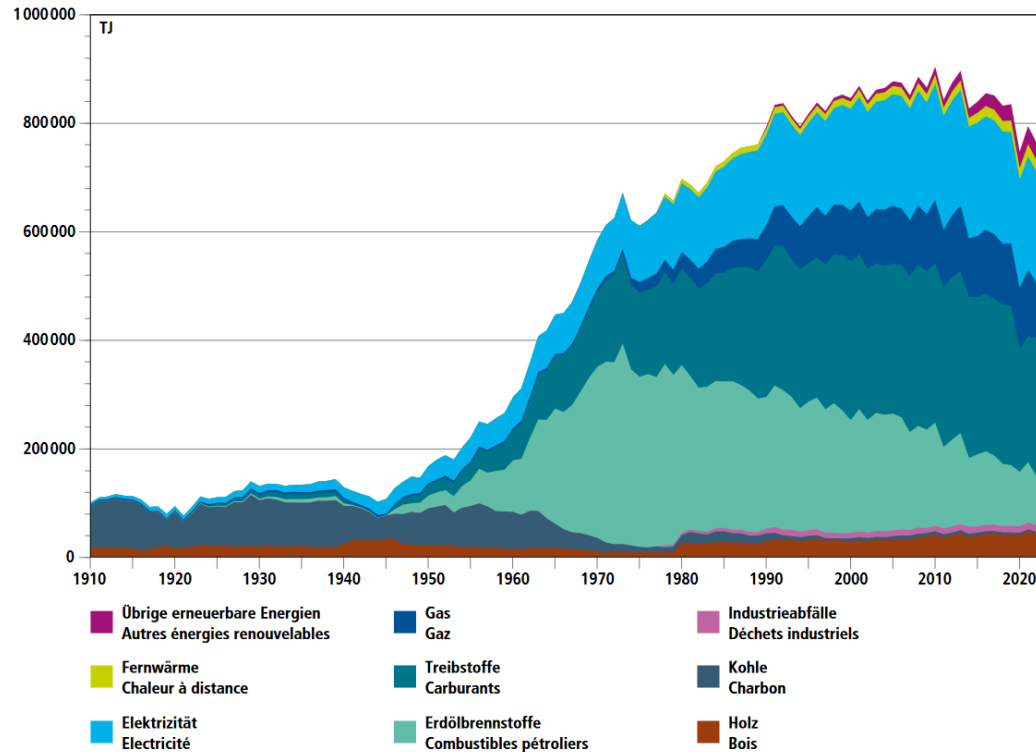


Seasonal energy storage with the steam-iron process

Dr. Samuel Heiniger
Functional Materials Laboratory
ETH Zürich



Introduction



BFE, Schweizerische Gesamtenergiestatistik 2023 (Fig. 1)
OFEN, Statistique globale suisse de l'énergie 2023 (fig. 1)

First “Bio-based” energy (muscles, wood, ..)

