Hochschule Kempten
University of Applied Sciences

Fakultät Maschinenbau

Hydrogen Technologies

Lecture 1: Introduction

Prof. Matthias Klingele

Introduction

- **Matthias Klingele**
  - B.Sc. and M.Sc. in physics (University of Konstanz)
  - PhD „Manufacturing and Characterization of Fuel Cells“ (University of Freiburg)
  - Group leader „Fuel Cell Analysis and Materials“ at Fraunhofer ISE in Freiburg
  - Professor for „Wasserstoffproduktion und –logistik“ since October 2022
  - Spare time: Two little children, climbing, biking

Introduction

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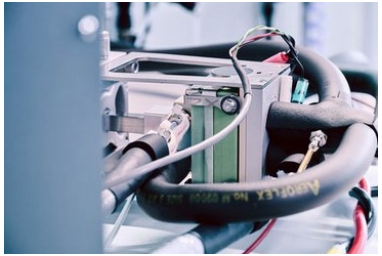
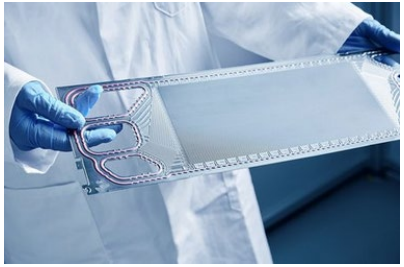
- **Experimental research on electrolyzers and fuel cells**

https://www.hs-kempten.de/fakultaet-maschinenbau/labore/labor-fuer-wasserstofftechnologien/team





Lecture Material

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- **Eglish slides, flexible language.**

- **Everything is on moodle:**
  - Hydrogen Technologies (WiSe 2025/2026)
  - Password: HYTECH-2526

Lecture Outline

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Where and why does in make sense to use Hydrogen?

Lecture Outline

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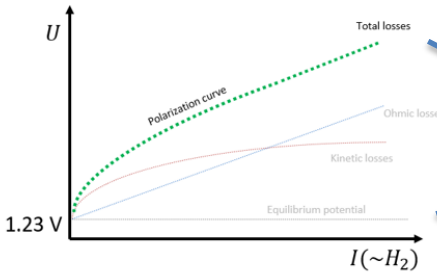
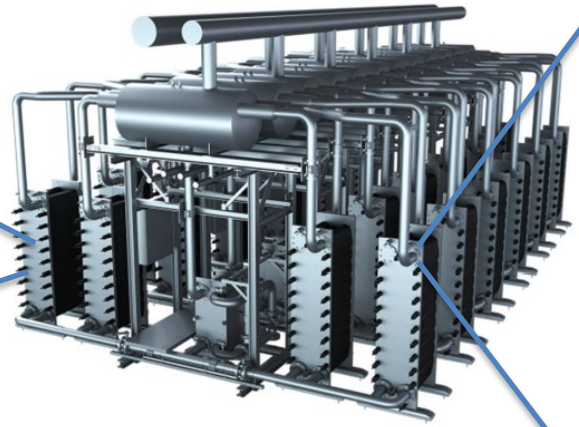
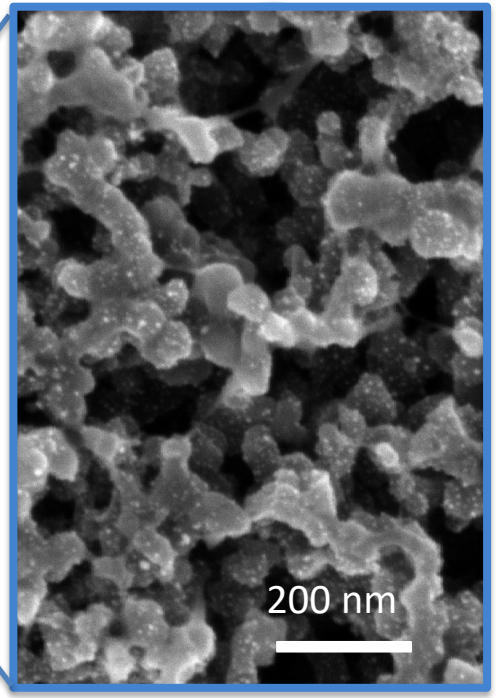
How can Hydrogen be produced?

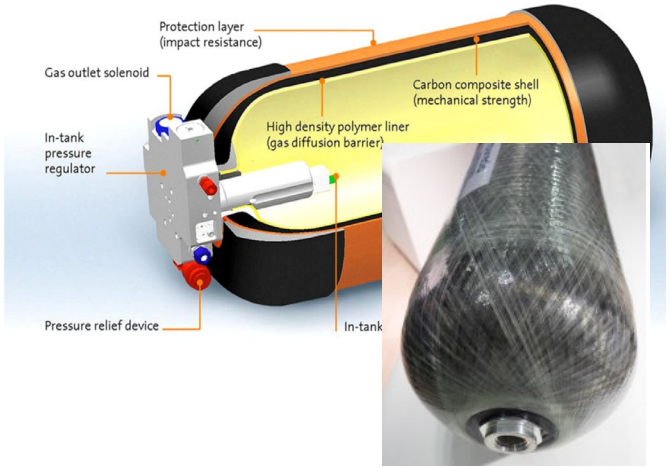


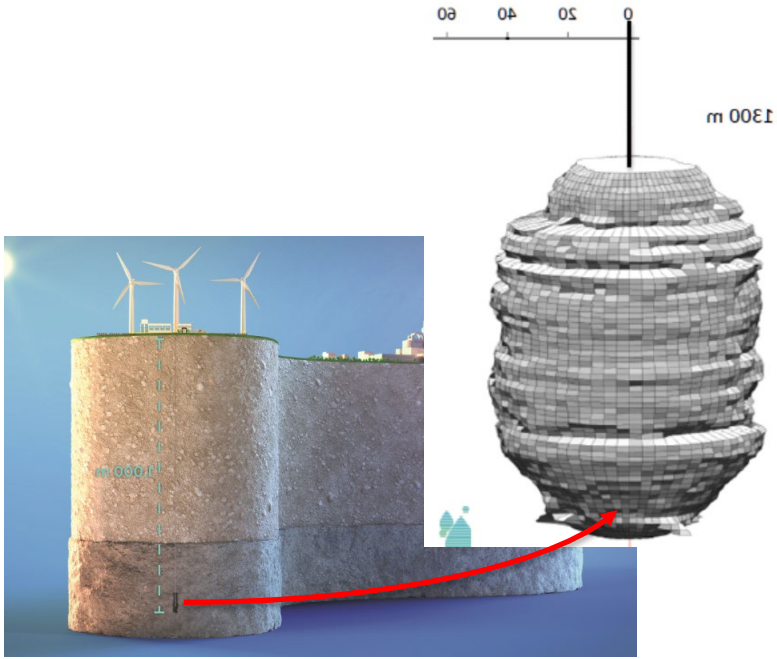




Lecture Outline

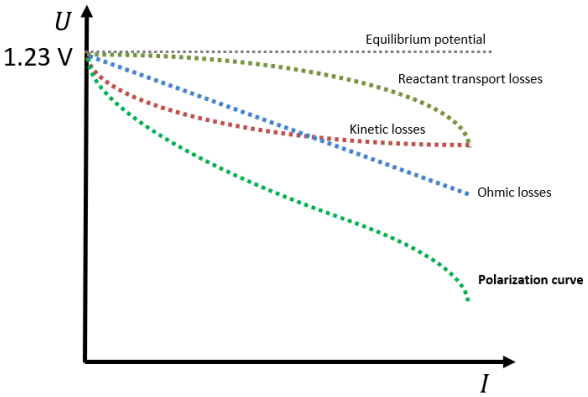
How can Hydrogen be stored and transported?





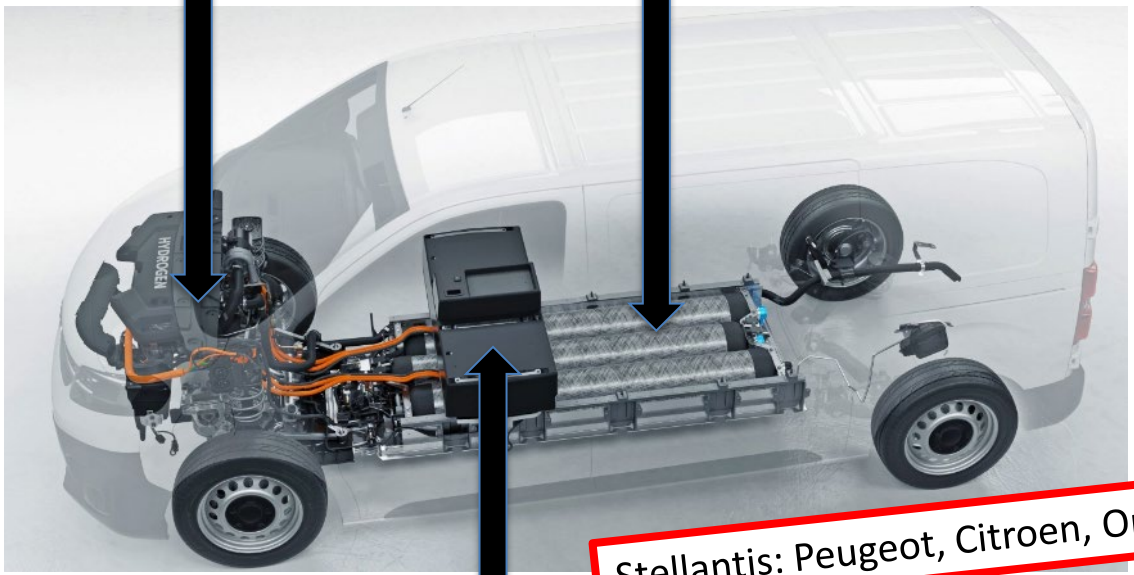
Lecture Outline

How can Hydrogen be used?



45 kW PEMFC

4.4 kg H_2

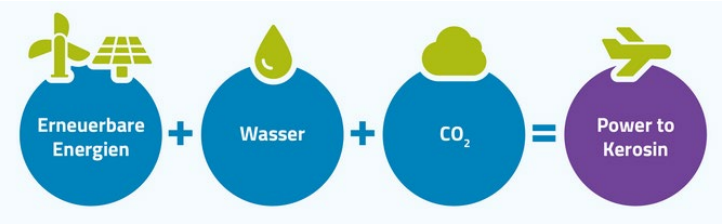


Stellantis: Peugeot, Citroen, Opel

10.5 kWh battery

Lecture Outline

How can Hydrogen be used?



