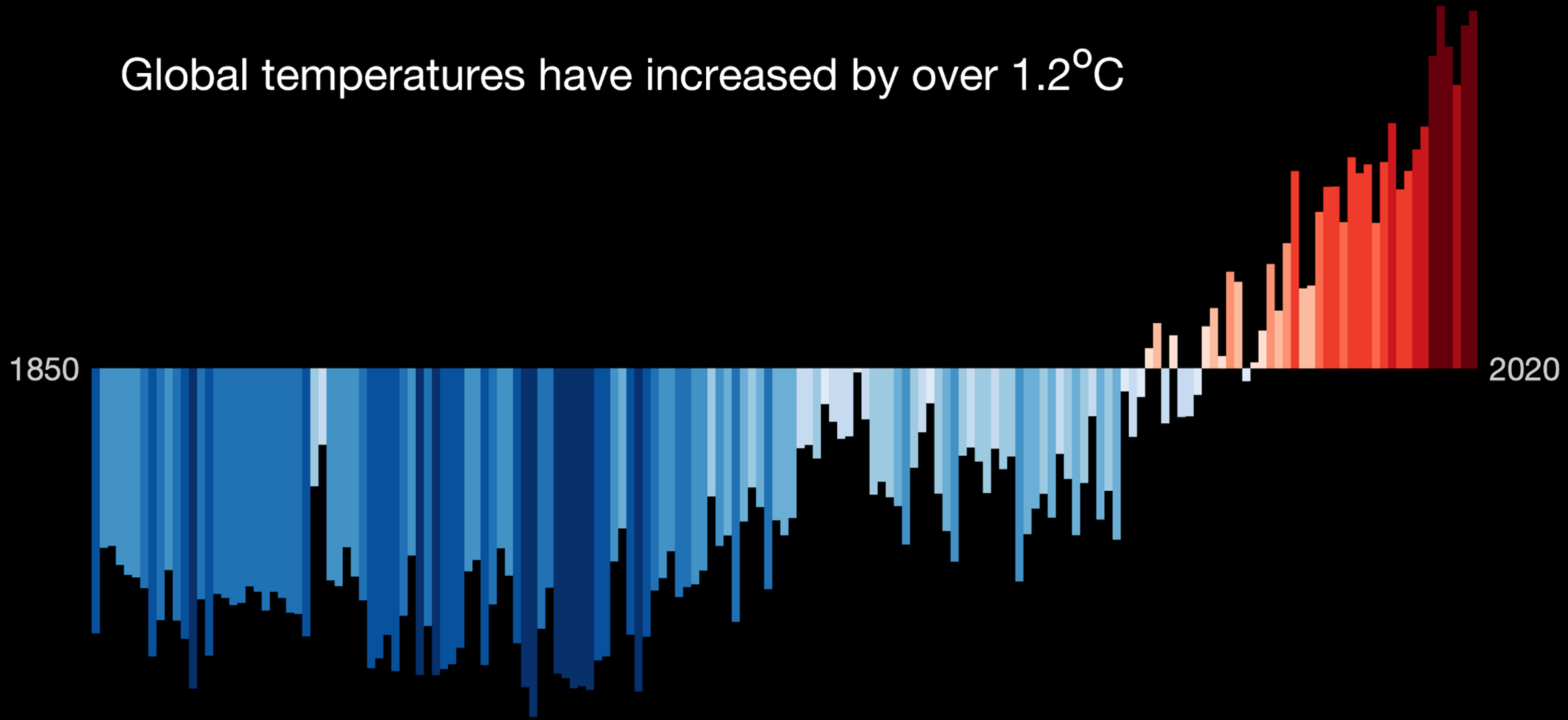
Wasserstoff – Energieträger für die Mobilität der Zukunft?

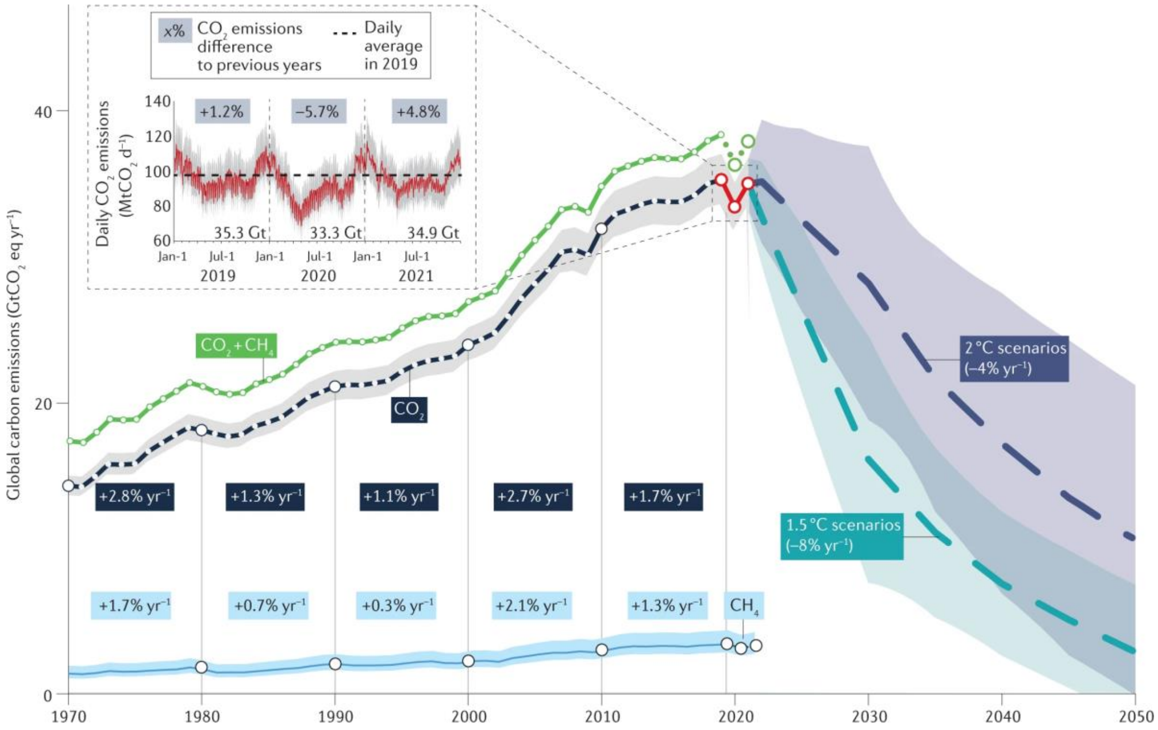
Impulsvortrag zu „Krieg, Klima, Kraftstoffe: Wie bringen wir die Verkehrswende durch die Krise?“ – 24.11.2022

Prof. Dr.-Ing. Clemens Biet – FG Integrierte Modellierung energieeffizienter Fahrzeugantriebsstränge