Late 18rds -> Coal

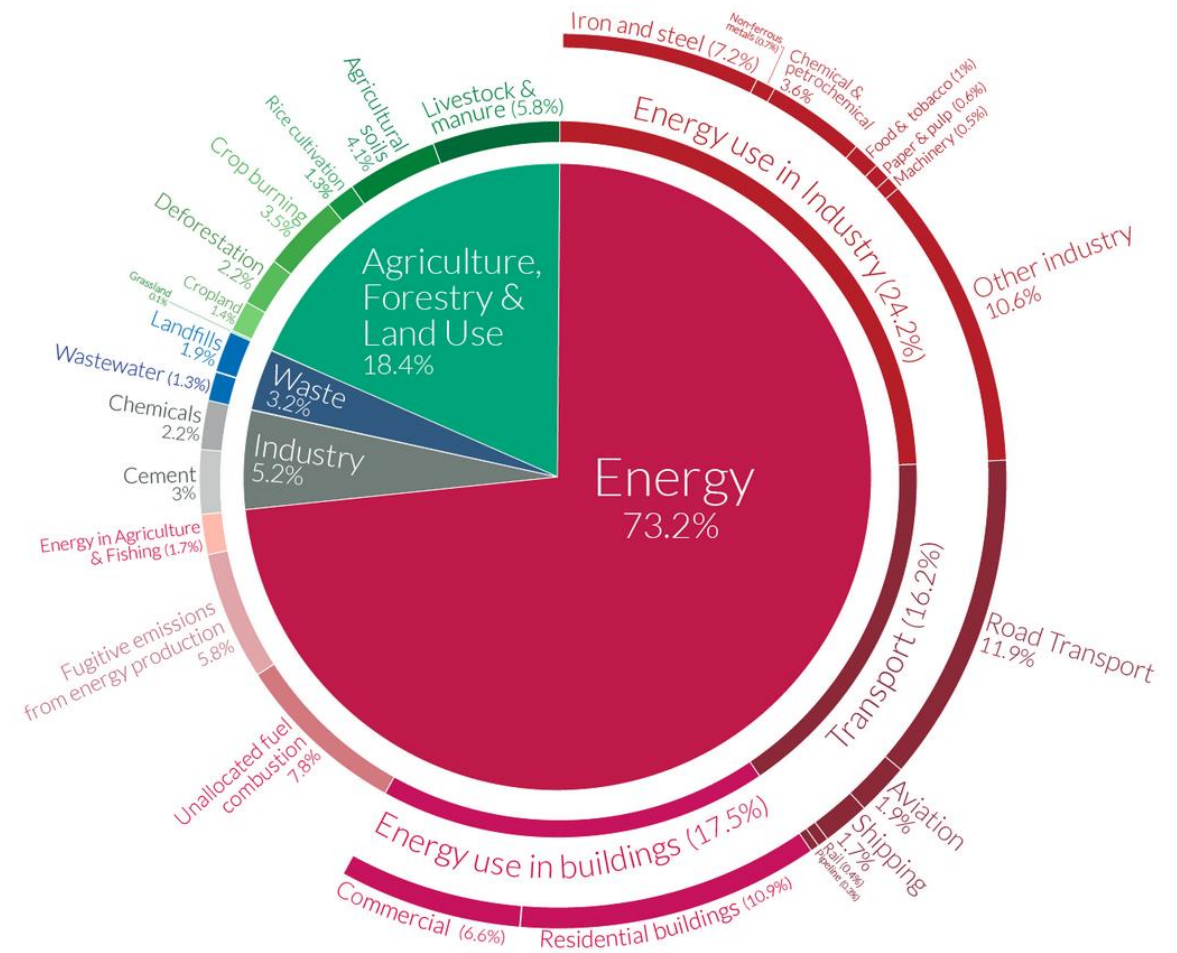
Early 20th century -> Oil and electricity

Early 21st century -> renewables

1. Swiss federal office of energy (BFE), *Schweizerische Gesamtenergiestatistik 2023*, 2023

Introduction

- **Energy** is the main contributor to CO₂ emissions!
- Rapid **electrification** of heat, production and transportation
- **Renewable power** sources are key for a sustainable future



Greenhouse gas emissions by sector in 2016 [1]

1. H. Ritchie, *Climate change and flying: what share of global CO2 emissions come from aviation*, 2020, OurWorldInData.org

