FROM STORAGE TO STABILITY: TECHNOLOGIES FOR TOMORROW'S GRID

HYDROGEN

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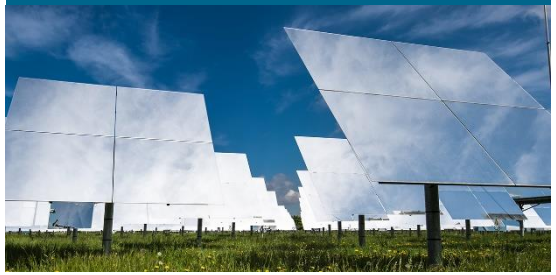
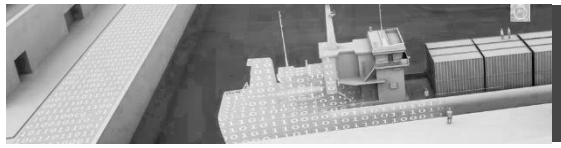
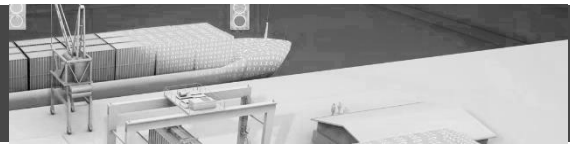
German Aerospace Center - DLR

DLR - Research Organisation + Space Agency + Project Management Agency

Aeronautics	Aerospace	Energy	Transport
			



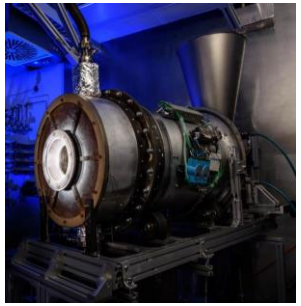
Security
security research (civil & defense)

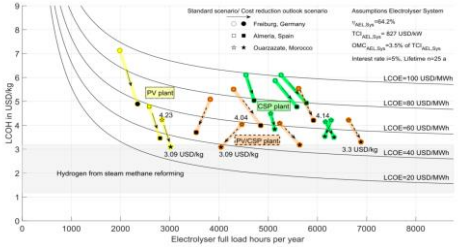


Digitalisation
Quantum technologies & system modelling

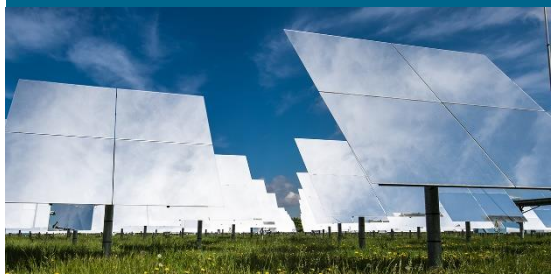
- Largests European research organisation for engineering and aerospace
- Close cooperation with research, economy and industry actors
- Institutionally funded by Federal Ministry for Economic Affairs and Climate Action, additionally by Federal Ministry of Defence, project funding by many others (e. g. Federal Ministry of Education and Research)

DLR - Research Organisation





Energy



Institute of Future Fuels (FF)

- Technology development and assessment for efficient and economical production of energy sources for a global, renewable energy economy
- Contributions to the decarbonization of energy, aviation and transport

Motivation: Hydrogen as an energy carrier

- **Hydrogen**:
  - Not primary source energy like sunlight but energy carrier
  - Energy density 1kg of hydrogen contains as much energy as 2.1 kg of natural gas or 2.8 kg of petrol
- **Challenges**:
  - Climate neutrality
  - How can stable year-round system operation with renewable energy be guaranteed while minimising overall costs
  - How can non-electrifiable industries become carbon neutral