Global temperatures have increased by over 1.2°C

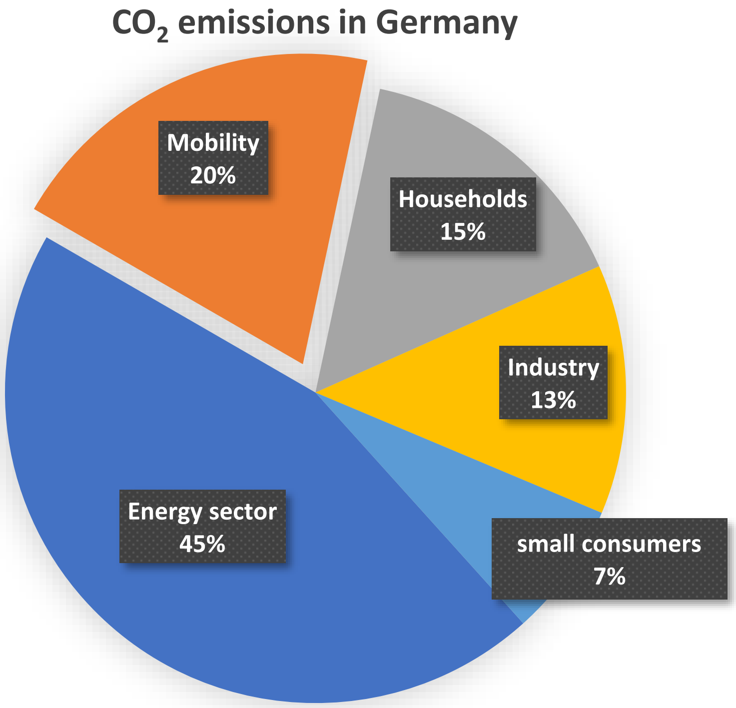


Global carbon emissions



Liu, Z., Deng, Z., Davis, S.J. *et al.* Monitoring global carbon emissions in 2021. *Nat Rev Earth Environ* **3**, 217–219 (2022). https://doi.org/10.1038/s43017-022-00285-w

What share belongs to traffic? (Germany)



Development since 1990:

- Doubling of the transport volume in passenger km
- Doubling of the amount of transported goods

- 70% of freight traffic is on the road

- 100 million new vehicles per year
- Turnover of 4 trillion US$
  (approximately equal to Germanys gross national product)
- 9 million direct employees
- 114 billion Euro for research and development

Dilemma

Climate change

Dependency on crude oil and natural gas as primary energy source

Steady growth of private and freight transport

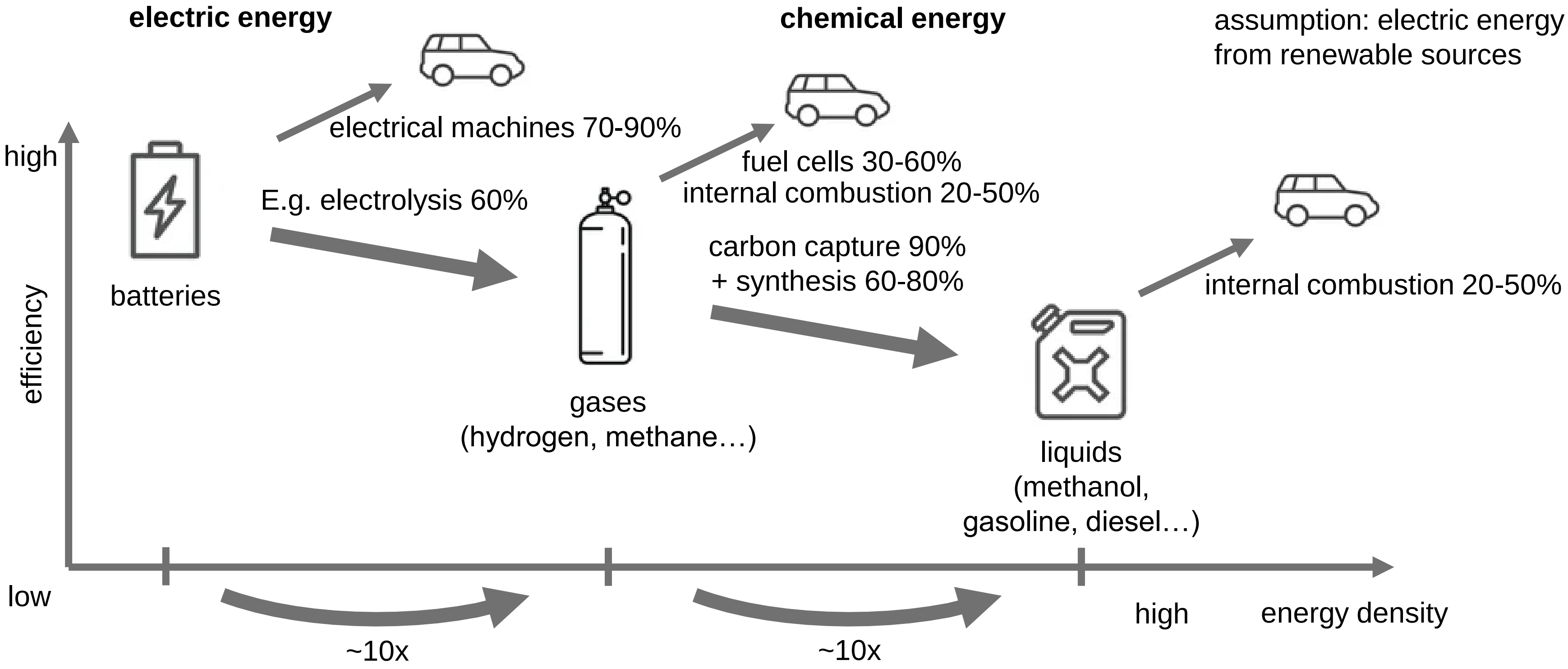
Conventional powertrains rely exclusively on fossil energy carrier

