Multi-controlled electrodes in Electrochemical Systems

From intermittent renewable electricity input to 24/7 sustained hydrogen output

B. Weninger, 21-6-2019

ECCM conference, The Hague

TU Delft

Holland

NWO Applied and Engineering Sciences

Sustainable planet for next generations

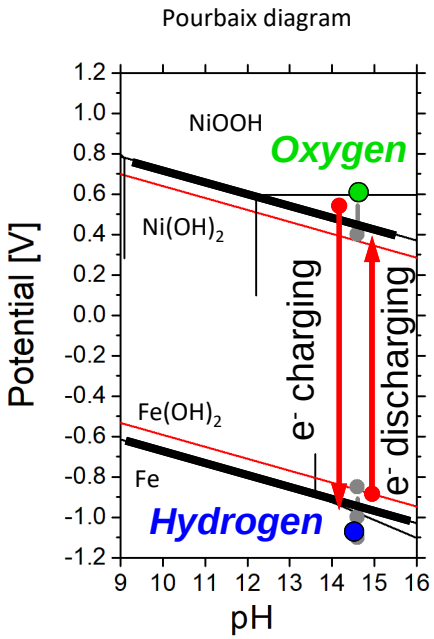
Renewable generation:
- time patterns, location,..

Distribution:
- export - import
- storage and transport
- electrification,..

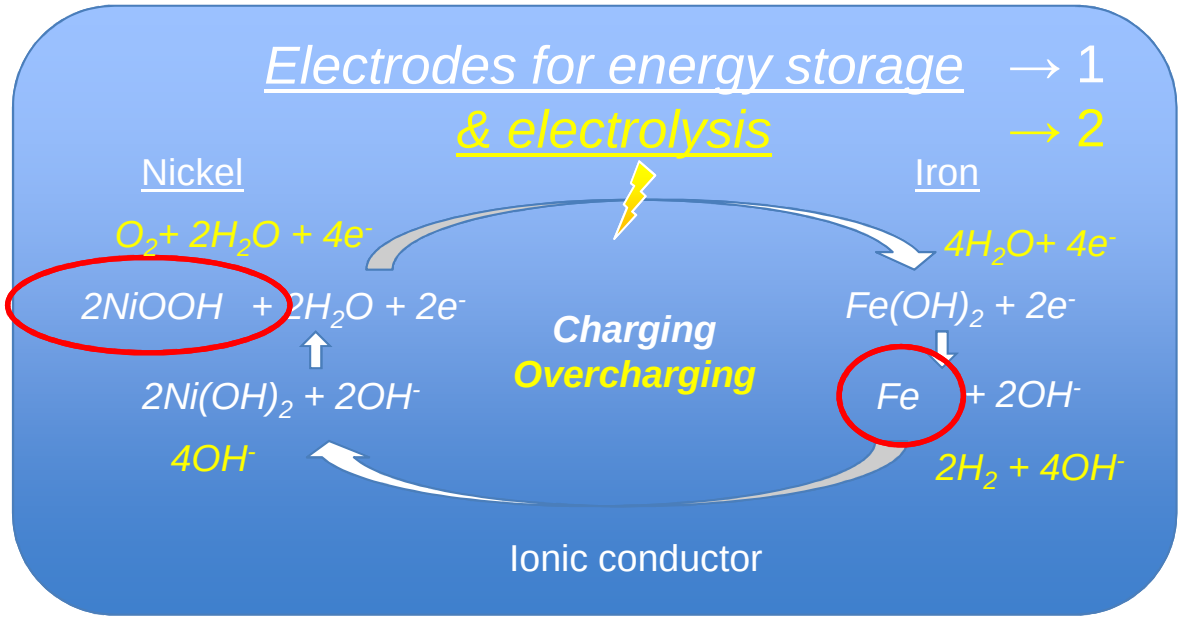
e-Refinery
Towards sustainable production of chemicals and fuels

Users requirements:
- households,
- industry,
- transport,..

Nickel-Iron battery



Functions



Overcharge protection: $2H_2O \rightarrow 2H_2 + O_2$

System Integration

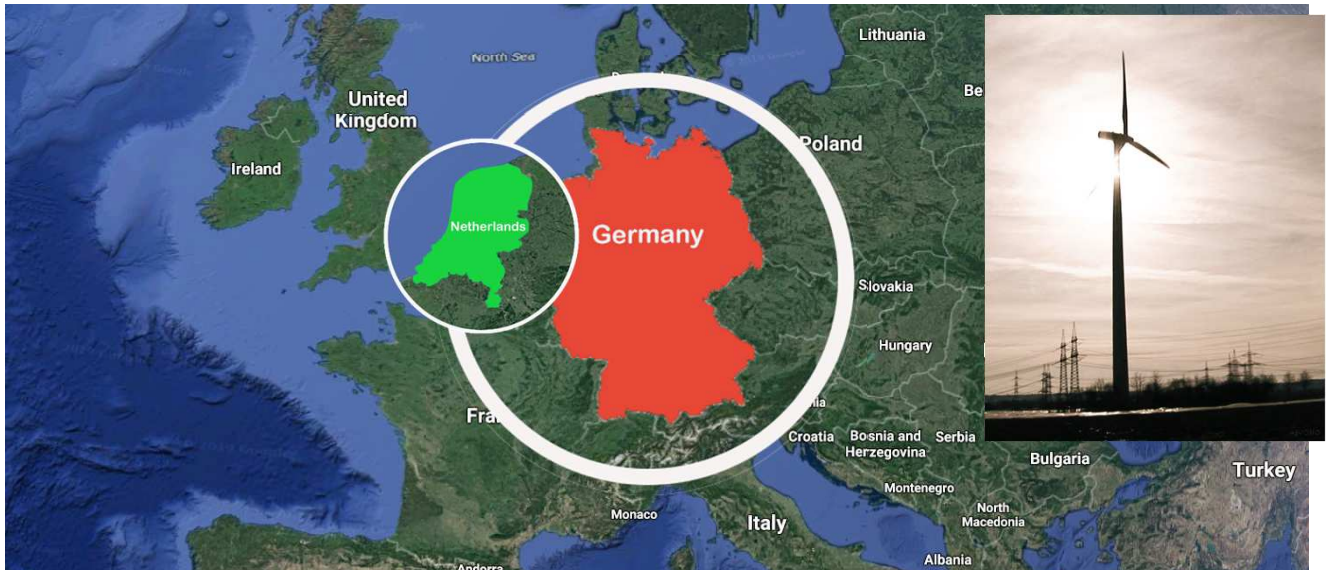
BATT-ery & electr-*OLYSER*

⇩

BATTOLYSER

"The battolyser is a device that works as a rechargeable battery, and that is capable of performing highly efficient electrolysis with any excess electricity."

