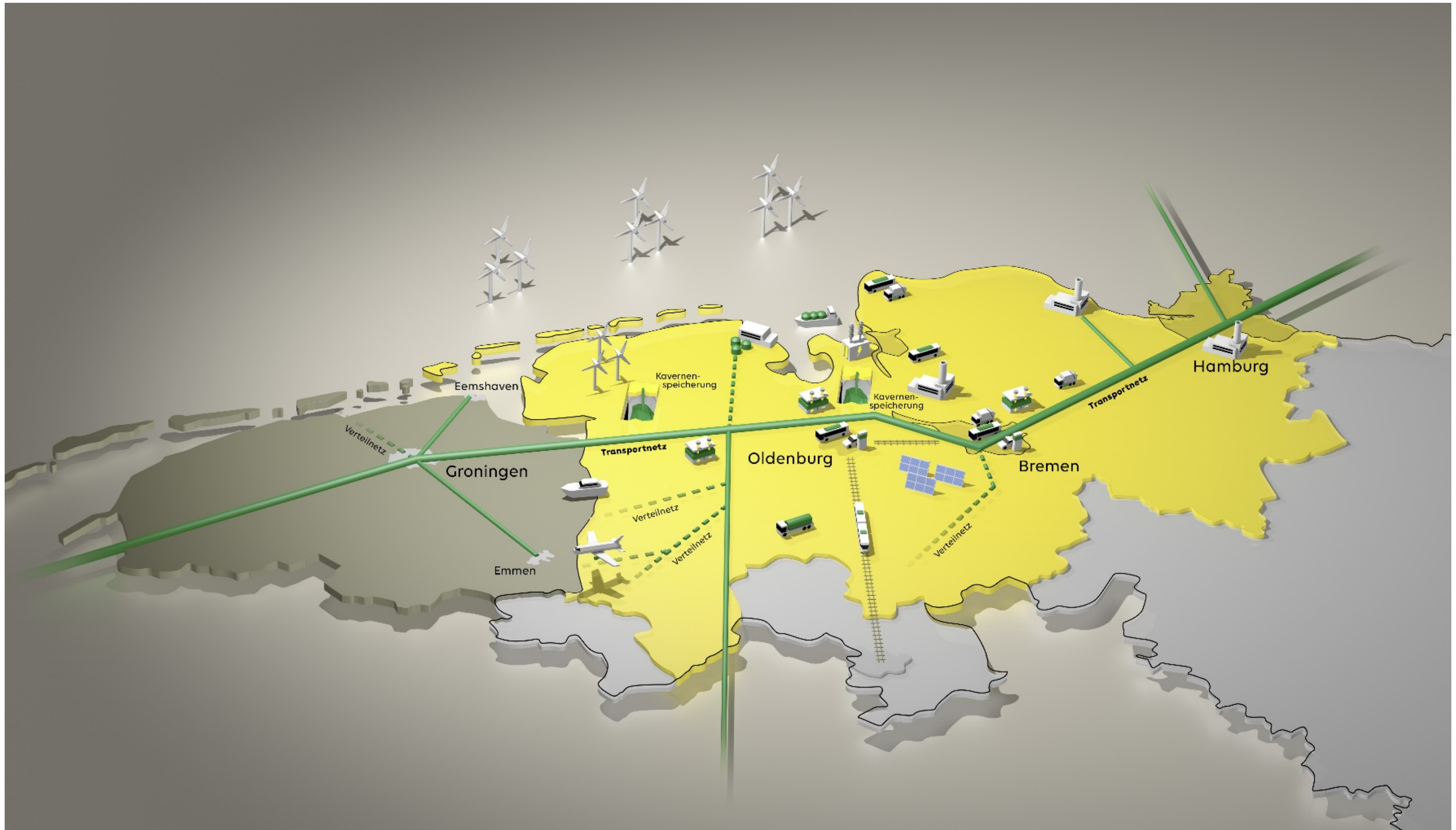


- Potential cavern storages
- Refineries
- Steel industry
- Chemical industry
- Possible new construction for hydrogen pipelines
- Possible hydrogen pipelines (converted from natural gas)

