The Hydrogen Economy

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Outline

- DTU Energy
- Hydrogen as the solution
- Main hydrogen technologies
- Challenges
- When and when not hydrogen

DTU Energy on a shoestring

Department of Energy Conversion and Storage
Established 2012
Ca. 230 staff including ca. 50 PhD students

Relevant technologies

- Electrolyzers
- Fuel cells
- Batteries
- Flow batteries
- Thermal storage
- Power-to-X
- CO_2 capture (in progress)

Development and test

- Functional materials
- Components (electrodes, electrolytes, cells, (stacks))
- Electrochemical techniques

Non-experimental

- Computational chemistry
- Energy planning

My academic activities

Research

- High-temperature PEM fuel cells (160 ºC)
- Alkaline electrolysis (AEC and AEMEC)

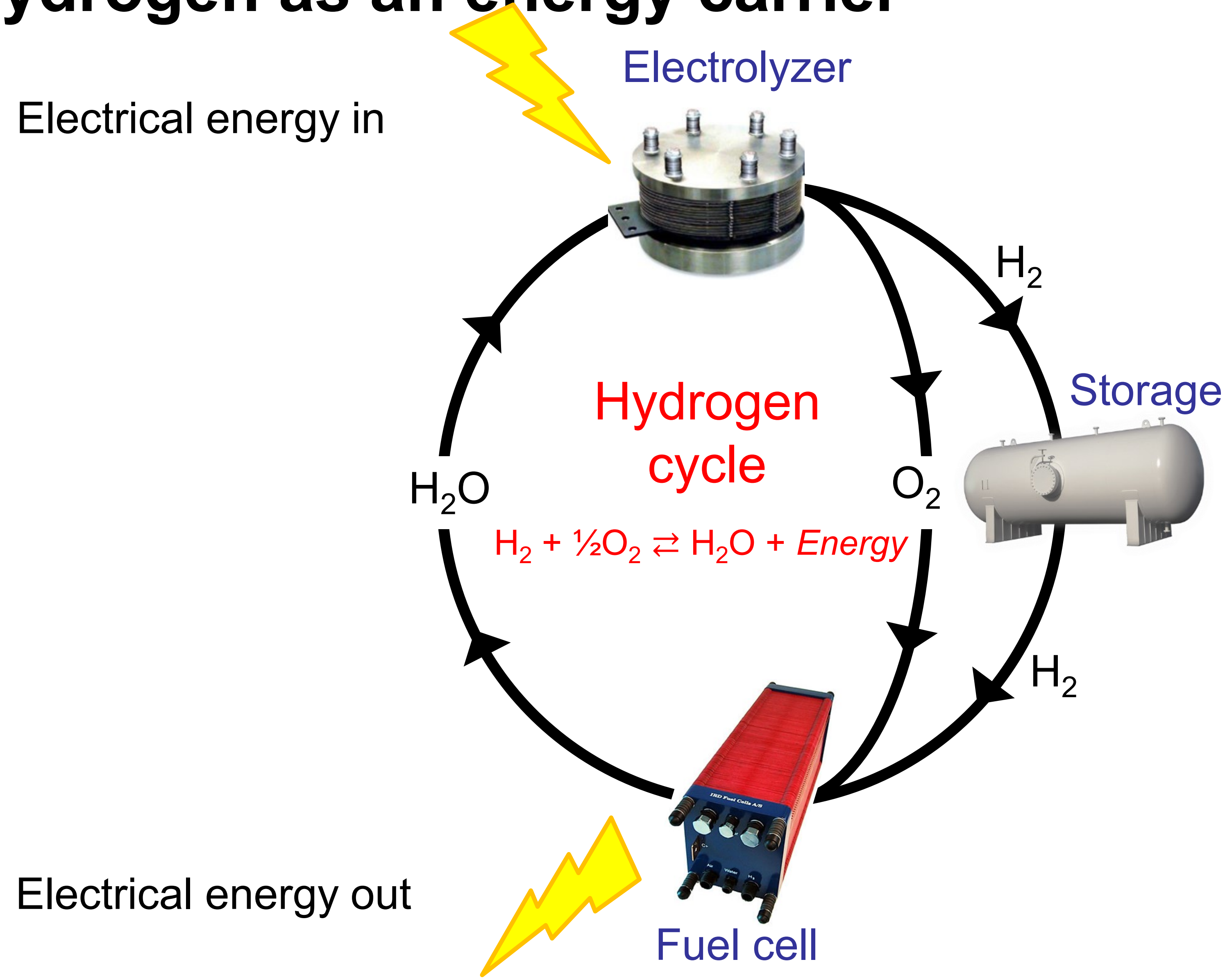
Teaching

- BSc, MSc and PhD
- Hydrogen Energy and Fuel Cells (Master, 100+ students, no. 47301)
- Introduction to Future Energy (Bachelor, ca. 150 students, no 47202)
- Exergy Analysis (Master, 10-15 students, no. 47317)
- Joint European Summer School (JESS) (PhD, 40-80 students, no 47507)

