Role of Hydrogen for Sustainability

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Abstract

Governments have too high expectations of the of Hydrogen in the Energy System. This presentation shows what Hydrogen may contribute, and why and how.

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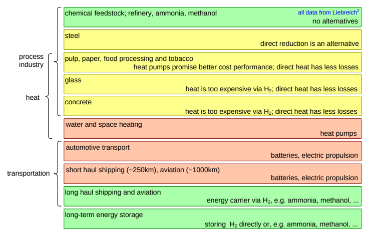
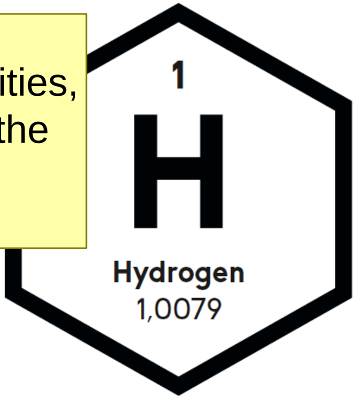


excerpt from:
Hydrogen— study Opportunities, potentials & challenges in the global energy system[16]
published in 2021

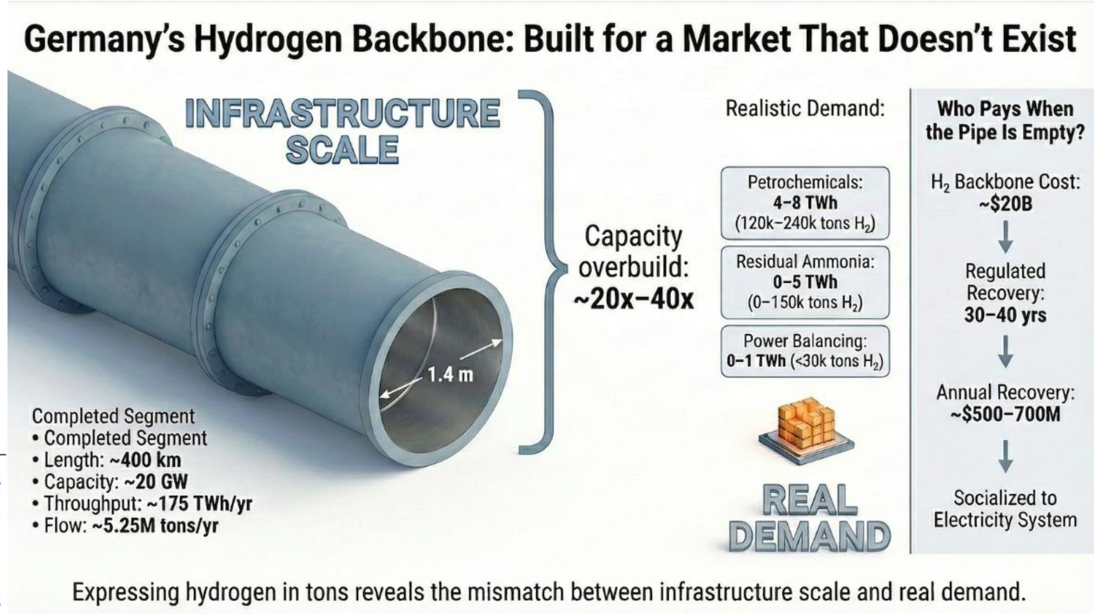


For aircrafts, no long–term alternatives to traditional propulsion with kerosene via jet engines are fore–seeable because here in particular, high energy densities with respect to the energy carriers are crucial. Rising air passenger numbers, however, are increasing pressure on governments and companies in the sector to find a sustainable alternative to fossil fuels. As a raw material or the production of synthetic fuels, hydrogen will also play a crucial role in this respect.

Enormous potential

Hydrogen technology has enormous potential to reduce costs across the entire energy transition and, like photovoltaic and wind energy, needs start–up financing. Subsidies for these renewable energies mean the technologies today produce energy at competitive prices. Major industrial countries such as China and Japan, as well as the US Federal State of California, plus Canada, are increasingly focusing on the integration of hydrogen in industry and mo–bility. Despite having different approaches, the countries named have two things in common: a roadmap and a clear government position.

A survey carried out by umlaut among participants in the future hydrogen industry in Germany paints a clear picture. Company representatives agree that sustainably produced hydrogen is unavoidable in the long–term if our energy system is to be transformed in line with the energy transition. The international hydrogen production will fundamentally change dependencies in global energy trade, and support Germany and Europe in meeting their demand for



Google Gemini generated this infographic illustrating the stark mismatch between the massive scale of Germany's planned hydrogen infrastructure and current realistic demand.