Source: FNB Gas, Netzentwicklungsplan Gas 2020–2030

Cross Border Hydrogen Infrastructure

The Netherlands / Germany



- Cooperation agreement between EWE and Gasunie (Nov 2020)
- Infrastructural linkage of transport and distribution networks for hydrogen

Source: https://www.ewe.com/de/presse/pressemitteilungen/2020/11/niederschsisch-niederlndische-wasserstoff-kooperation-ewe-und-gasunie-vereinbaren-enge-zusammenarbeitewe-ag

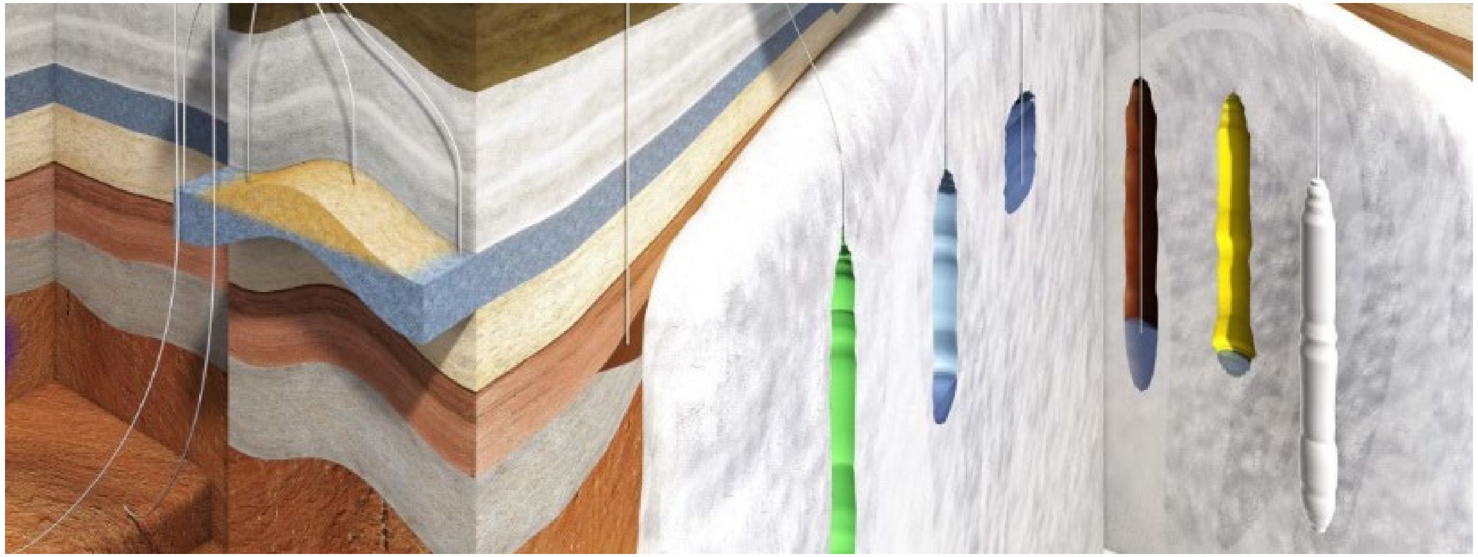
Cross Border Hydrogen Infrastructure

The Netherlands / Germany

- Vision of **Port of Rotterdam**
- **Expansion** of the **existing** pipeline **infrastructure** for the delivery of hydrogen
- **Connection** of large industrial clusters in **The Netherlands** (Rotterdam, Antwerp, Chemelot) and in **Germany** (North Rhine-Westphalia)

Source: https://www.portofrotterdam.com/sites/default/files/vision-port-of-rotterdam-pipeline-structure-rotterdam-chemelot-nrw.pdf?token=DvUK73mB

Difference in transition to hydrogen



Energy Conversion - *today*

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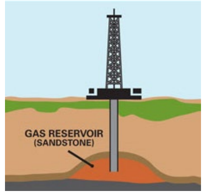
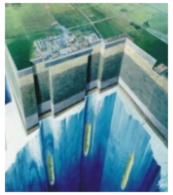
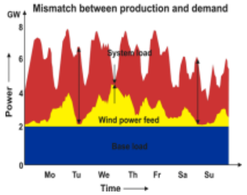
Primary Energy