Curtailment: wasting the renewables



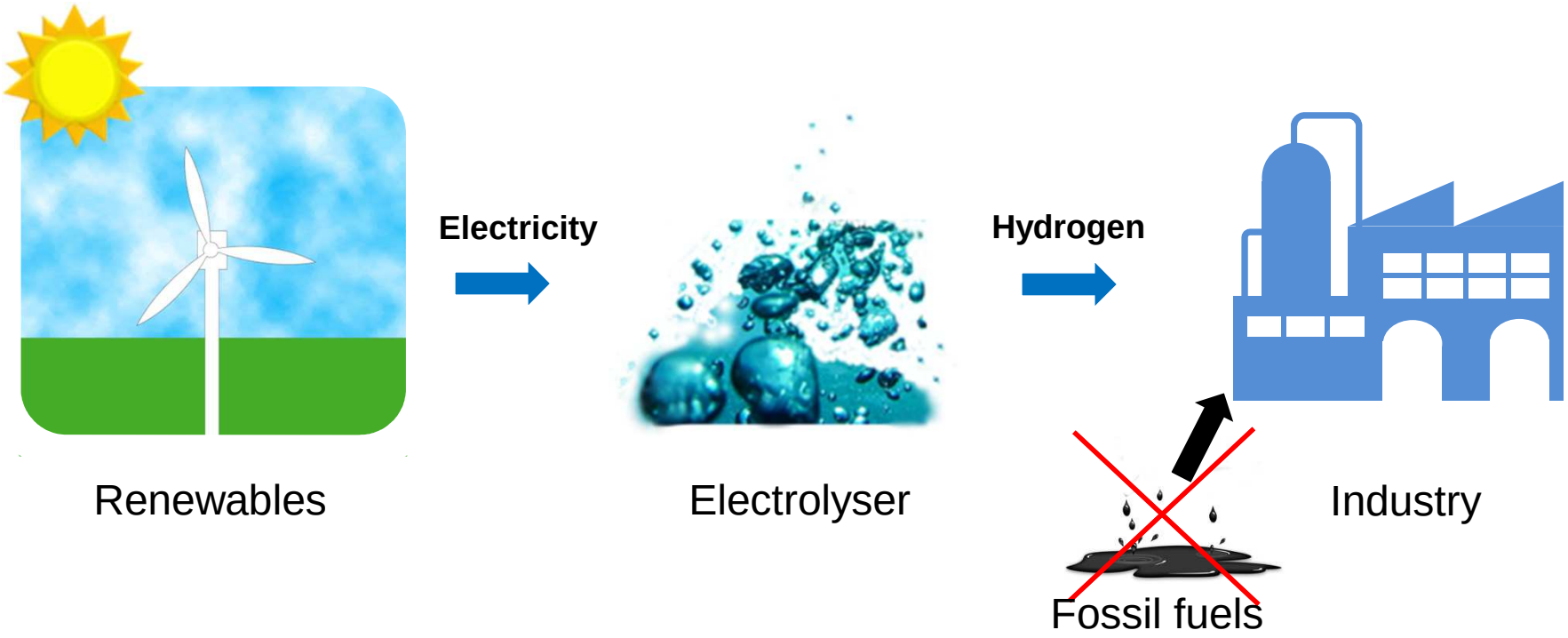
Total wind energy
Netherlands 2018

10 TWh!

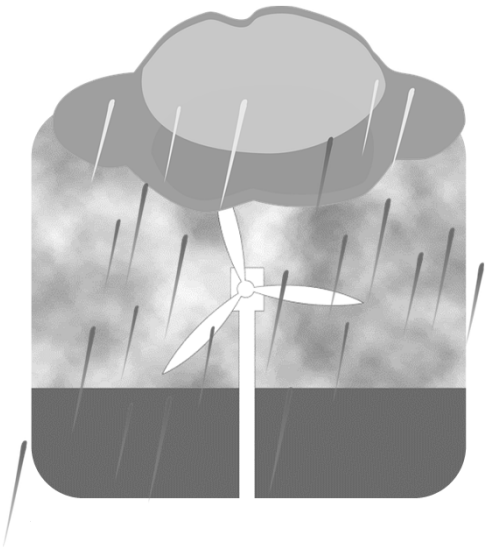
Curtailment renewables
Germany 2018

5.4 TWh

Hydrogen production from renewables

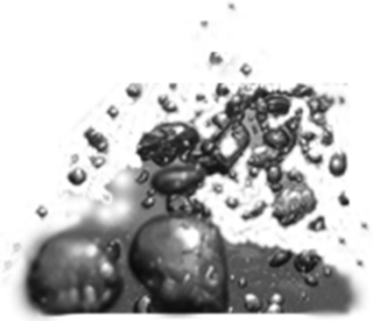


Hydrogen production from renewables



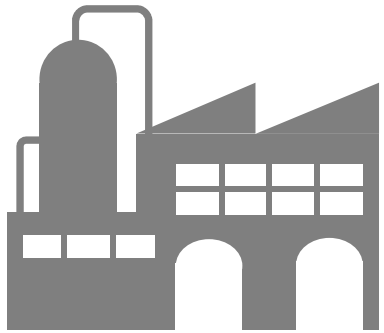
Renewables

Electricity



Electrolyser

Hydrogen



Industry

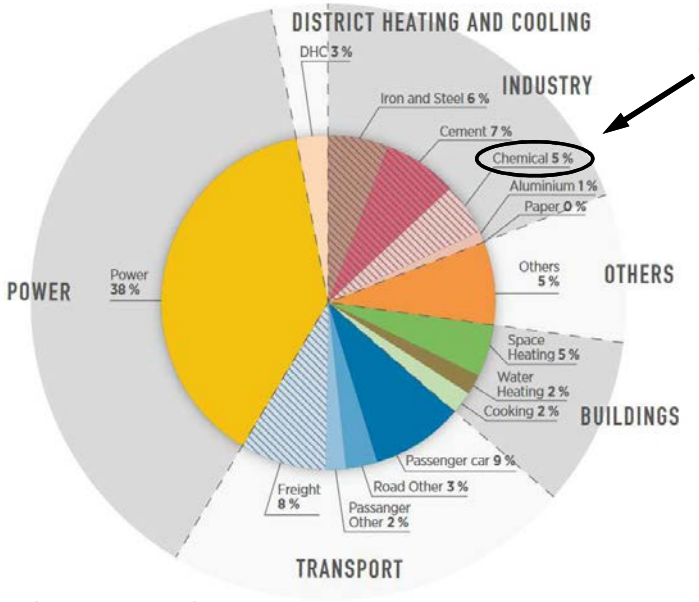
<u>Dynamic operation:</u>

1. High turndown ratio
2. Designed for maximum input

Same output in less time → larger infrastructure

Fossil fuel usage

Global energy-related CO_2 Emissions 2015



(IRENA, 2018)

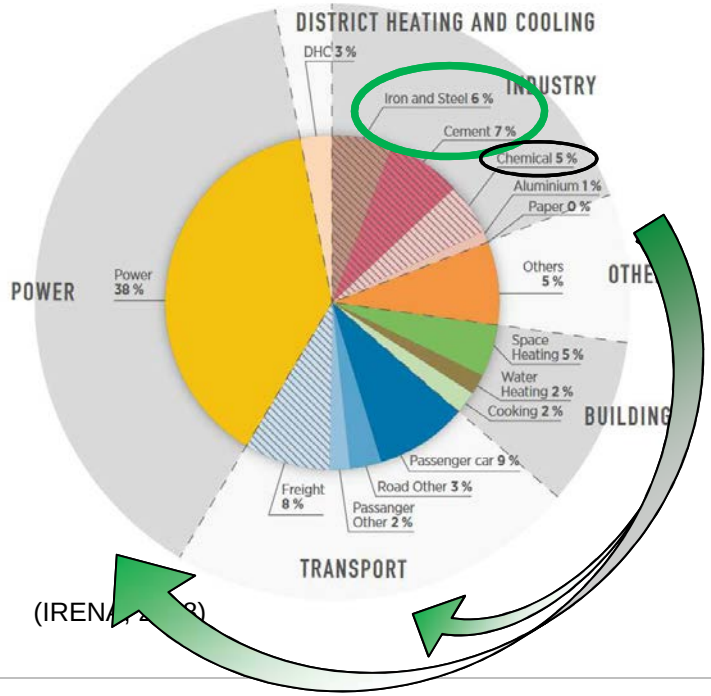
Currently a fraction of CO_2 Emissions: Hydrogen from fossil fuels

(image: www.rank-ag.de)

Industry

Future: Shifting from fossil fuels to renewables

Hydrogen/Hydrogen derived fuels for: Power and Transportation



(IREN

(image: www.rank-ag.de)

- Substantial increase of green hydrogen
- Substantial increase of wind/solar required

Hydrogen production from renewables + backup power

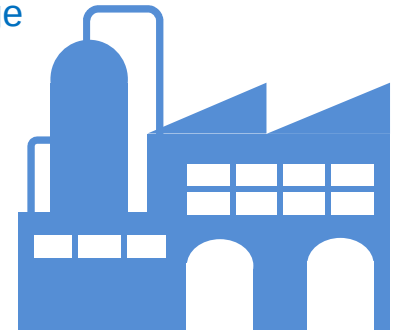
Renewables

Electricity

- Hydro-power
- Pumped air storage
- Batteries, CSP,..