„Power-to-X“

$$FeO_x + C \rightarrow Fe + CO_2$$

$$FeO_x + H_2 \rightarrow Fe + H_2O$$

Lecture Outline

1	07.10.2025 S0.13b	HYTECH 1	Hydrogen and Energy transition
1	07.10.2025 S0.13b	HYTECH 2	Hydrogen Production Overview
2	14.10.2025 S0.13b	HYTECH 3	Electrolysis - Electrochemistry and Thermodynamics
2	14.10.2025 S0.13b	HYTECH 4	Electrolysis - Kinetics, U-I-Curve
3	21.10.2025 S0.13b	HYTECH 5	Tutorial Hydrogen Production
3	21.10.2025 S0.13b	HYTECH 6	Tutorial Hydrogen Production
4	28.10.2025 S0.13b	HYTECH 7	Electrolysis - Membrane Materials
4	28.10.2025 S0.13b	HYTECH 8	Electrolysis - Catalysis, Electrodes
5	04.11.2025 S0.13b	HYTECH 9	Hydrogen Storage - Compression, Liquefication
5	04.11.2025 S0.13b	HYTECH 10	Hydrogen Storage - Metal Hydrides, LOHCs, Ammonia
6	11.11.2025 S0.13b	HYTECH 11	Fuel Cells - Introduction
6	11.11.2025 S0.13b	HYTECH 12	Fuel Cells - Thermodynamics and Polarization
7	18.11.2025 S0.13b	HYTECH 13	Fuel Cells - Systems
7	18.11.2025 S0.13b	HYTECH 14	Fuel Cells - Materials
8	25.11.2025 S0.13b	HYTECH 15	Characterization Methods
8	25.11.2025 S0.13b	HYTECH 16	Characterization Methods
9	02.12.2025 S0.13b	HYTECH 17	Tutorial Fuel Cells
9	02.12.2025 S0.13b	HYTECH 18	Tutorial Fuel Cells
10	09.12.2025 S0.13b	HYTECH 19	Electrolysis and Fuel Cells: Material Level Degradation
10	09.12.2025 S0.13b	HYTECH 20	Electrolysis and Fuel Cells: System Level Degradatiion
11	16.12.2025 S0.13b	HYTECH 21	Power to Liquid
11	16.12.2025 S0.13b	HYTECH 22	Power to Liquid
12	23.12.2025 S0.13b	HYTECH 23	Lab-Tour
12	23.12.2025 S0.13b	HYTECH 24	Lab-Tour
12	13.01.2026 S0.13b	HYTECH 25	?
12	13.01.2026 S0.13b	HYTECH 26	?
13	20.01.2026 S0.13b	HYTECH 27	Repetition und exam preparation
13	20.01.2026 S0.13b	HYTECH 28	Repetition und exam preparation

Introduction

H_2 production

H_2 storage and logistics

H_2 Utilization

TBA

Why?

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Goals for Lecture 1

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Unterstanding of:

- **How is our (german) energy system built?**
- **What‘s the plan for the „Energiewende“?**
- **Why will Hydrogen play a major role in the „Energiewende“?**

Energy System ~ 1960

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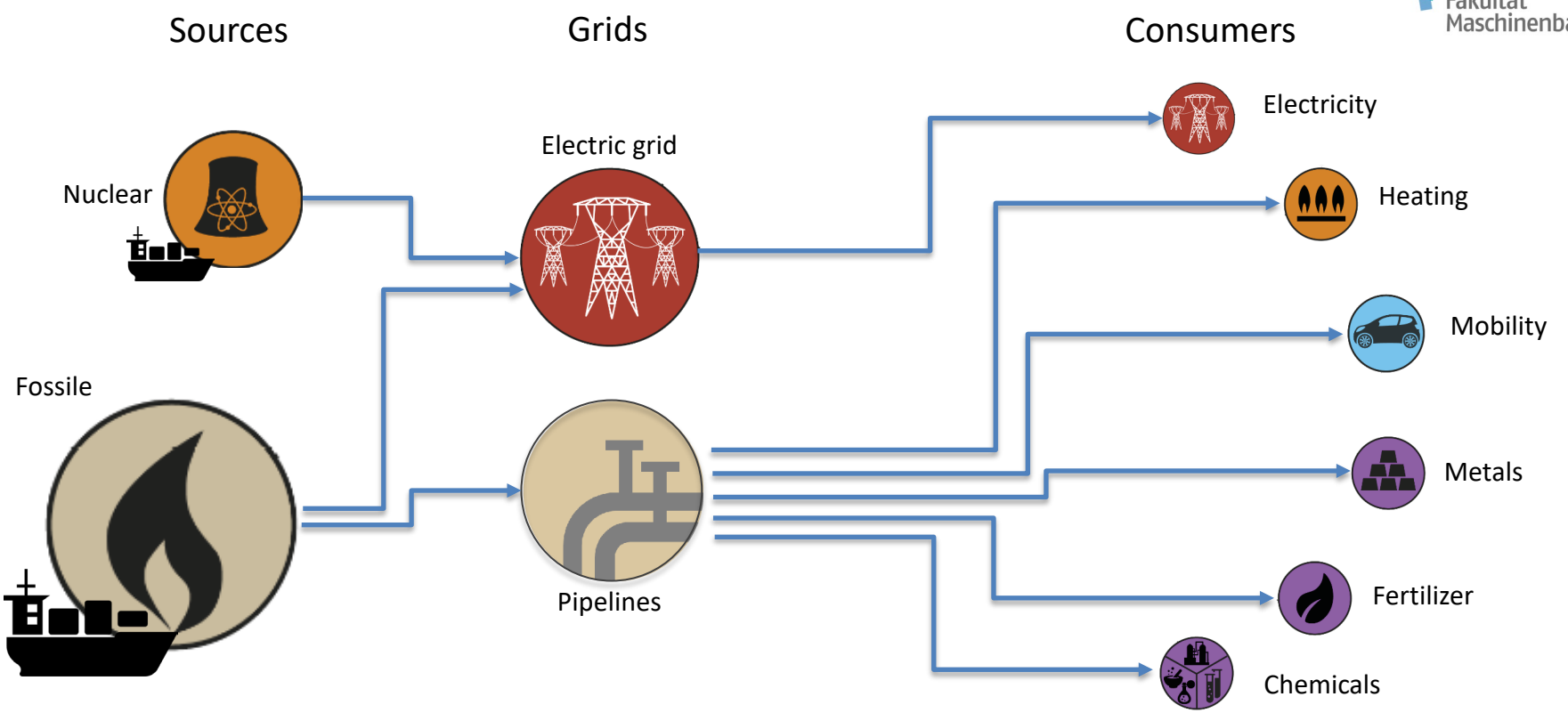
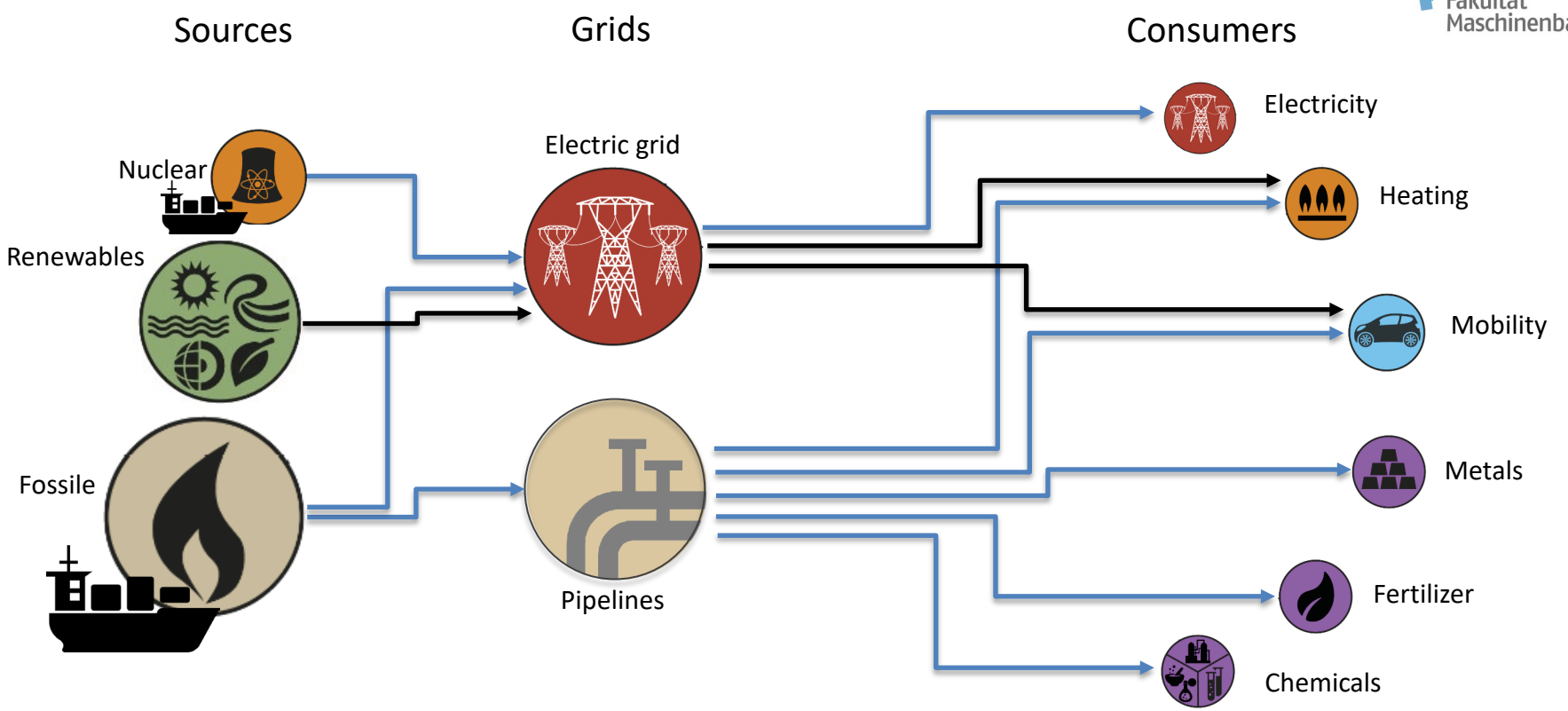