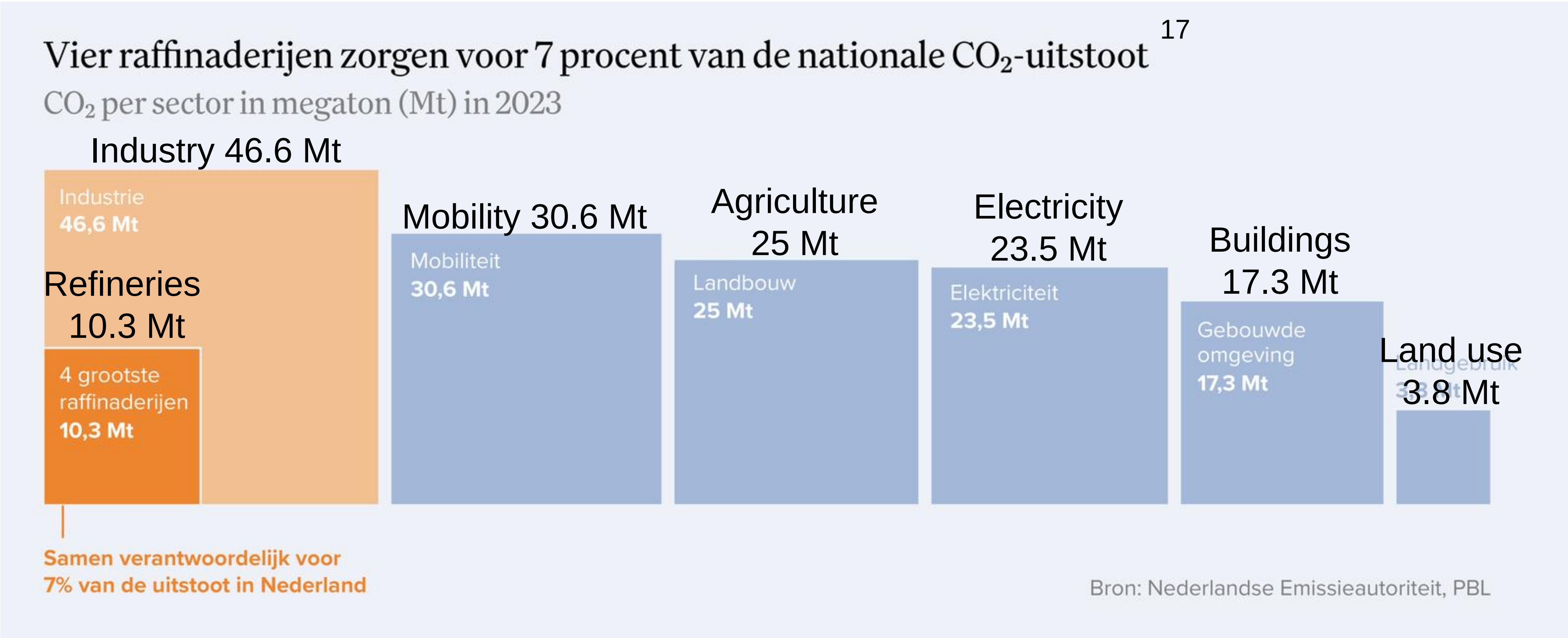
400km Hydrogen Pipeline With No Users Will Raise Germany's Electricity Prices [14, 15]