Size and inertia of the automobile industry

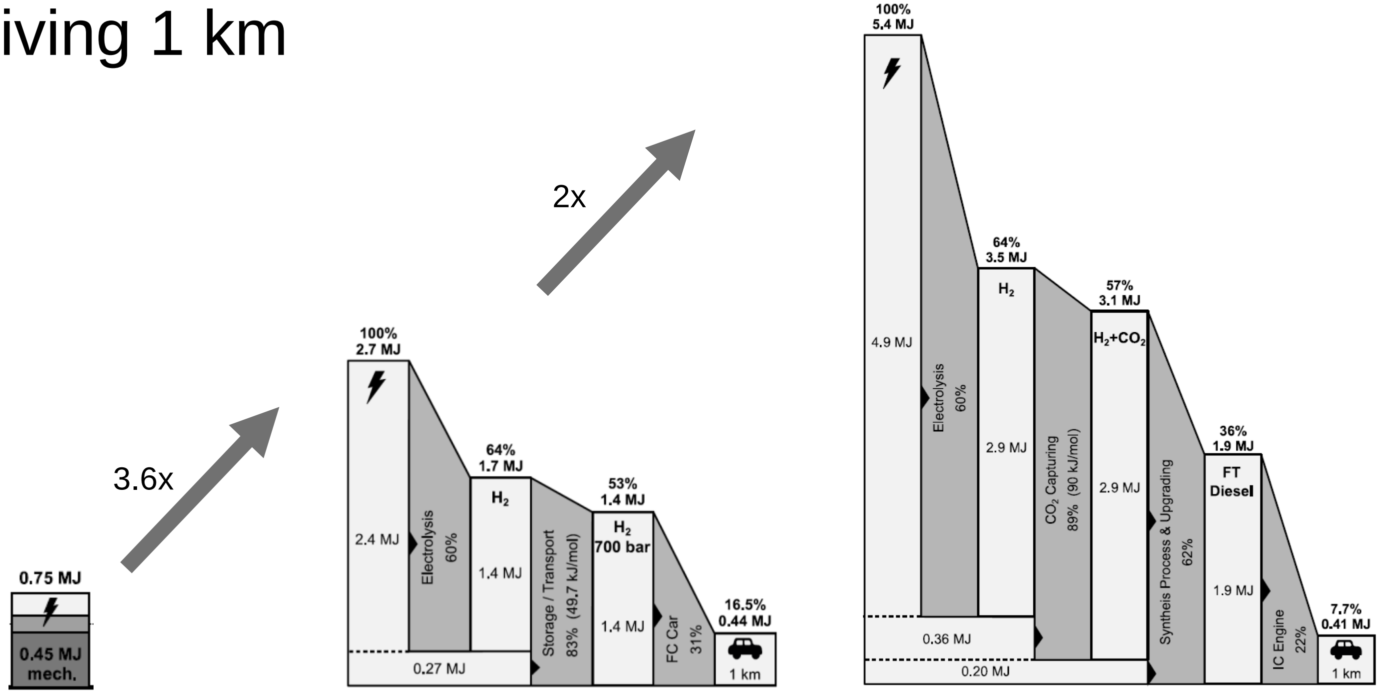
Solution approach: abandon fossil energy carrier
(for mobility as well as the energy sector in general)

Bild: National Geographic

Energy density and conversion losses



Energy demand from renewable sources for driving 1 km



Battery electric vehicle | Fuel cell electric vehicle | Internal combustion diesel vehicle

Severin Hänggi, Philipp Elbert, Thomas Bütler, Urs Cabalzar, Sinan Teske, Christian Bach, Christopher Onder "A review of synthetic fuels for passenger vehicles", Energy Reports, vol. 5, 2019, doi: 10.1016/j.egyr.2019.04.007

Choice of energy carrier is crucial

Requirements for energy carriers

- High energy content
- Easy transportation
- Easy storage
- Safety
- Compatibility
- Sustainability
- Low cost of production

motor cycles

Passenger cars

trains

Air transport

Boats and ships

Heave duty trucks

busses

agriculture

construction

Micro mobility

Highly dependent on the application

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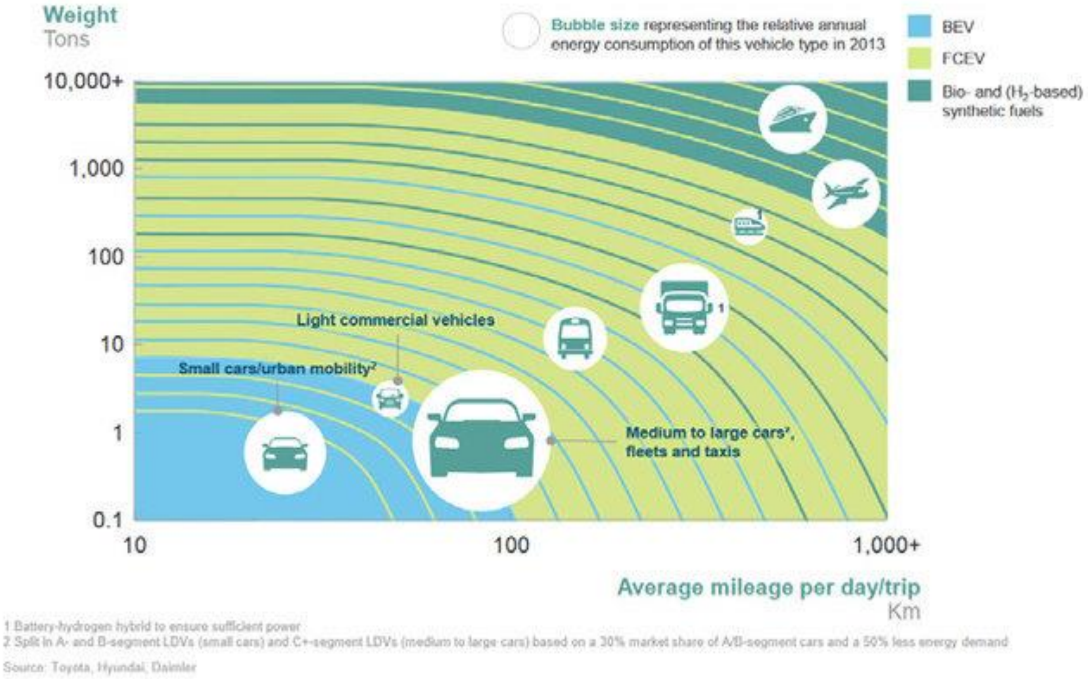
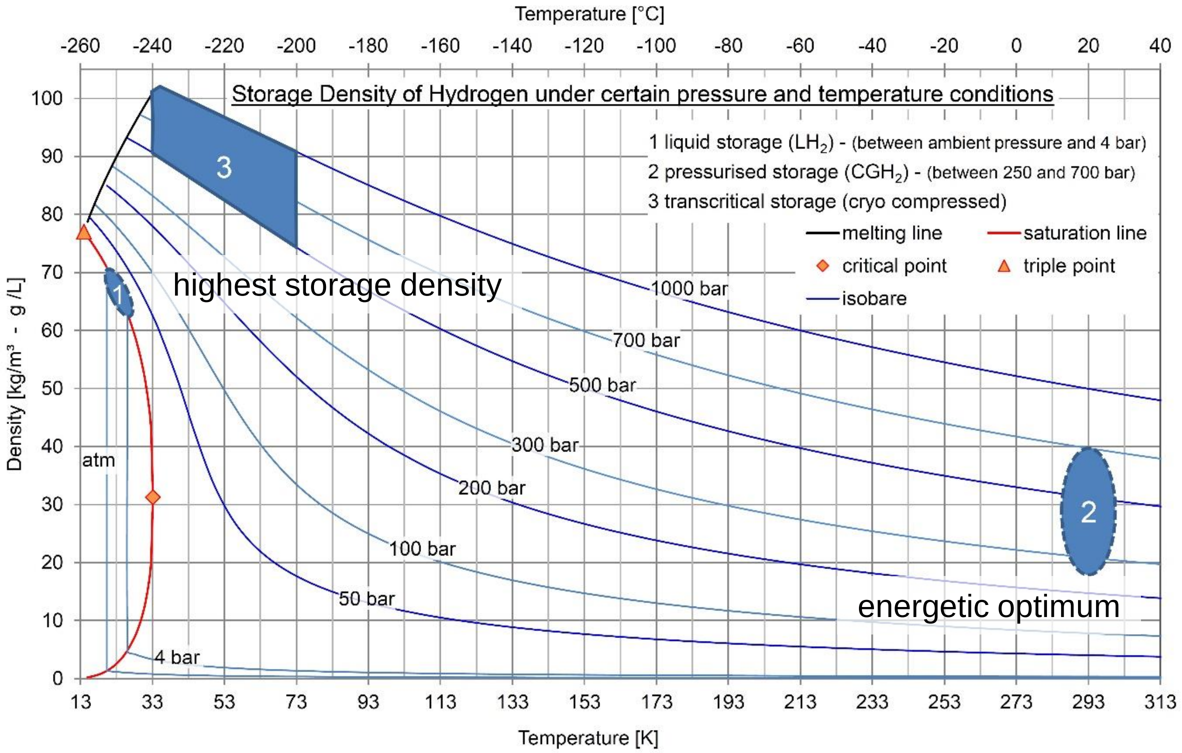