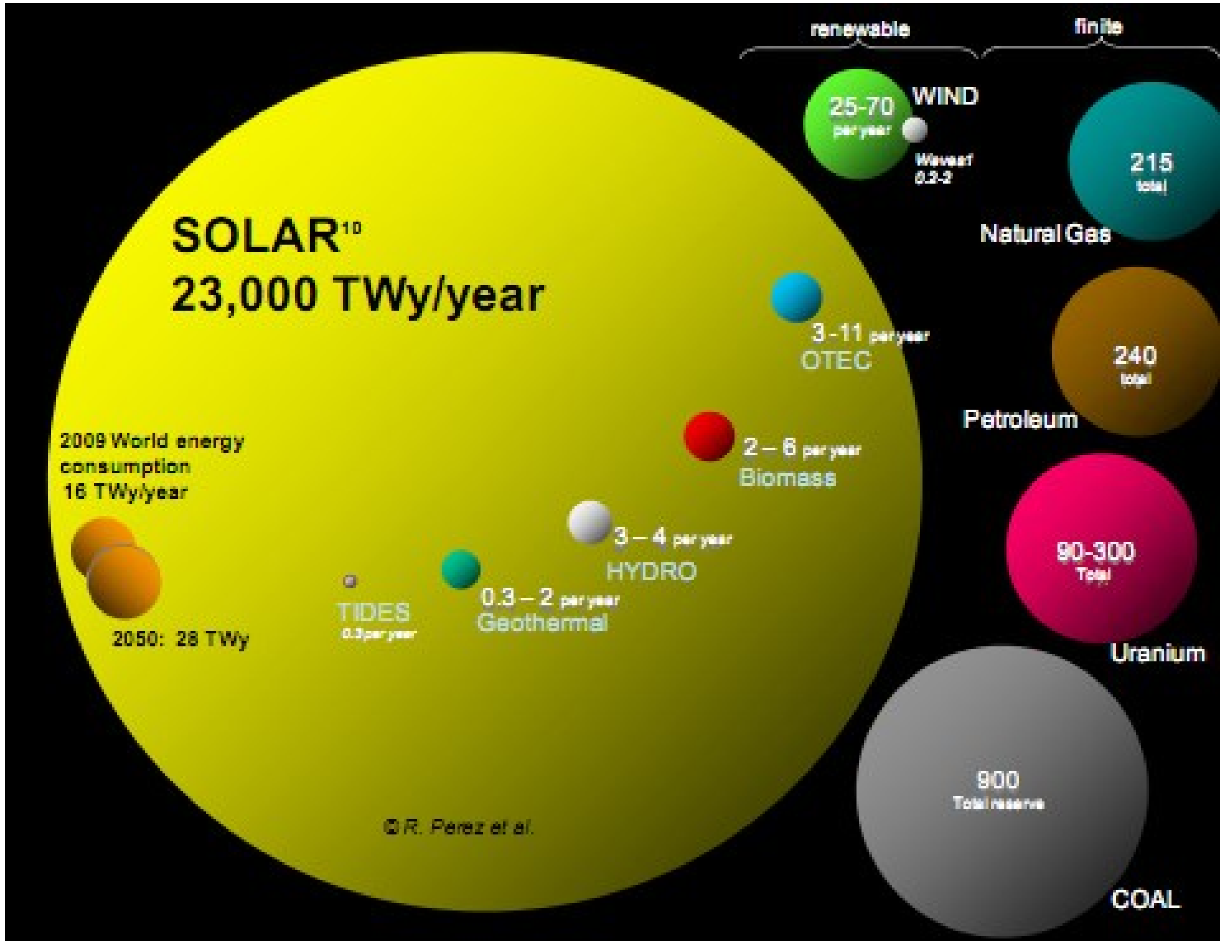
https://www.jess-summerschool.eu

The recent decades

Hydrogen as an energy carrier



Renewable energy reserves and the need for hydrogen

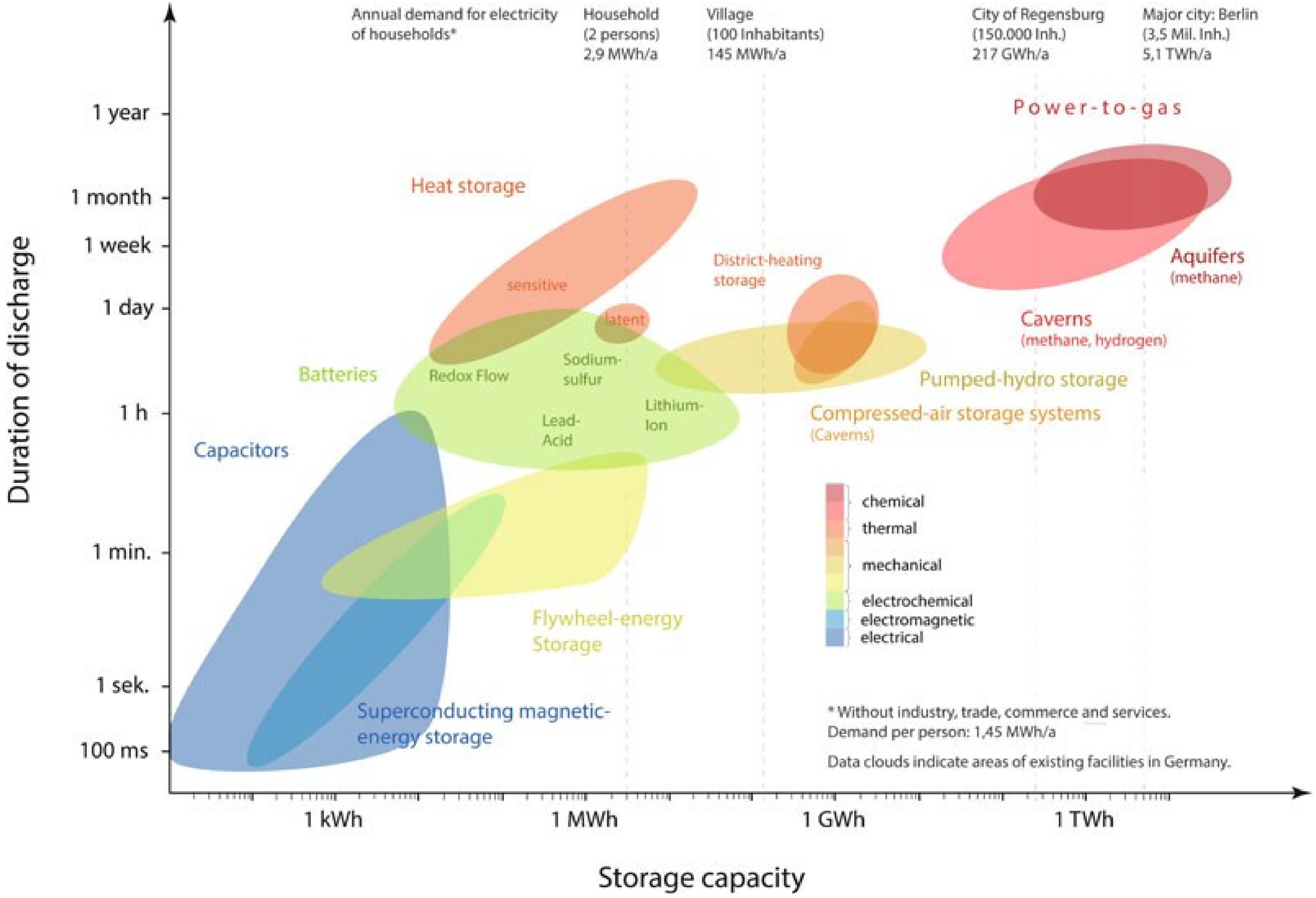


- Most renewables generate electricity
- Electrification makes sense for many applications

- How do we store electricity?
- How do we fuel trucks, ships and airplanes?

Source: Perez & Perez, 2009 + update 2015 IEA-SHCP-Newsletter Vol. 62, Nov. 2015 – draft

Storage potential and time domains



Michael Sterner, Ingo Stadler (Eds.). Handbook of Energy Storage. Demand, Technologies, Integration. Springer 2019

Main hydrogen technologies

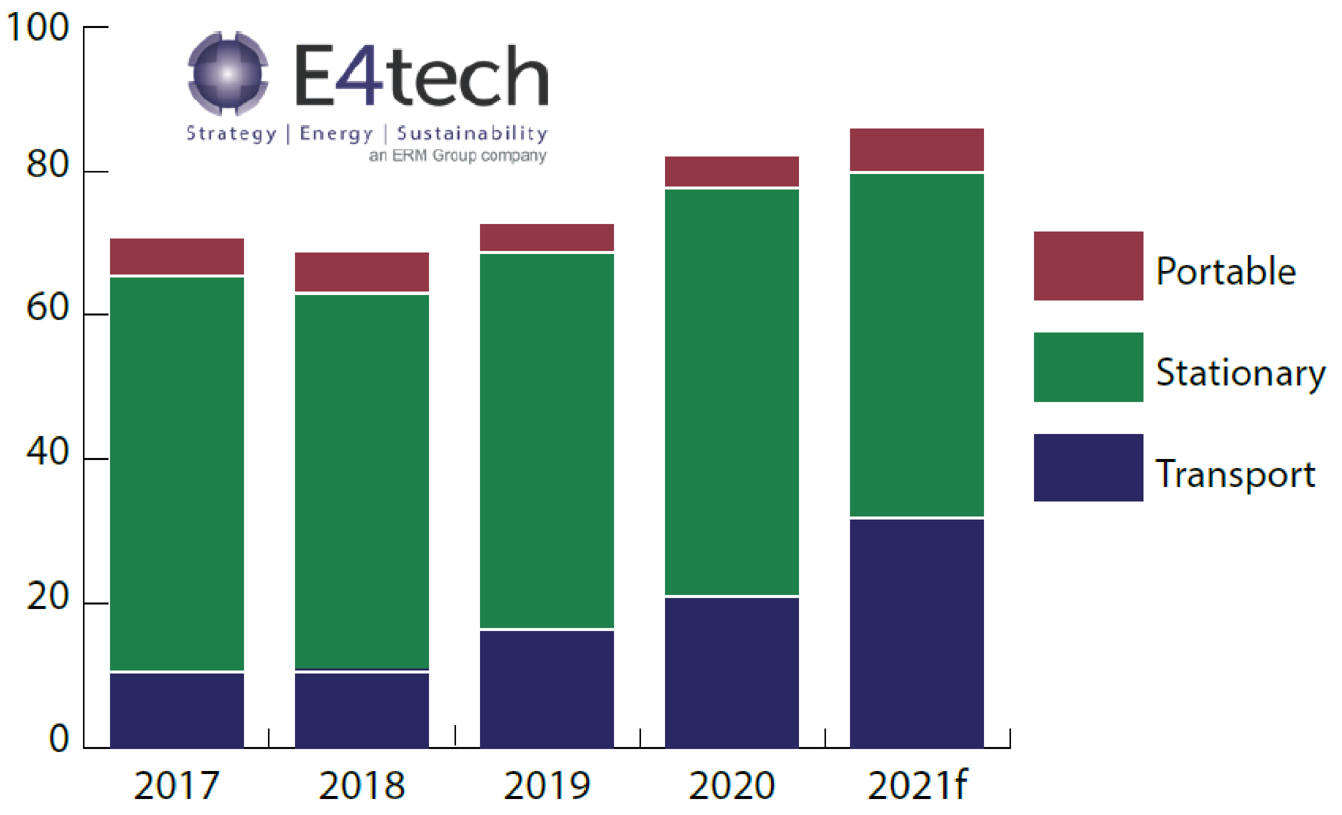
	Acidic systems	Alkaline systems	Ceramic (high temp.)
Electrolyzers	PEMEC [Mature]	AEC [Mature] (AEMEC)	SOEC [Quite mature]
Fuel cells	PEMFC [Mature]	AFC [Development] (AEMFC)	SOFC [Quite mature]
Characteristics	• Noble metal catalysts • Compact stacks • High power density • Expensive	• Very large scale • Inexpensive abundant materials • Low power density	• Superior efficiency • Partly commercial