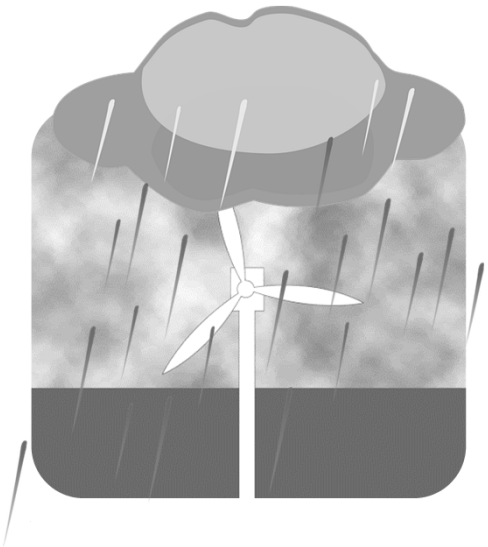
Electrolyser

Hydrogen



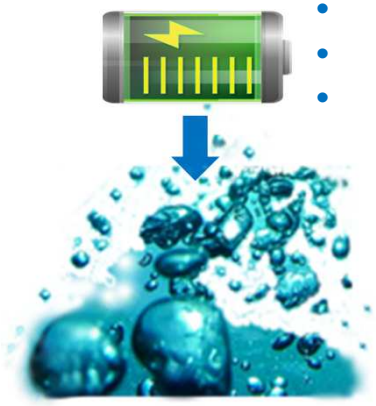
Industry

Hydrogen production from renewables + backup power



Renewables

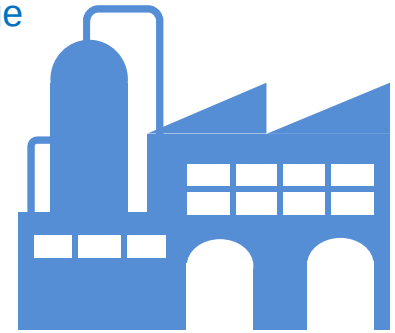
Electricity



- Hydro-power
- Pumped air storage
- Batteries, CSP,..