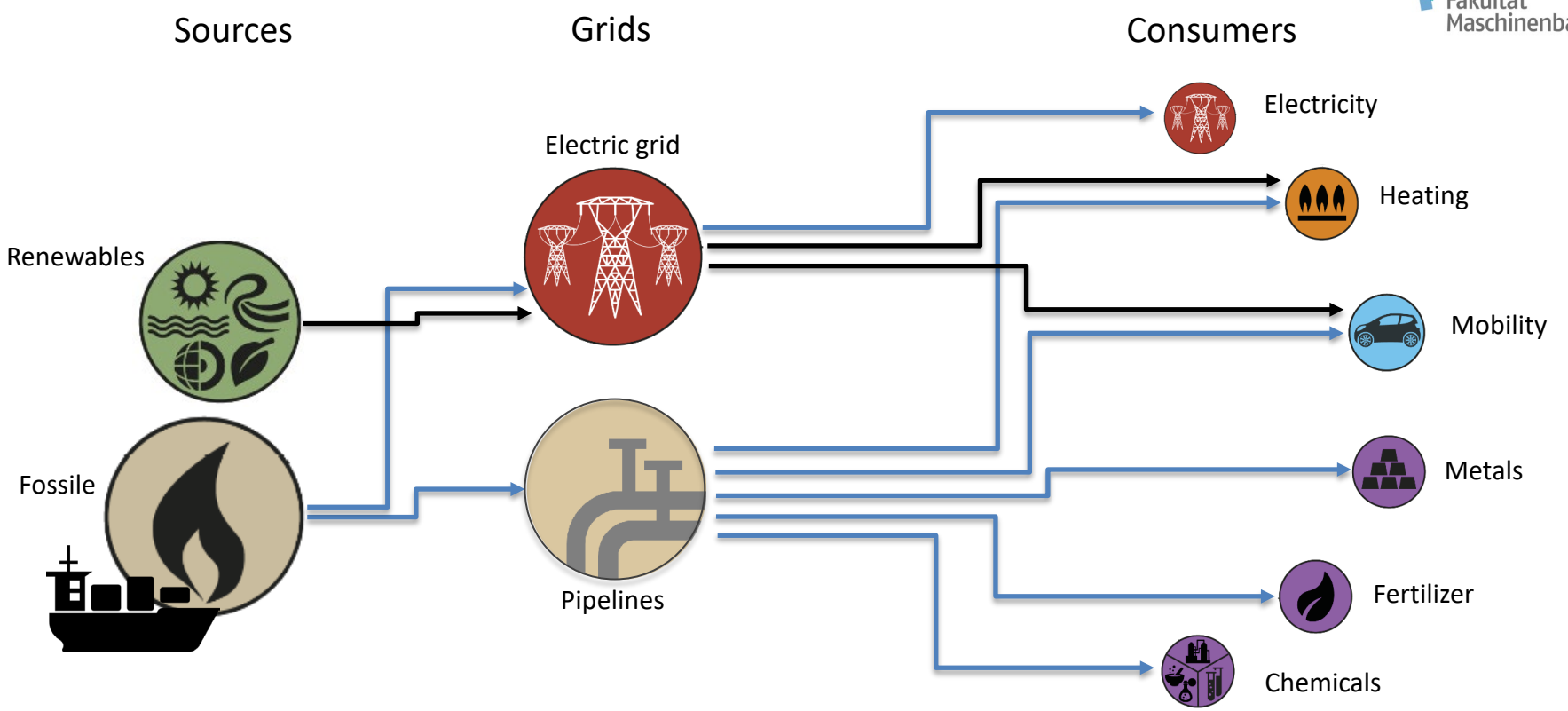
Icons by NREL

Energy System at the moment



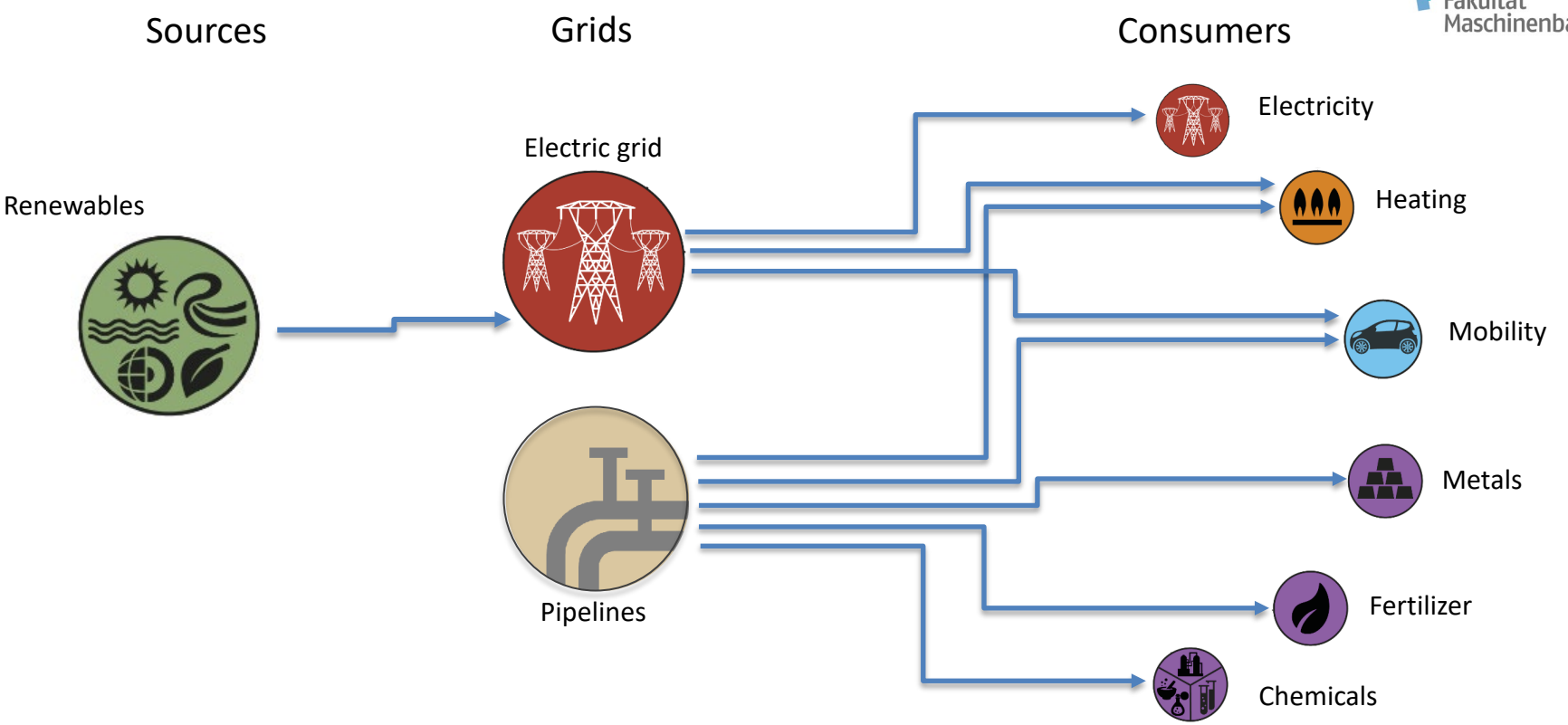
Icons by NREL

Energy System at the moment (update 2023)



Icons by NREL

Energy Transition Means: No Fossile Primary Sources!



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Energy Transition Means: No Fossile Primary Sources!

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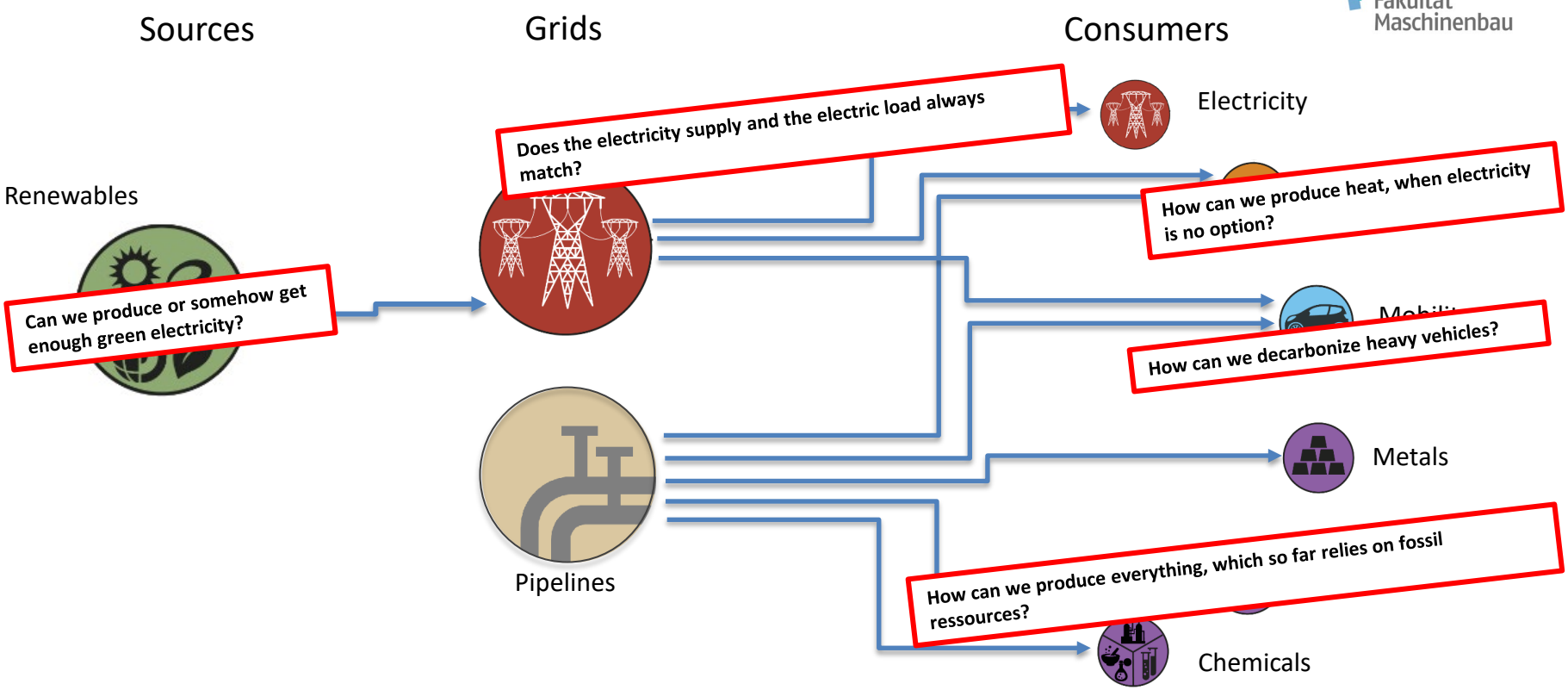