Proton Exchange Membrane …

Solid Oxide …

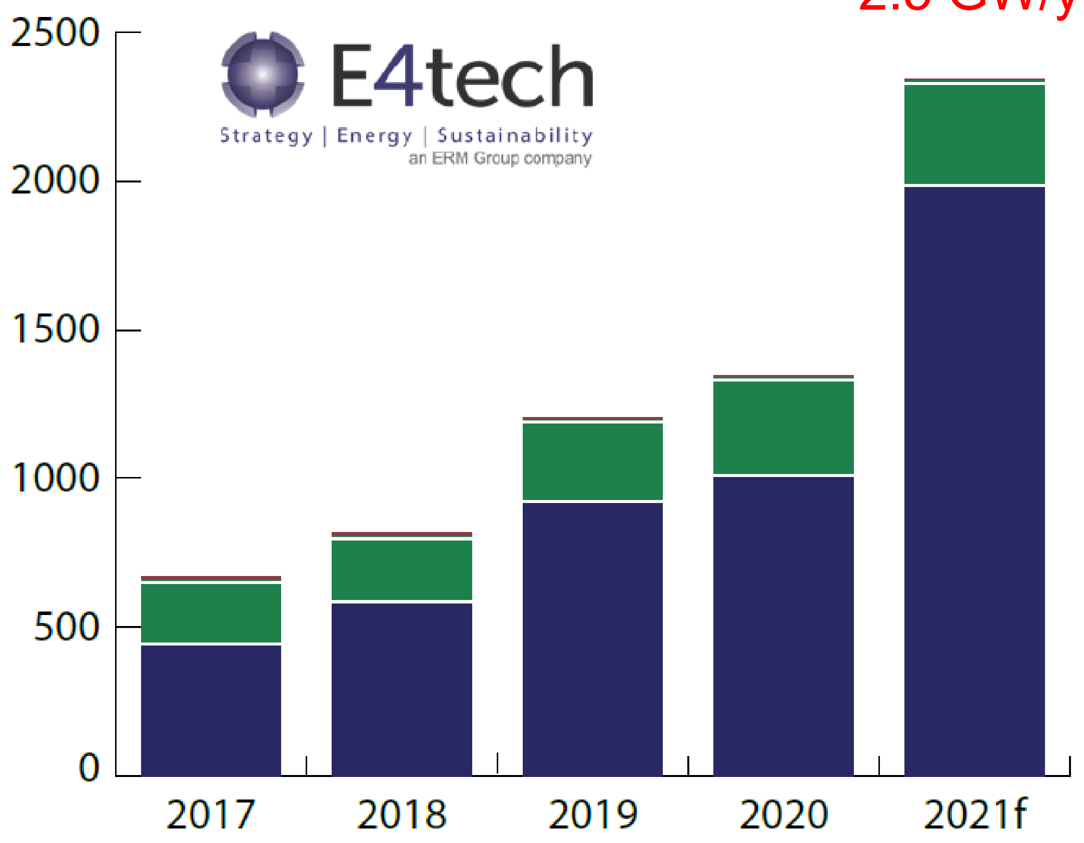
Shipment of fuel cells (by application)

Shipments by application 2017 - 2021 (1,000 units)



Megawatts by application 2017 - 2021

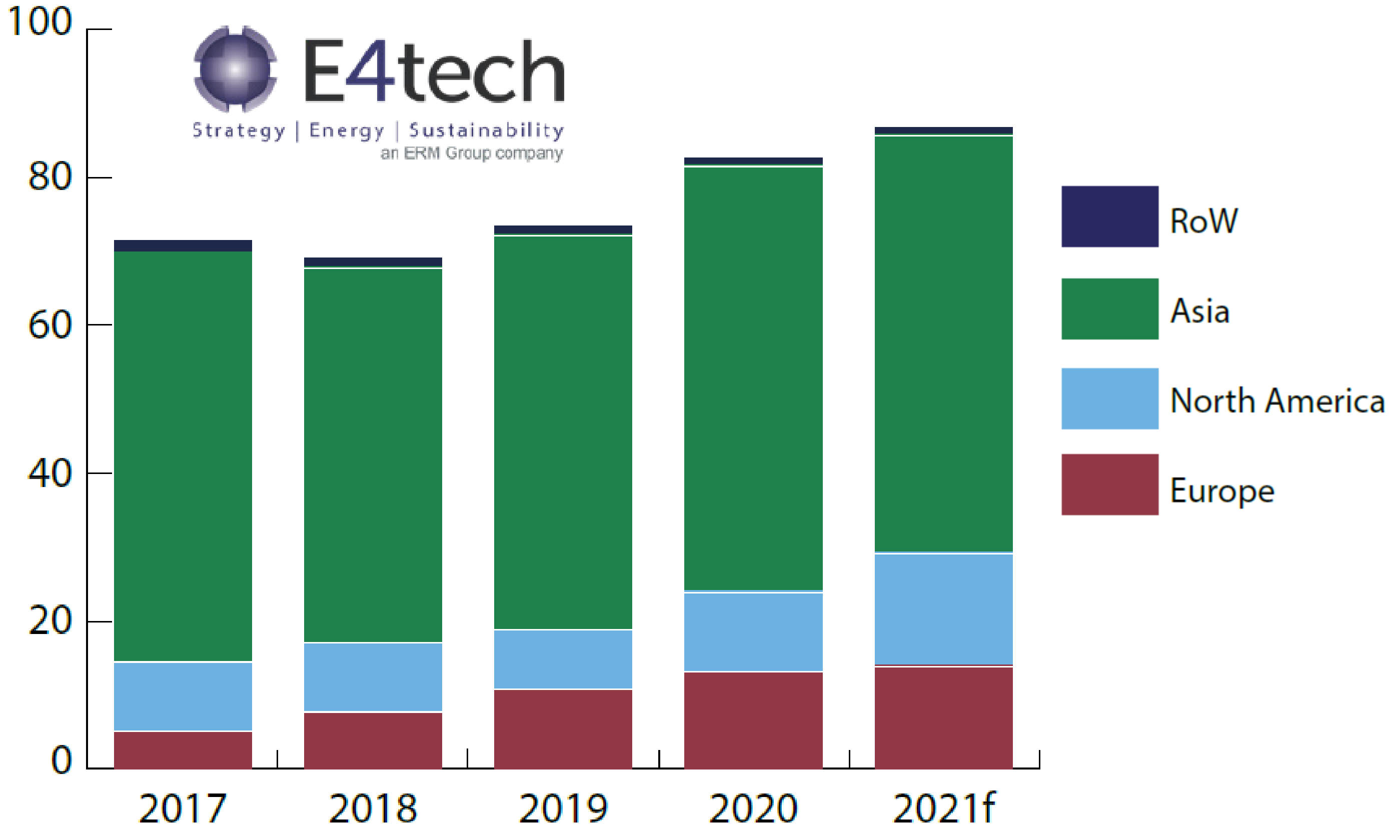
~2.5 GW/y



www.FuelCellIndustryReview.com

Shipment of fuel cells (by country)

Shipments by region of adoption 2017 - 2021 (1,000 units)