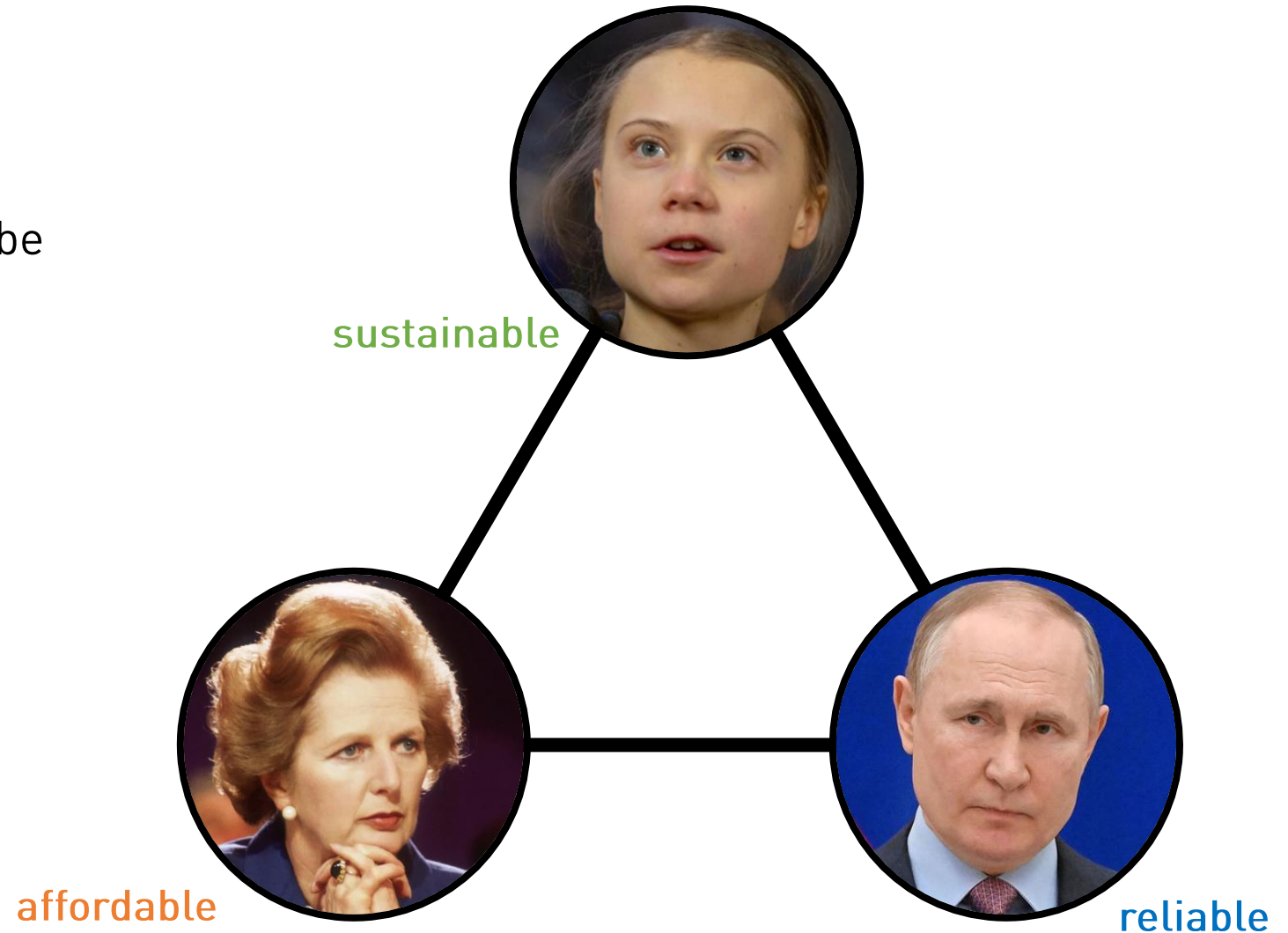
Energy Trilemma

However energy supply must not only be

- environmentally sustainable

but also

- affordable
- reliable
- (and socially/politically acceptable)



Is renewable power affordable?

- Renewable power is **cheaper than fossil fuels**
- **Cost** of new renewables are **sinking**



- Problem solved?

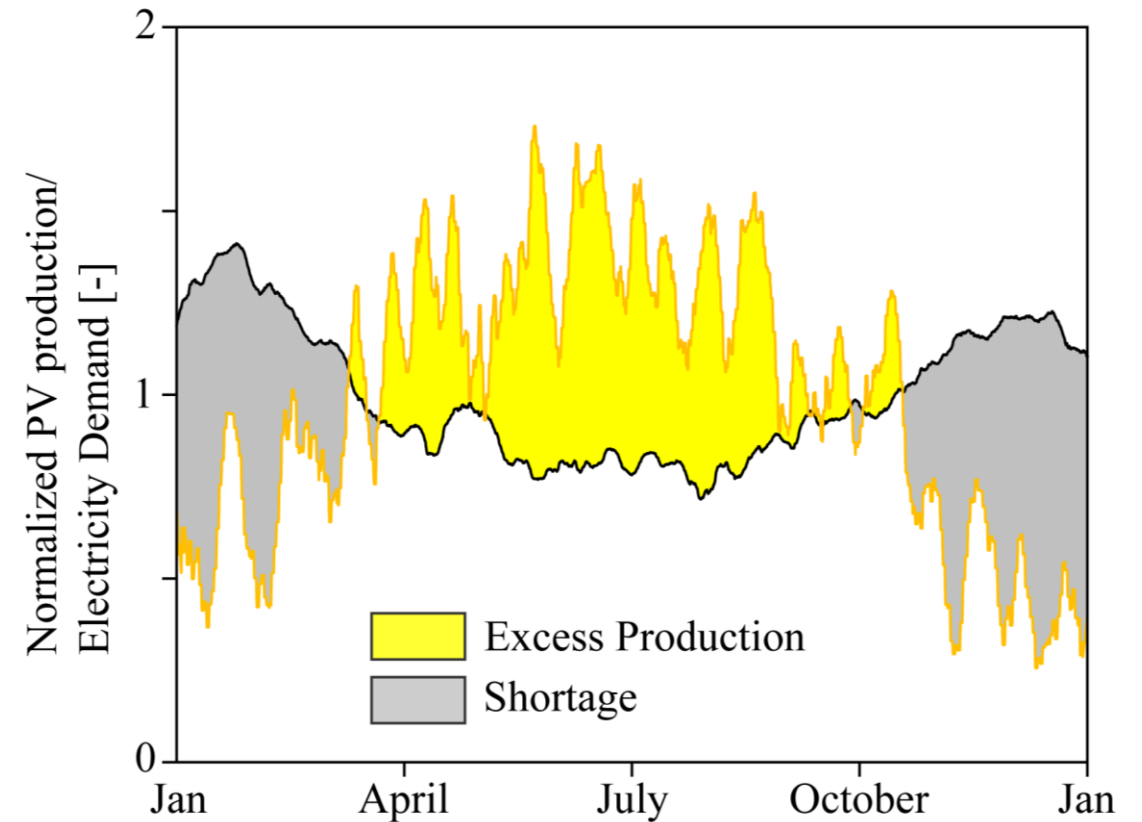


Global weighted average LCOE learning curve trends for solar PV, CSP, onshore and offshore wind, 2010 – 2022 [1]

1. International renewable energy agency, *Renewable power generation – costs in 2022, 2023*

Is renewable power reliable?