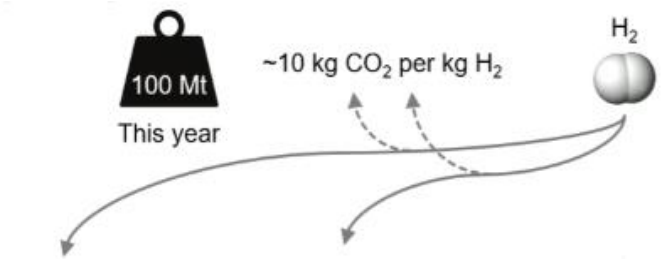
Motivation: Hydrogen as an energy carrier

- **Hydrogen**:
  - Key role as energy carrier for the transport sector
  - Industrial processes (e.g. production of fertilisers)
  - As energy buffer for integration of large amounts of renewable energy into the grid
    - Goal of climate neutrality requires a massive expansion of renewable electricity generation, especially wind and PV
    - Fluctuating renewable electricity is becoming the most important primary energy source
    - Need for long-term storage to bridge dark doldrums

Motivation: Hydrogen as an energy carrier

- **Hydrogen Market:**

Year	1975	1990	2000	2010	2018	2021	2025	2030*	2040
H_2 consumption [Mio. Ton]	18,2	34	52,4	62	73,9	94	100	>140	~200



- Over 96% of current hydrogen production: fossil fuels with significant associated CO_2-emissions
  - Steam methane reforming (SMR): most common way to produce hydrogen
  - Oil and coal gasification: also widely used (China and Australia)

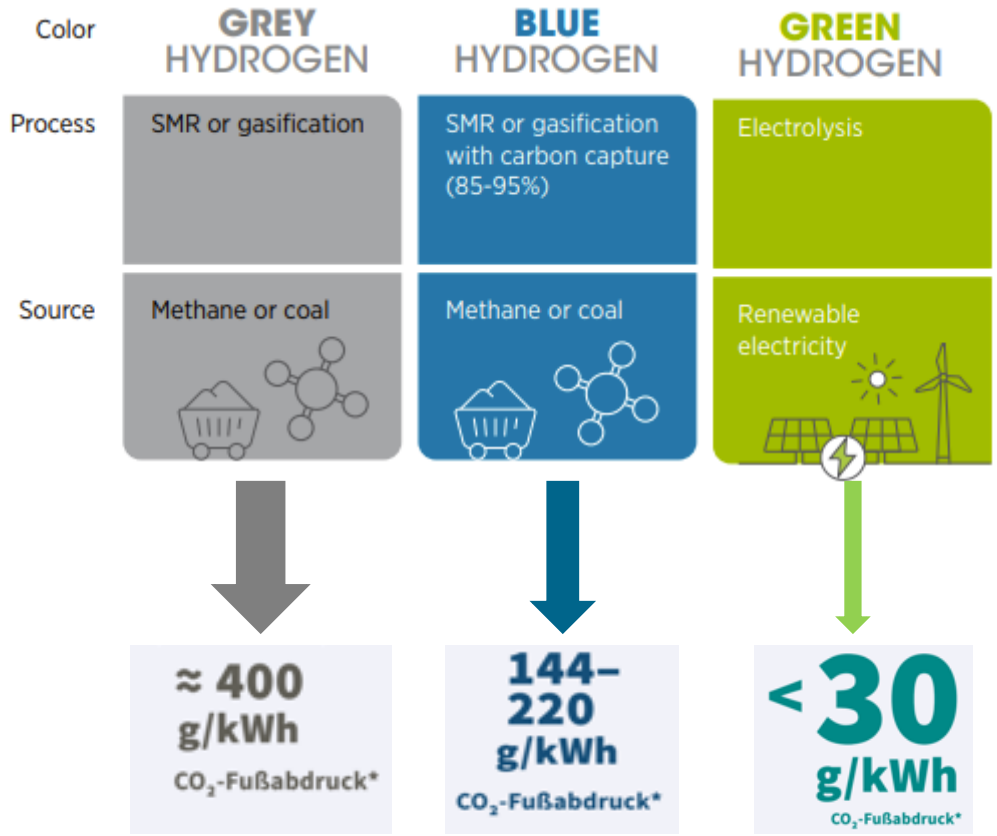
- 2023: associated emissions of about 920 Mt CO_2