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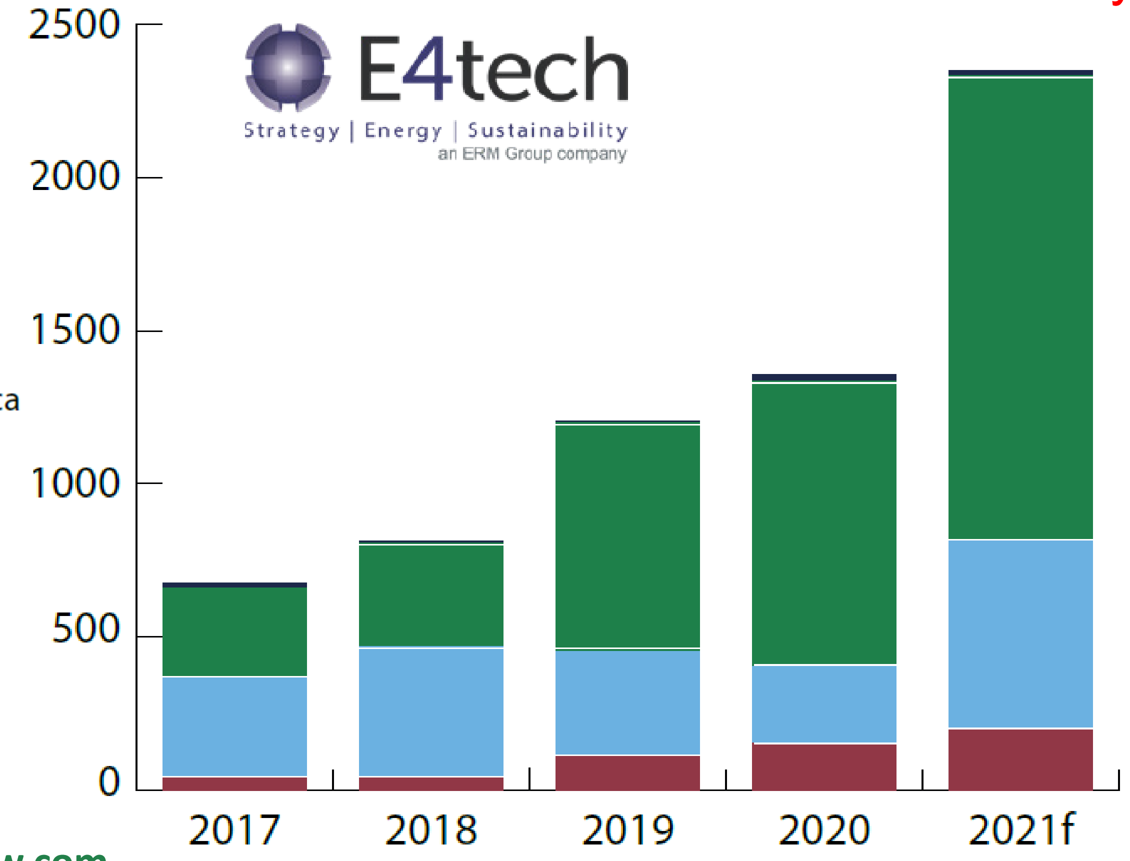
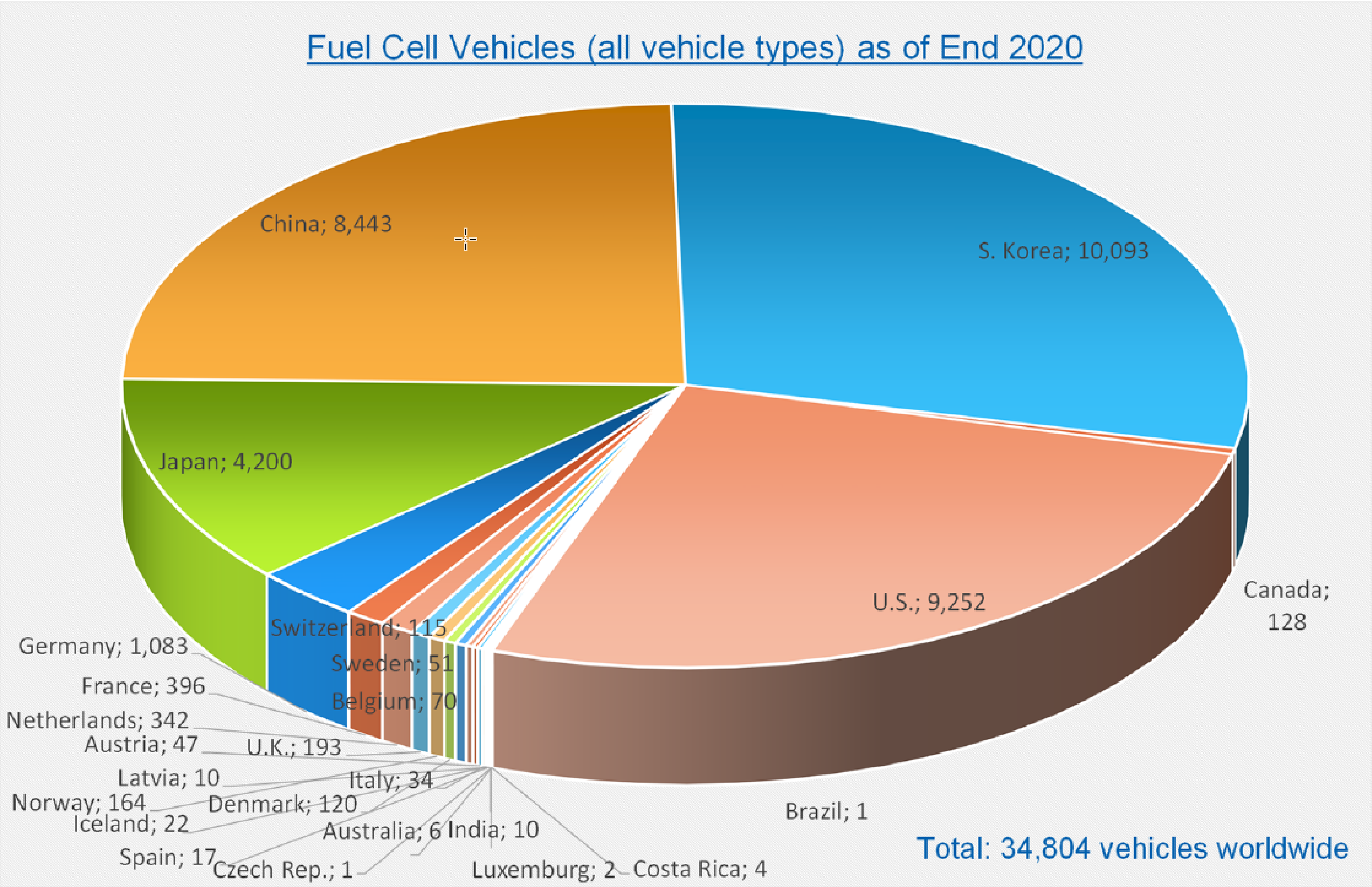
Megawatts by region of adoption 2017 - 2021

~2.5 GW/y



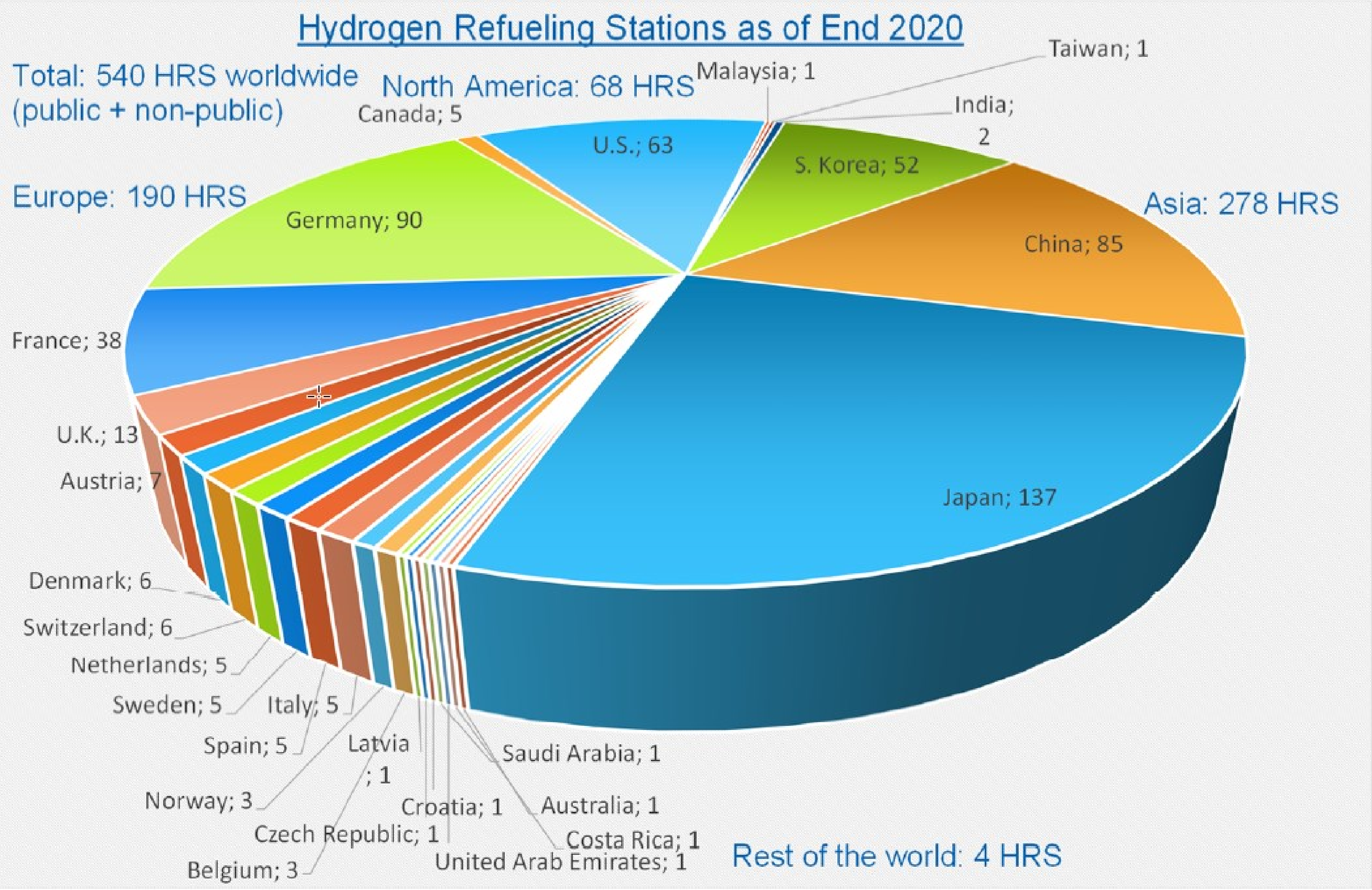
(RoW = Rest of the World)