- Highest productivity of PV modules in summer
- Highest demand of energy in winter
- Demand supply mismatch

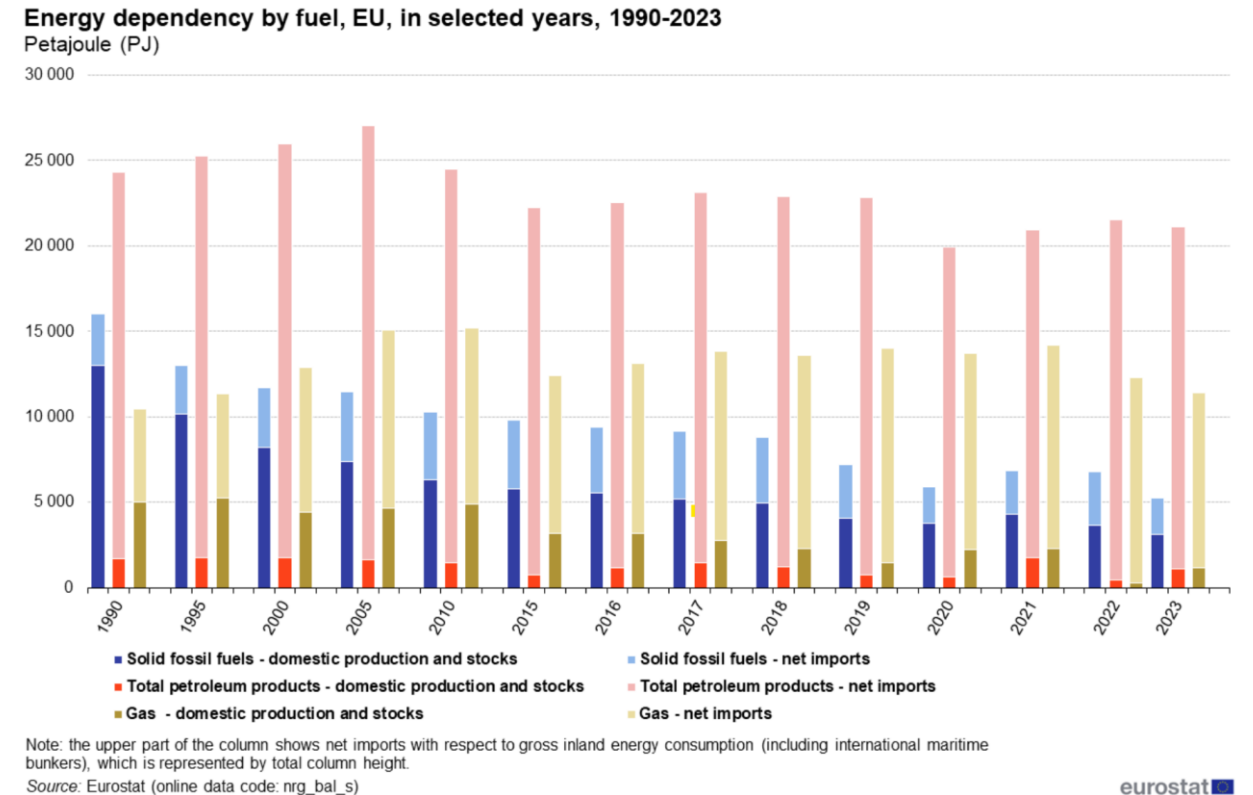


Normalized PV production and electricity demand for the year 2017. Figure shown in [1]

1. S.P. Heiniger, Z. Fan, W.J. Stark, *Safe seasonal energy and hydrogen storage in a 1: 10 single-household-sized pilot reactor based on the steam-iron process*, 2024, *Sust. Ener. Fuel*

Is our energy supply reliable?