Icons by NREL

Energy System of the Future

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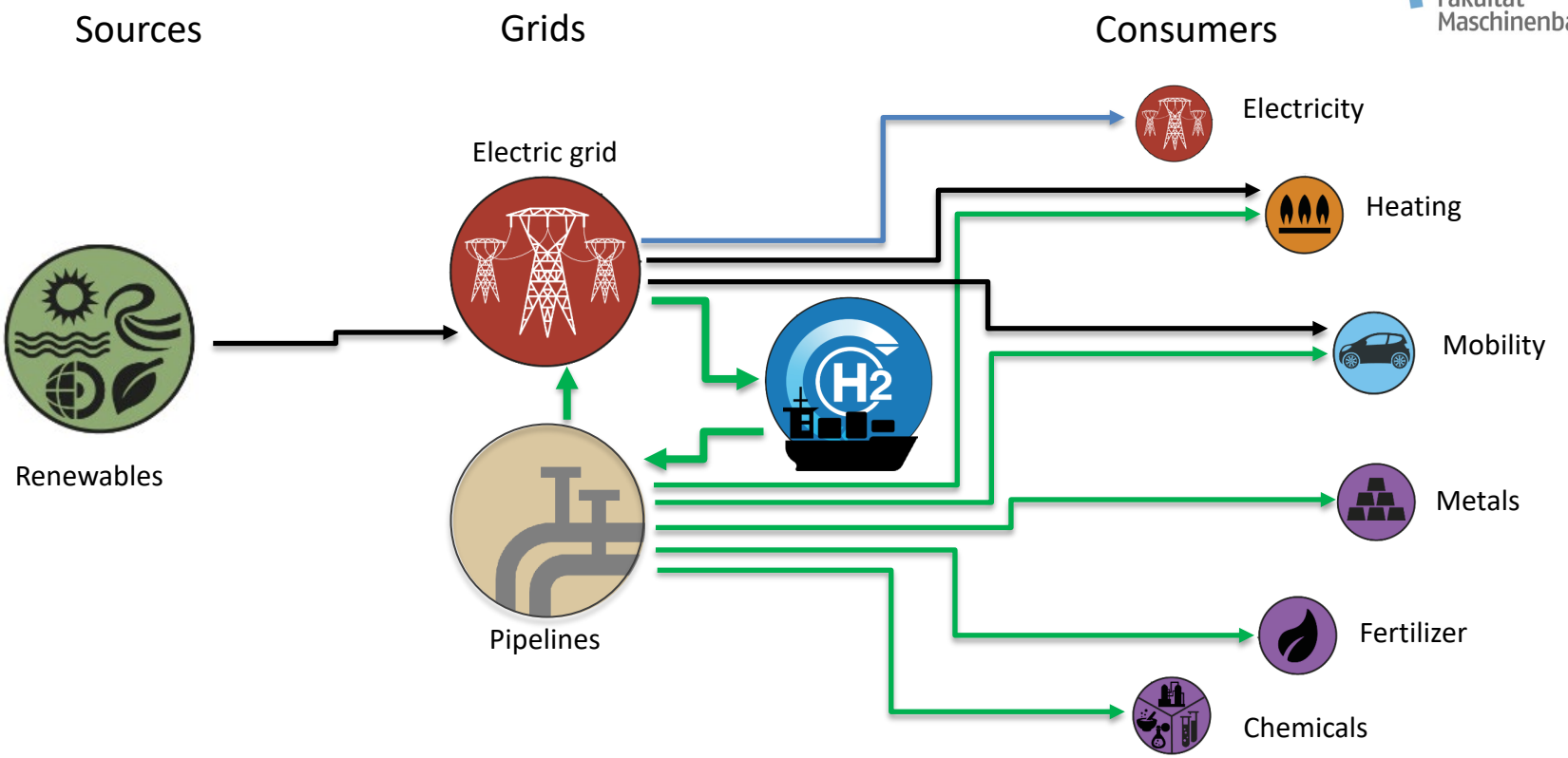

Icons by NREL

Numbers: Why is Hydrogen a „must have“?

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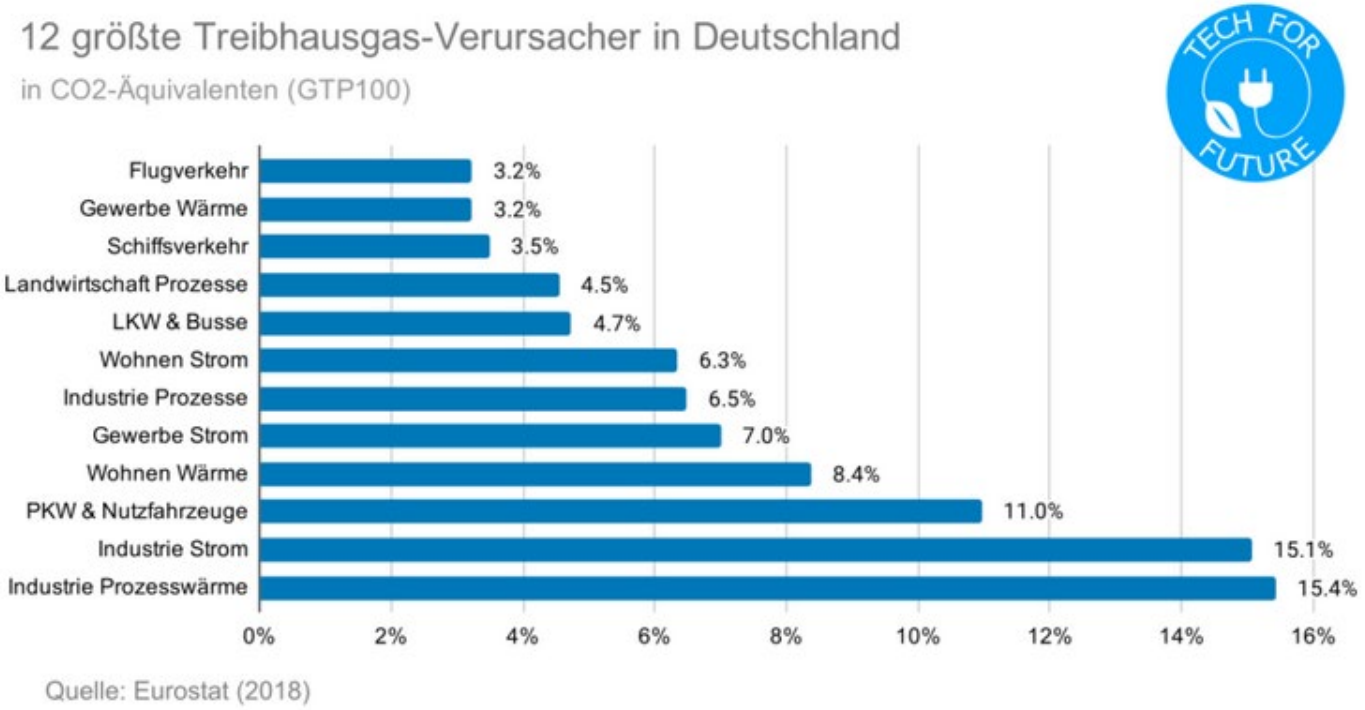

Numbers: Why is Hydrogen a „must have“?

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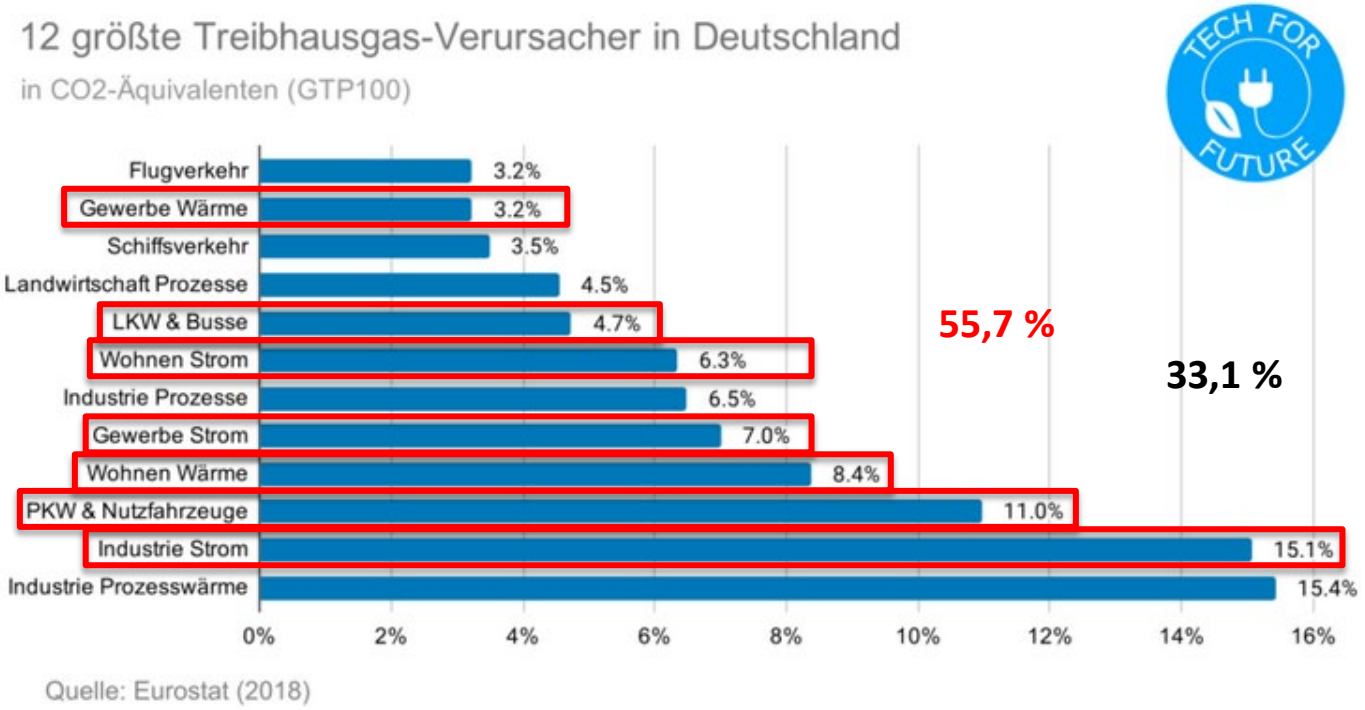

- Green electricity unfortunately isn‘t directly applicable everywhere!

How much Energy are we talking about?

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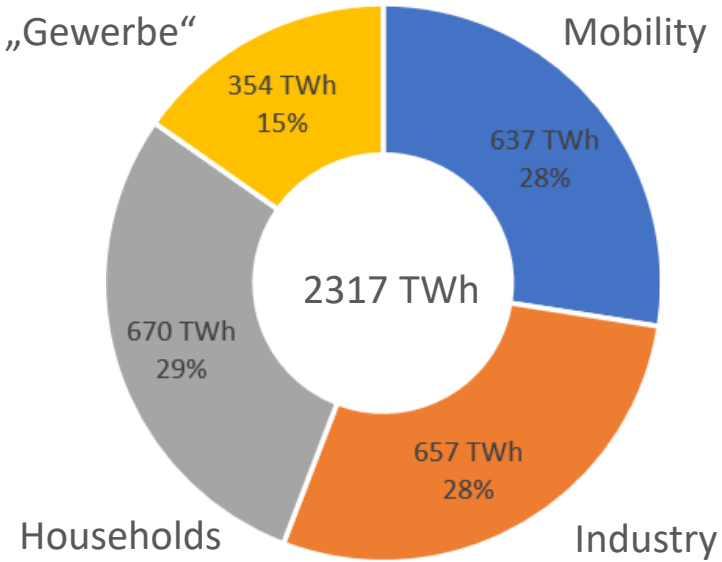
How much energy do we use, and where do we get it from?



