



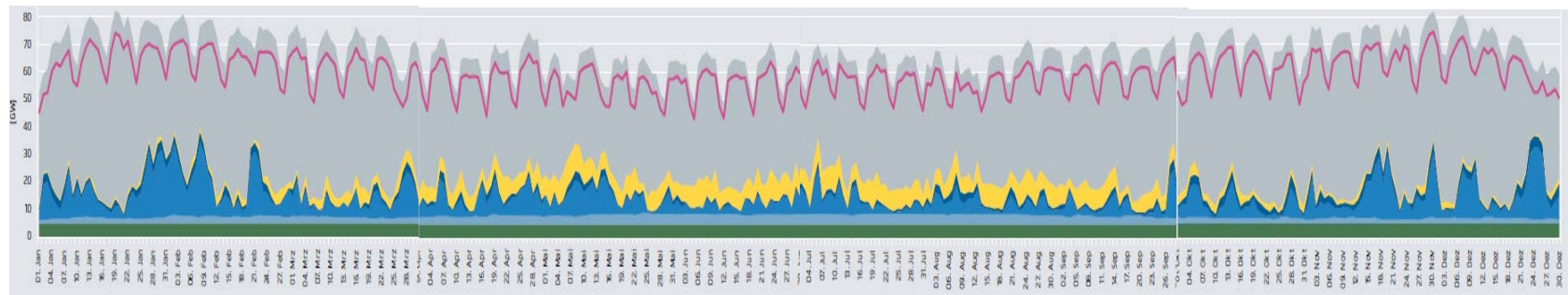
Electricity storage & hydrogen feedstock production with a battolyser

Renewable energy system?

100% Renewable?

Die Energiewende im
Stromsektor:
Stand der Dinge 2016
Rückblick auf die wesentlichen Entwicklungen
Strom: August 2015 auf 2017
ANALYSE