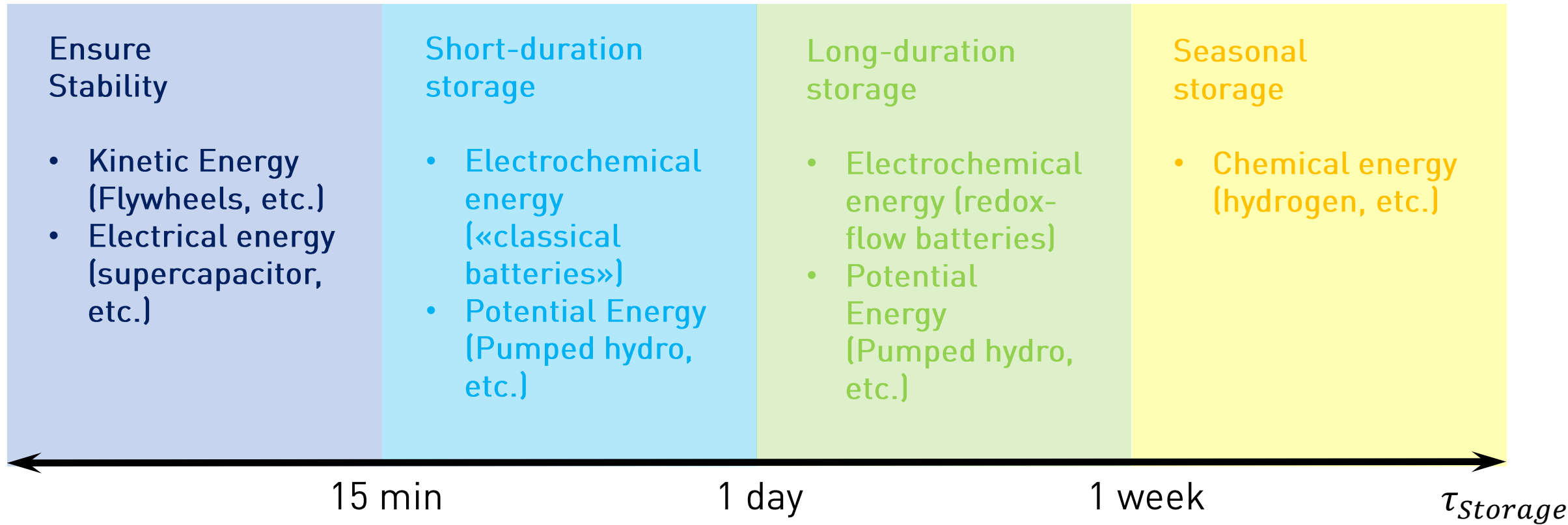
- Strong dependency on imports for fossil energy
- The EU imports ~300 BioEUR of fossil energy per year (15 % of total imports) [1]
- Main suppliers are Norway and the US (each ~20%) [1]



Energy dependency by fuel, EU, selected years, 1990 - 2023.
Figure shown in [1]