Electrolyser

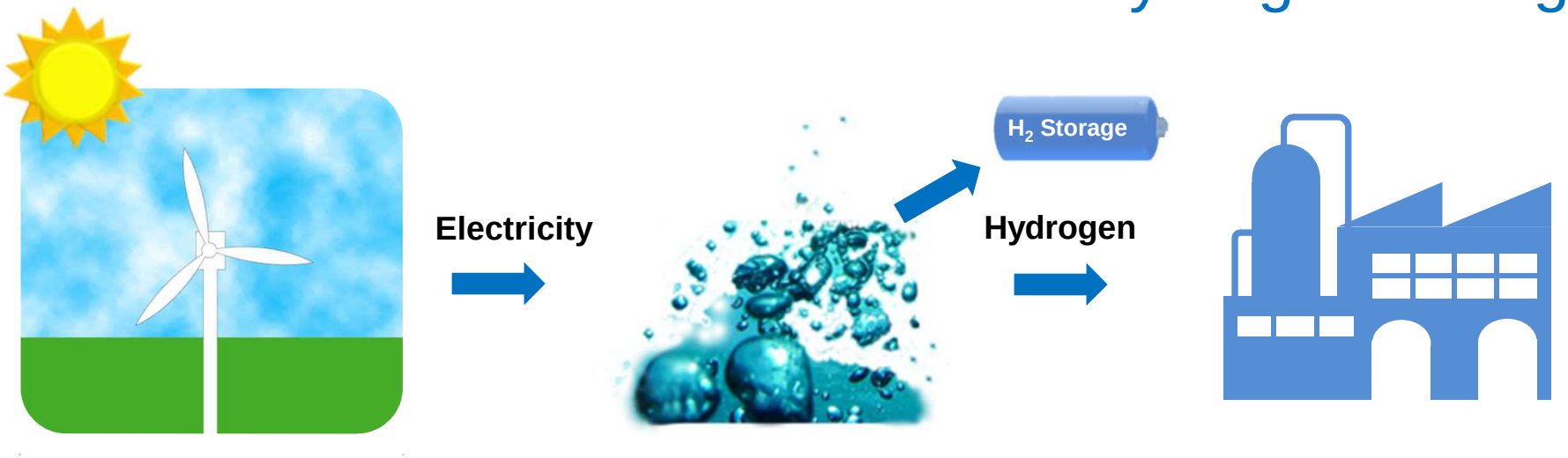
Hydrogen



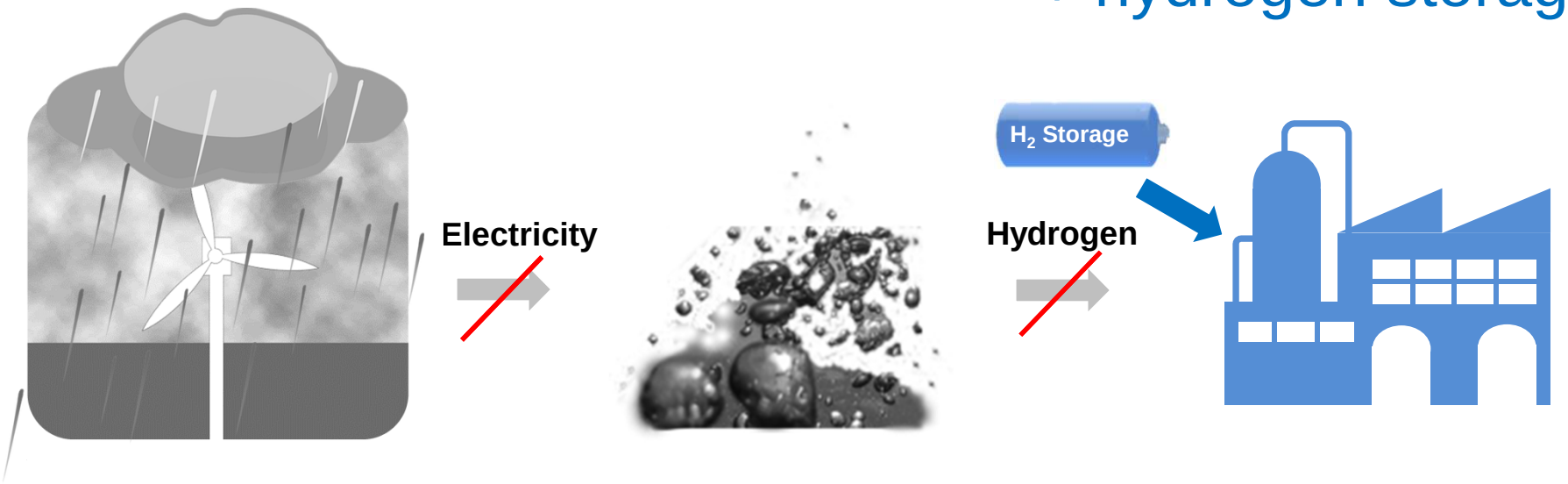
Industry

Continuous electrolyser operation → smaller electrolyser

Hydrogen production from renewables + hydrogen storage

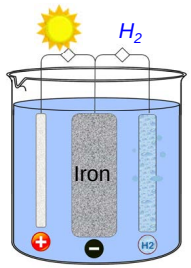


Hydrogen production from renewables + hydrogen storage



Dynamic electrolyser with continuous industry

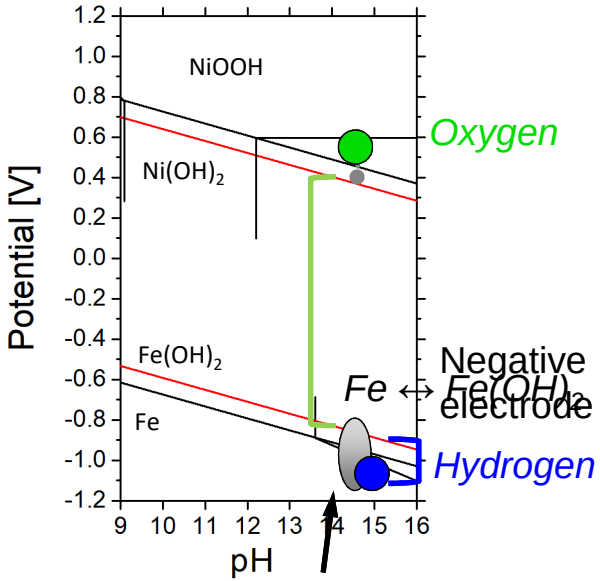
New: Hydrogen production from renewables with Multi-controlled Electrodes

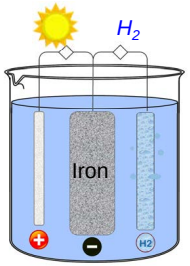


- Backup power
  - Reduction of required electrical storage capacity -85%
  - 7 times more H_2 release with the same backup power
- Hydrogen storage
  - Easy and instantaneous H_2 storage and release
  - H_2 storage density 18.5 kg H_2/m³ (~300 bar gas cylinder)

Only 3% additional electricity for time-shifting 50% of the hydrogen production

H_2 Storage & MC electrodes





Split functionality negative electrode

- H_2 storage electrode = Iron
- H_2 evolution electrode

Controller for H_2 evolution

$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2$$

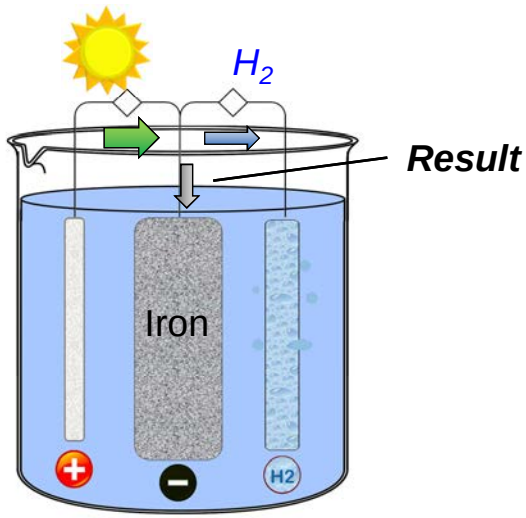
Controller for charging

$$2Fe(OH)_2 \rightarrow 2Fe + 2H_2O + O_2$$

H_2 Storage

Simultaneous operation of 3 electrodes in one cell with two controllers

H_2 Storage & MC electrodes



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Controller for charging

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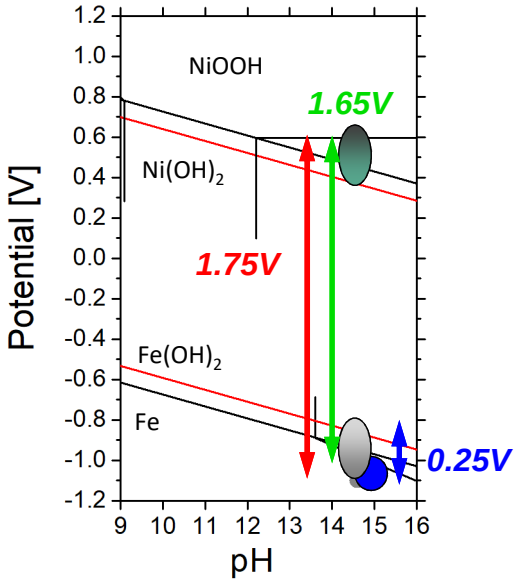
H_2 Storage

Simultaneous operation of 3 electrodes in one cell with two controllers

→ *Multi-controlled: decoupling of external conditions & H_2 production*

Implications MC electrodes



Adjust material usage to storage demands

- Electricity: Ni, Fe
- Hydrogen: Fe
- Oxygen: Ni

Addition of Fe -> H_2 storage

Remove Ni -> Electrolyser with H_2 storage

Charge + O_2 generation when electricity is abundant

H_2 generation with little backup power

Comparison: *continuous electrolyser*

7 x H_2 from charged Fe with same backup power

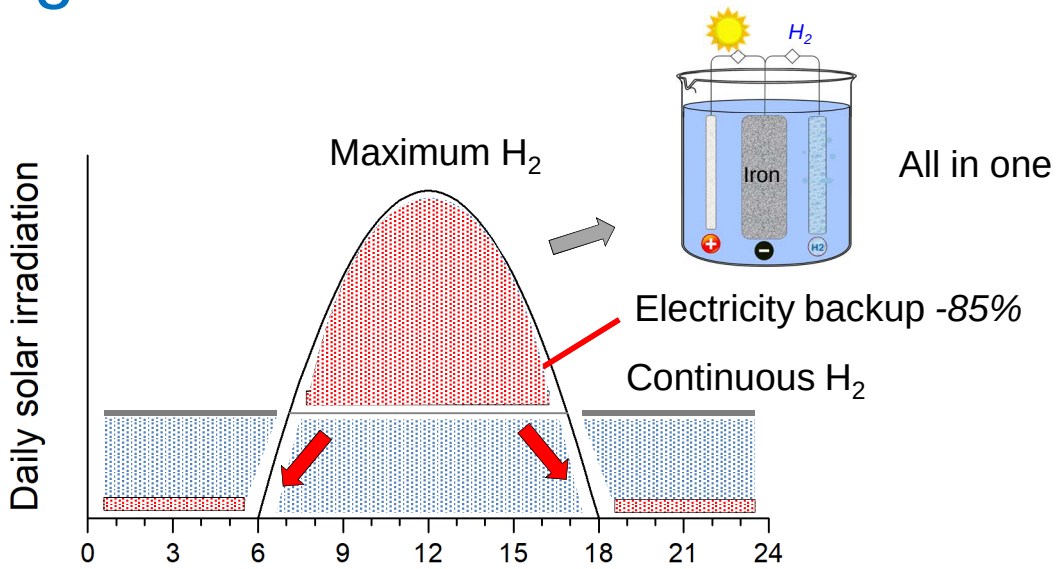
7 x H_2 from charged FE with MC electrodes