What are Viable and Feasible Hydrogen Applications

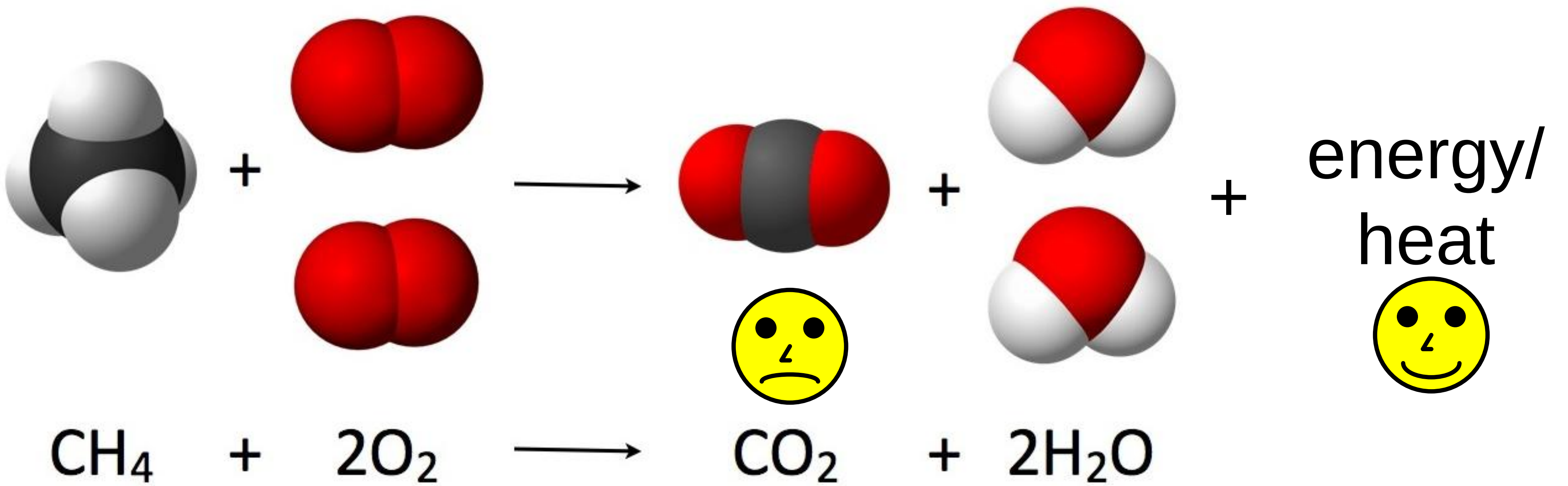
all data from Liebreich[2]

- **process industry**
  - chemical feedstock; refinery, ammonia, methanol — no alternatives
  - steel — direct reduction is an alternative
  - **heat**
    - pulp, paper, food processing and tobacco — heat pumps promise better cost performance; direct heat has less losses
    - glass — heat is too expensive via H_2; direct heat has less losses
    - concrete — heat is too expensive via H_2; direct heat has less losses
- **heat**
  - water and space heating — heat pumps
- **transportation**
  - automotive transport — batteries, electric propulsion
  - short haul shipping (~250km), aviation (~1000km) — batteries, electric propulsion
  - long haul shipping and aviation — energy carrier via H_2, e.g. ammonia, methanol, ...
- long-term energy storage — storing H_2 directly or, e.g. ammonia, methanol, ...

Dutch CO2 Emissions in 2023 per Sector



Current Situation: Using Methane Causes CO2 Emissions



from: https://commons.wikimedia.org/wiki/File:Combustion_reaction_of_methane.jpg I added Smileys and energy/heat.