Highly dependent on the application

(pure) Hydrogen storage



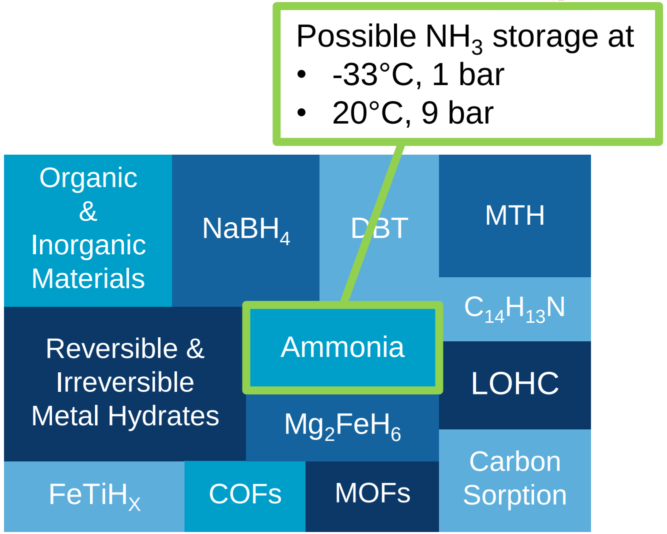
Hydrogen storage – vehicle

Overview of Short Term H_2-Storage Solutions (e.g. for Transportation)

Current state of the art for vehicles

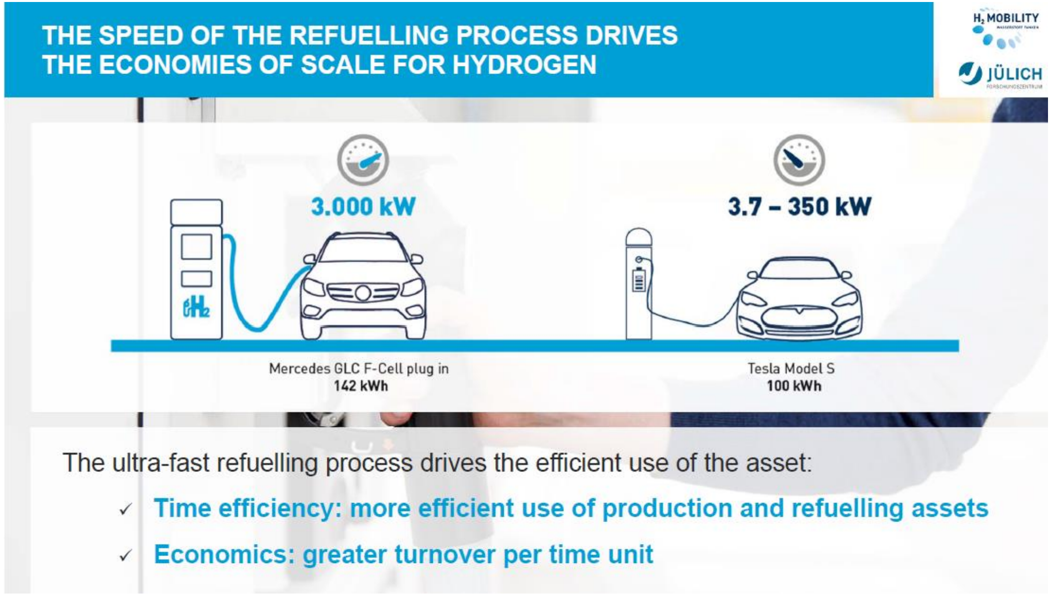
Gaseous (CGH_2)
~ 20°C,
350 or 700 bar

Cryogenic (LH_2/CcH_2)
-250°C,
LH_2 5 bar, CcH_2 up to 350 bar



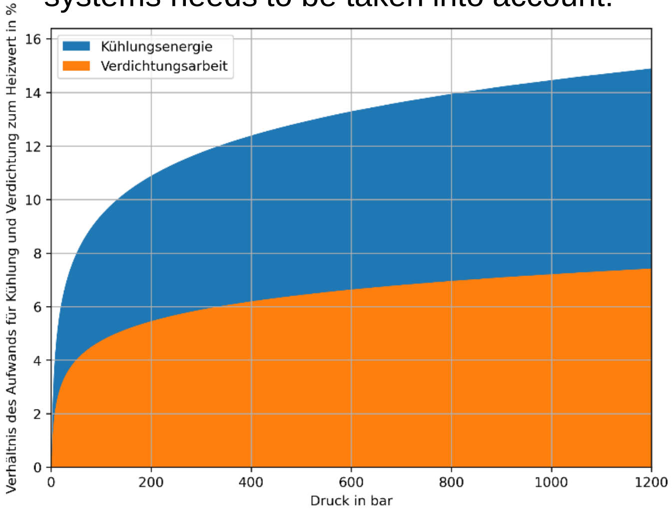
Material Based Alternatives
often ambient temperature
and low pressures

Refueling hydrogen vs. Charging a battery



Quelle: H2 Mobility

Energy input for hydrogen high pressure systems needs to be taken into account!