➡ Development of carbon lean technologies producing hydrogen from renewable sources: of utmost importance

* Global Hydrogen Review 2024

CO_2 emissions from Hydrogen

- **Grey hydrogen**: produced from methane (CH_4), split with steam into CO_2 – the main culprit for climate change – and H_2. Grey hydrogen has increasingly been produced also from coal, with significantly higher CO_2 emissions.
- **Blue hydrogen**: same process as grey, with the additional technologies necessary to capture the CO_2 produced when hydrogen is split from methane (or from coal) and store it for long term.
- **Green hydrogen**: produced by splitting water into hydrogen and oxygen using renewable energy.



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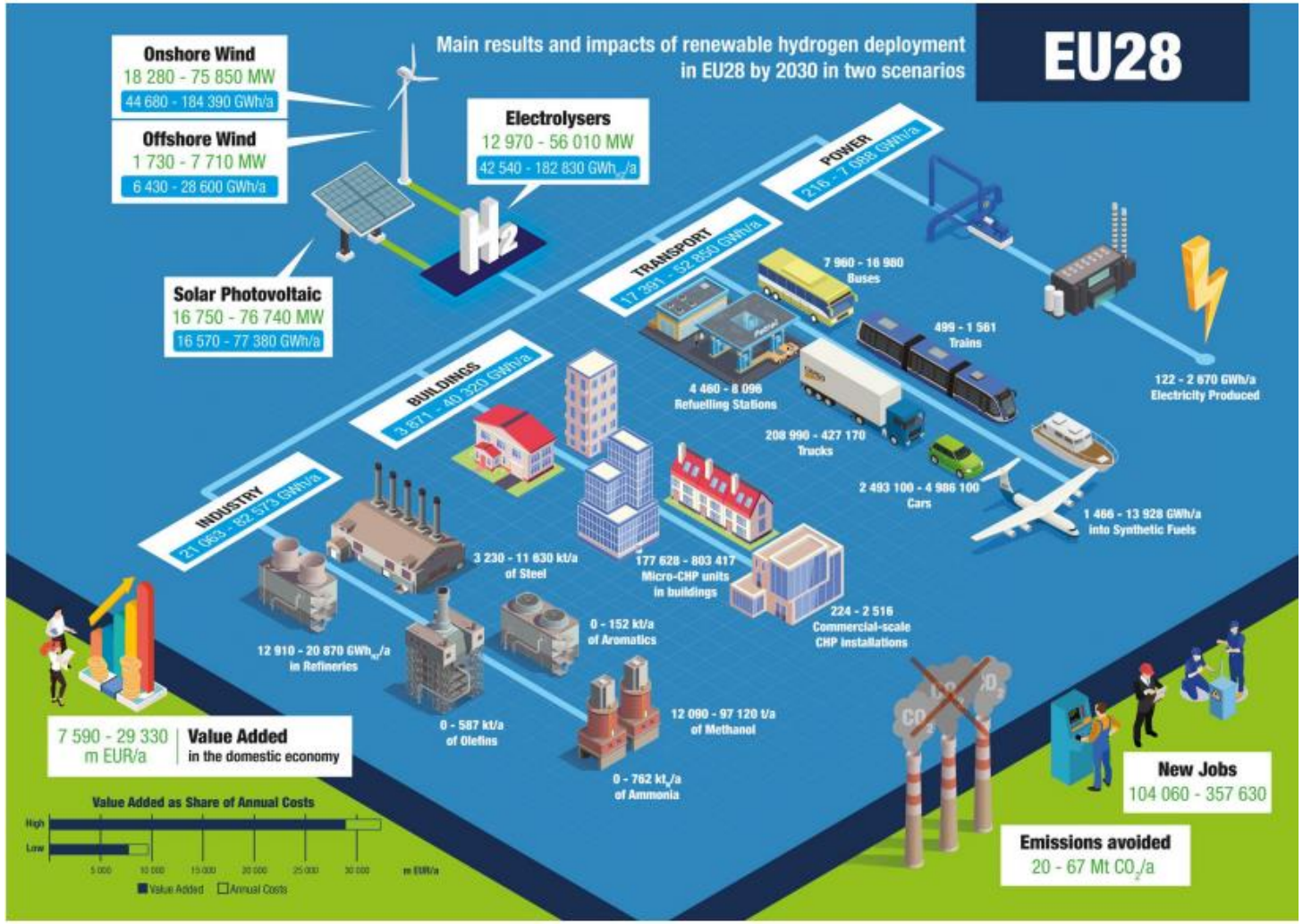
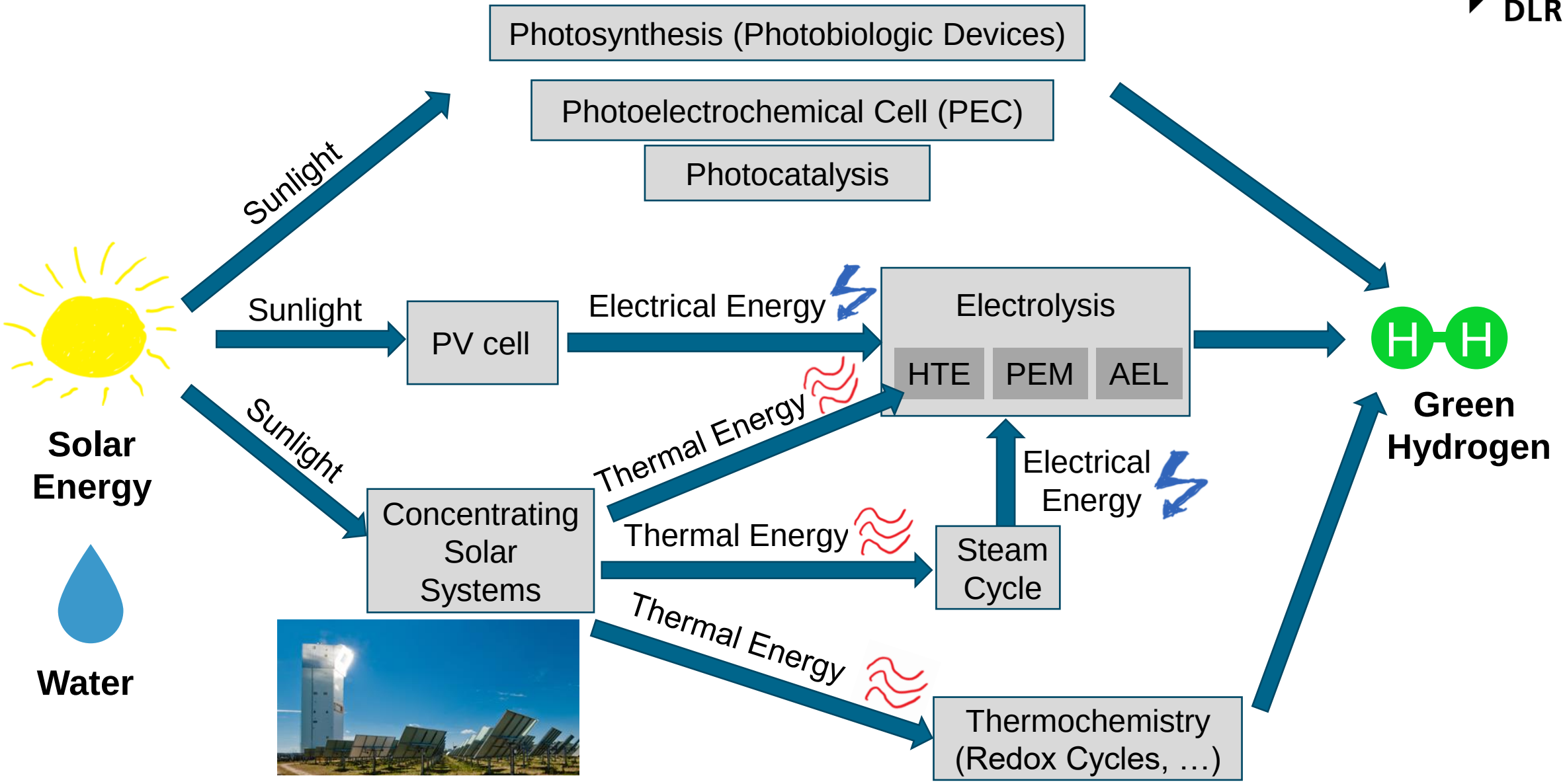
DENA 2020: dena-Factsheet Wasserstoff