Relevant Chemistry, 4 Elements Play a Main Role

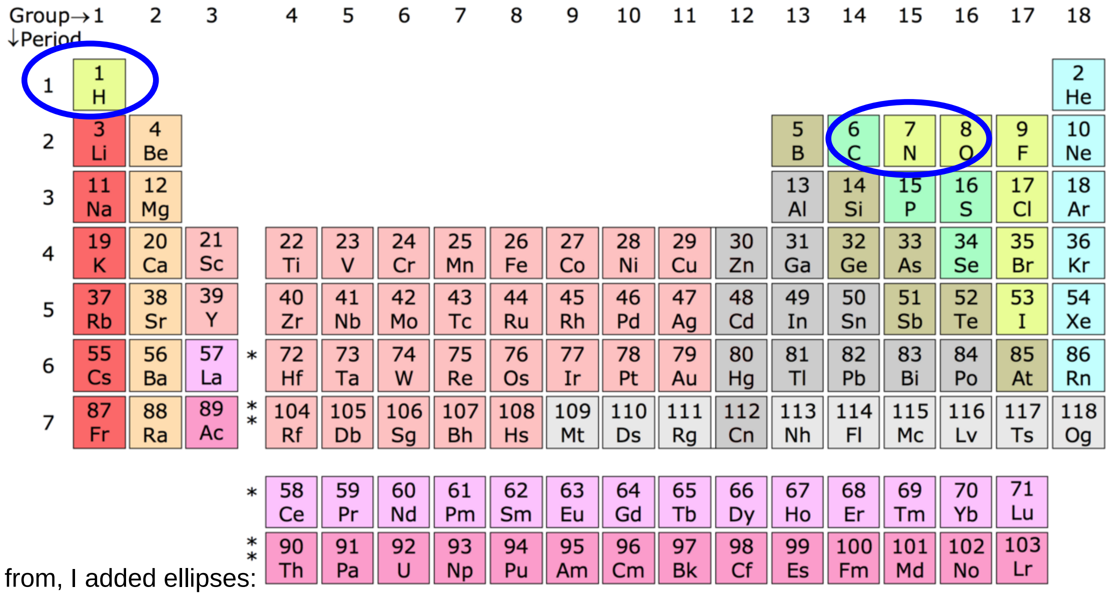
atoms

Symbol	name	atomic weight
H	Hydrogen	1
C	Carbon	12
N	Nitrogen	14
O	Oxygen	16

from: https://en.wikipedia.org/wiki/Standard_atomic_weight

molecules

formula	name	gas/liquid
H_2	Hydrogen	gas
O_2	Oxygen	gas
N_2	Nitrogen	gas
CO_2	Carbondioxide	gas
CH_4	Methane	(natural) gas
CH_3OH	Methanol	liquid
H_2O	water	liquid
$NH_3(aq)$	Ammonia	liquid
HCOOH	formic acid	liquid



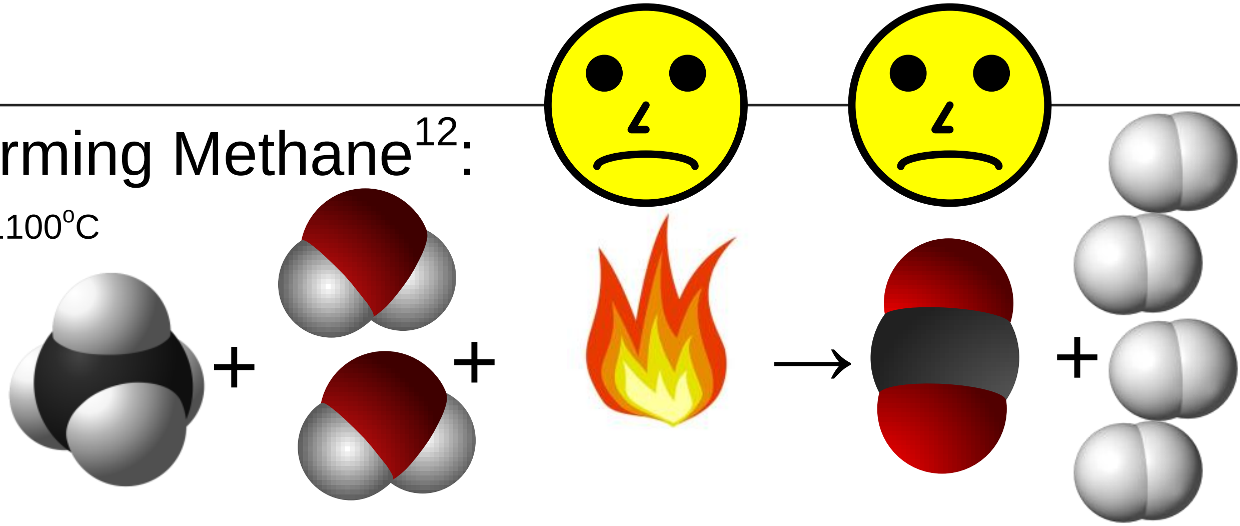
from, I added ellipses:
https://upload.wikimedia.org/wikipedia/commons/thumb/9/9d/Periodic_Table_Chart.png/1280px-Periodic_Table_Chart.png

Production of Hydrogen, Main Options

Grey Hydrogen from reforming Methane[12]:

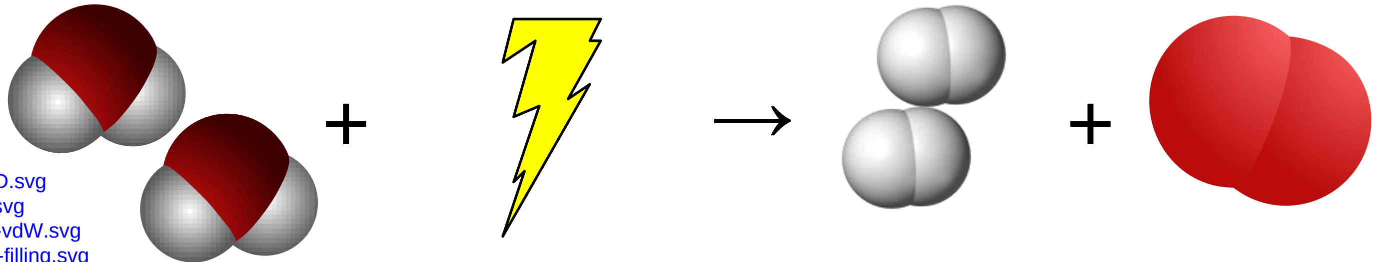
$CH_4 + H_2O + 206$ kJ/mol $\rightarrow CO + 3H_2$ @700-1100°C