New ways of storing hydrogen

Example „Powerpaste“ (Frauenhofer IFAM)
Homogeneous, viscous paste based on magnesium hydroxide $Mg(OH)_2$

Manufacturing (mechano-chemical process)

- Hydrogenation of magnesium in a stirring reactor: $Mg + H_2 \rightarrow MgH_2$
- Magnesium hydride, carboxylic acid ester and metal salts in an agitator bead mill to create paste
- Low energy process

Properties

- Very high energy density of up to 1.9 kWh_{el}/liter
- Highly dynamic reaction with water for an instantaneous fuel cell start/stop
- Orientation-independent dosing possible (up to +/- 90° tilt in all directions)
- Non-toxic and safe formulation
- Easily disposable or recyclable
- Long shelf life (up to 5 years)
- Low manufacturing costs (estimated down to ~ 2 EUR/kg POWERPASTE)

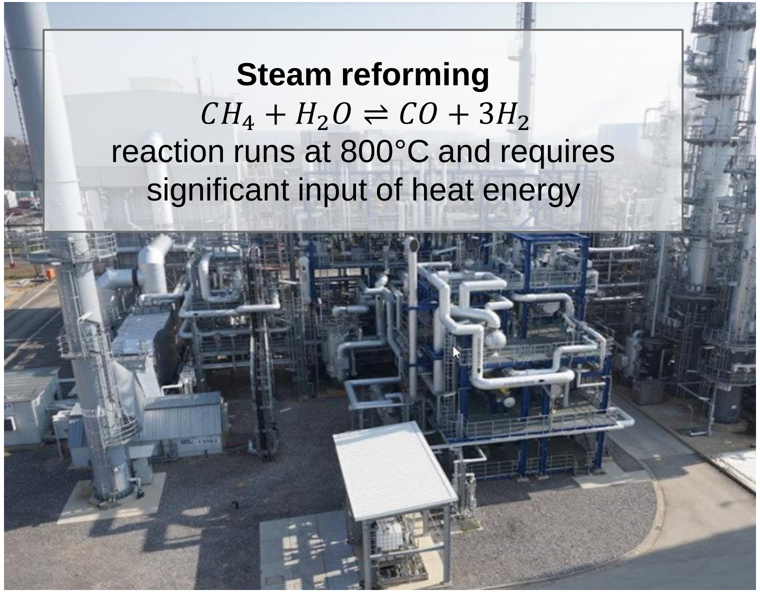
Usage:
Release of hydrogen simply through the addition of water
$MgH_2 + H_2O \rightarrow 2\ H_2 + Mg(OH)_2$

Pilot plant in Braunschweig
Start in Q3 2023 (production of 4t /a)

Quelle: Frauenhofer (POWERPASTE white paper)

Where does our hydrogen come from?

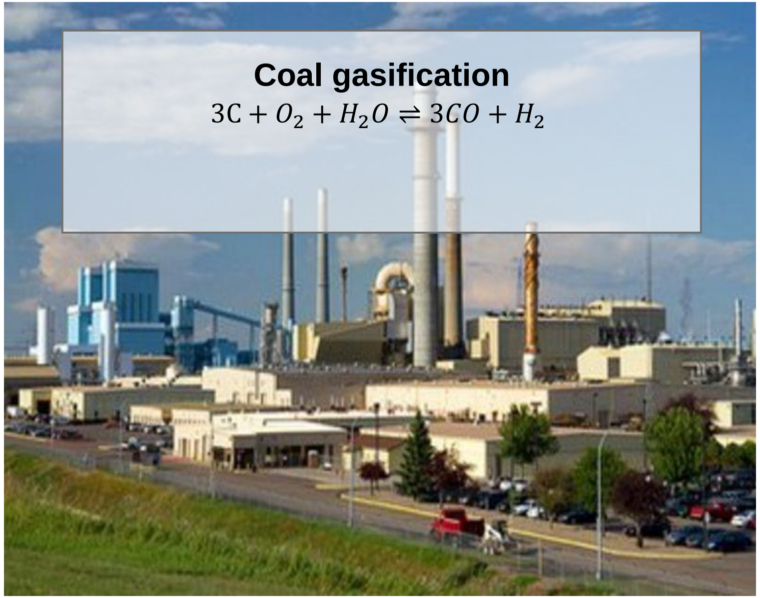
Where does our hydrogen come from?



Steam reforming

$$CH_4 + H_2O \rightleftharpoons CO + 3H_2$$

reaction runs at 800°C and requires significant input of heat energy



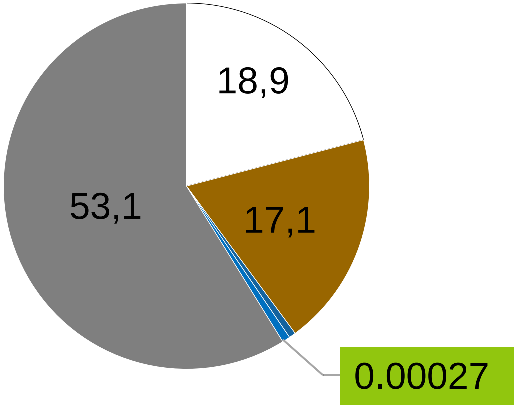
Coal gasification

$$3C + O_2 + H_2O \rightleftharpoons 3CO + H_2$$

- 60% of hydrogen production is based on natural gas, 19% on coal and the rest on crude oil and electricity
- The total worldwide production of 90 Mt H2 in 2020 resulted in 900 Mt direct CO2 emissions (comparable to the combined CO2 emissions of Great Britain and Indonesia)

Hydrogen production

H_2 Production in Mt H_2/year



Source: Compare IEA, Global Hydrogen Review, 2021

Colors of Hydrogen

GREEN
Hydrogen produced via water electrolysis using renewable sources like wind, hydro, PV.
0 carbon emissions

GREY
Hydrogen from natural gas via steam-methane reforming.
about 10 kg of carbon emissions per kg hydrogen

BLUE
Hydrogen from fossil fuels with CO_2 capturing and storing or repurposing.
e.g. 3 kg of carbon emissions per kg hydrogen

TURQUOISE
Hydrogen produced via thermal splitting of methane. Carbon is not emitted but produced as solid state.
Carbon neutral if heat comes from renewable sources.

RED (violett/pink)
Hydrogen produced via water electroysis using nuclear electric power.
0 carbon emissions