Hydrogen – Application Spectrum

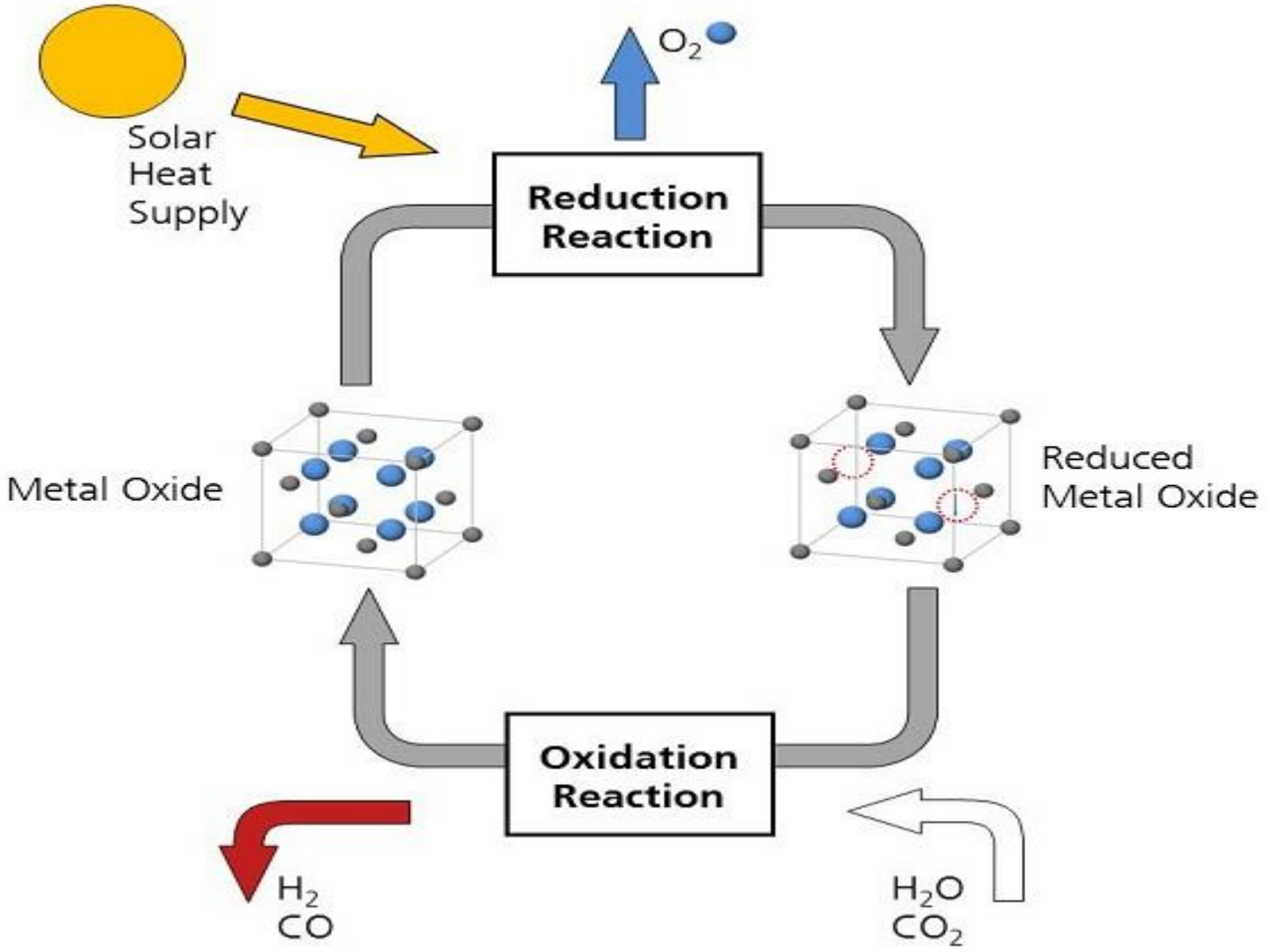
- Goal: fast and sustainable climate neutrality
  - The variety of water splitting technologies are not known enough
- Green hydrogen – will play an important role
  in the changing energy system and
  in the changing chemical industry
- Hydrogen will be used as
  - Energy vector (fuel)
  - Reducing agent (iron …)
  - Building block (ammonia …)