$CO + H_2O \rightarrow CO_2 + H_2 + 41$ kJ/mol @130°C



in totaal: $CH_4 + 2\ H_2O + 165$ kJ/mol $\rightarrow CO_2 + 4\ H_2$

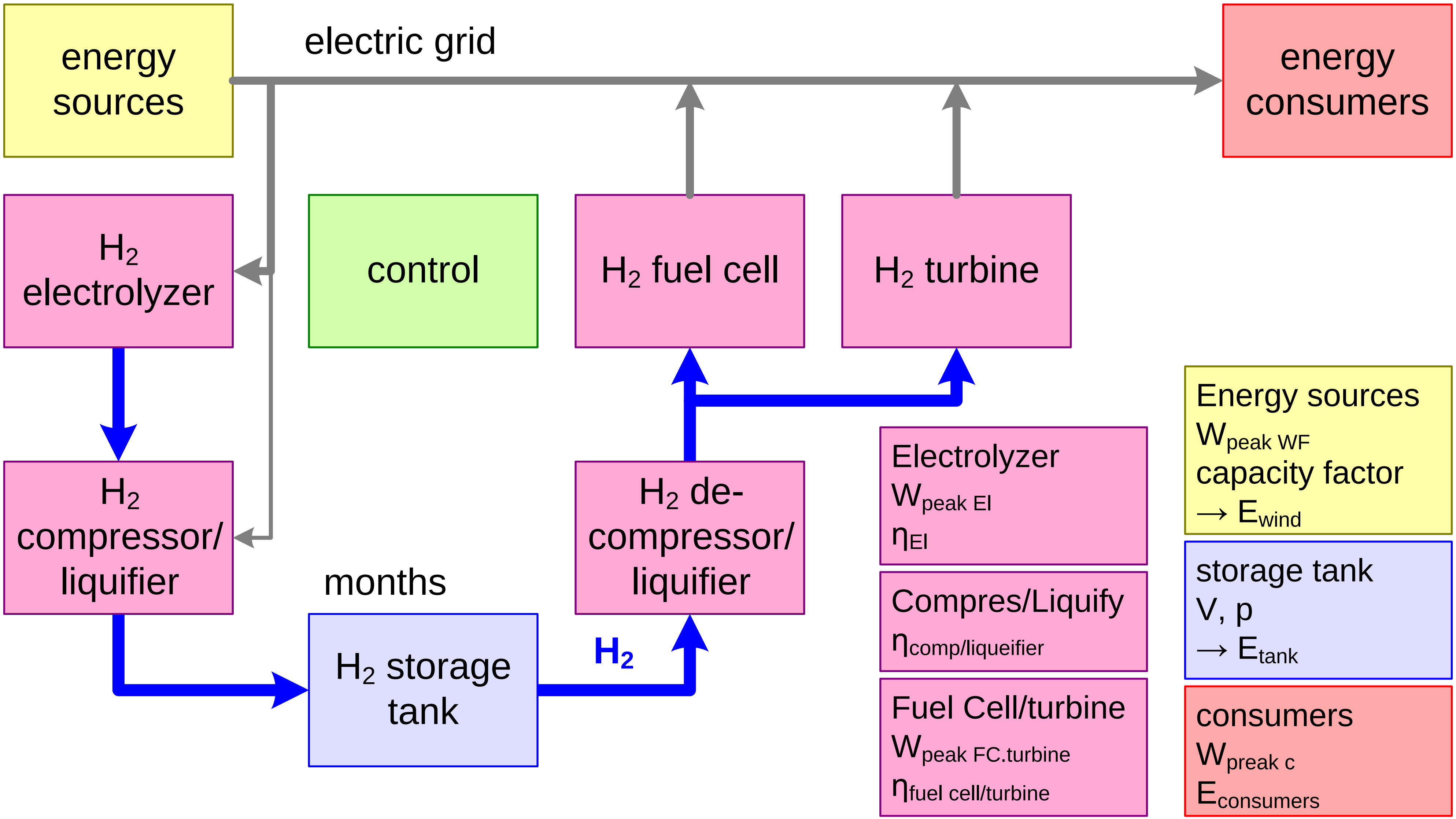
Green Hydrogen through electrolysis[13]:



$2\ H_2O + 286$ kJ/mol $\rightarrow 2\ H_2 + O_2$

https://commons.wikimedia.org/wiki/File:Water_molecule_3D.svg
https://commons.wikimedia.org/wiki/File:Oxygen_molecule.svg
https://commons.wikimedia.org/wiki/File:Carbon-dioxide-3D-vdW.svg
https://commons.wikimedia.org/wiki/File:Methane-3D-space-filling.svg
https://commons.wikimedia.org/wiki/File:Dihydrogen-3D-vdW.png
https://fr.wikisource.org/wiki/Fichier:Fireicon.svg

Block Diagram of Hydrogen Production and Consumption



Simplified Electrolysis Diagram

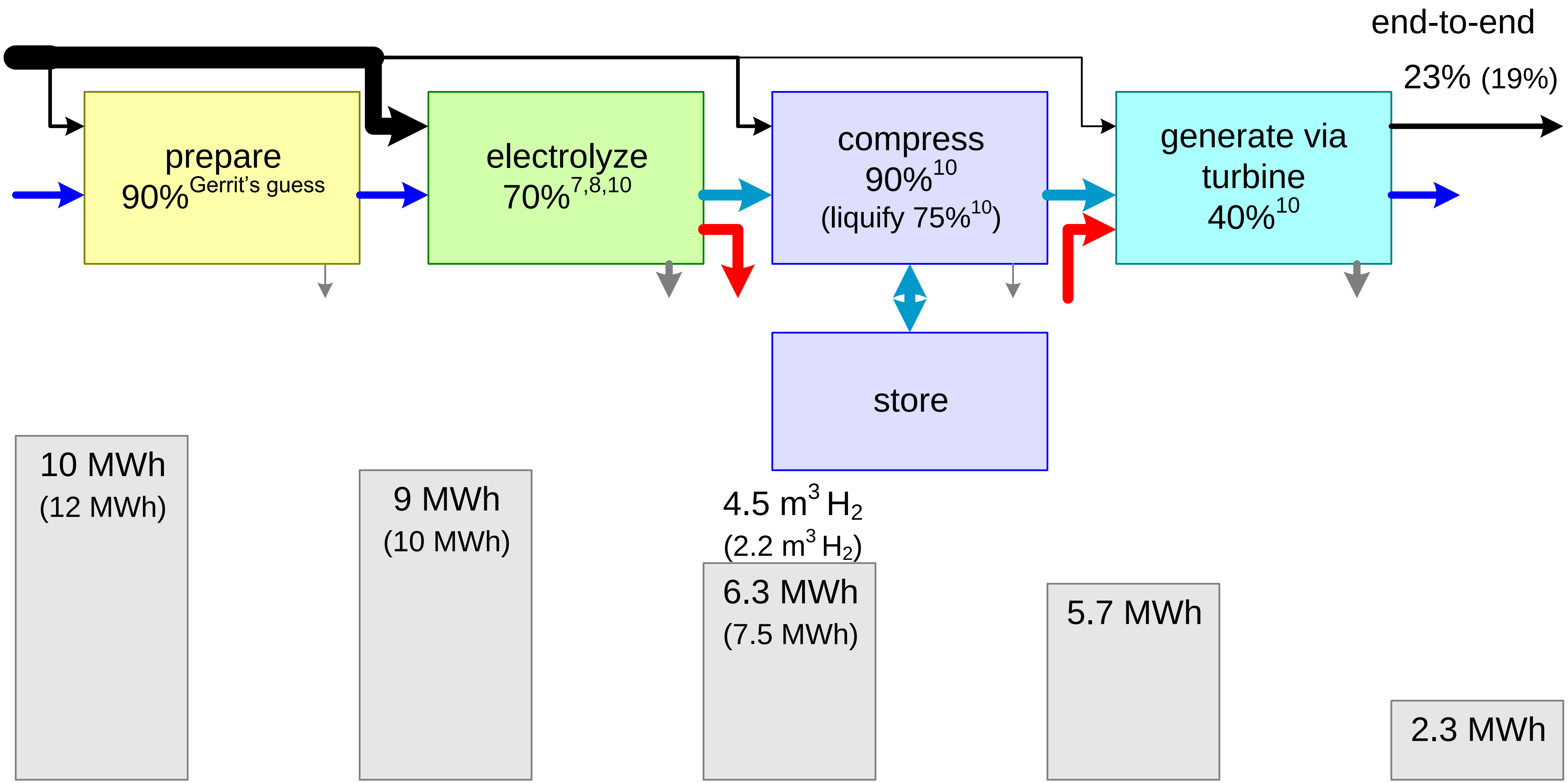
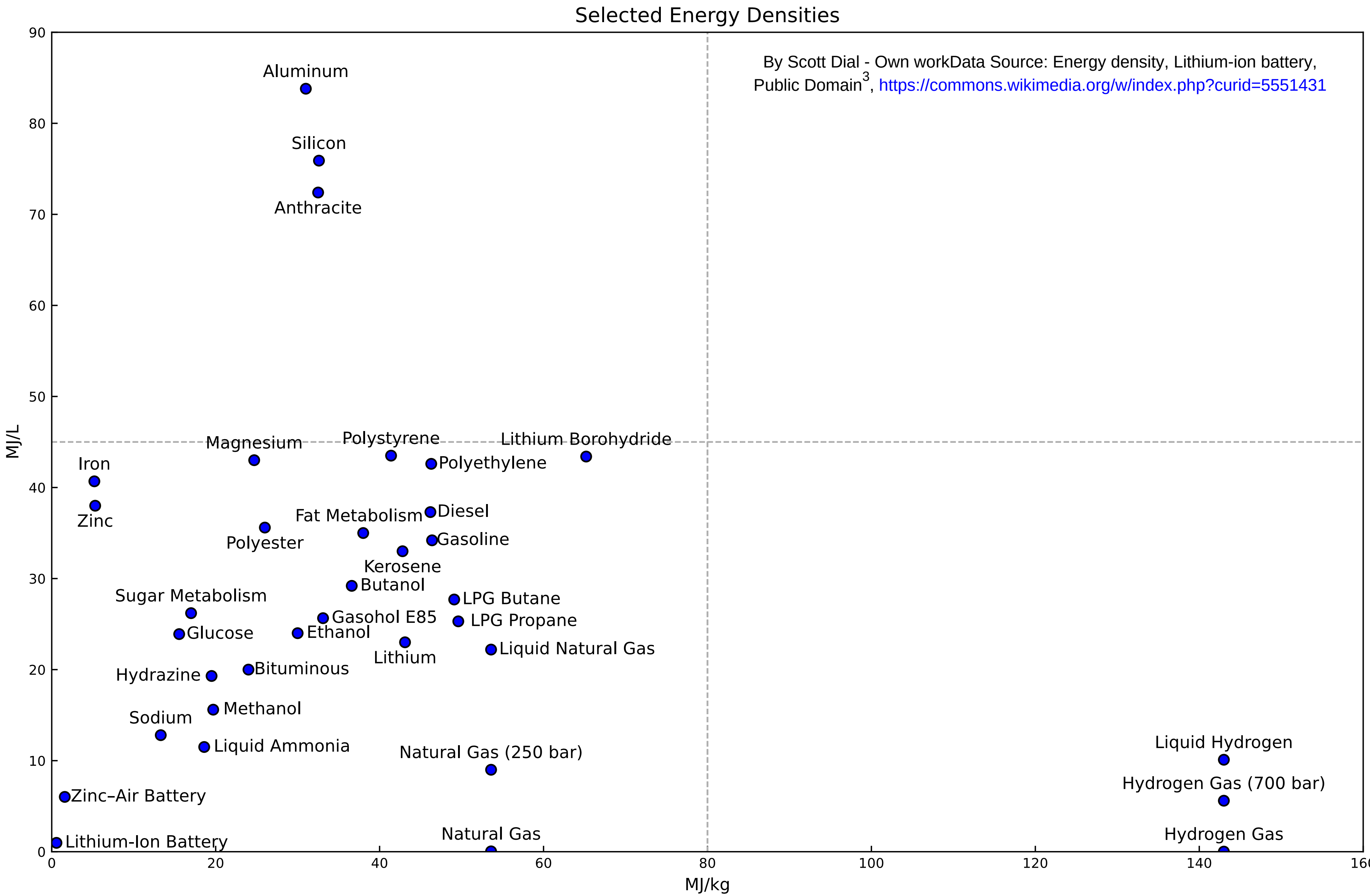