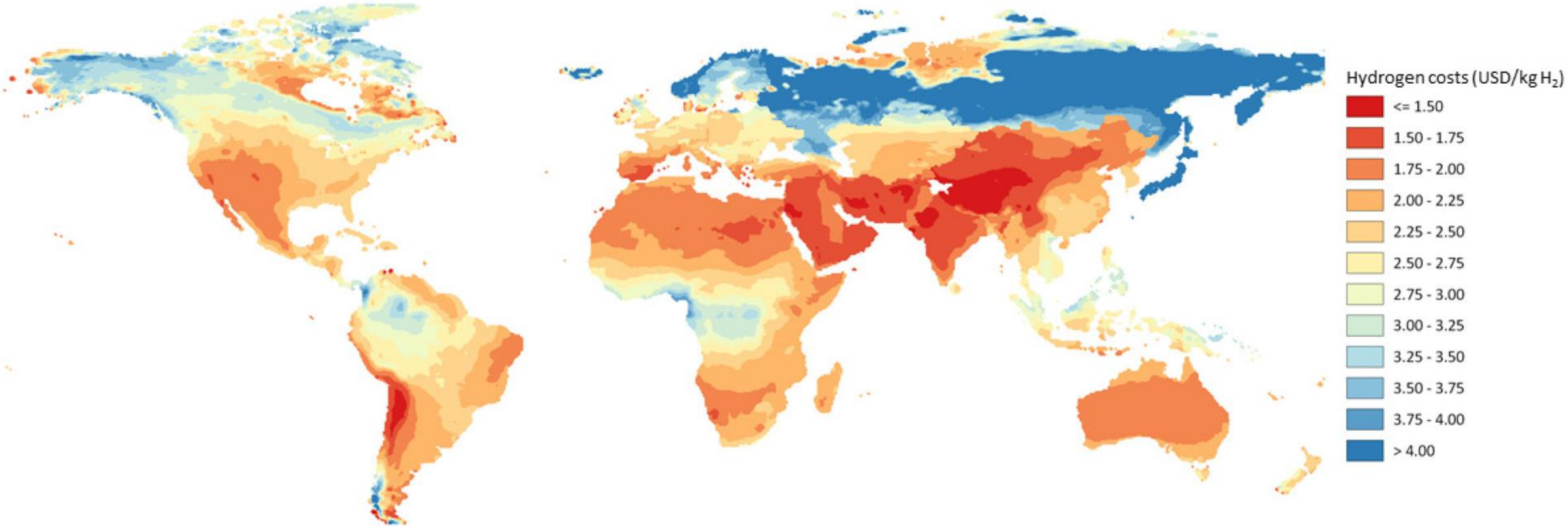
YELLOW
Hydrogen produced via water electrolysis using grid electricity (and electricity mix).
ca. 17,5 kg of carbon emissions per kg hydrogen

BROWN
Hydrogen extracted from fossil fuels via gasificiation. Mainly based on coal.
ca. 19 kg of carbon emissions per kg hydrogen

WHITE
Hydrogen produced as a byproduct of industrial processes or hydrogen found (rarely) in nature in underground deposits.

Examples for vehicle CO_2 emissions:
Toyota Mirai II: 0.63 kg_{H2} /100 km: yellow: 110 g_{CO2} / km, grey: 63 g_{CO2} / km, green: 0 g_{CO2} / km
VW Golf Diesel: 110 g_{CO2} / km; **VW ID.3:** yellow: 67 g_{CO2} / km; green: 0 g_{CO2} / km)

Hydrogen production cost from hybrid solar PV and wind systems in 2030



IEA: Global Hydrogen Review 2021

Conclusion

- Hydrogen provides good properties as a carbon free energy carrier
- Hydrogen will likely be part of the future mobility, especially in high energy applications
- Technical solutions for hydrogen storage exist
- Implementation of hydrogen mobility is slowly staring
- Production of green hydrogen is the biggest challenge

Technology alone will not solve the climate change issue

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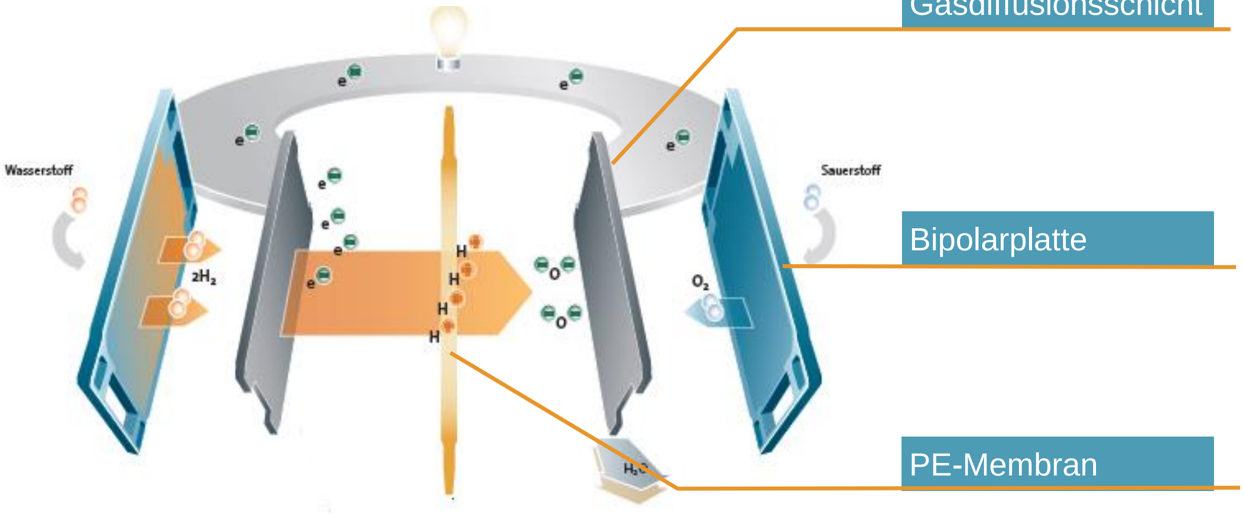
Backupfolien

Aufbau & Funktionsweise einer PEM-Brennstoffzelle

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

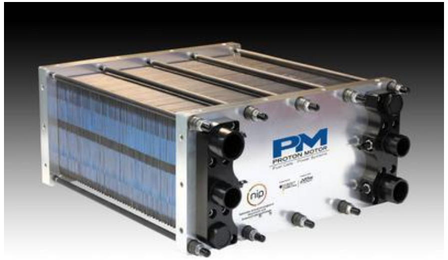
$$2H_2 \rightarrow 4H^+ + 4e^-$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$



Anode (-)

Kathode (+)



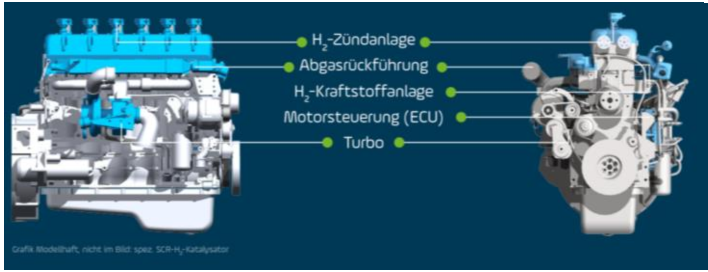
Kenngrößen Fahrzeugstapel

aktive Fläche	Ca. 15 m²
max. Spannung	300 – 400 V
Spannung bei Volllast	230 – 260 V
Strom bei Volllast	~ 600 A
max. Leistung	ca. 130 kW

Quelle: Proton Motor Fuel Cell GmbH

Wasserstoffnutzung im Verbrennungsmotor: Beispiel BMW, 2006 und KEYOU 2019

Quelle: BMW



Quelle: KEYOU

Kernkomponenten KEYOU-H_2-Technologie:

Integration von:
+ H_2-Zündanlage
+ H_2-Kraftstoffanlage
+ Abgasnachbehandlung

Anpassung & Optimierung:
+ Aufladegruppe
+ Abgasrückführung
+ Verdichtungsverhältnis
+ Brennraum
+ Motorsteuerung