Green Hydrogen from Water Splitting by Solar Energy



Schematic of the two-stage cycle with metal oxides



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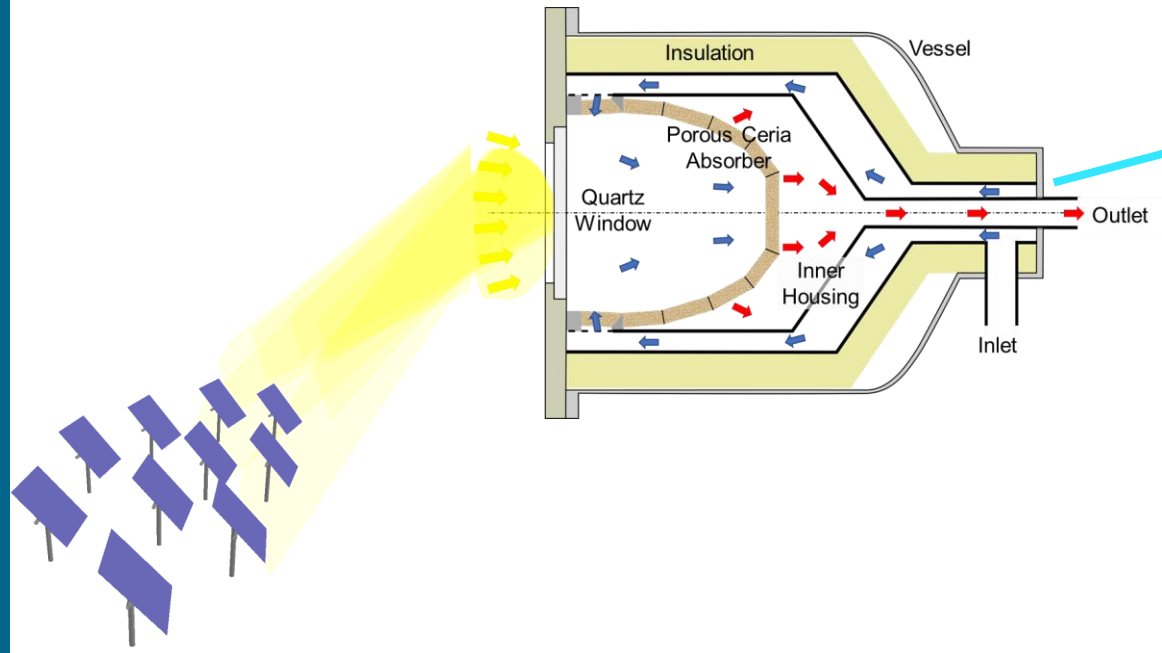