Discontinuous Electrolyser

+

Continuous Electrolyser

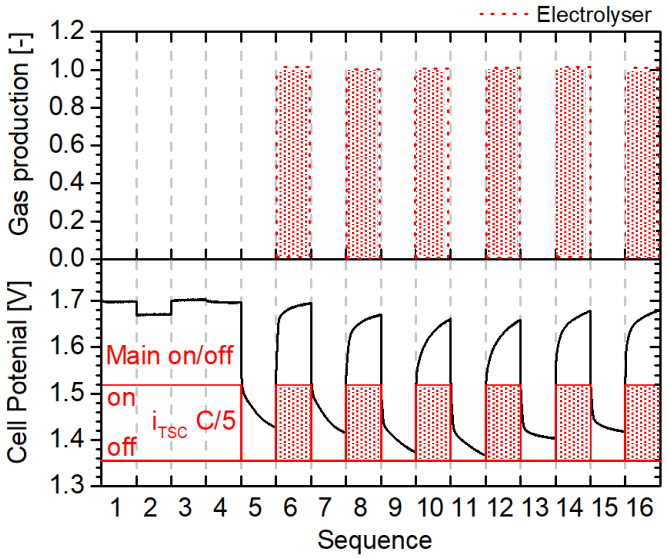
+

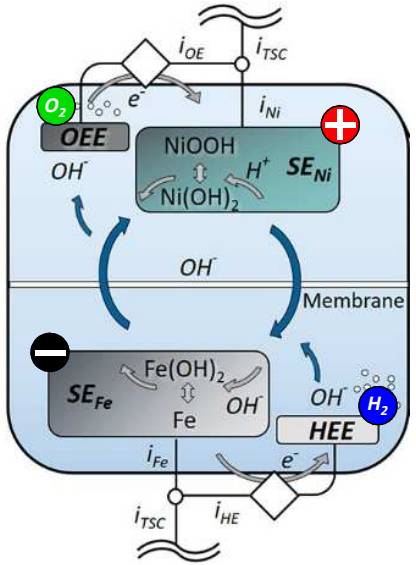


- Ratio max/continuous output: ~3
- Ratio max installed power / backup power: ~20

Electrolyser with hydrogen and oxygen storage

MC test series with 4 electrodes operational simultaneously





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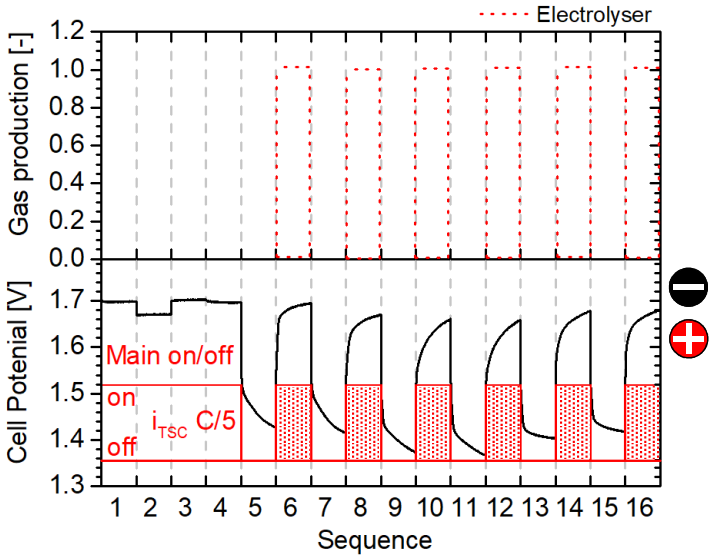

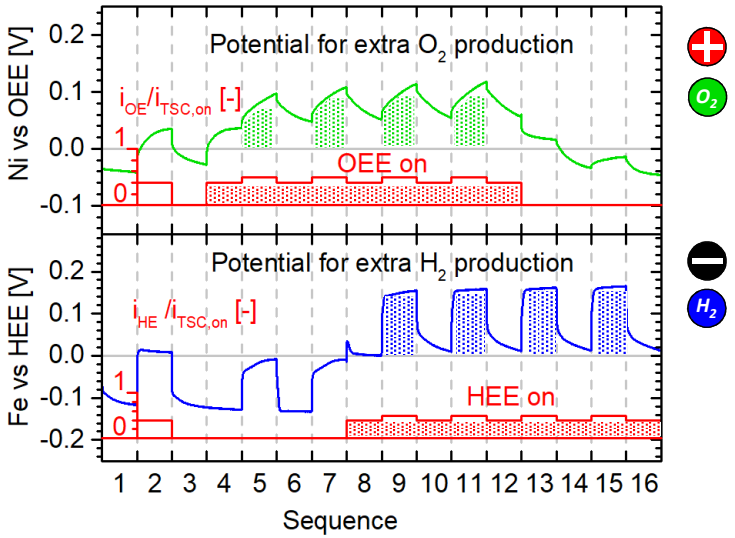

Gas production
from storage electrodes: <0.2V

Electrolyser with hydrogen and oxygen storage

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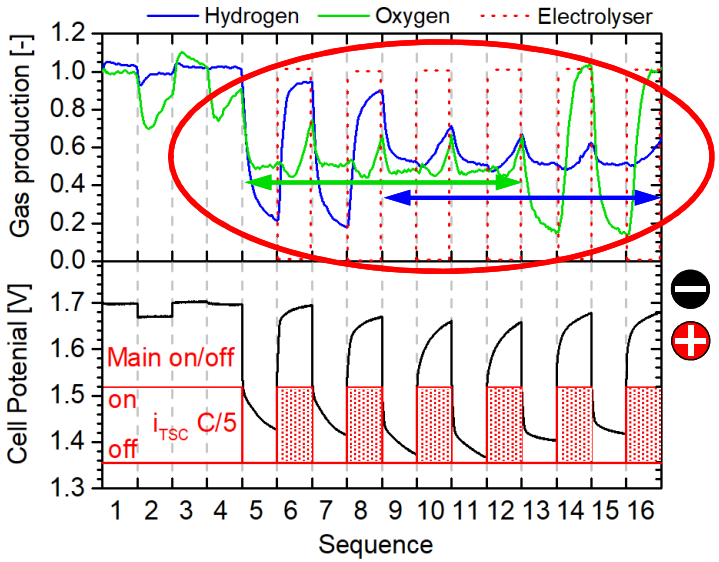
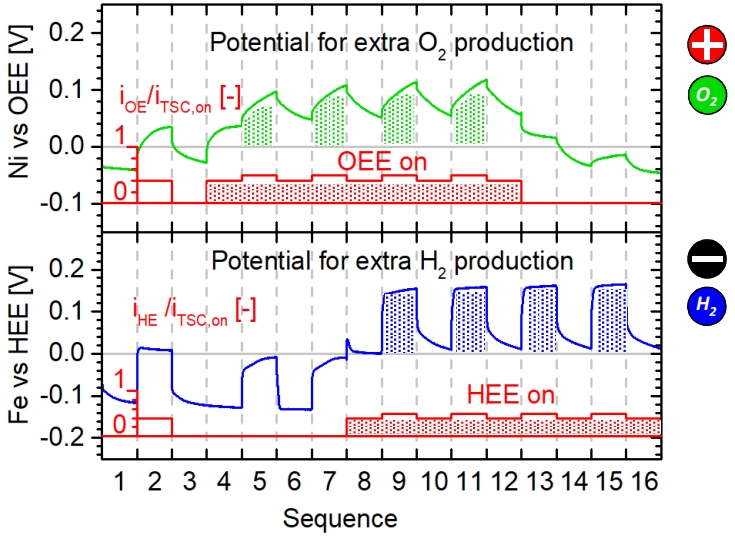