Demand driven production

Electrical Energy







Primary energy source → Storage → Conversion to electric. Power → Grid → Storage

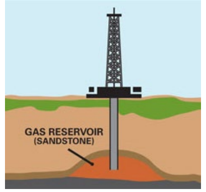
Storage of primary energy source

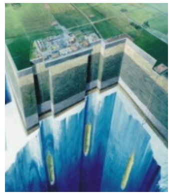
Energy Conversion – *today …and tomorrow*

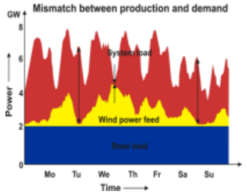
Primary Energy

Production on demand

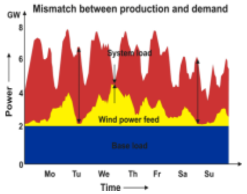
Electrical Energy

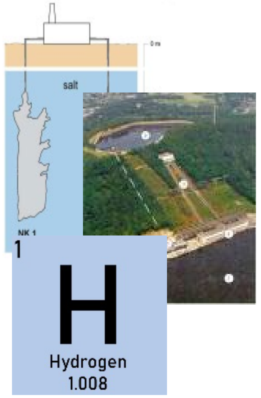






Primary energy source → Storage → Conversion to electric. Power → Grid → Storage





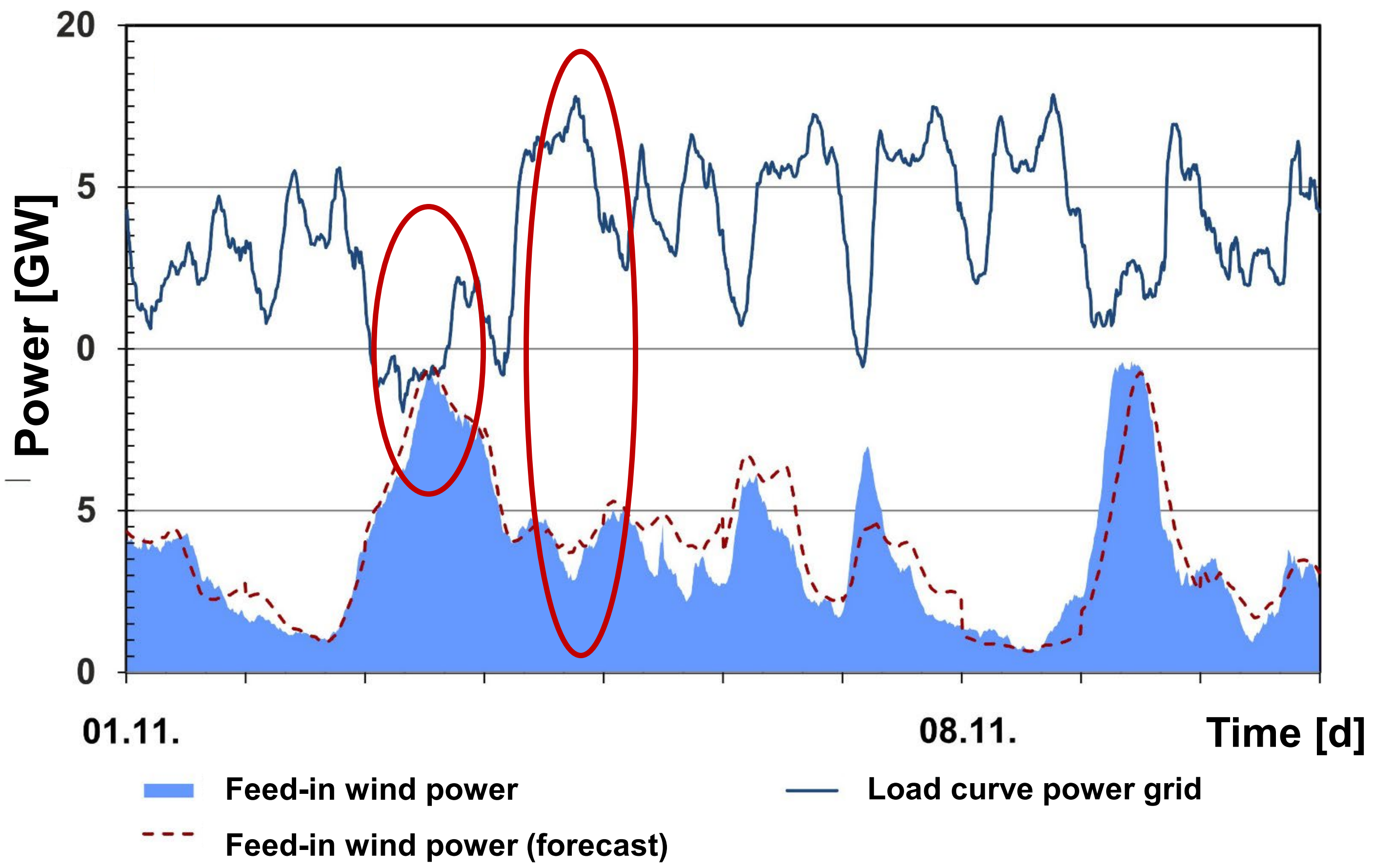
Demand-independent production

Storage of converted energy

Fluctuating Production of Renewable Energy

Wind power

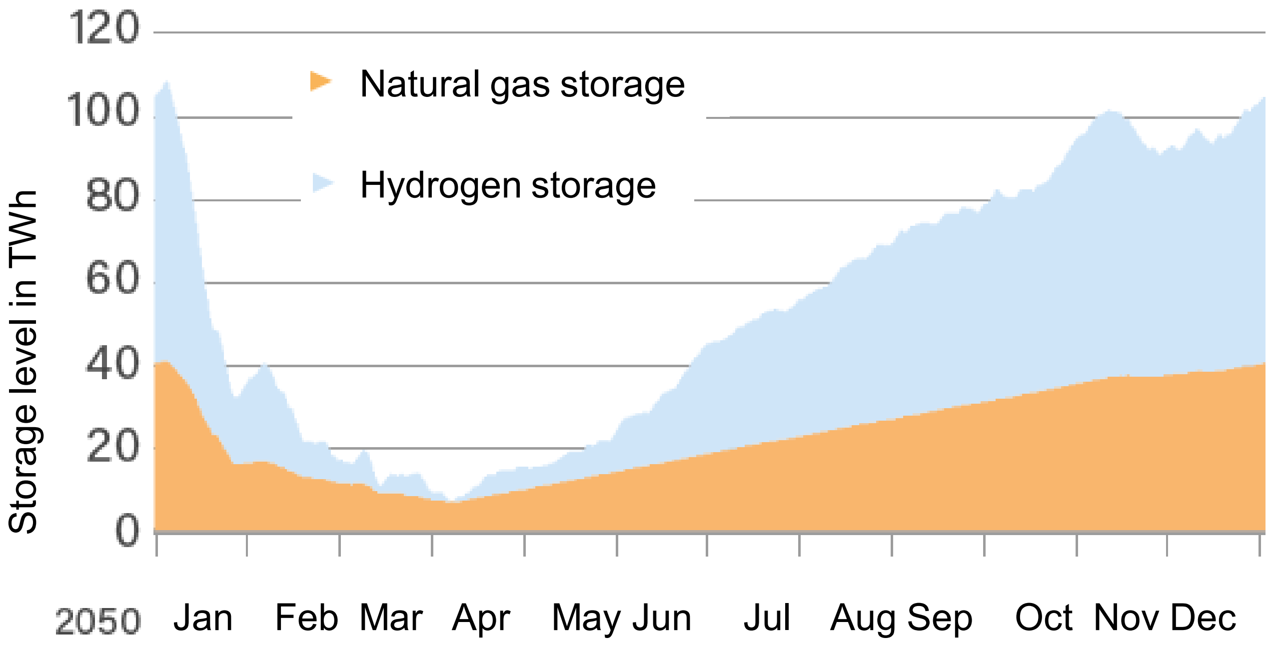
- **Fluctuating hydrogen production** in case of using renewable energies and electrolysis



- **Demand vs. production**: Realizing of necessary quantities of hydrogen in the corresponding time?