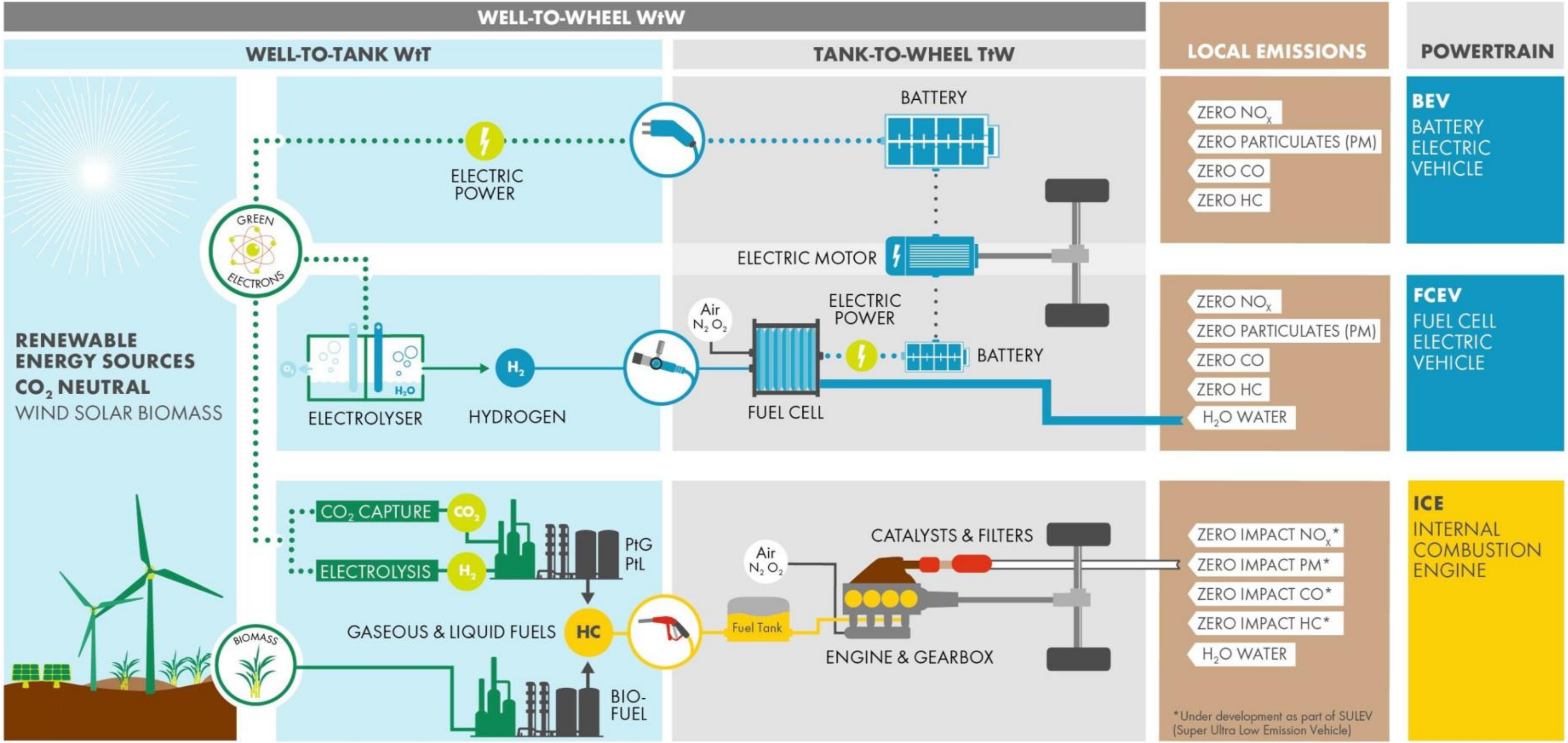
Materialanpassung:
+ Ventile
+ Ventilsitze

Customer Benefits and Costs:

Range:	> 500 km
Engine power:	> 200 kW
Availability:	> 95 %
Operational lifetime:	> 700,000 km
Total cost:	≈ Diesel engine

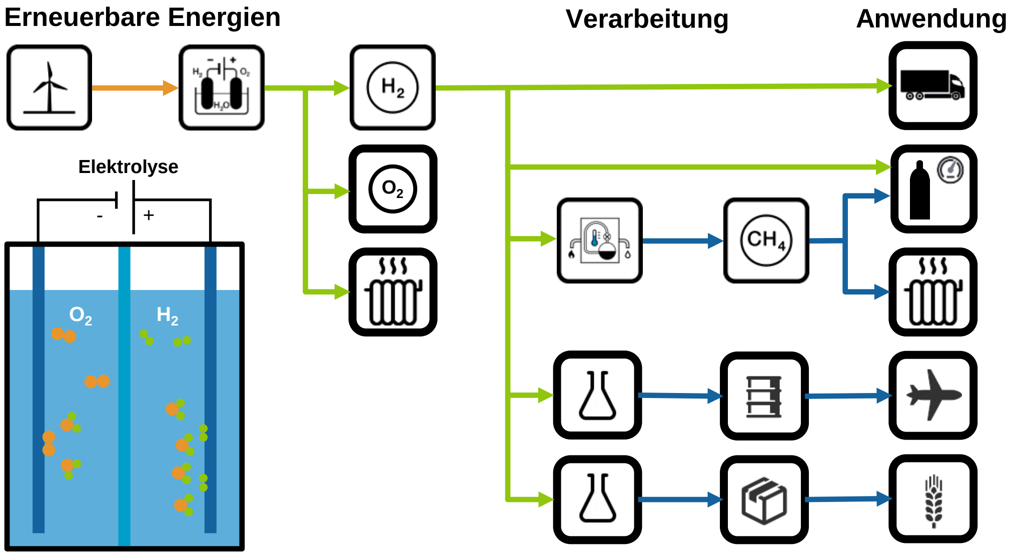
Local Emissions: Only H_2O, no CO_2, no particles

Pathways for CO2 neutral mobility



W. Warnecke: ENERGY PATHWAYS AND THE IMPACT ON PROPULSION; 6th Int. Engine Congress ATZ live February 26th, 2019 in Baden Baden