Umweltbundesamt auf Basis AG Energiebilanzen, Stand 09/21

„Energiewende“ and Energy Consumption per Year

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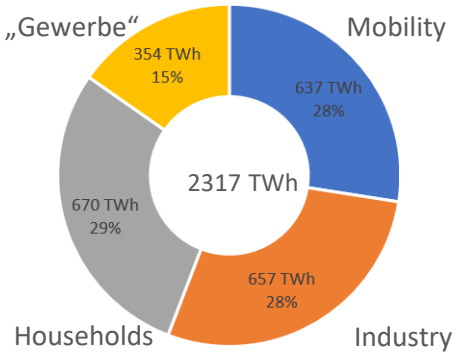
How much energy do we use, and where do we get it from?



Umweltbundesamt auf Basis AG Energiebilanzen,
Stand 09/21

Example 1: Nuclear Power Plant: 1400 MW

- 2317 TW/ 1400 MW = 1.6 Mio.
- 2317 TWh: Would require 1.6 Mio. nuclear power plants if produced within one hour
- 2317 TWh: Would require 182 nuclear power plants if produced within 1 year

Example 2: Coal

- Heating value: 8kWh / kg
- 2317 TWh: 289.625 Mio. T

„Energiewende“ and Energy Consumption per Year

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University of Applied Sciences
Fakultät Maschinenbau

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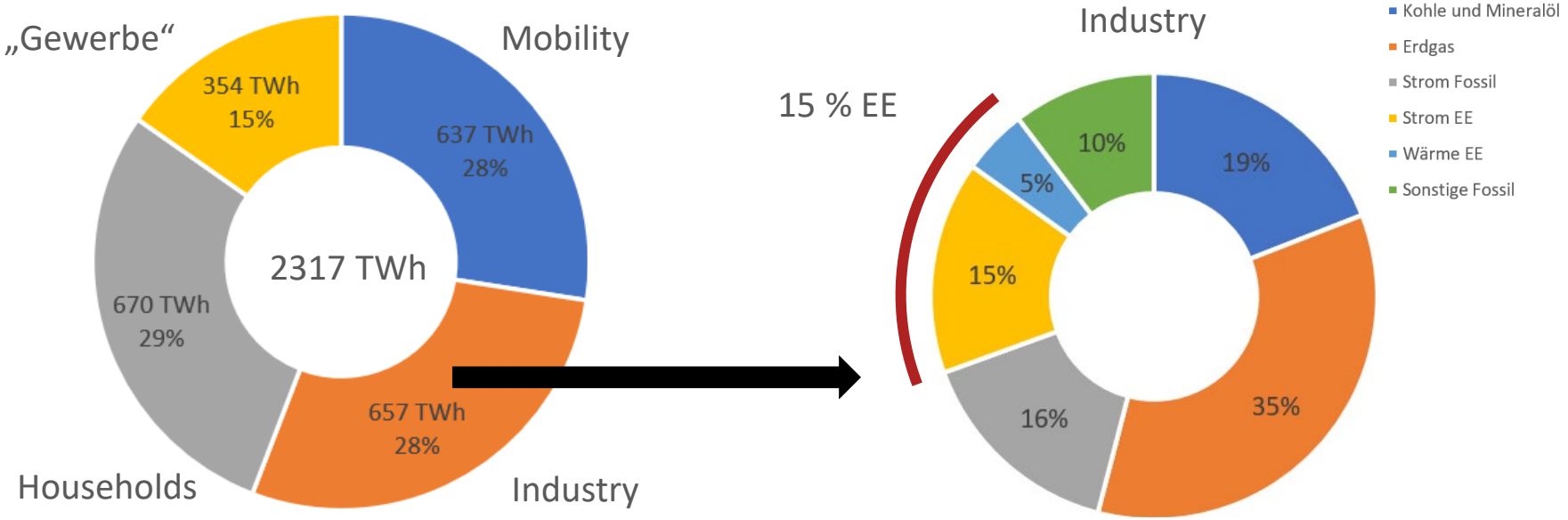

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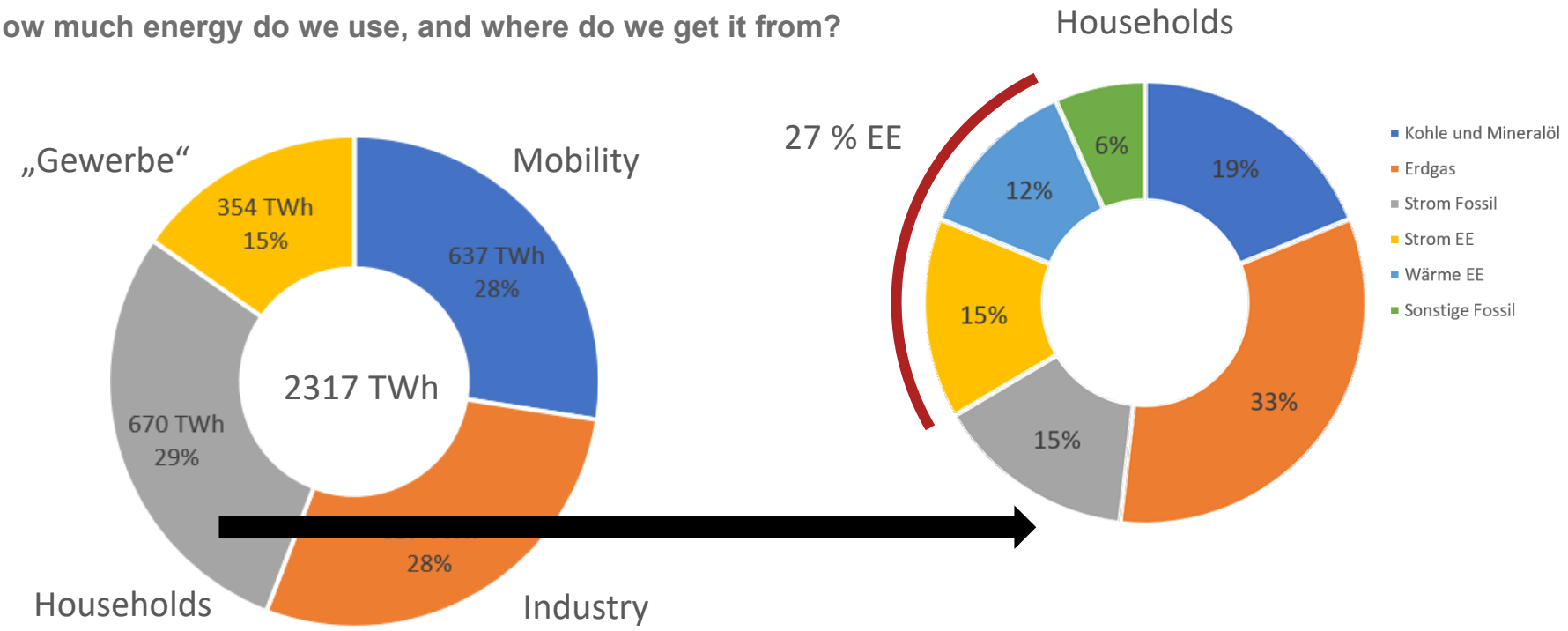

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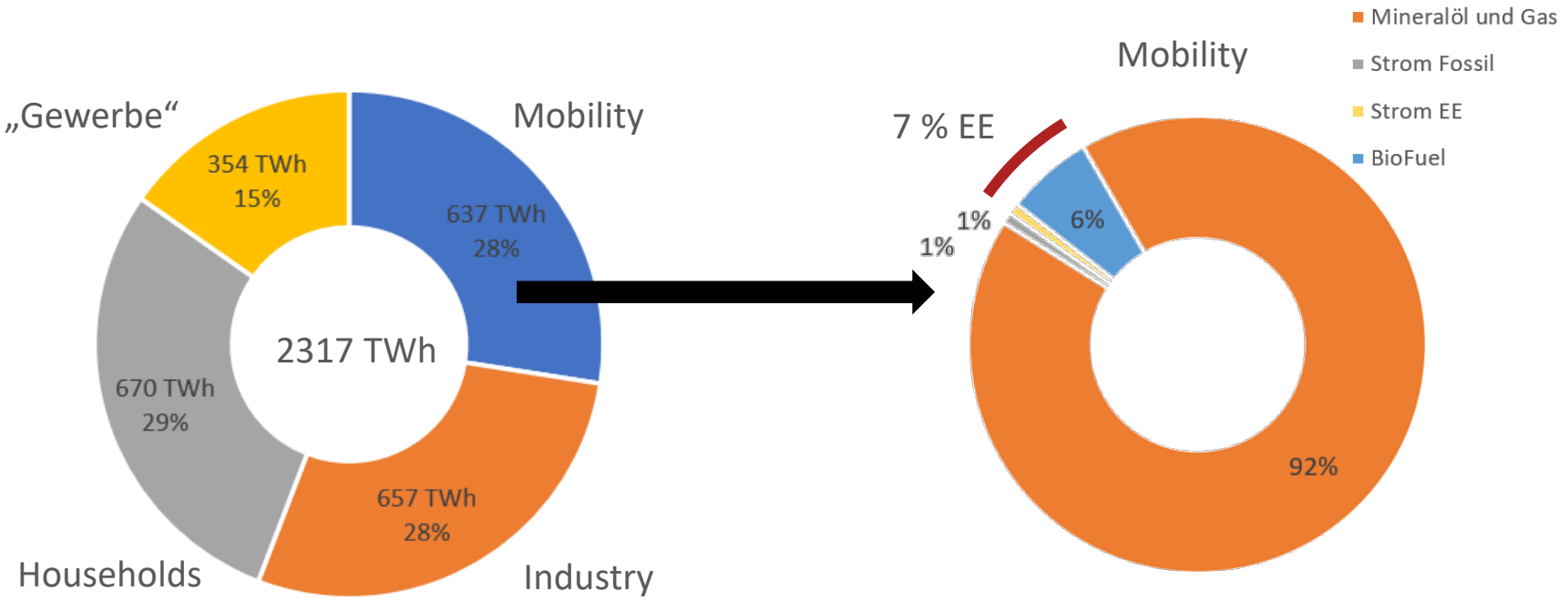