Agora
Energiewende

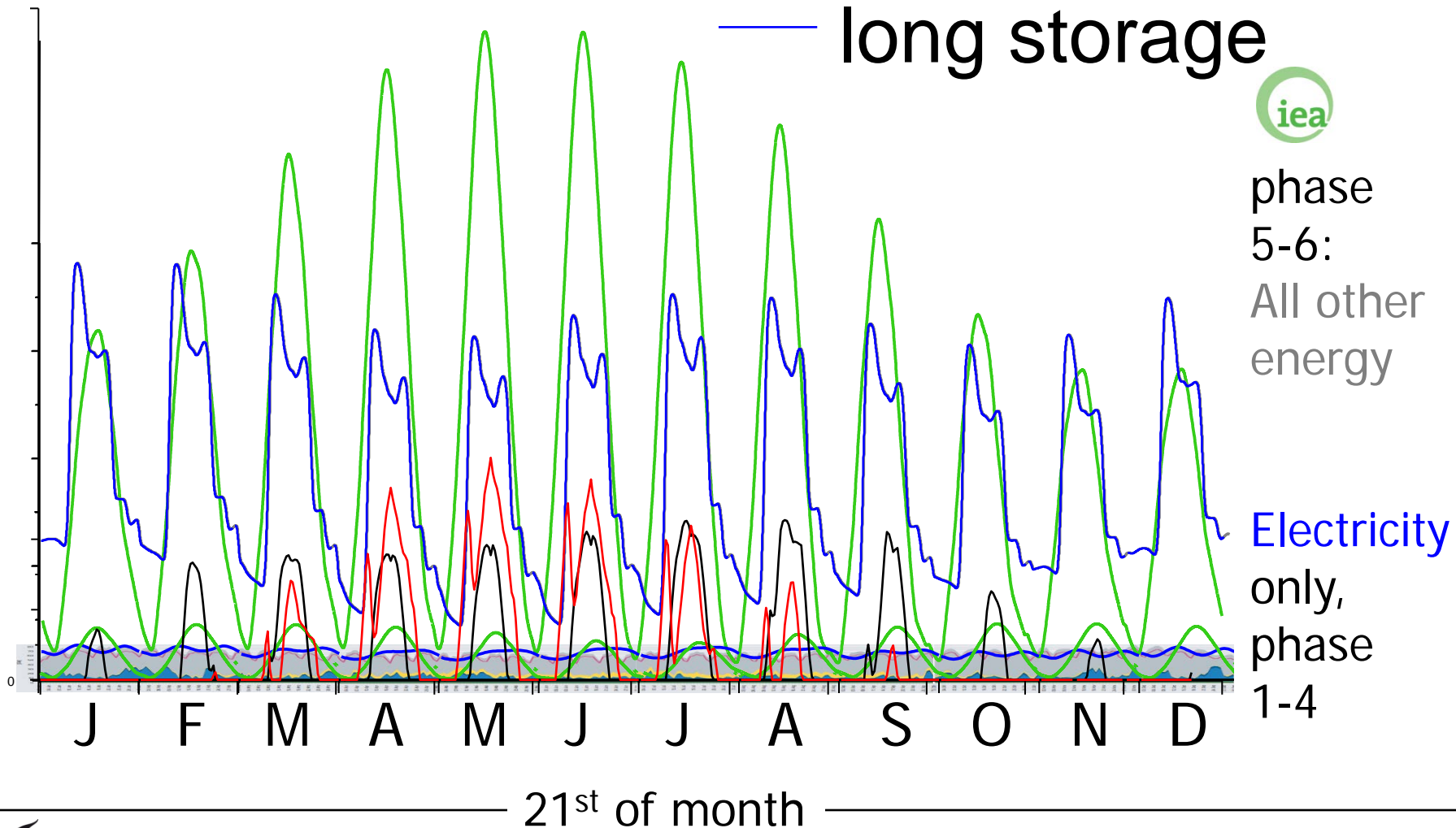


Energy transition?

100% Renewable?

Solar power dominance...

— short storage
— long storage



Efficient use of renewable electricity:

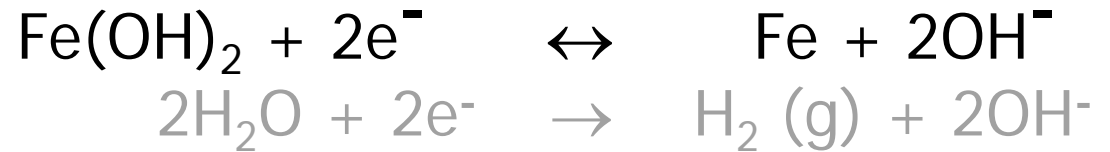
- | | |
|------------------------------------|----------------|
| 1. Direct use: | most efficient |
| 2. Short term storage in batteries | very efficient |
| 3. Long term storage in fuels | less efficient |

Battolyser:

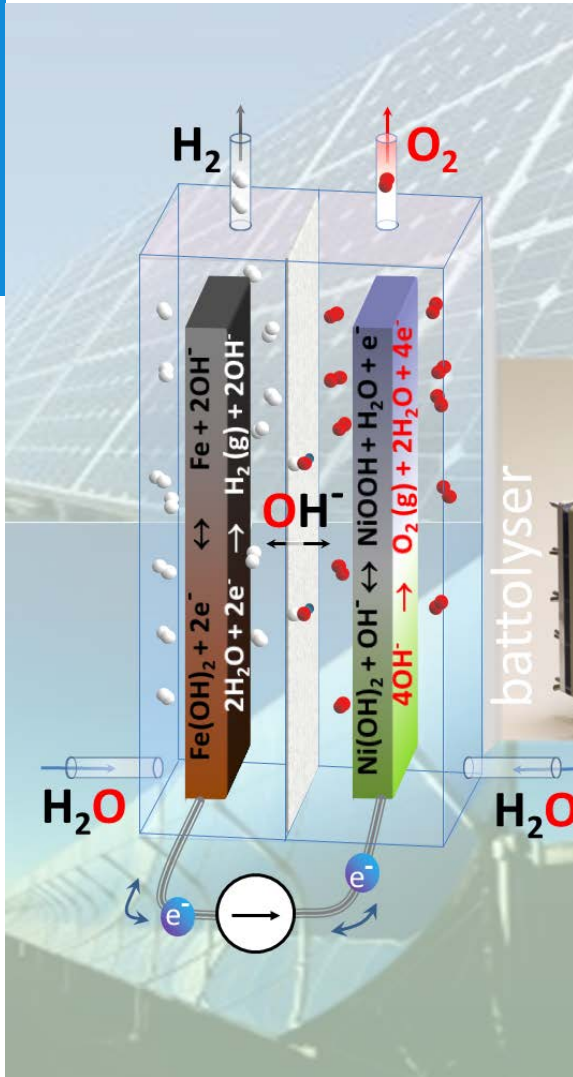
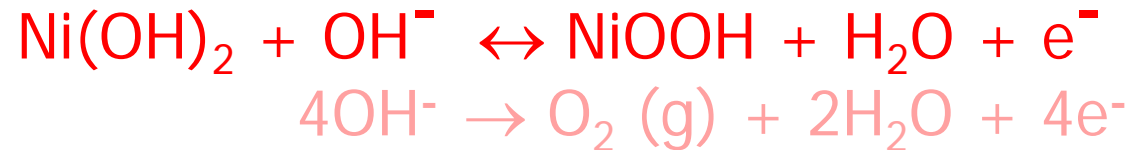
integrate short & long term storage
in one device