Demand for Large-Scale Hydrogen Storage?

Case „Germany“



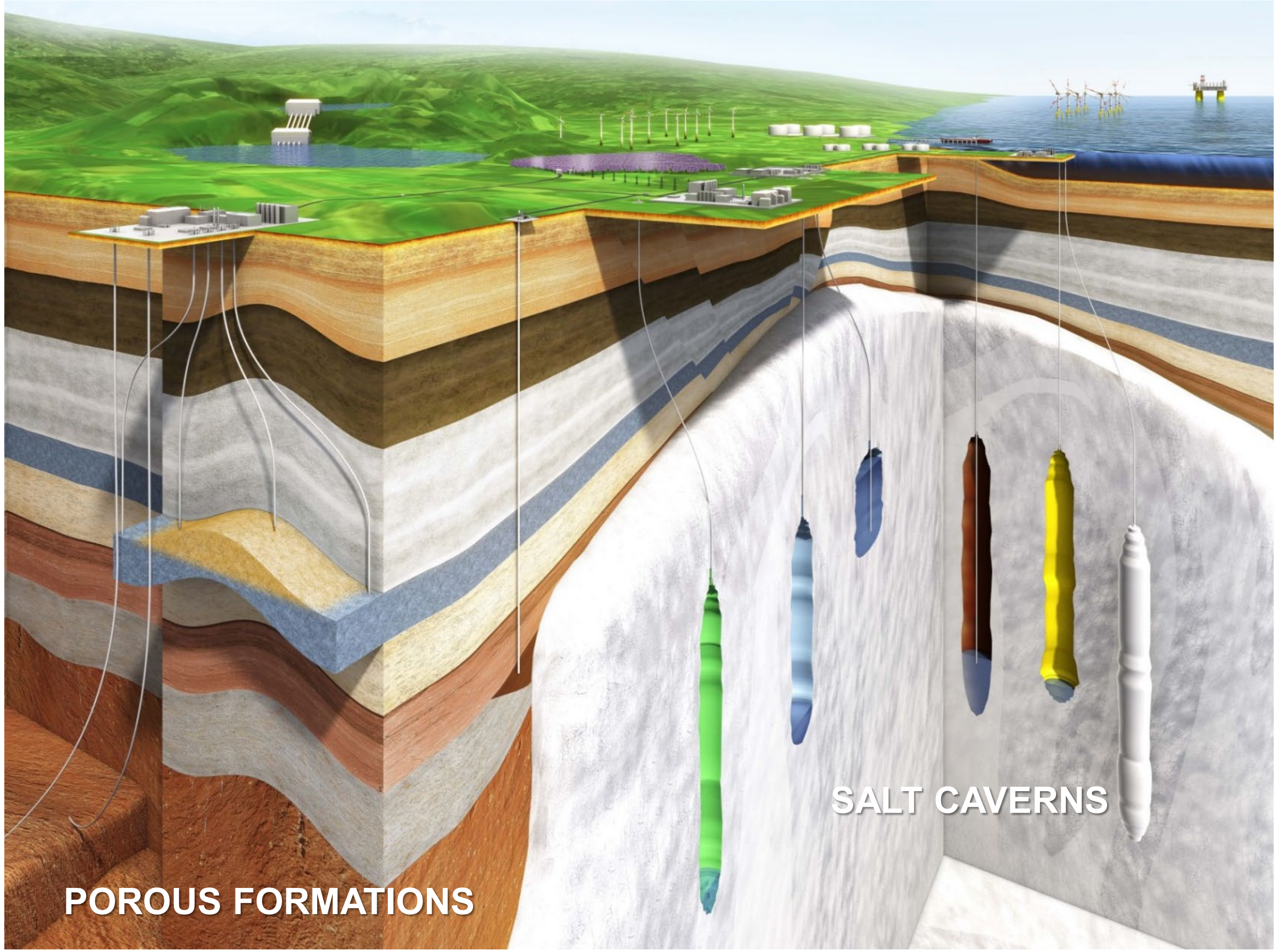
Source: Wege für die Energiewende. Kosteneffiziente und klimagerechte Transformationsstrategien für das deutsche Energiesystem bis zum Jahr 2050, FZ Jülich, 2019