Table with Efficiency of Process Steps

	fuel cell, compressed limited capacity	fuel cell, liquified limited capacity	turbine compressed	combustion compressed very immature
preparing, e.g. cleaning[author's guess]	90%	90%	90%	90%
electrolyzer alkaline	70%[7, 8, 10]	70%[7, 8, 10]	70%[7, 8, 10]	70%[7, 8, 10]
compressor decompressor	90%[10]		90%[10]	90%[10]
liquifier deliquifier		75%[5]		
fuel cell alkaline @ partial load 70%[9] alkaline @ viable load	60%[10]	60%[10]		
turbine			40%[10]	
combustion engine				50%[10]
end-to-end **(25% to 30%[11])**	34%	28%	23%	28%

Energy Density of Energy Carrier Candidates



Energy Density of Energy Carrier Candidates

	gravimetric energy [3,4] MJ/Kg	packaged	volumetric energy [3,4] MJ/L	packaged
Hydro @100m height	0.001		0.001	
Li-ion	1.6	1	4.3	2.8
wood	16			
methanol	20		16	
coal	24			
ethanol	30		24	
diesel, gasoline	45		35	
natural gas	54		0.03	
Compressed Natural Gas @25Mpa	54		9	
Liquid Natural Gas	54		22	
liquid H_2	140		10	
compressed H_2 @69Mpa	140		5	
gaseous H_2	140		0.01	
Uranium 235	3.9M			

Some Future Developments

high temperature (750°C) electrolyser, 90%

https://www.solar365.nl/nieuws/bollenbedrijf-zet-overschot-zonnestroom-om-in-waterstof--67A6ACB4.html

HOLTHAUSEN ENERGY POINTS

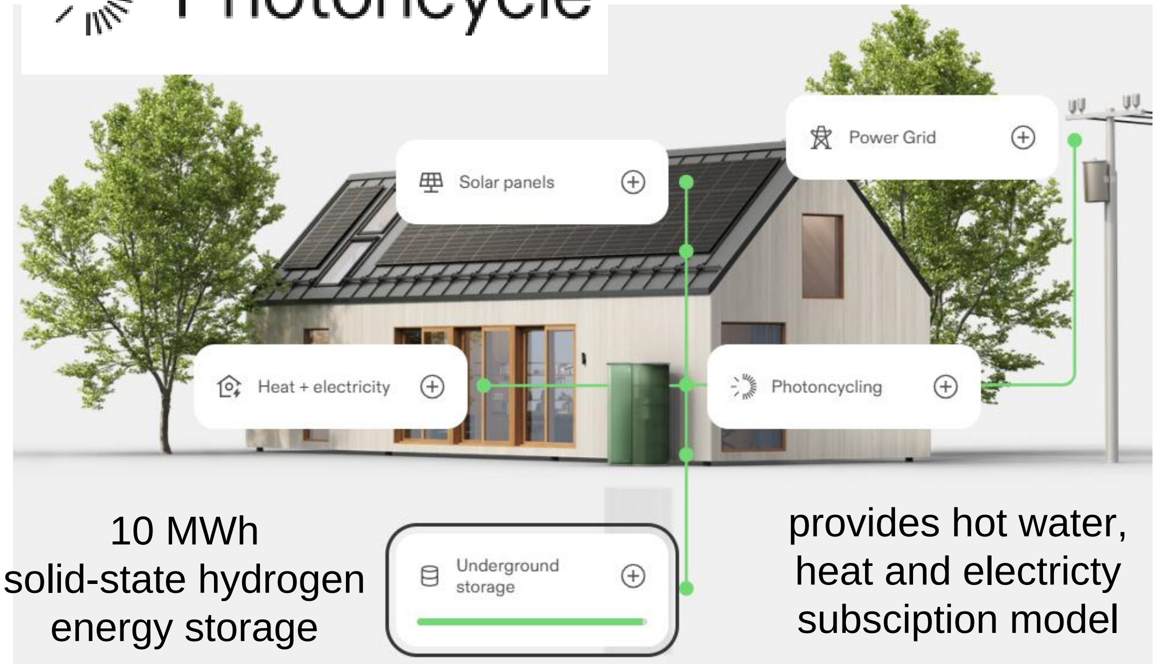
Local Hydrogen production using low cost electricity

https://www.energypoints.nl

https://www.rvo.nl/praktijkverhalen/pionieren-met-betaalbare-waterstofproductie

https://www.photoncycle.com

Photoncycle



10 MWh solid-state hydrogen energy storage

provides hot water, heat and electricty subsciption model

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