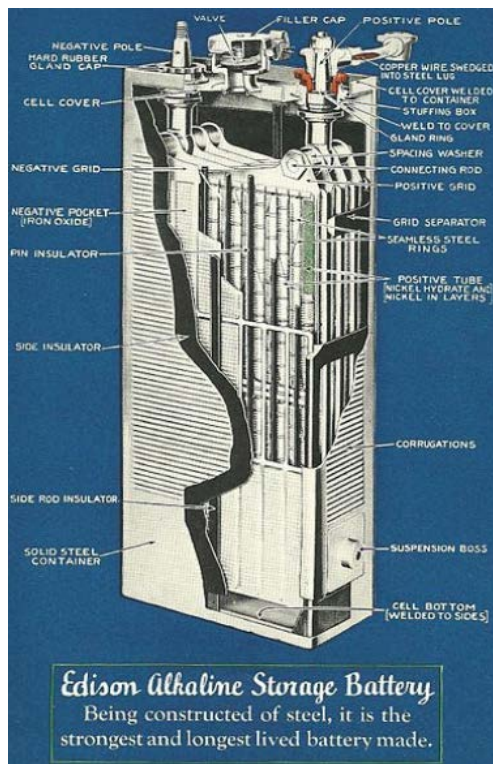
'Battolyser' basic reactions:

Negative electrode:



Positive electrode:



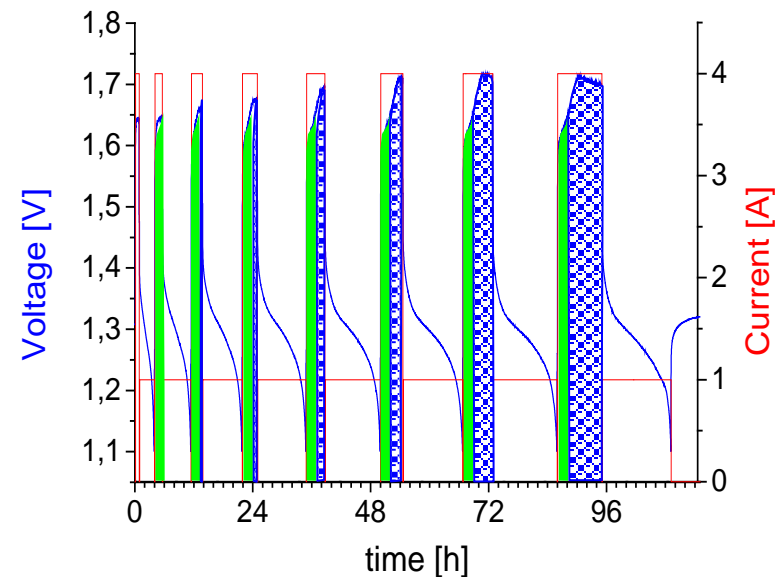
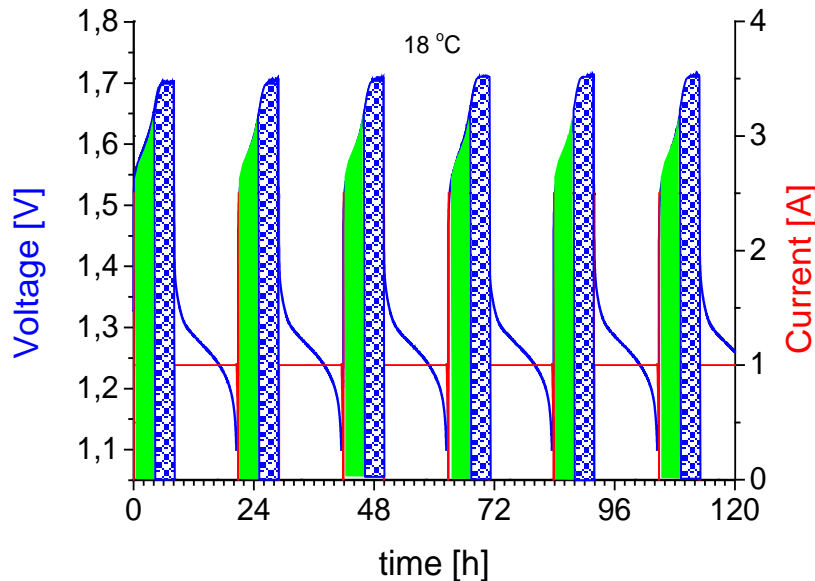