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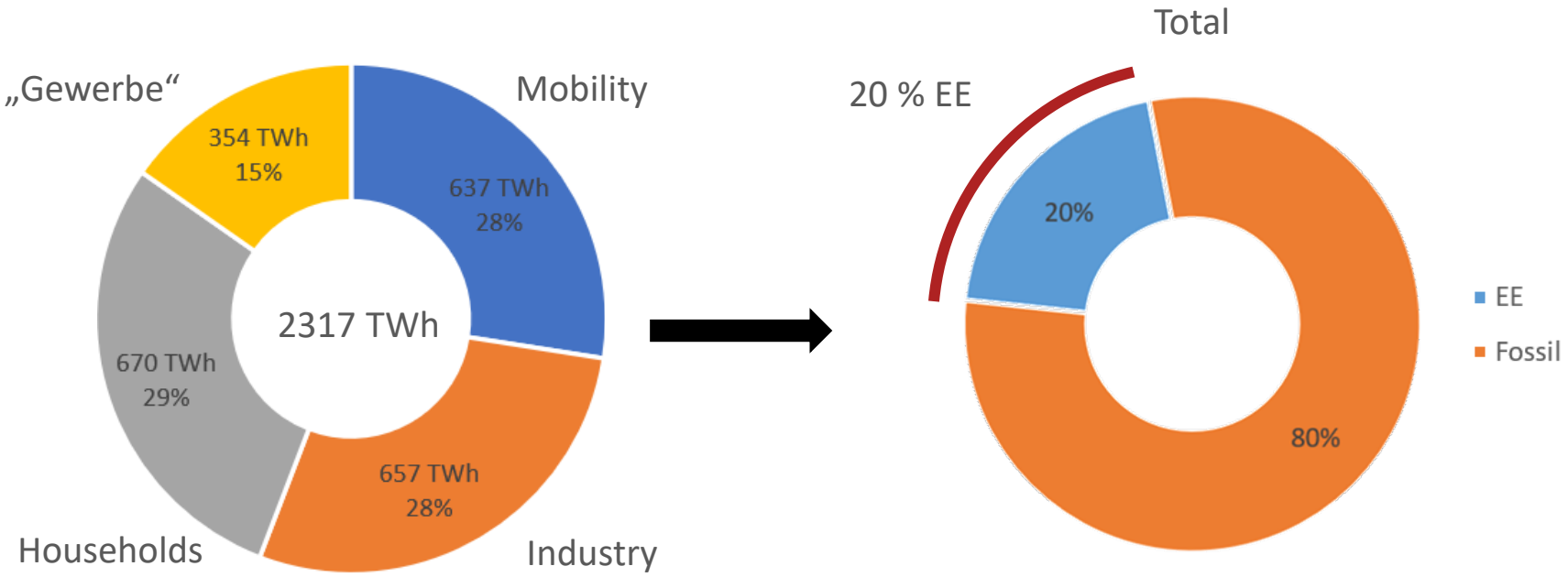

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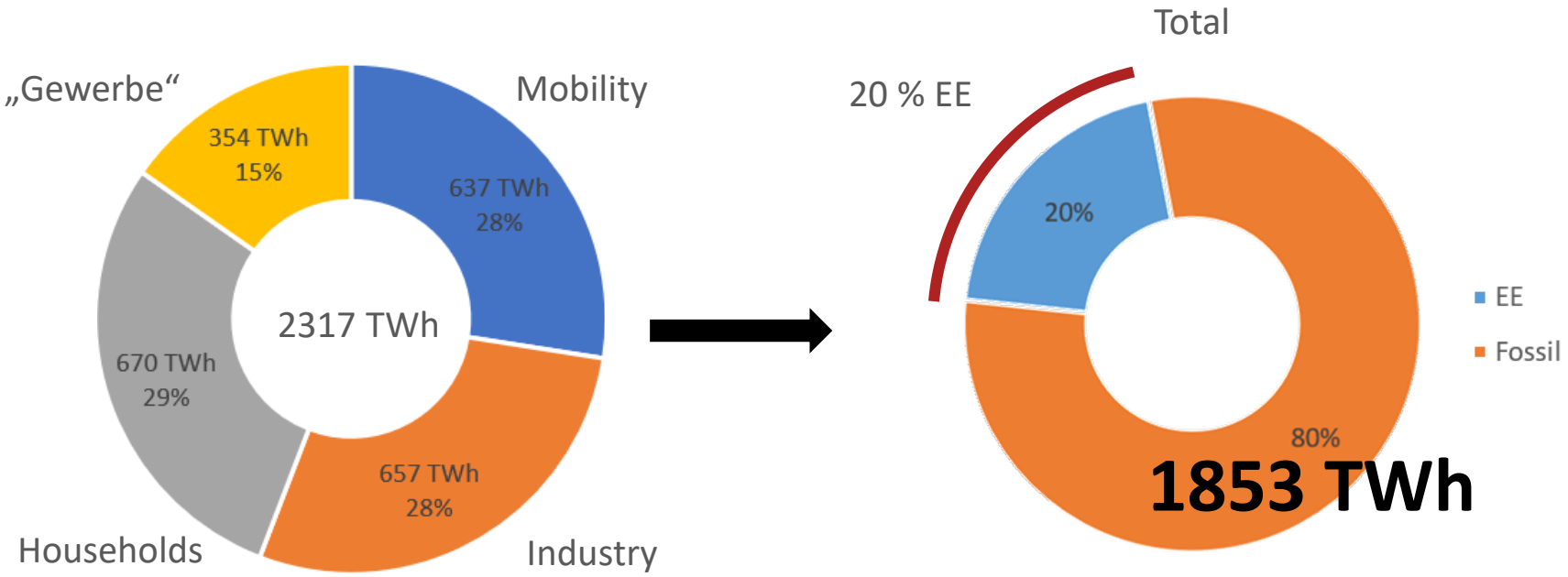

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„Energiewende“ and Energy Consumption

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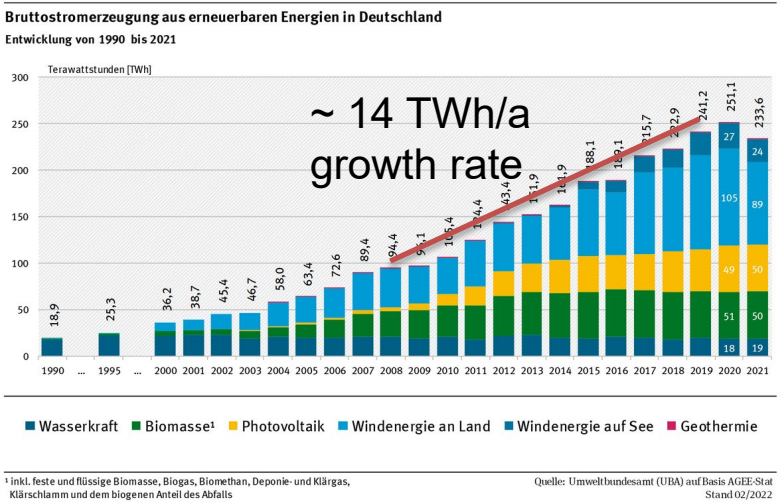
- Energiewende means substitution of 1853 TWh fossil energy in all sectors
- For comparison: 2021 produced 233 TWh clean electricity!
- „Ausbau“ is too slow
  - ~ 100 years



- We have too little green electricity for a succesfull „Energiewende“

„Energiewende supply-demand mismatch“

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- **We mostly have green electricity when the sun is shining and winds are blowing**

www.energy-charts.info

Current prolems of electricity-based „Energiewende“ (summary)

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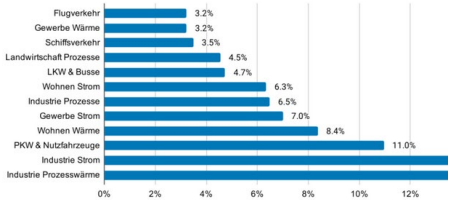
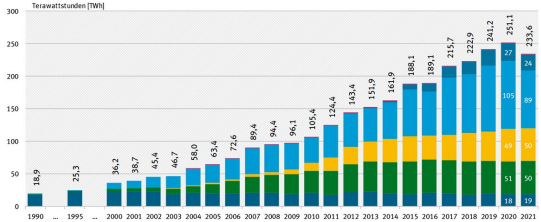
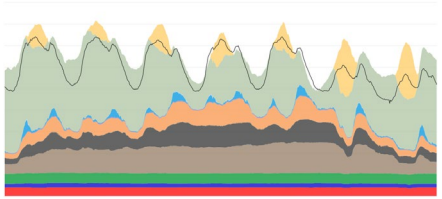
- **Green electricity unfortunately isn‘t directly applicable everywhere!**
- **We have too little green electricity**
- **We mostly have green electricity when the sun is shining and winds are blowing**







Current prolems of electricity-based „Energiewende“ (summary)

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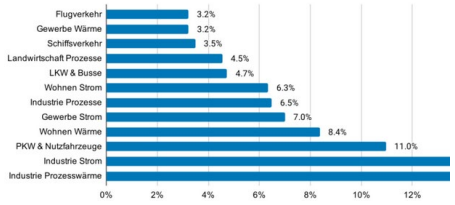
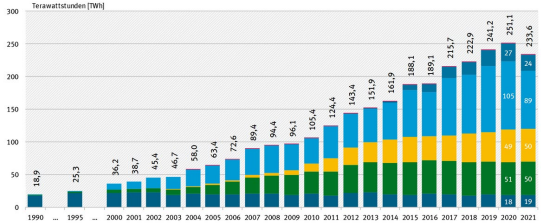
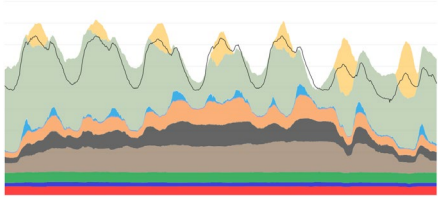
- **Green electricity unfortunately isn‘t directly applicable everywhere!**
  - Find green solutions for emitters which can‘t be electrified
- **We have too little green electricity**
  - Scale up local green electricity production as fast as possible
  - Find a way for importing green energy
- **We mostly have green electricity when the sun is shining and winds are blowing**
  - Scale up green energy storage







For a sucessful „Energiewende“, we need to…

- Find green solutions for emitters which can‘t be electrified
- Scale up local green electricity production as fast as possible
- Find a way for importing green energy
- Scale up green energy storage

For a sucessful „Energiewende“, we need to…

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- Find green solutions for emitters which can‘t be electrified
- Scale up local green electricity production as fast as possible
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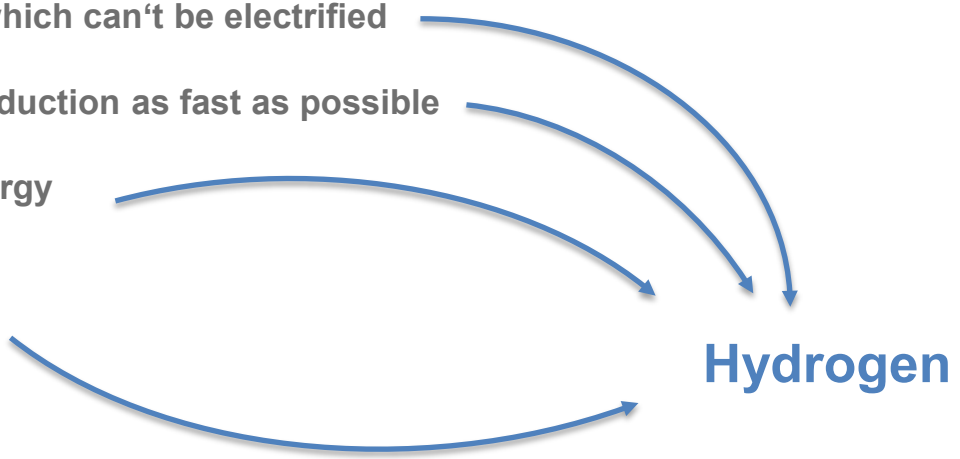