Estimate depends on selected scenario with regard to GHG reductions (e.g. 80%, 90%), share of renewable energy and considered time (incl. longer phases with less power generation due to less wind and solar at the same time)

- **Expected storage demand** associated with a proportion of renewable energies in the **range of TWh**

Large-Scale Energy Storage

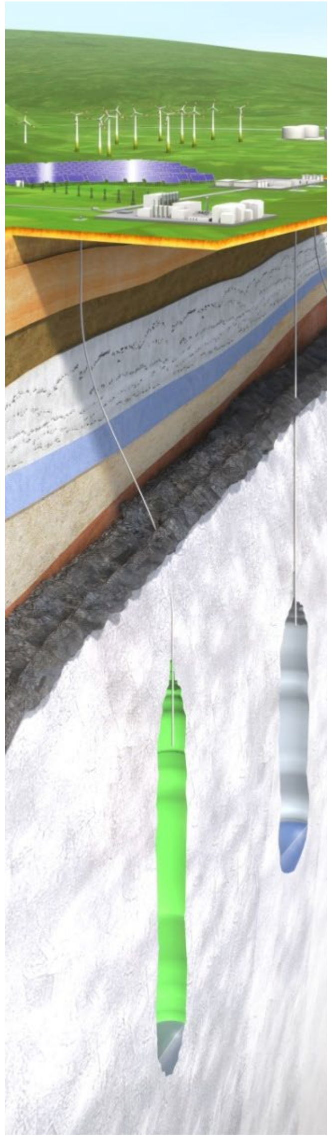
Options for Underground Storage



Advantages Underground Gas Storage

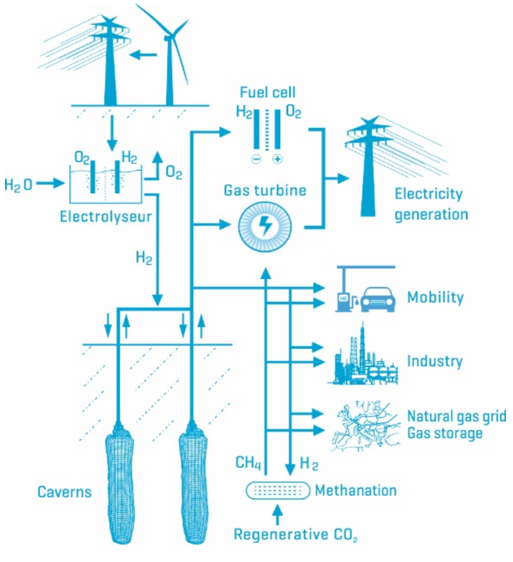
Main advantages of underground storages include:

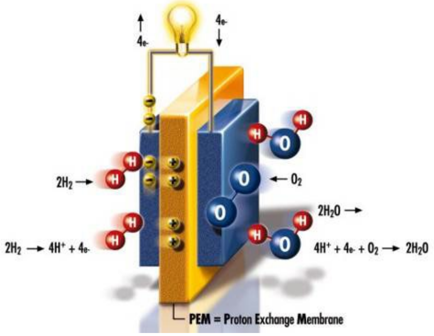
- Very **high storage capacities**
- Small land consumption
- **Increased safety** due to very deep and thick sealing geological formations
- **Low specific** investment and operating **costs**
- Operating **lifetimes** of more than 30 years
- **Proven technology**