1. Energy statistics – an overview, Eurostat, May 2025, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview

Characteristic time of storage



Chemical energy carriers

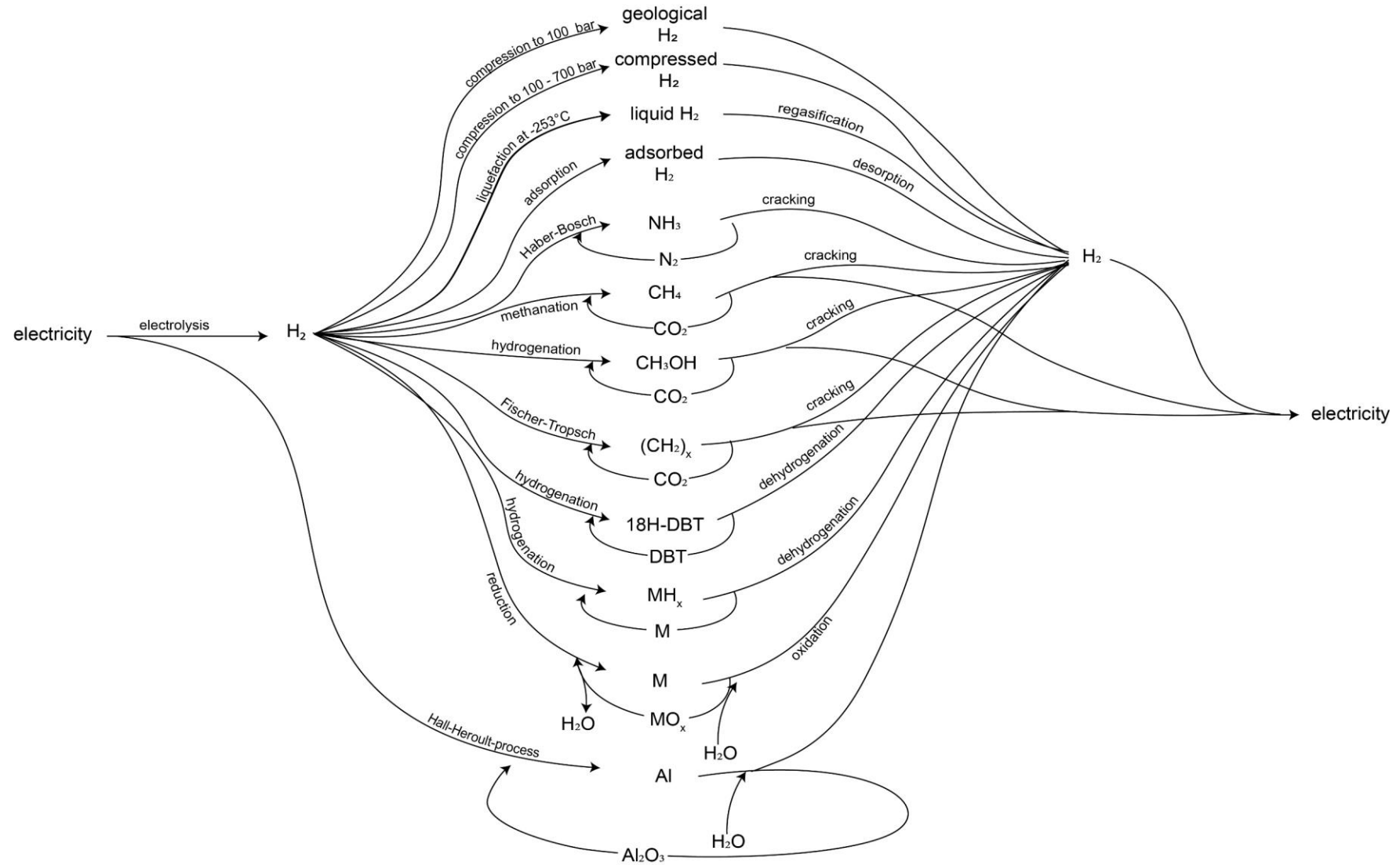
Today

Oil
Natural gas
Coal
Wood

Future

Building blocks of chemical industry
High temperature heat for processes
Ship/Aviation fuels
Transportation of energy
Stationary storage