Erzeugung, Verarbeitung und Anwendungen



Brennstoffzelle oder H2-Verbrennungsmotor für Fahrzeuge

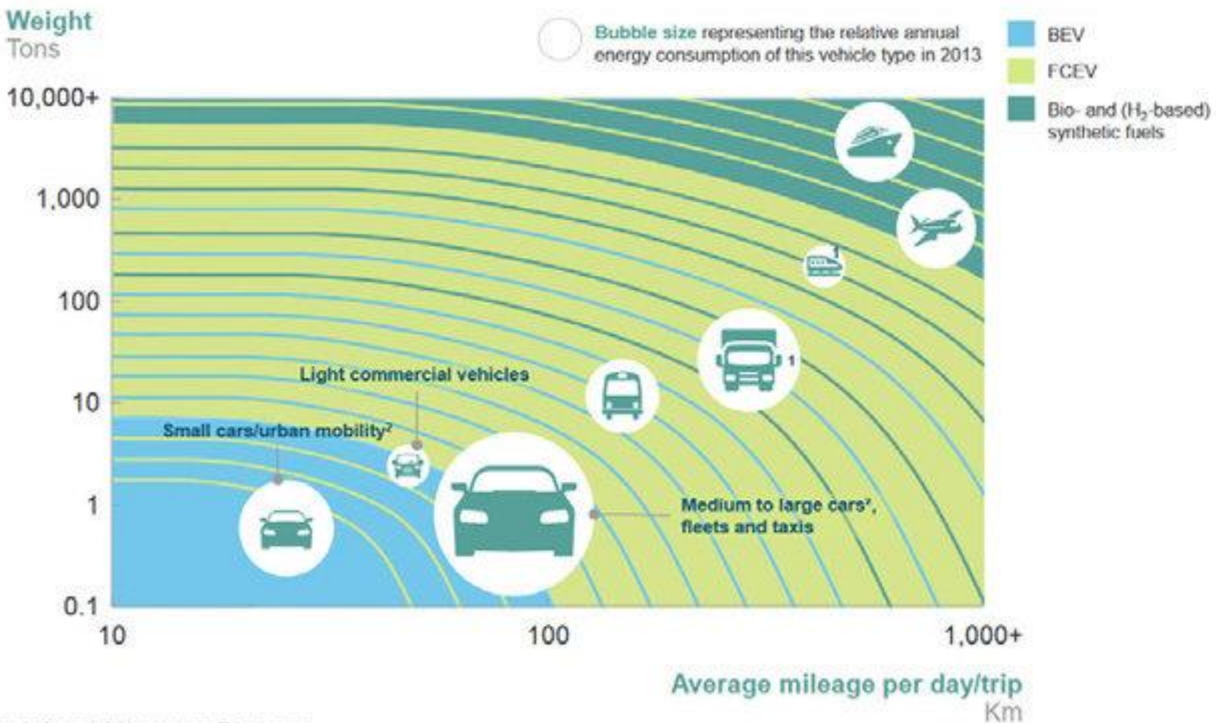
Saisonaler Energiespeicher

Dekarbonisiertes Heizen

Power-to-Liquid

Chemie- und Stahlindustrie

Mögliche Anwendungen



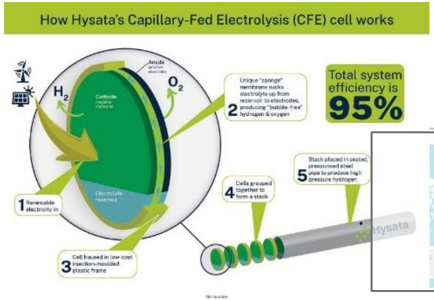
1 Battery-hydrogen hybrid to ensure sufficient power
2 Split in A- and B-segment LDVs (small cars) and C+-segment LDVs (medium to large cars) based on a 30% market share of A/B-segment cars and a 50% less energy demand

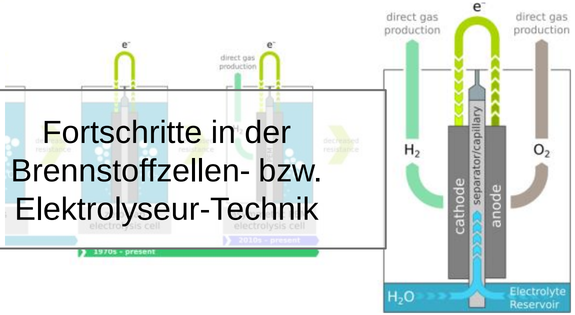
Source: Toyota, Hyundai, Daimler

W. Warnecke: ENERGY PATHWAYS AND THE IMPACT ON PROPULSION; 6th Int. Engine Congress ATZ live February 26th, 2019 in Baden Baden

Aktuell spannende Technologien und Entwicklungen

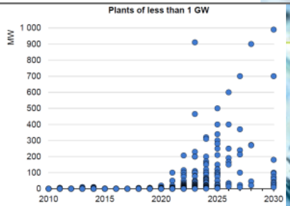
Neue Arten der Wasserstoffspeicherung





Fortschritte in der Brennstoffzellen- bzw. Elektrolyseur-Technik

Starkes Wachstum CO2-neutraler Wasserstoffproduktion



Branchenbericht | Japan | Energie, übergreifend

06.06.2019

Japan will Wasserstoffgesellschaft werden

Regierung und Unternehmen erwarten viele Vorteile / Von Jürgen Maurer

Tokyo (GTAI) - Japan soll sich in Richtung einer Wasserstoffwirtschaft entwickeln. Eine Lieferkette und die Infrastruktur sind im Aufbau. Für viele Vorhaben ist 2020 ein wichtiger Starttermin.

Stärkere Förderung des Wasserstoff-Sektors

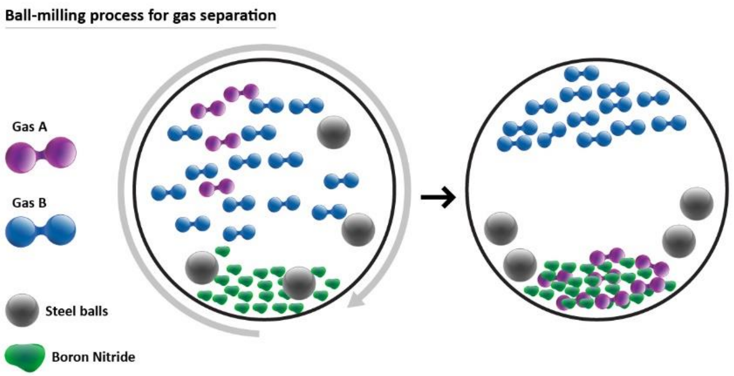
Ausbau der Wasserstoff-Infrastruktur

Alternative Wasserstoffspeicherung

Bornitrit-Pulver

Herstellung (mechano-chemisch)

- Bornitritpulver in Kugelmühle + Wasserstoffgas
- Sehr energieeffizient
- Keine Abfallprodukte, keine aggressiven Chemikalien;
  Bornirit ist sicherheitstechnisch unbedenklich



Nutzung

- Sichere und einfache Lagerung/Transport
- Freisetzung des Wasserstoffs über Wärmezufuhr
- Pulver kann mehrfach wiederverwendet werden

Clip notes

- Klimawandel wegen fossilen Energiequellen
- Neuer Energieträger wird gebraucht – H_2 ist ein vielversprechender kohlenstofffreier Energieträger
- Hohe Energiedichte als wesentlicher Vorteil gegenüber Batterien
- Technische Lösungen zur Speicherung in Fahrzeugen sind bereits auskonstruiert und etabliert, neue materialgebundene Speichermöglichkeiten werden derzeit erforscht
- Die größte Herausforderung ist die Herstellung von grünem Wasserstoff
    - Aktuell ist H_2 Produktion noch mit großen CO_2 Emissionen verbunden