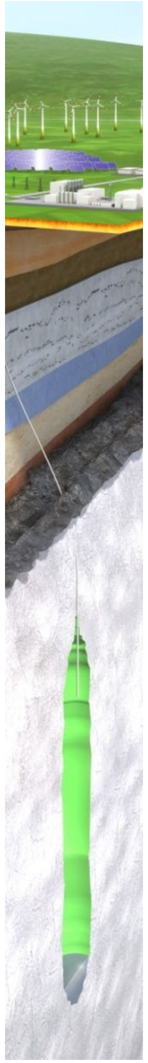


Single Elements of Future Hydrogen Network

Proven Technology…and open questions







→ still further development requirements for technical implementation

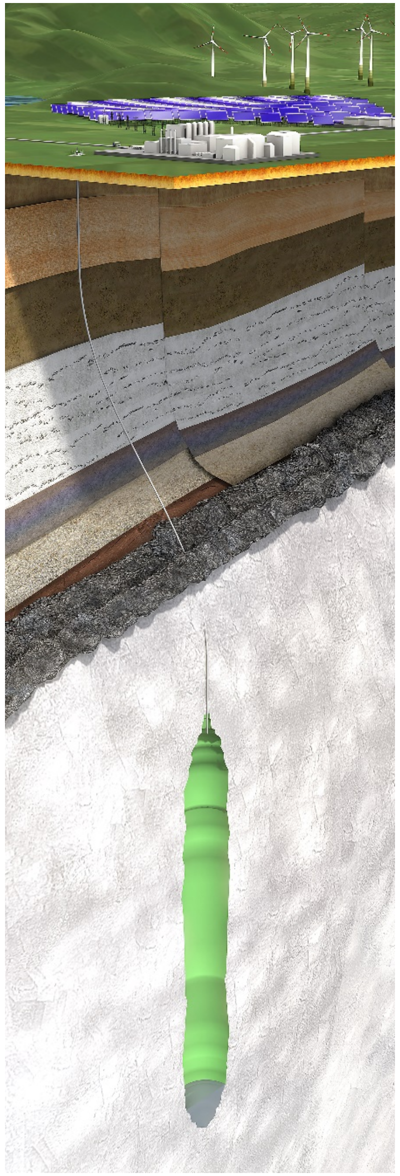
- Adjustment of the existing natural gas network to 100% hydrogen (materials, tightness, leakage monitoring)
- Ensuring high purity of hydrogen for certain applications (e.g. fuel cells)
- Safety aspects

Beyond Technical Aspects

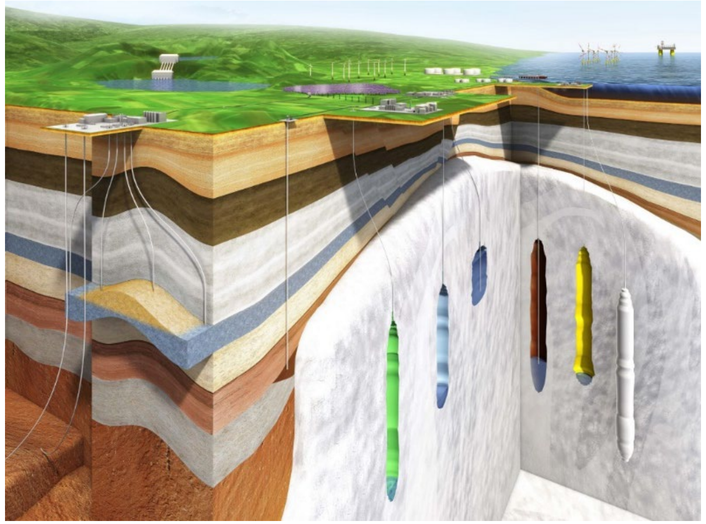
- Technical implementation also affects society
- Social aspects touch on legislation, legal framework and other policy areas
- Public acceptance through transparency, public participation and clear agreements
- Generation of public acceptance with focus on transparency, participation and information
- How can the politically driven development be used to increase the acceptance of technology?

Conclusion

- **Change** of the energy system due to the use of renewable energy such as wind and solar
- **Hydrogen**, produced from electrical energy via electrolysis, as **key element** of the future global energy mix
- **Usage** of hydrogen in sector electricity, mobility, heat and industry
- **Coupling** of these different **sectors** via hydrogen to achieve a **hydrogen network**
- Demand for large-scale **hydrogen storage** to ensure **security of supply** in a cross-border hydrogen network
- **Technical dependance** also on social and regulatory aspects



DEEP.KBB



Thank you!
Questions?

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Q&A

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