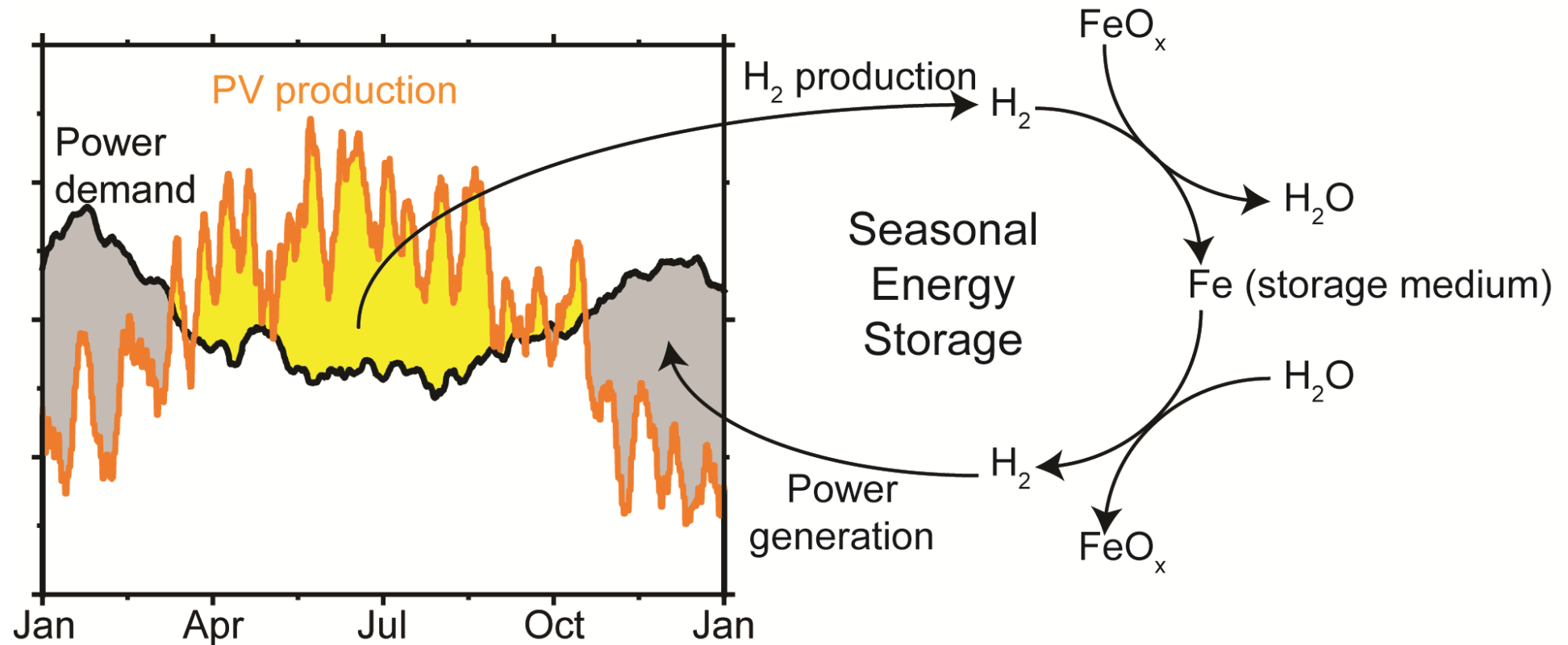
Power2X technologies



Which X is desirable?

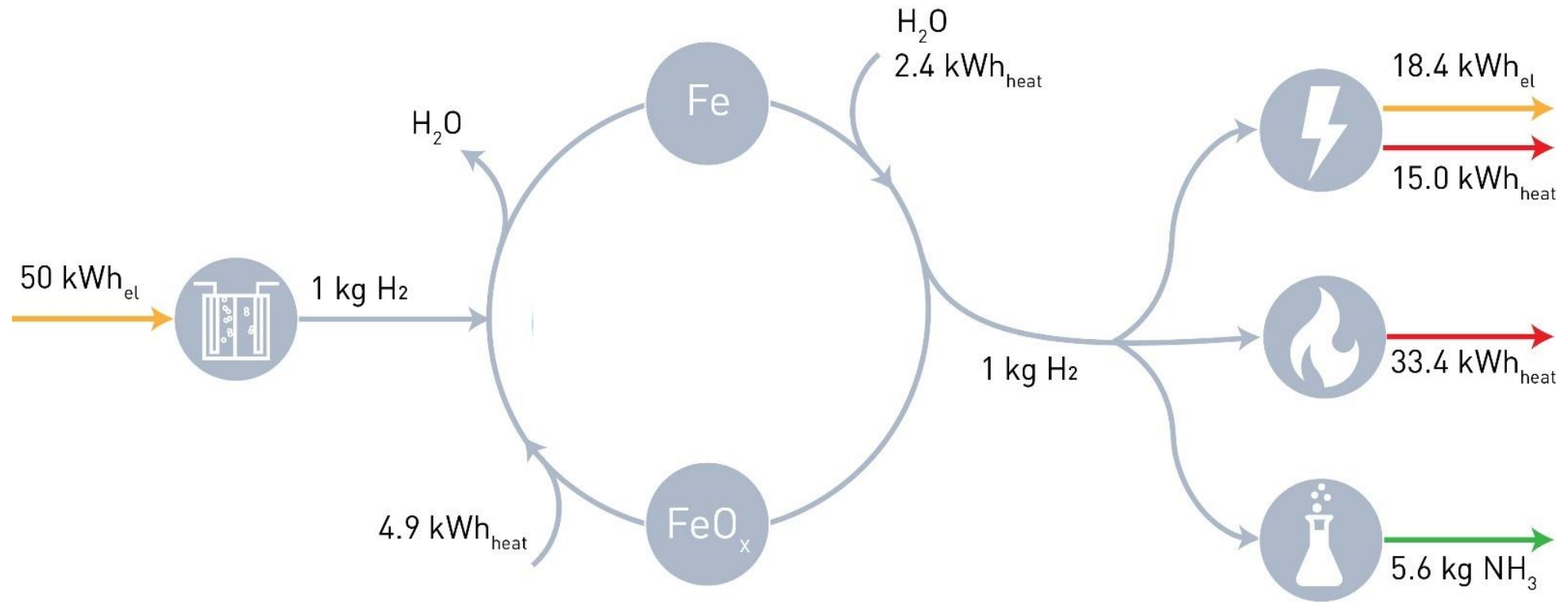
- Cheap → Economical feasibility
- Abundant → Ecological feasibility
- Safe → Not explosive, no pressure and non toxic
- Simple → Cheap and reliable
- Dense → Limits space use

how does Power to Iron work?