Heliostat Field

MO = ferrites, ceria, perovskites…

Long thermal stability
High O_2 storage capacity
Lower sintering
High melting point
Good redox reactivity

- Various metal oxide redox pairs
- Reaction with cerium oxide

1st step: **Reduction**

$$CeO_2 \rightarrow CeO_{2-\delta} + \frac{\delta}{2} O_2$$

1500 °C, reduced p_{O2}

2nd step: **Oxidation**

Water splitting

$$CeO_{2-\delta} + \delta H_2O \rightarrow CeO_2 + \delta H_2$$

CO_2 splitting

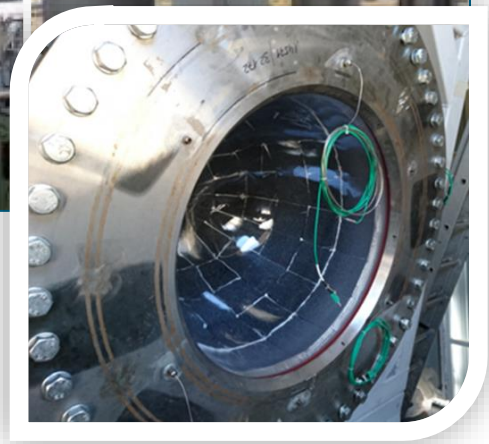
$$CeO_{2-\delta} + \delta CO_2 \rightarrow CeO_2 + \delta CO$$

900 °C, atmospheric pressure

Solar Thermochemical Hydrogen Production

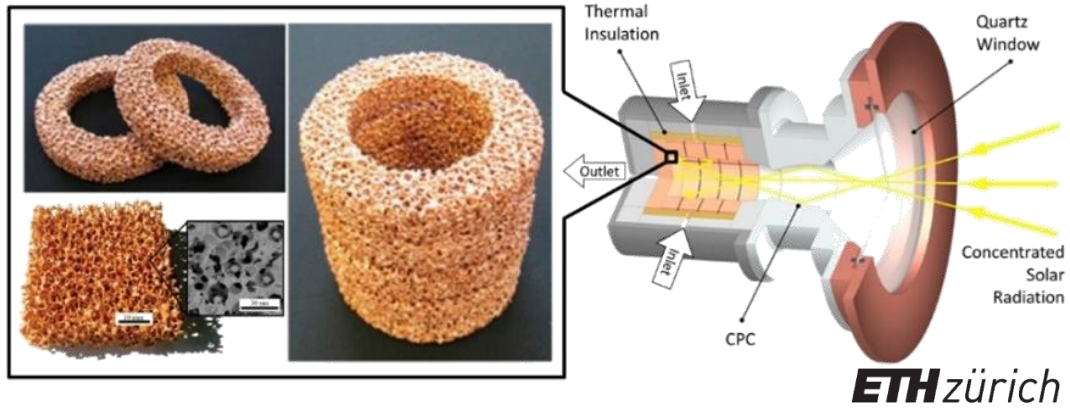
State of the Art: Batch Reactors with Fixed, Porous Monoliths of Redox Material

Source: Plataforma Solar de Almeria (Owned by the Spanish research centre CIEMAT)



Source: DLR

Source: IMDEA / SUN-to-LIQUID project



Conclusion

- **Hydrogen:**
  - Key role: energy carrier for the transport sector, industrial processes, energy buffer
  - Could become one of the most powerful fuel of our lifetime

- **Green Hydrogen:**
  - One of the solutions for an energy transition toward zero or net-zero emissions
  - Current wave focuses on creating a link between renewable electricity and hard-to-electrify end uses
  - Different pathways of production
  - National pledges to achieve net-zero emissions
  - More extensive base of interested stakeholders

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Thank you for your attention!