German national „Wasserstoffstrategie“

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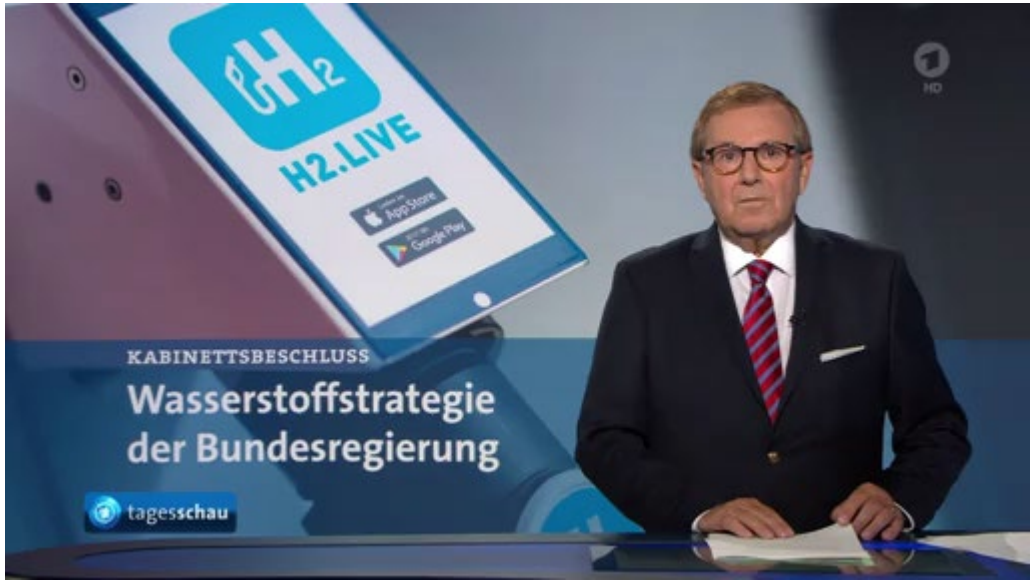
This insight lead to the German national „Wasserstoffstrategie“ in 2020.



Tagesschau, 10.06.20

Find green solutions for emitters which can‘t be electrified

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Chemicals (e.g. Ammonia)

~2 % of global CO2 emissions!

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Green H2 instead of „grey“ H2

Steel

~8 % of global CO2 emissions!

$$FeO_x + C \rightarrow Fe + CO_2$$

$$FeO_x + H_2 \rightarrow Fe + H_2O$$

Green hydrogen as reduction agent

Find green solutions for emitters which can‘t be electrified

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tagesschau Sendung verpasst?

Startseite ▸ Wirtschaft ▸ Unternehmen ▸ Grüner Stahl: EU genehmigt Milliarden-Beihilfe für Thyssenkrupp

Grüner Stahl

EU erlaubt Milliarden-Beihilfe für Thyssenkrupp

Stand: 20.07.2023 14:44 Uhr

Für den Bau einer Anlage zur grünen Stahlproduktion soll Thyssenkrupp bis zu zwei Milliarden Euro erhalten. Nun hat auch die EU-Kommission die Hilfen genehmigt. Mit dem Projekt könnten fast 60 Millionen Tonnen CO2 eingespart werden.

Find green solutions for emitters which can‘t be electrified

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Heavy Duty Transportation

H2 fuel cells or direct combustion
instead of using fossile fuels

Aviation

H2 fuel cells or direct combustion
instead of using fossile fuels

Find green solutions for emitters which can‘t be electrified

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Kirchheim

EU-Hürden für Brennstoffzellen aus Kirchheim: Politik soll helfen

Wirtschaft Auf europäischer Ebene werden den Brennstoffzellen-Pionieren von Cellcentric mit Sitz in Nabern derzeit einige Steine in den Weg gelegt. Grünen-Fraktionschef Andreas Schwarz sagt bei einem Besuch Unterstützung zu. *Von Thomas Zapp*

12.09.2023

Cellcentric-CEO Dr. Matthias Jurytko (r.) und Prof. Christian Mohrdieck (2. v. r.) zeigen der Gruppe mit Tayfun Tok, Felix Herkens, Andreas Schwarz und Muhterem Aras (v. l.) die ursprüngliche Brennstoffzelle für Autos. Sie wurde weiterentwickelt, und zwei von ihr treiben heute einen Lkw an. Foto: Carsten Ried

BRENNSTOFFZELLEN-FLUGZEUG

HY4 fliegt mit flüssigem Wasserstoff weiter als zuvor

Brennstoffzellen mit flüssigem Wasserstoff zu betreiben, hat Vorteile. Das Flugzeug konnte doppelt so weit fliegen wie zuvor.

in Pocket speichern | merken

11. September 2023, 13:30 Uhr, Werner Pluta

(Bild: H2Fly)

Brennstoffzellenflieger HY4: 1.500 Kilometer Reichweite statt 750

Das Wasserstoffflugzeug HY4 ist erstmals mit flüssigem Wasserstoff als Treibstoff geflogen. Flüssiger Wasserstoff hat einige Vorteile gegenüber gasförmigem.

Scale up local green electricity production as fast as possible

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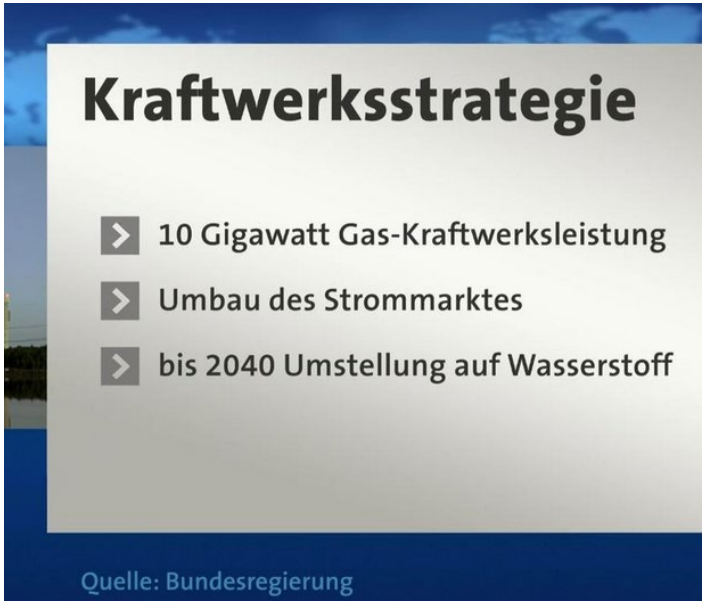
- In addition to the much needed „Ausbau“ of PV and wind, hydrogen power plants can add to a greener electricity mix!



Find a way for importing green energy

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- Importing electricity is very difficult (see Desert-Tec project)!
- Hydrogen (and hydrogen derivates) are promising carriert for importing green energy!

Scale up green energy (electricity) storage

Speichern von Wasserstoff: Kaverne besteht Test zur Dichtheit

Stand: 18.02.2023 13:14 Uhr

In den unterirdischen Speichern für Öl und Gas in Etzel (Landkreis Wittmund) ist erstmals testweise auch Wasserstoff gespeichert worden. Der Kavernenbetreiber Storag spricht von einem Meilenstein.

Scale up green energy (electricity) storage

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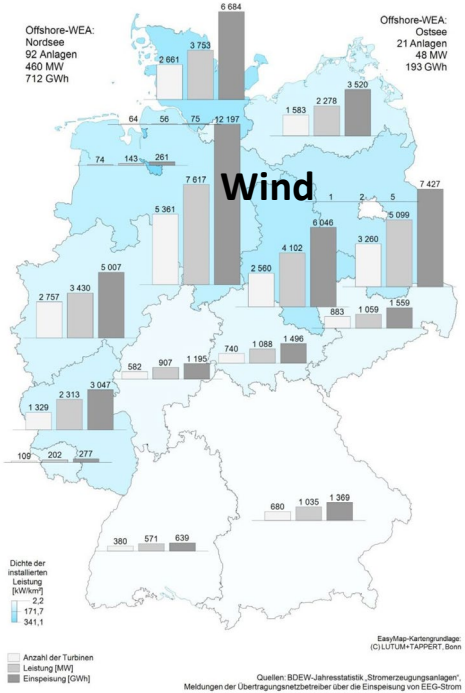
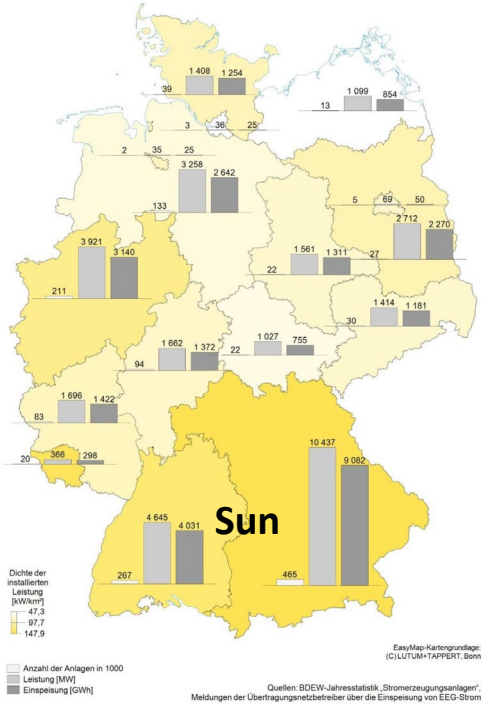
University of Applied Sciences