S.P. Heiniger, Z. Fan, W.J. Stark, *Safe seasonal energy and hydrogen storage in a 1: 10 single-household-sized pilot reactor based on the steam-iron process*, 2024, Sust. Ener. Fuel

Energetics



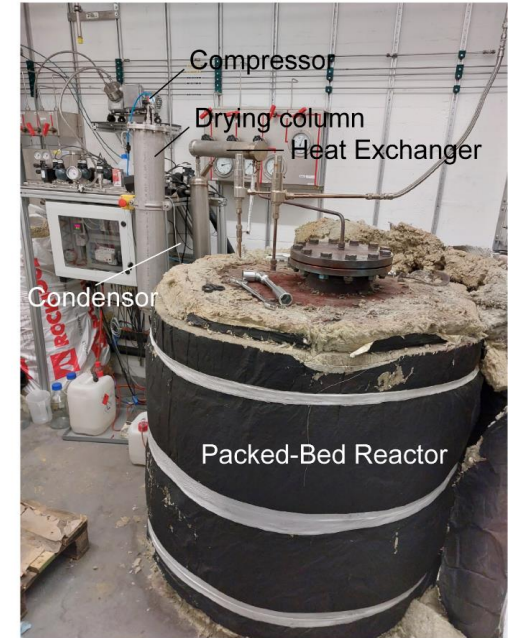
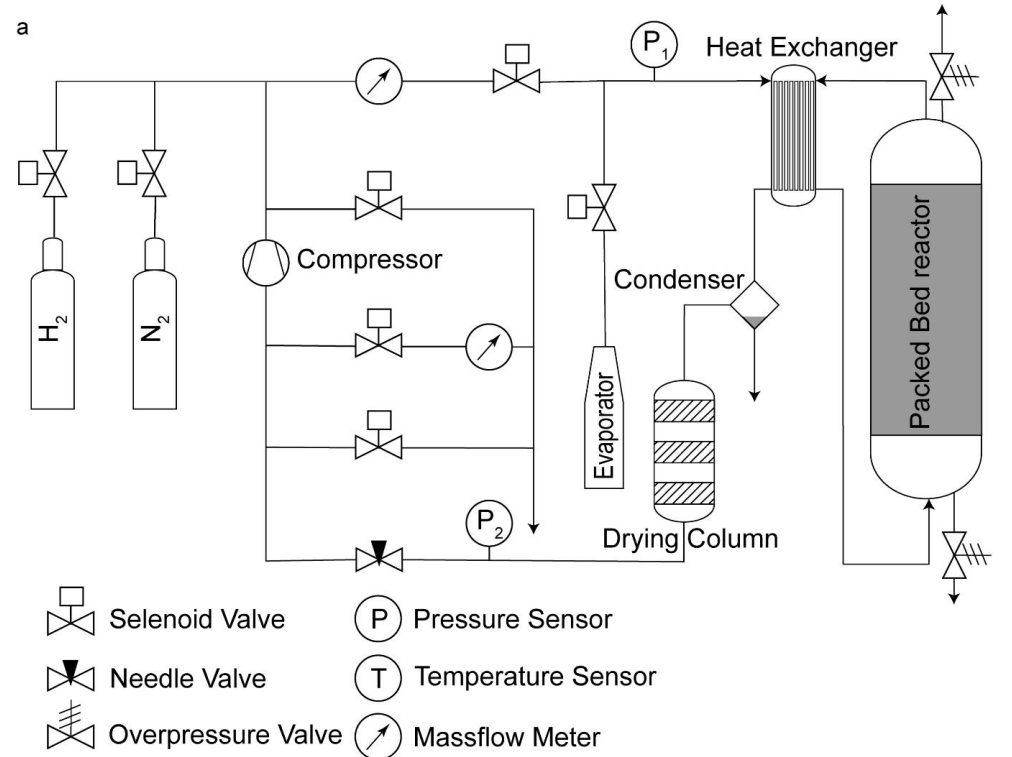
Pilot 1: 250 kWh size

Reactor of 210 L size [1-3]

2 successful cycles shown

7.1 kg H₂ stored

(10% of seasonal storage needs of a family)



a) Schematic representation of the lab scale pilot b) picture of the reactor after the 2nd charging after cool-down and removal of the insulation on top of it

1. S.P. Heiniger, Z. Fan, W.J. Stark, *Safe seasonal energy and hydrogen storage in a 1: 10 single-household-sized pilot reactor based on the steam-iron process*, 2024, *Sust. Ener. Fuel*
2. W. J. Stark and U. B. Lustenberger, EP3699991B1, 2020.
3. W. J. Stark and U. B. Lustenberger, EP3902040B1, 2021.

Pilot 2: ≈ 10 MWh size

3x 1.4 m³ storage tanks

natural iron ore

Each can cover 150% of winter
energy needs of a household

second cycle ongoing



10 MWh seasonal energy storage pilot plant at ETH Hönggerberg campus

Samuel Heiniger
samuel.heiniger@chem.ethz.ch

ETH Zürich
Functional Materials Laboratory
Vladimir-Prelog-Weg 1/HCI E112
8093 Zürich