Deployment of fuel cell vehicles



Deployment Status of Fuel Cells in Road Transport: 2021 Update. Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment Band / Volume 542

Deployment of fuel cell vehicles



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Latest fuel cell vhicle models

Hyundai Nexo 2018

Toyota Mirai 2020

Honda clarity 2018

BMW NEXT FCEV
concept car

Mercedes Benz
Plug-in hybrid

Taxi companies, DRIVR (Copenhagen area)

Taxi company with green cars
Hybrid or fuel cell vehicles

Drivr.com

- 2021: 100 FCV
- 2022: 200 FCV
- 2025: 500 FCV

Dutch fuel cell taxis

Fuel cell trucks

Hyundai: 1,600 trucks for Switzerland

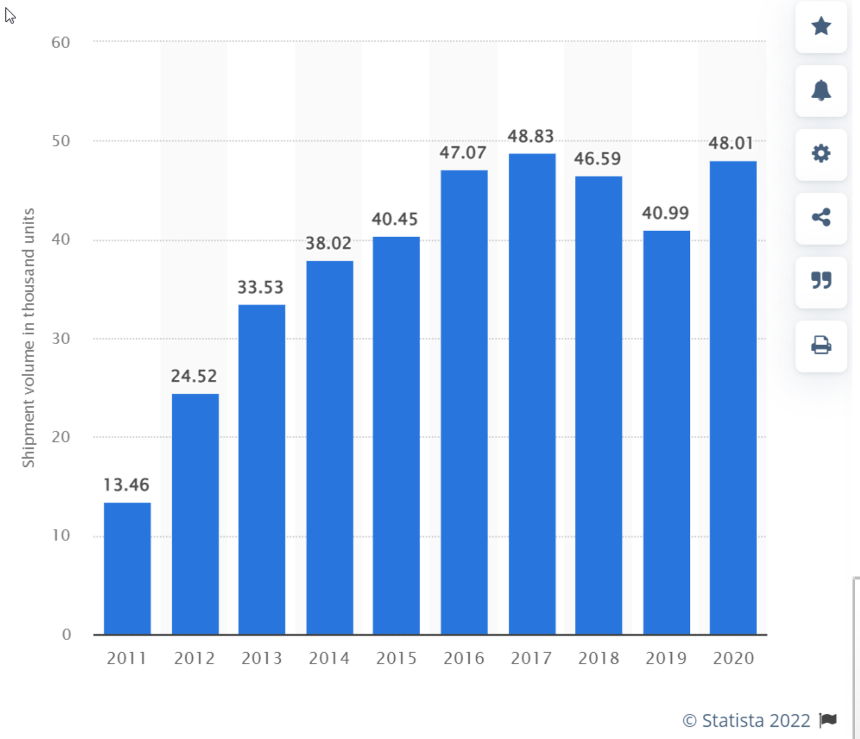
Nikola: 13,000 pre-orders (800 trucks for Anheuser-Busch)

Hyundai X2 Xcient.
2 Nexo stacks: 190 kW
7 pressure tanks 35 kg H_2
400 km

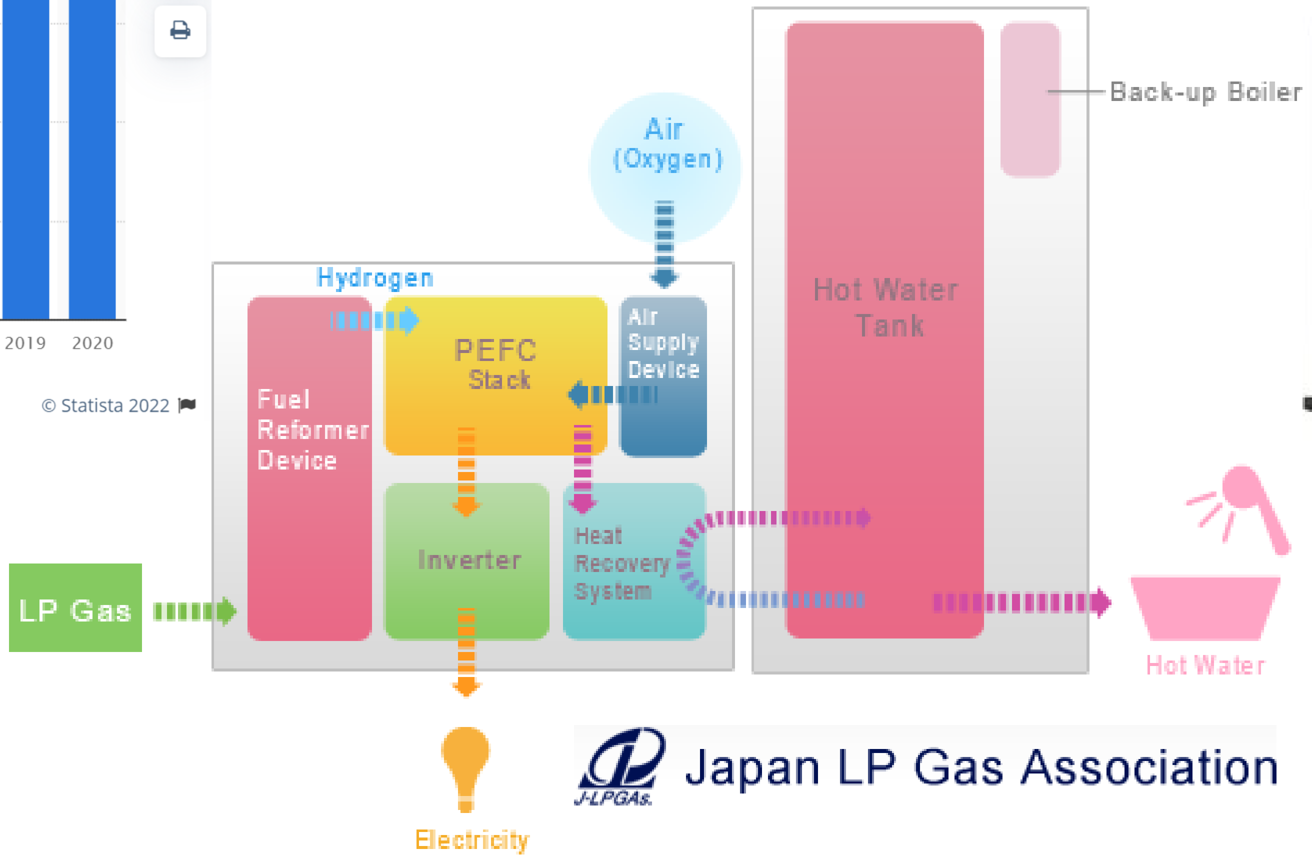
Hyundai ships first tucks to Switzerland, July, 2020

Nikola truck. Up to 750 kW (1000 hp)