Fakultät Maschinenbau

Hydrogen enables mobile energy storage

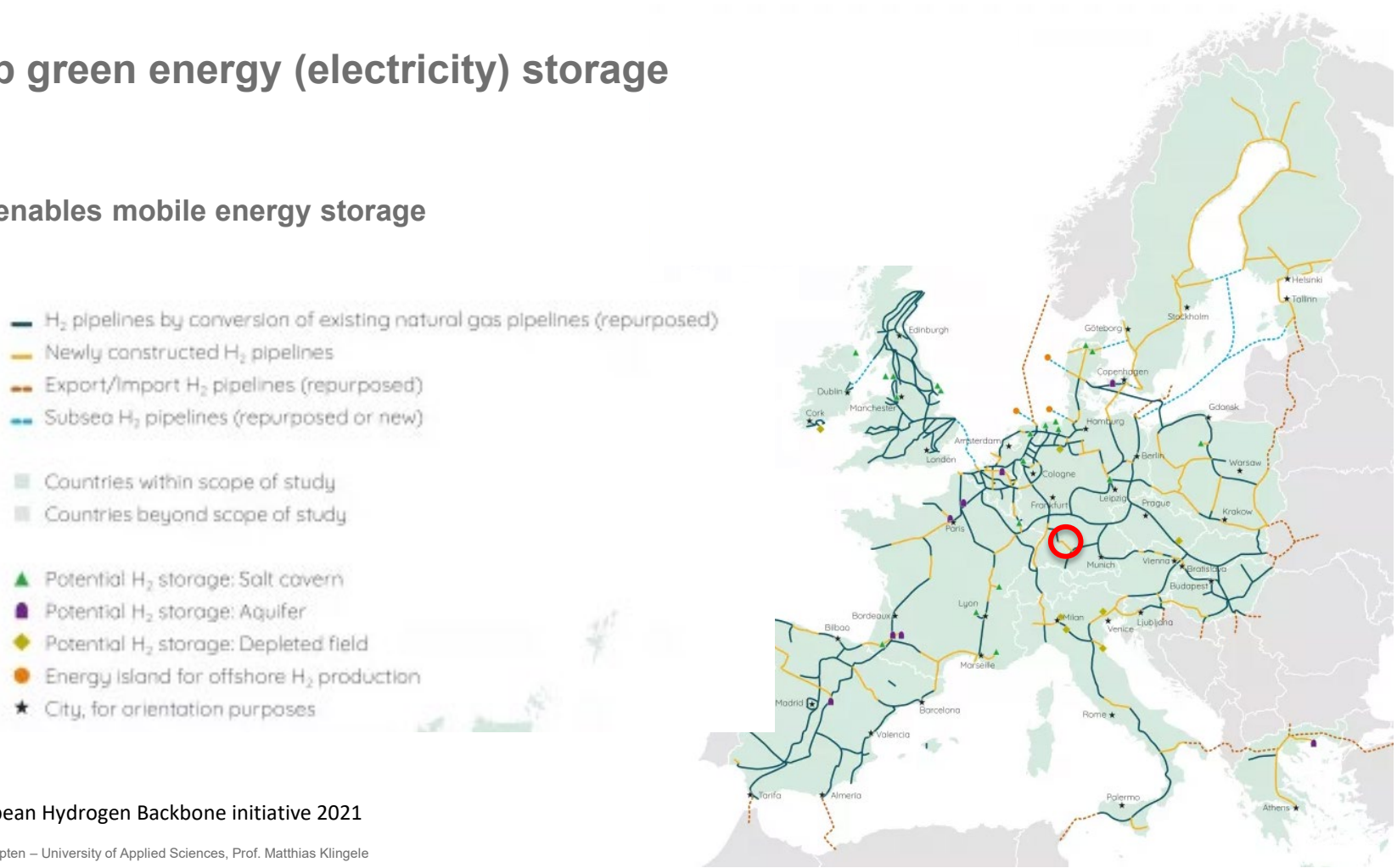




TH Regensburg FENES, 2013

Scale up green energy (electricity) storage

Hydrogen enables mobile energy storage



Source: European Hydrogen Backbone initiative 2021

Hydrogen is needed!

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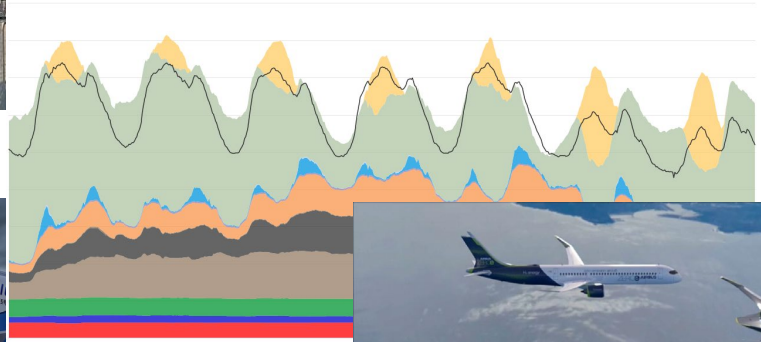
We need massive amounts of Hydrogen!



How much Hydrogen will we need in Germany?

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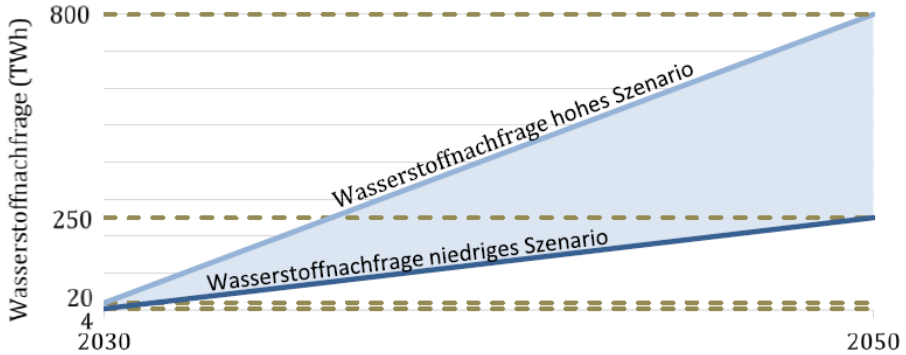
„Technologieoffenheit“ makes a precise prediction very difficult

Today: ~ 60 TWh (chemicals)

2050: ~ 250 – 800 TWh

Green Hydrogen demand in Germany per year



„TWh“ refers to lower heating value (1kg H_2 is 33 kWh)

800 TWh_{H2} are 24 Megatons H_2

Fraunhofer, „Eine Wasserstoff-Roadmap für Deutschland“, 2019

How much Hydrogen will we need in Germany?

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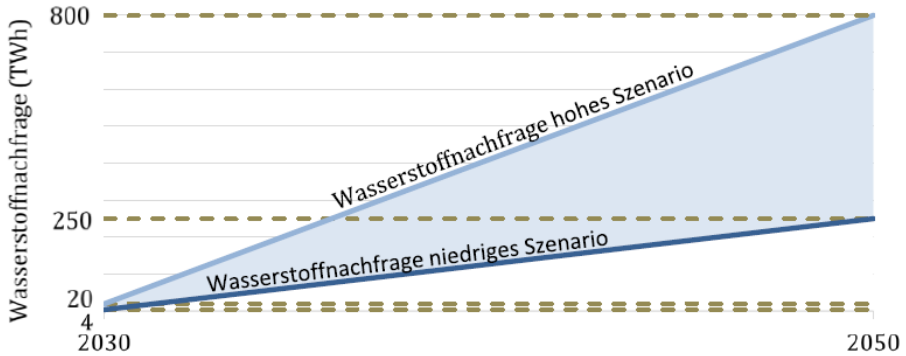
„Technologieoffenheit“ makes a precise prediction very difficult

Today: ~ 60 TWh (chemicals)

2050: ~ 250 – 800 TWh

Comparison: 75 Megatons natural gas/a in Germany!

Green Hydrogen demand in Germany per year



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Hydrogen gains political and public interest!

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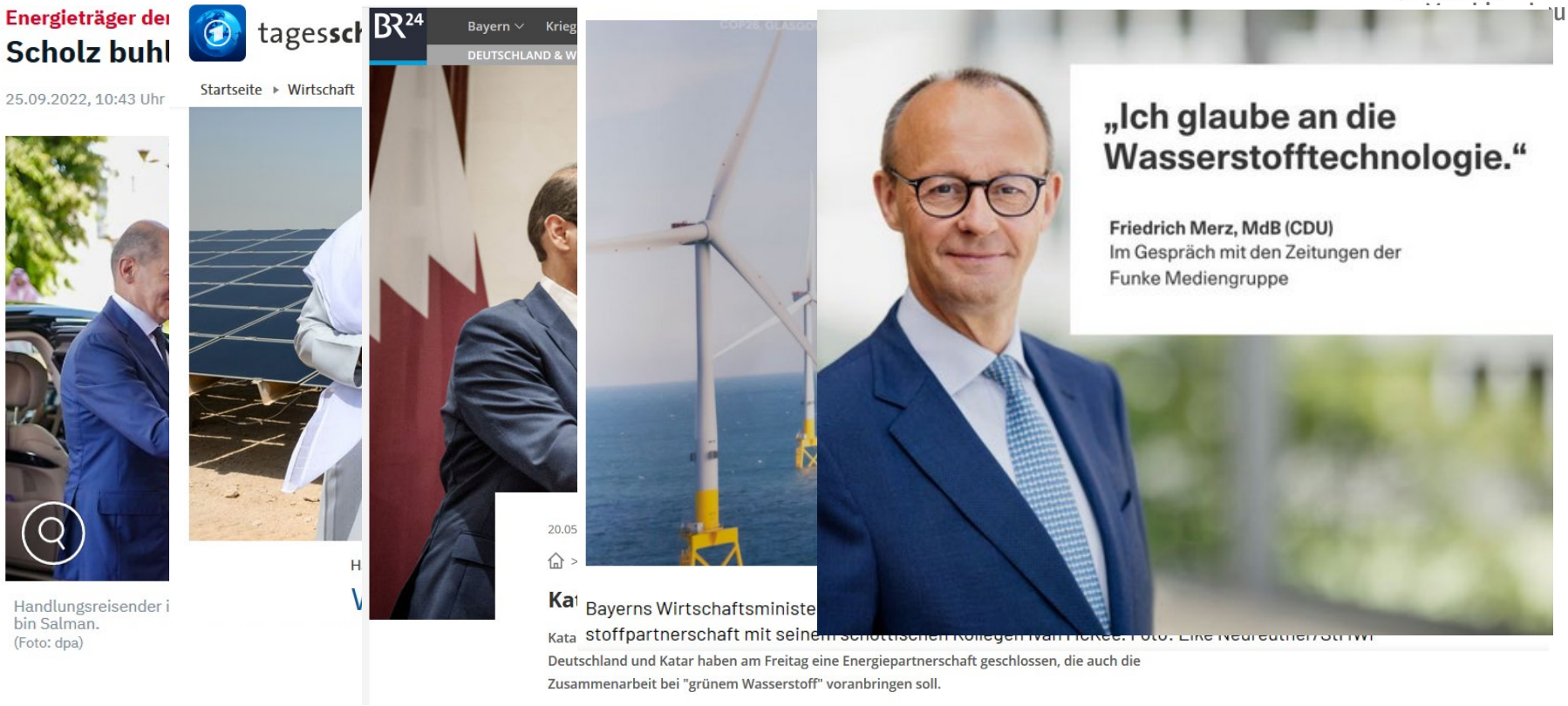

Next: Production of Hydrogen

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- Reformation of Methane
- Gasification of Coal
- Direct splitting of Hydrocarbons
- Direct splitting of water (Electrolysis)