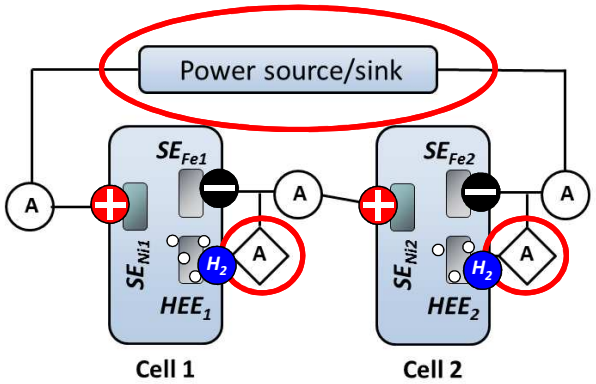


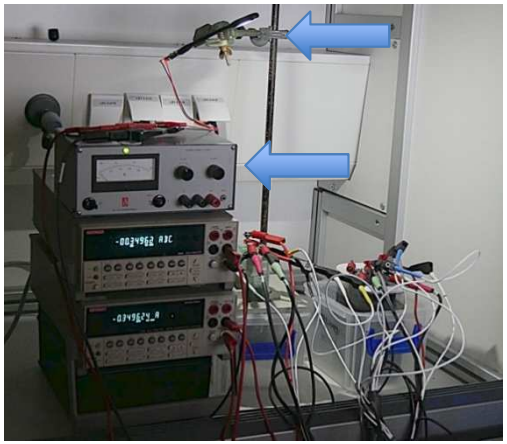
Time shift → No output peaks

→ Smaller downstream systems

Gas production
from storage electrodes: <0.2V

Upscaling: Battolyser with MC electrodes in array





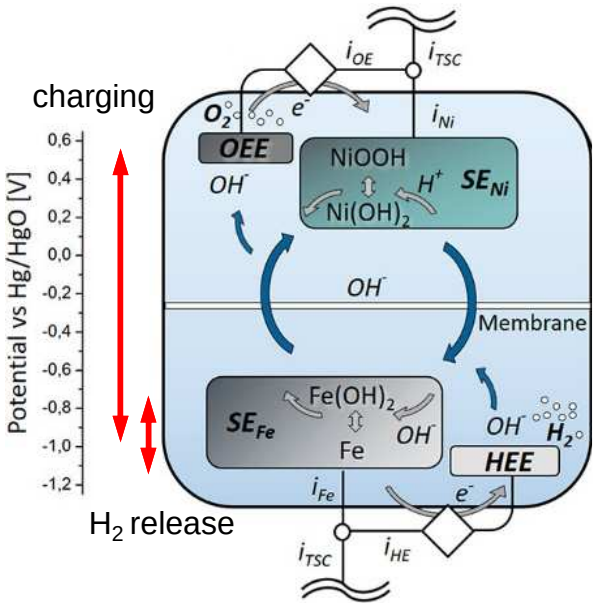
Independent control of all currents

(only redistribution of currents within assemblies of negative electrodes)

Simultaneous electrical discharging & H_2 production

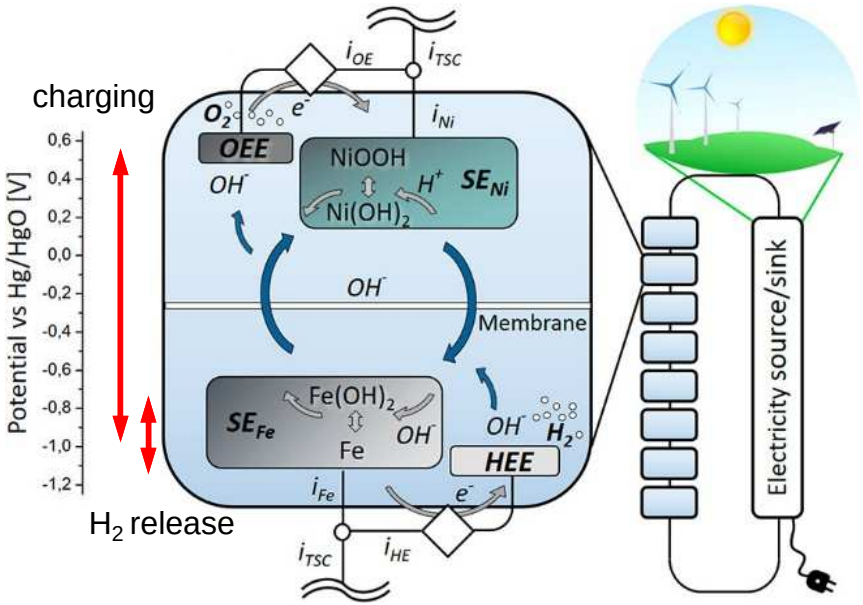
⊖ **Electrodes in array serve two purposes!**

Configuration with MC electrodes



- Simultaneous operation of electrodes
  - Storage
  - Production
  - Material usage to storage needs
- Scalable to larger arrays
- Electricity sink for renewables
  - Stop curtailment
  - Speed up wind/solar installation
- H_2 release with ***–85%*** backup power
- Only 3% extra energy input

Configuration with MC electrodes



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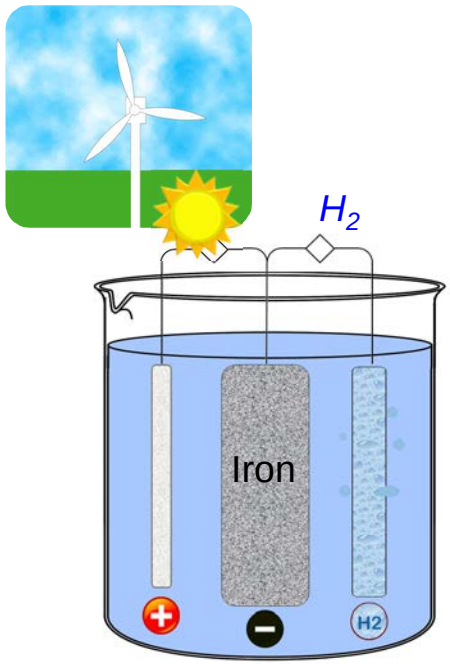
The future



(image: www.rank-ag.de)

From intermittent renewables to 24/7 sustained hydrogen output

Acknowledgements

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NWO | Applied and Engineering Sciences

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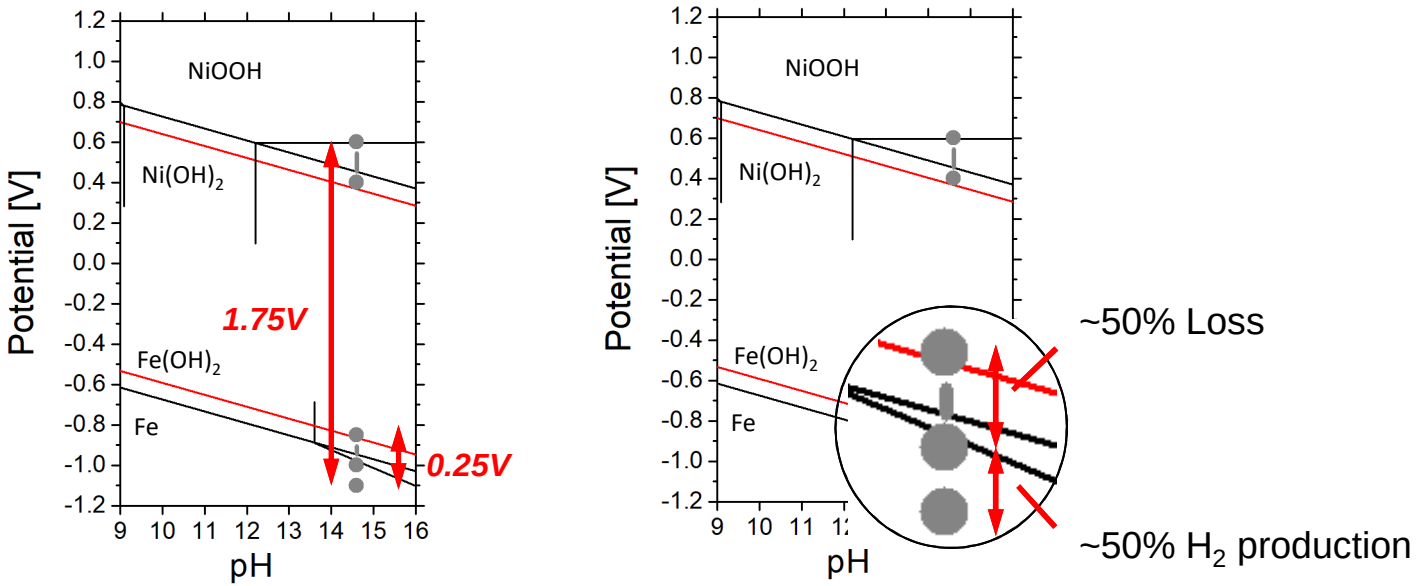
Publications:

F.M. Mulder, B.M.H. Weninger, J. Middelkoop, F.G.B. Ooms and H. Schreuders, Efficient electricity storage with a battolyser, an integrated Ni-Fe battery and electrolyser **Energy Environ. Sci.,** 2017, 10, 756-764, **DOI:**10.1039/C6EE02923J

B.M.H. Weninger and F.M. Mulder, Renewable Hydrogen and Electricity Dispatch with Multiple Ni-Fe Electrode Storage **ACS EnergyLett.,** 2019, 4, 2, 567-571, **DOI:**10.1021/acsenergylett.8b02488

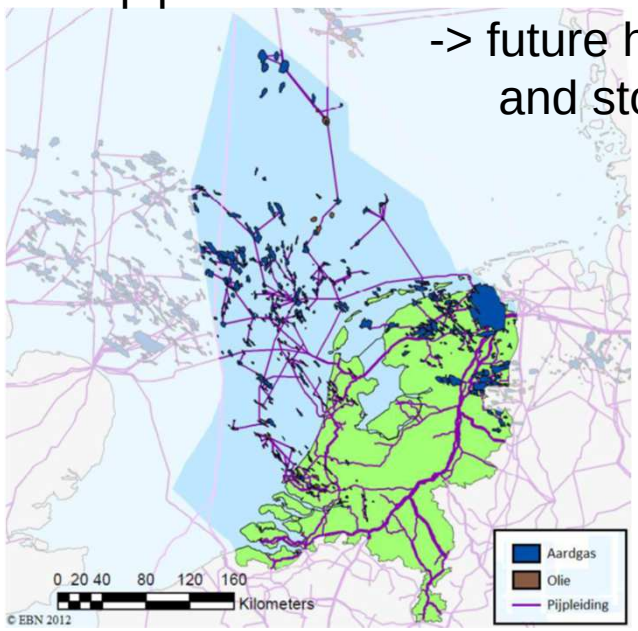
Losses



50% storage & delayed generation → 3% extra electricity input

Hydrogen production from renewables + hydrogen storage

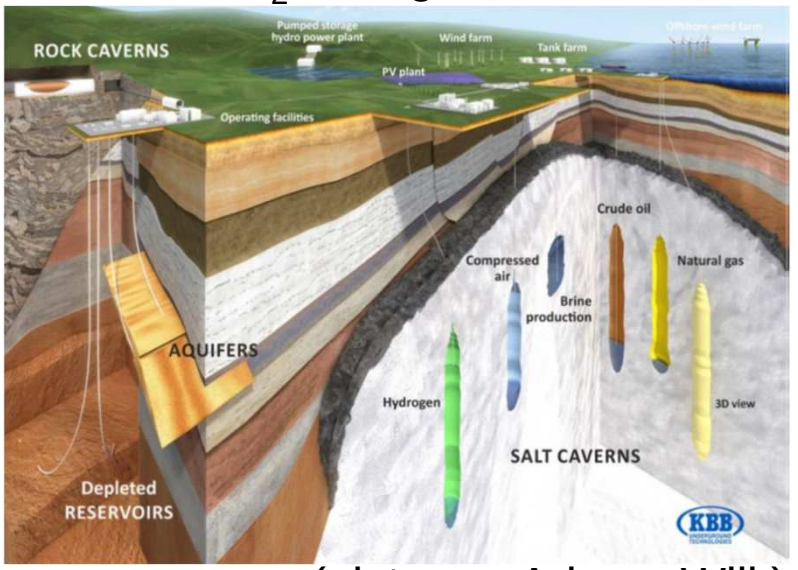
Gas pipelines



-> future hydrogen distribution and storage

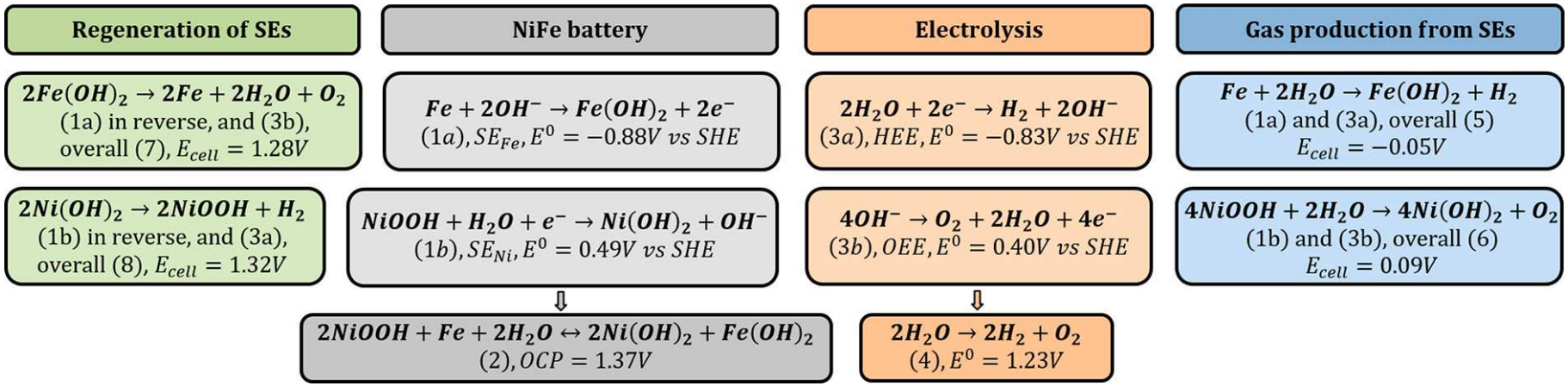
Infrastructure in NL

H_2 storage in salt caverns

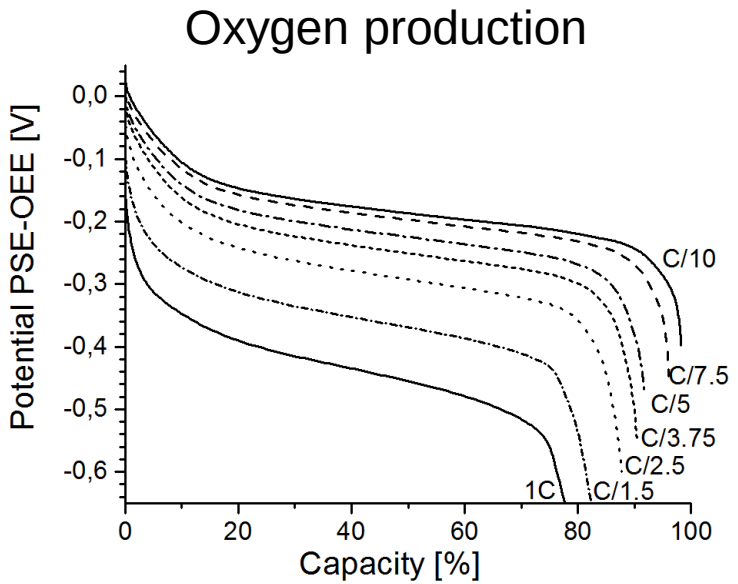


(pictures: Ad van Wijk)