Status for micro-CHP in Japan



Japan:
ENE-FARM programme from 2009.
+350.000 units installed.
Most PEMFC and some SOFC

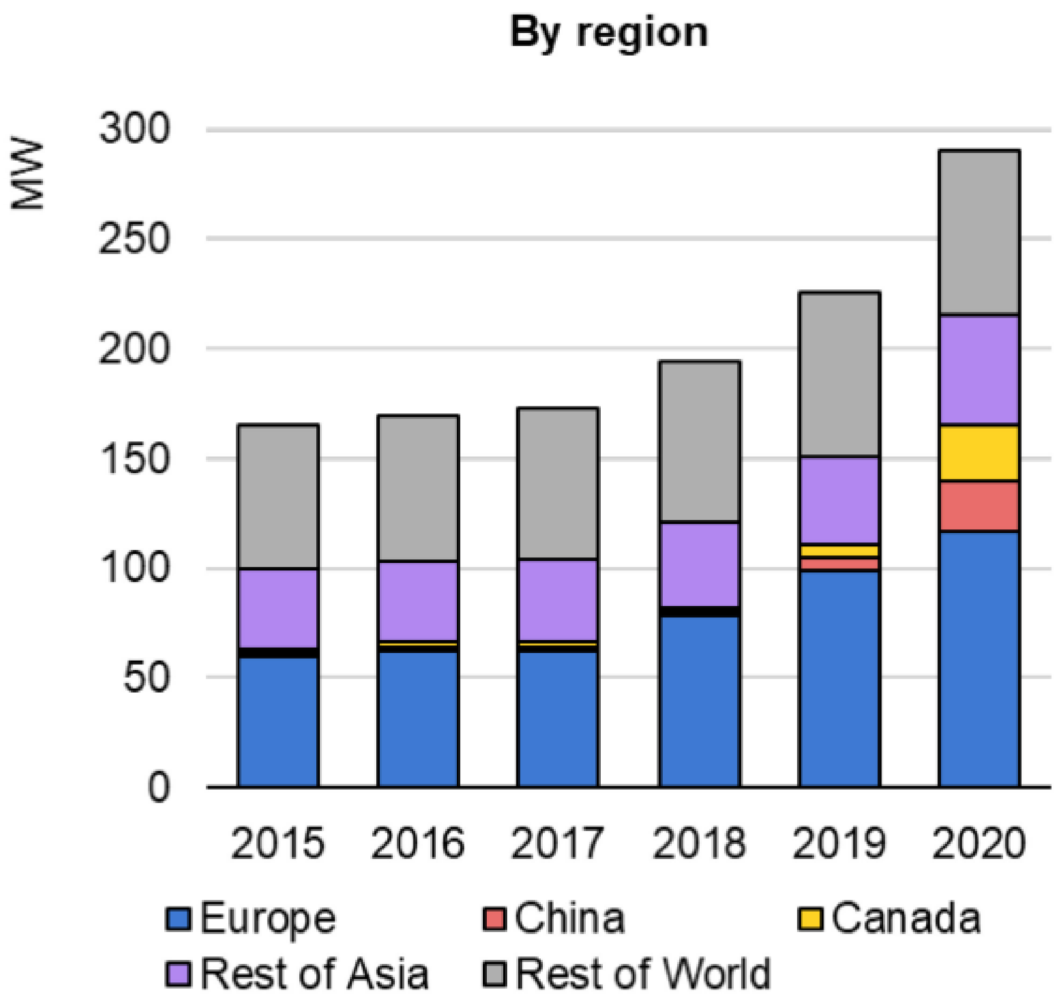


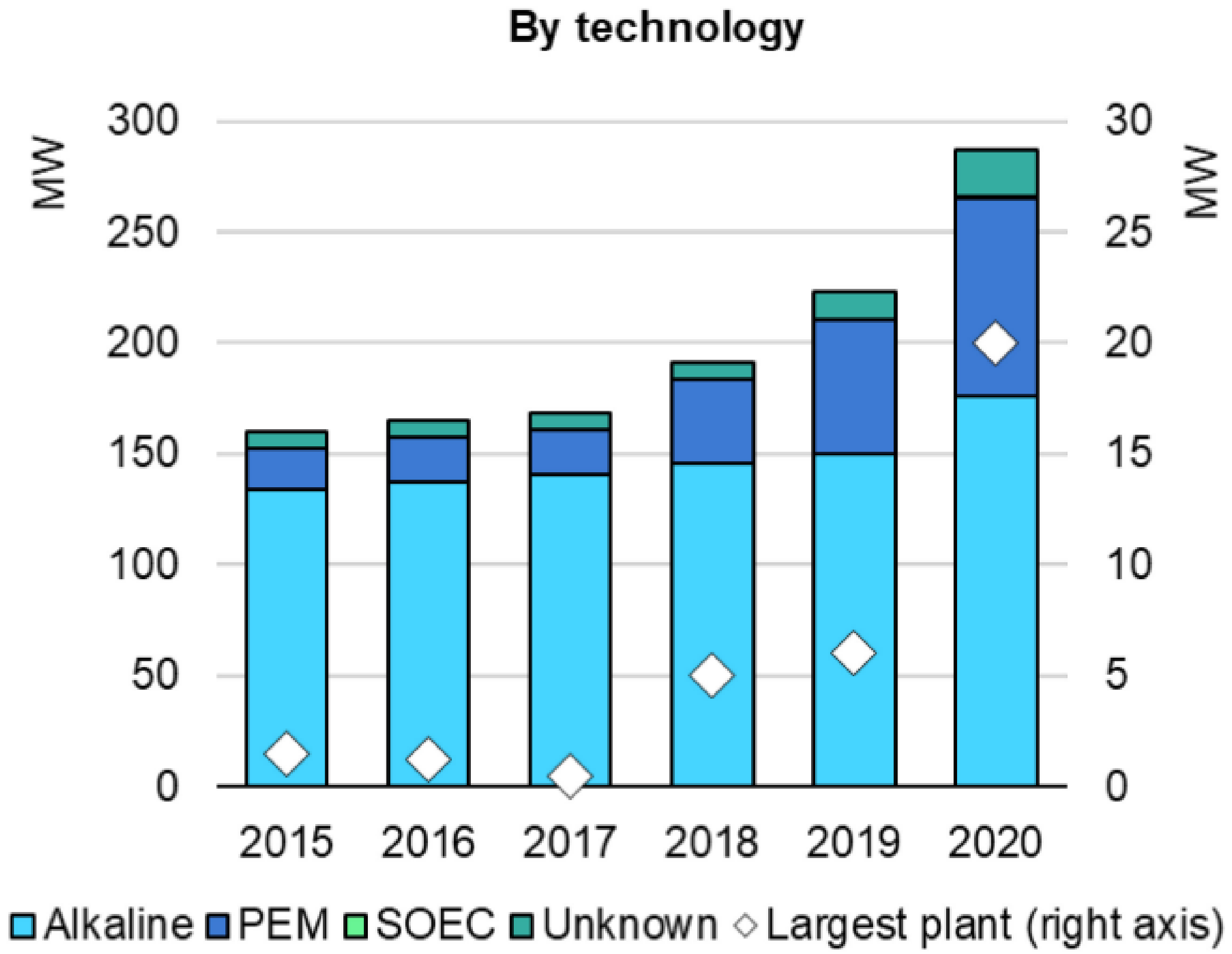
Panasonic µCHP
$700W_e$, $1000\ W_h$

Electrolysis - IEA, Global Hydrogen Review 2021

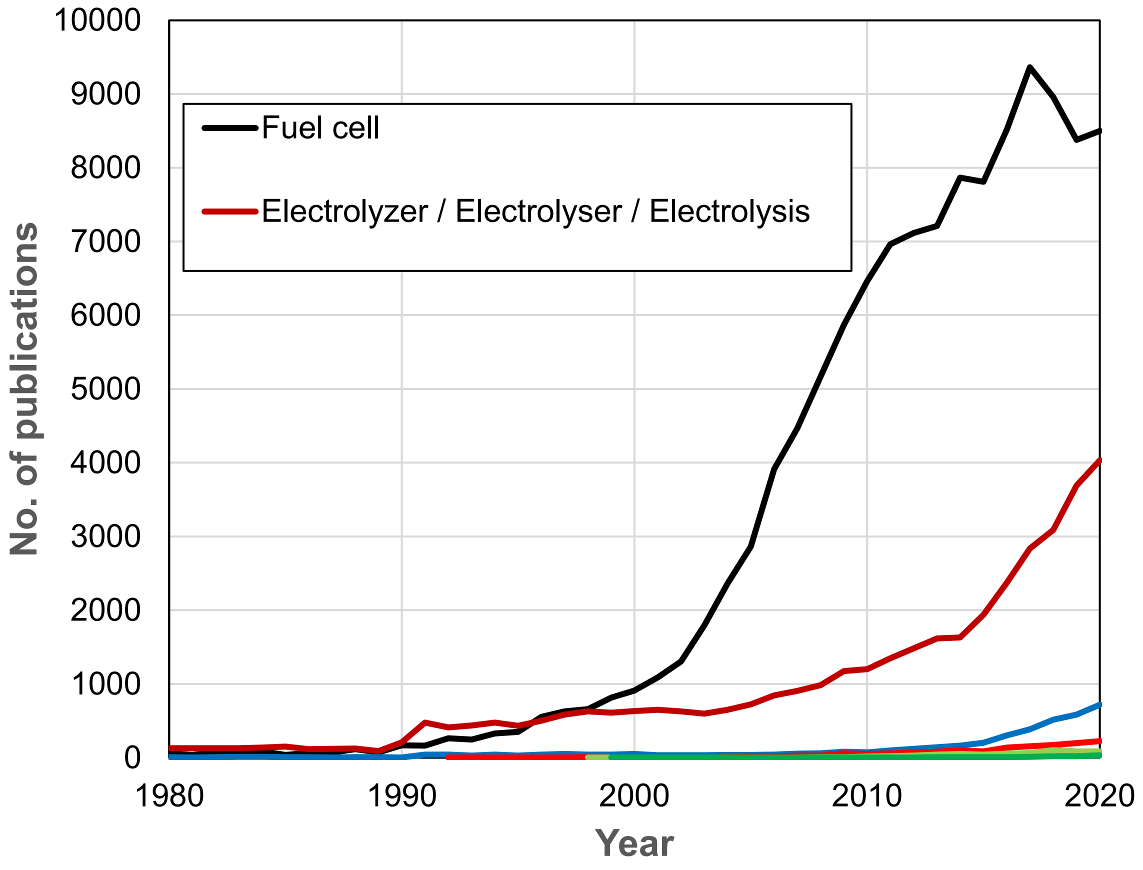
Global installed electrolysis capacity by region and technology, 2015-2020

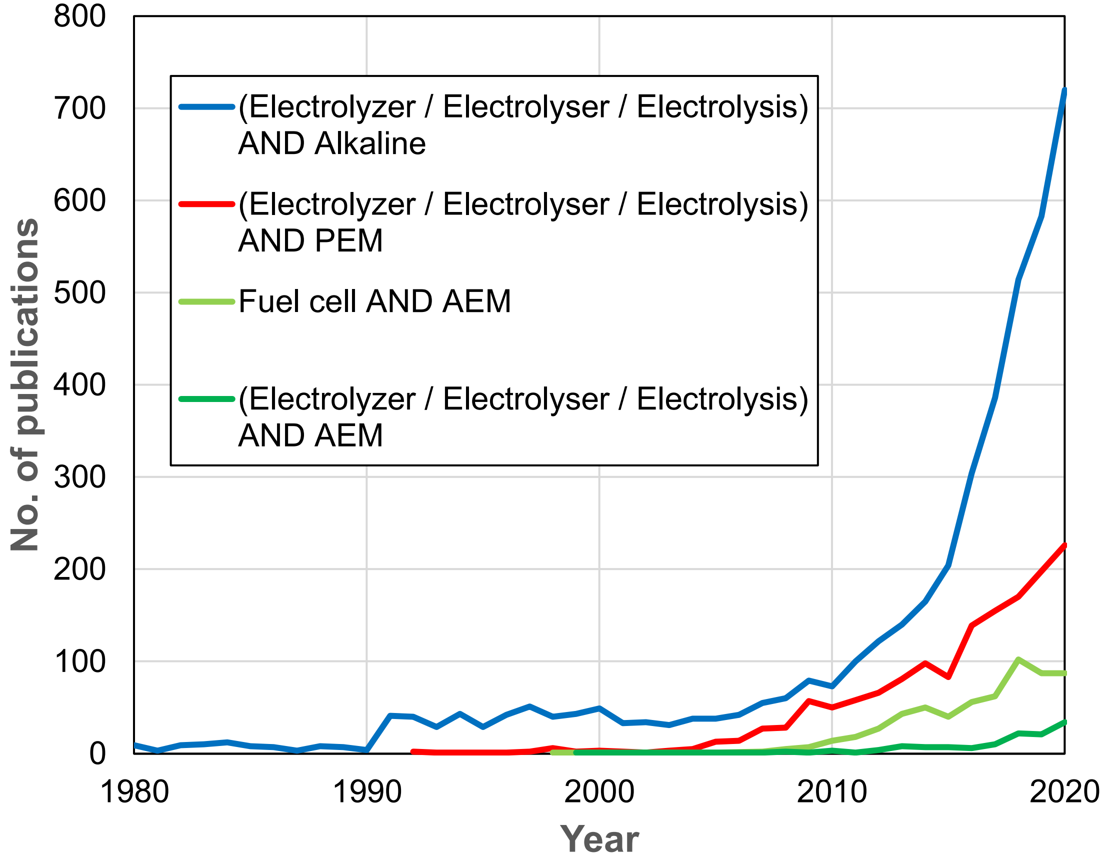
Fuel cells ~2.5 GW/y
= 10 times electrolyzers





Publication statistics (Web of Science)





A tremendous need for electrolysis

EU Hydrogen strategy 2020	