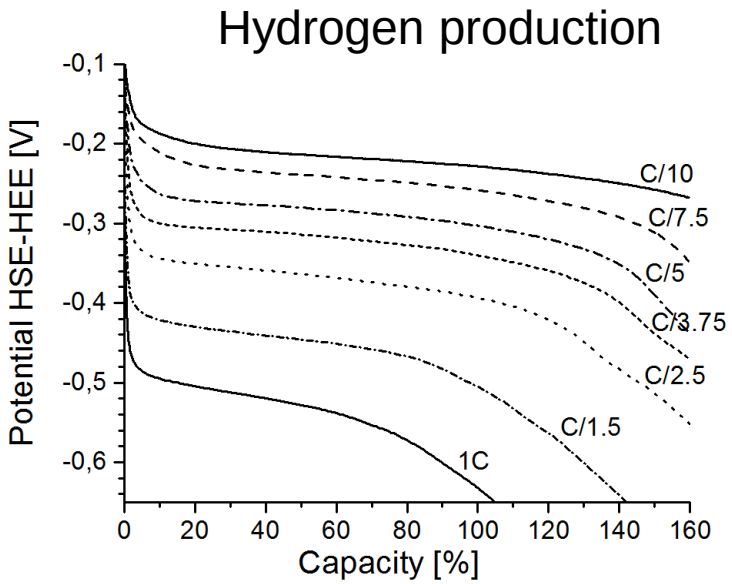
Reaction Scheme



Energy requirement for gas production from SE

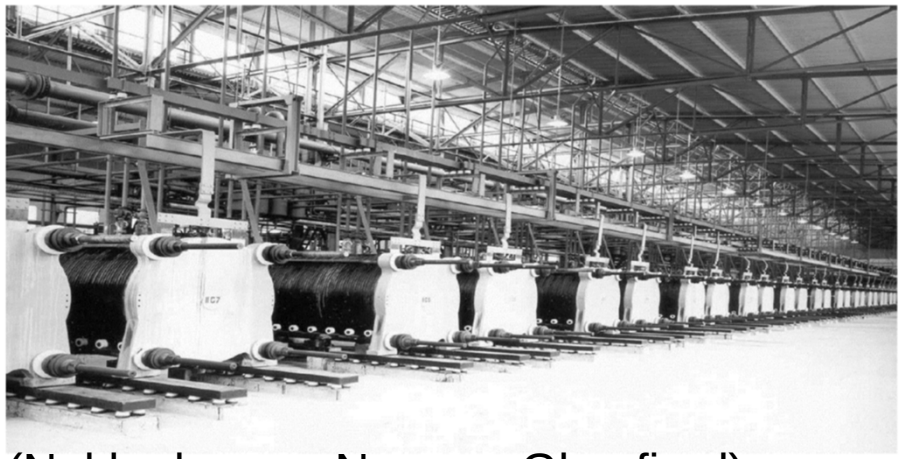


$$4NiOOH + 2H_2O \rightarrow 4Ni(OH)_2 + O_2(g)$$



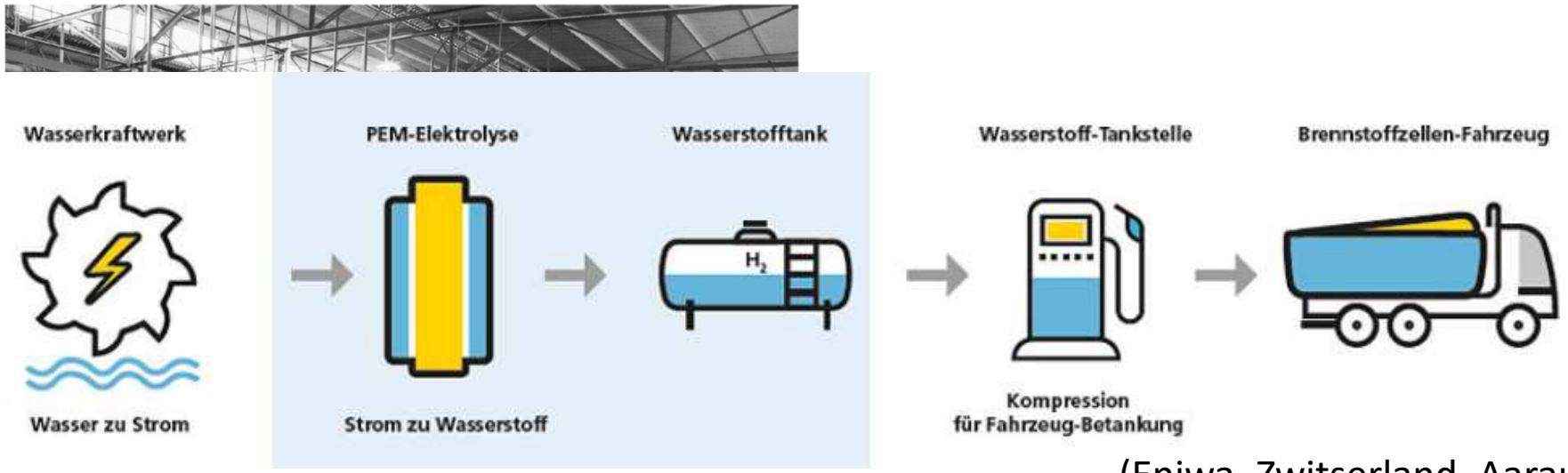
$$Fe + 2H_2O \rightarrow Fe(OH)_2 + H_2(g)$$

Hydrogen production from renewables + backup power



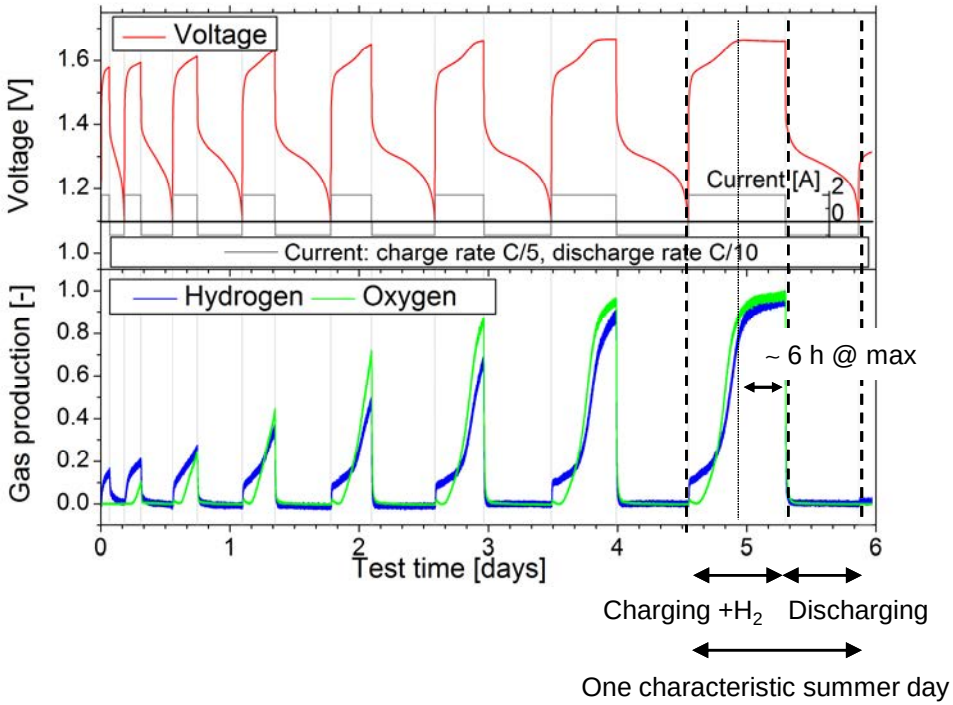
(Nel hydrogen, Norway, Glomfjord)

Hydrogen production from renewables + backup power



(Eniwa, Zwitserland, Aarau)

Battolyser: Hydrogen and oxygen output characteristics



- Gas output follows SOC of electrodes and electricity input
- Day/night fluctuations:
  1/3 of charge for electricity storage
  2/3 of charge for hydrogen production
- Infrastructure has to cope with H_2 output
  Requirement: sustained H_2 input

How can we turn intermittent electricity input into continuous hydrogen output?