2020-2024	6 GW of electrolysis, 1 million tonnes of hydrogen
2025-2030	40 GW of electrolysis, 10 million tonnes of hydrogen
2030-2050	13-14 % of total energy mix - hydrogen

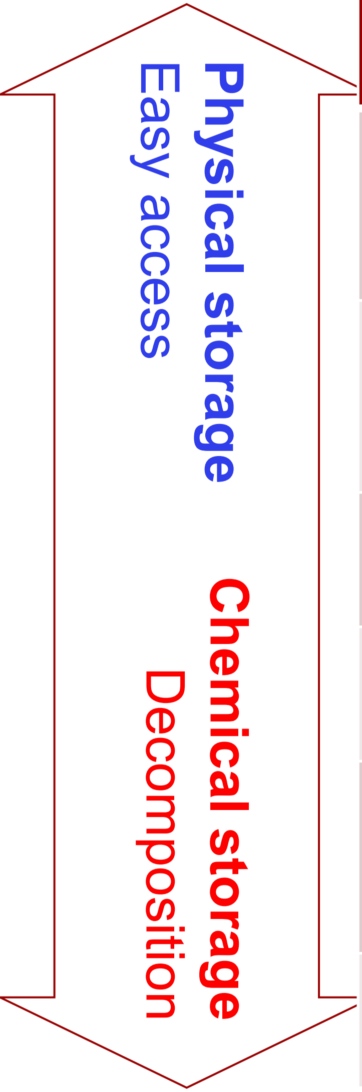
BloombergNEF's New Energy Outlook (NEO)	
2030	Green Scenario: 1.9 TW of electrolyzers to kick-start the hydrogen sector.
2050	Red (nuclear) Scenario 3.572 TW of nuclear capacity to power electrolyzers

- Total world average energy flow: 18 TW
- Several GW of electrolyzer projects in the European pipeline
- European production capacity for electrolyzers is currently below 2 GW per year

"Ask not who makes the best electrolyzer"

"Ask, who can deliver"

Overview of hydrogen storage

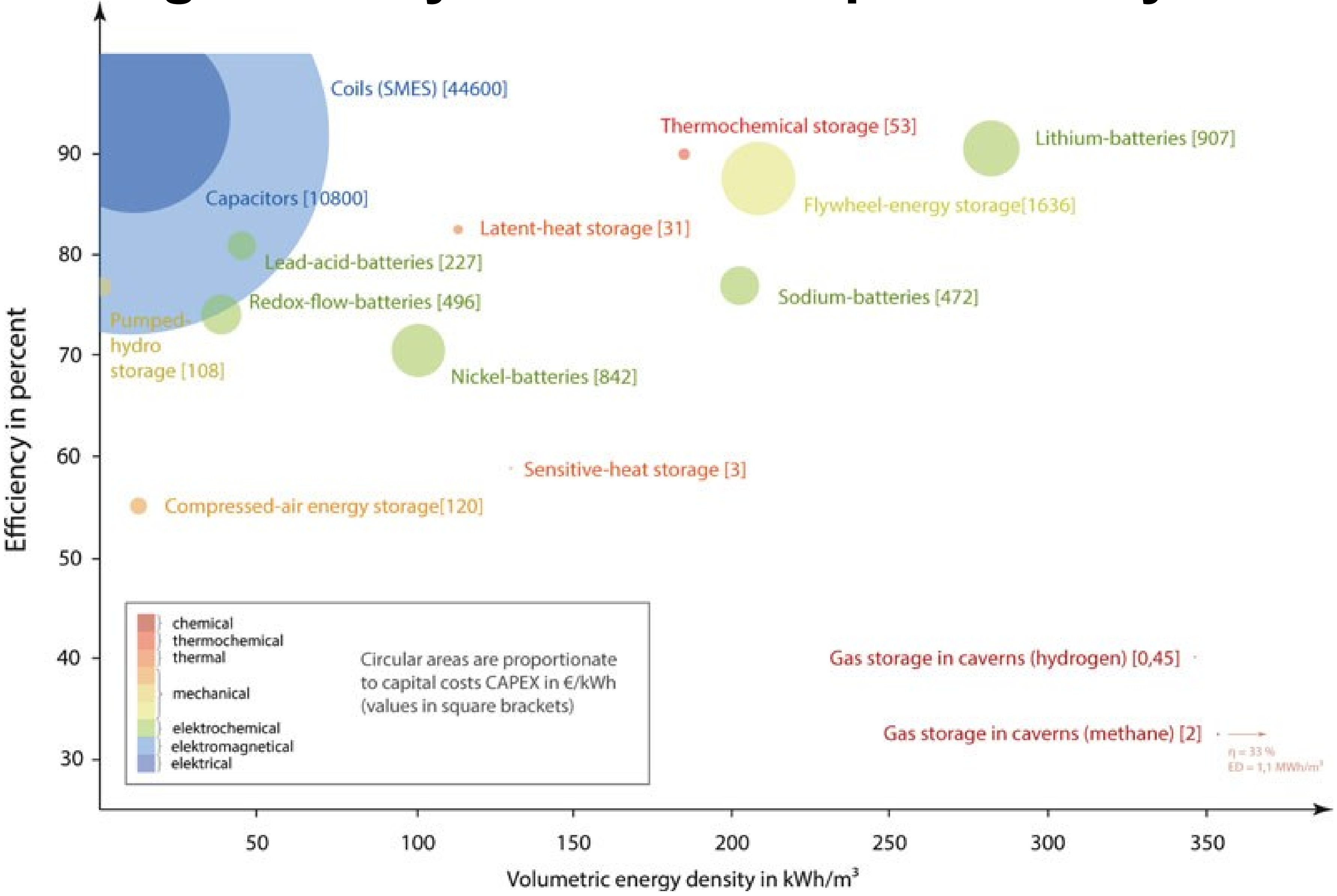


Method	Pros	Cons	State of implementation
High pressure	Practical. Quite high energy density. Easy access.	Energy for compression. Safety. Cost of cylinder	**Standard (almost exclusively)**
Liquid	High energy density. Liquid fuelling. Potential for large scale transportation of energy.	Energy for liquefaction. Boil-off. Cost of tank	Only demo
Adsorbed	Potential for higher storage density than high pressure	Only dense at 77 K.	Not practical
Metal hydride	Low equilibrium pressure. Tailoring pressure.	High mass of host. Large heat of reaction. Cost	Only demo
Liquid organic (LOHC)	Liquid. Easy to transfer. Potential for large scale transportation of energy.	Heat of reaction. Cost	Only demo
Synthetic fuels	Liquid. High energy density.	Energy loss on conversion	In progress (Power-to-X)

When and when not hydrogen

Storage density and round trip efficiency

SMES: Superconducting magnetic energy storage



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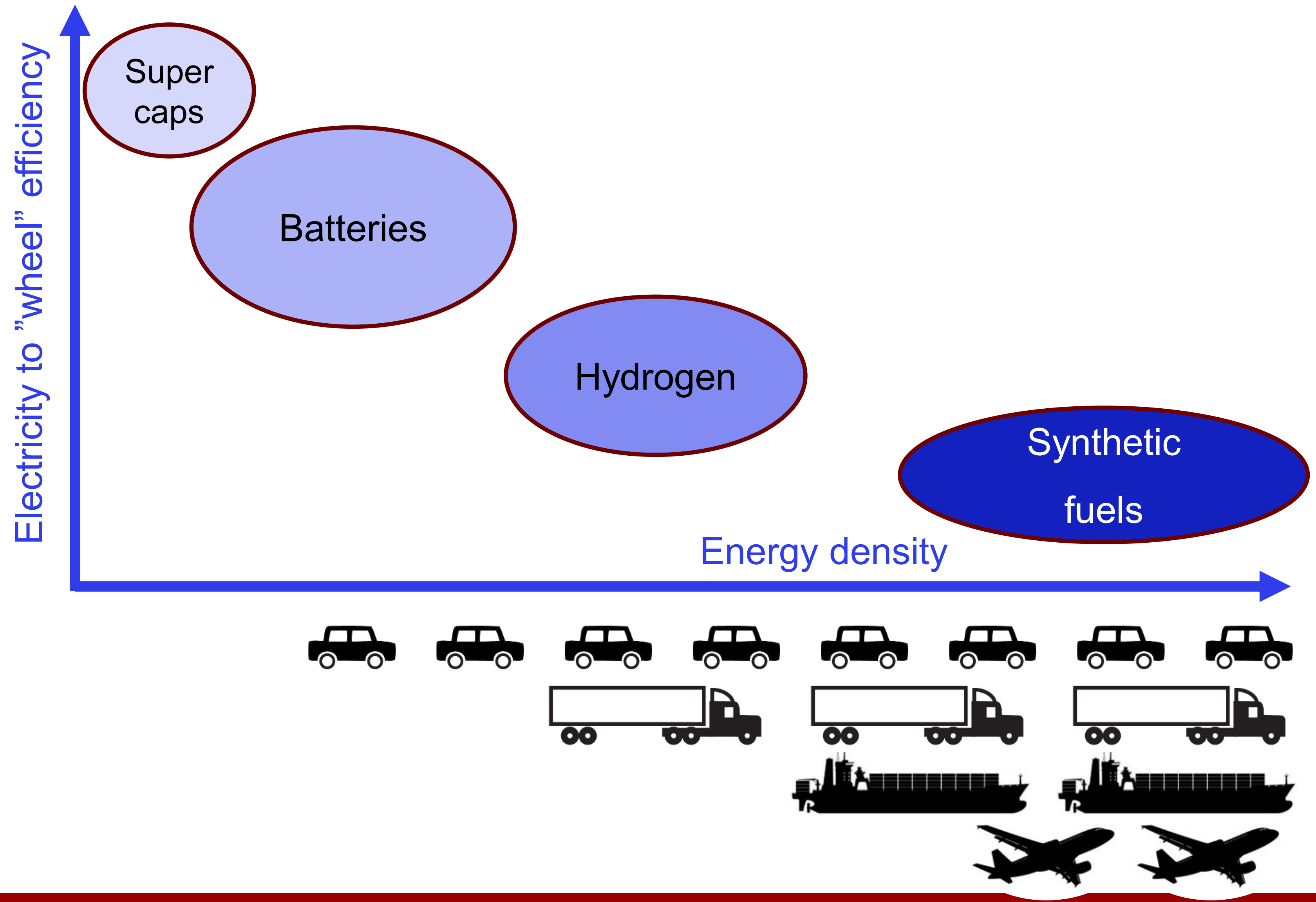
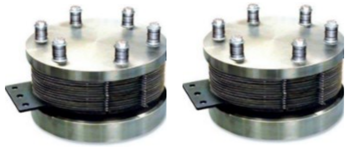
Efficiency vs. energy density (schematic)



Scaling with power and energy

	Scaling with power	Scaling with energy
Batteries		
Hydrogen		
Synthetic fuels		 (Only storage tank)

The battle with the batteries

Driving range	√	√
Efficiency	÷	√
Fuelling time	√	÷
Emissions	√	√
Weight	(√)	(√)
Infrastructure	÷	÷
Home charging	÷	√
Apartment charging	√	÷

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