Combine the
most durable
Alkaline Ni-Fe battery
and
most durable
Alkaline electrolyser
in one



Electric car from
1912 with Ni-Fe
battery,
still operational

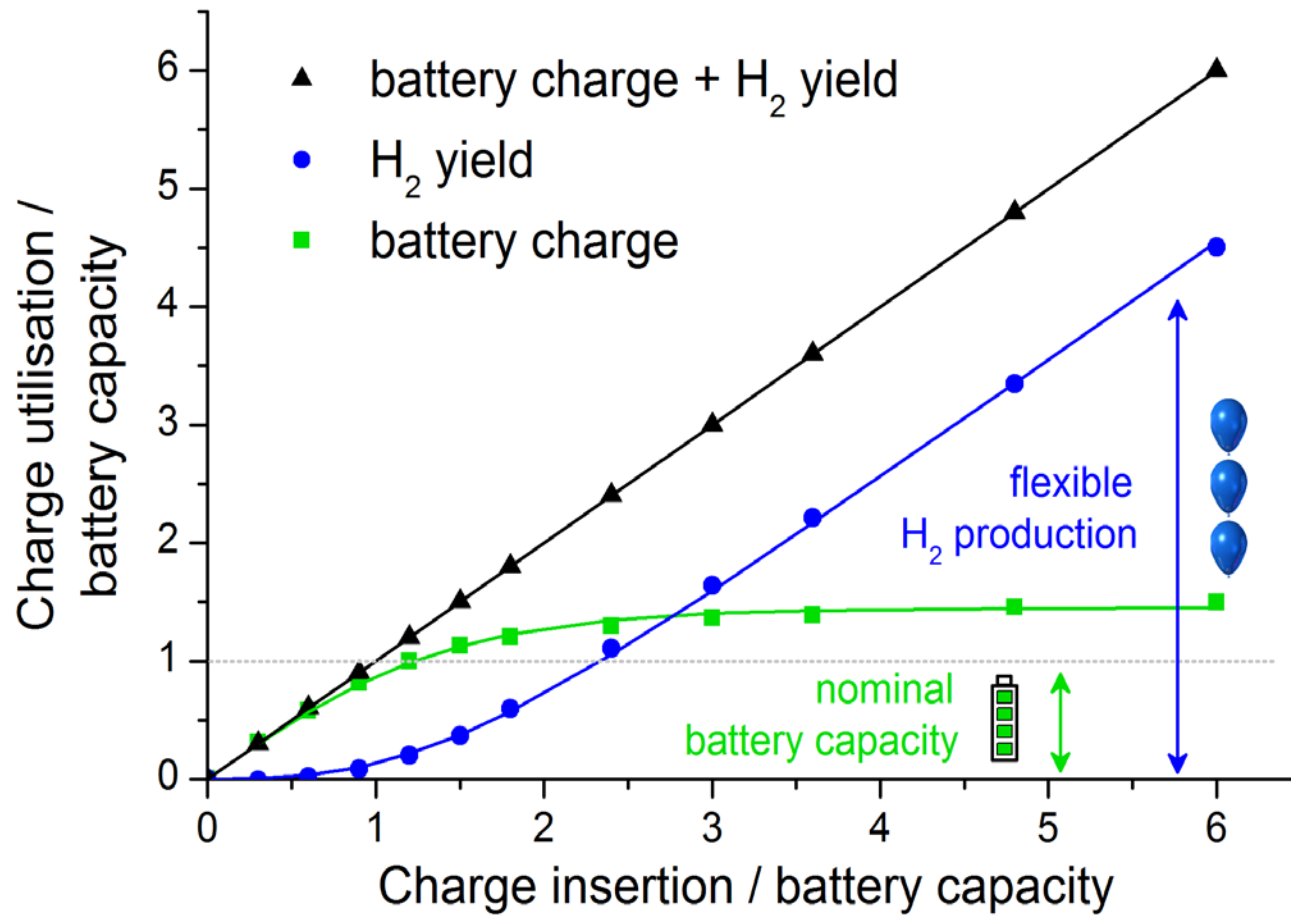
Charge (green) + electrolysis (bubbles) and discharge (white)



Current: applied currents during charge, electrolysis, and discharge

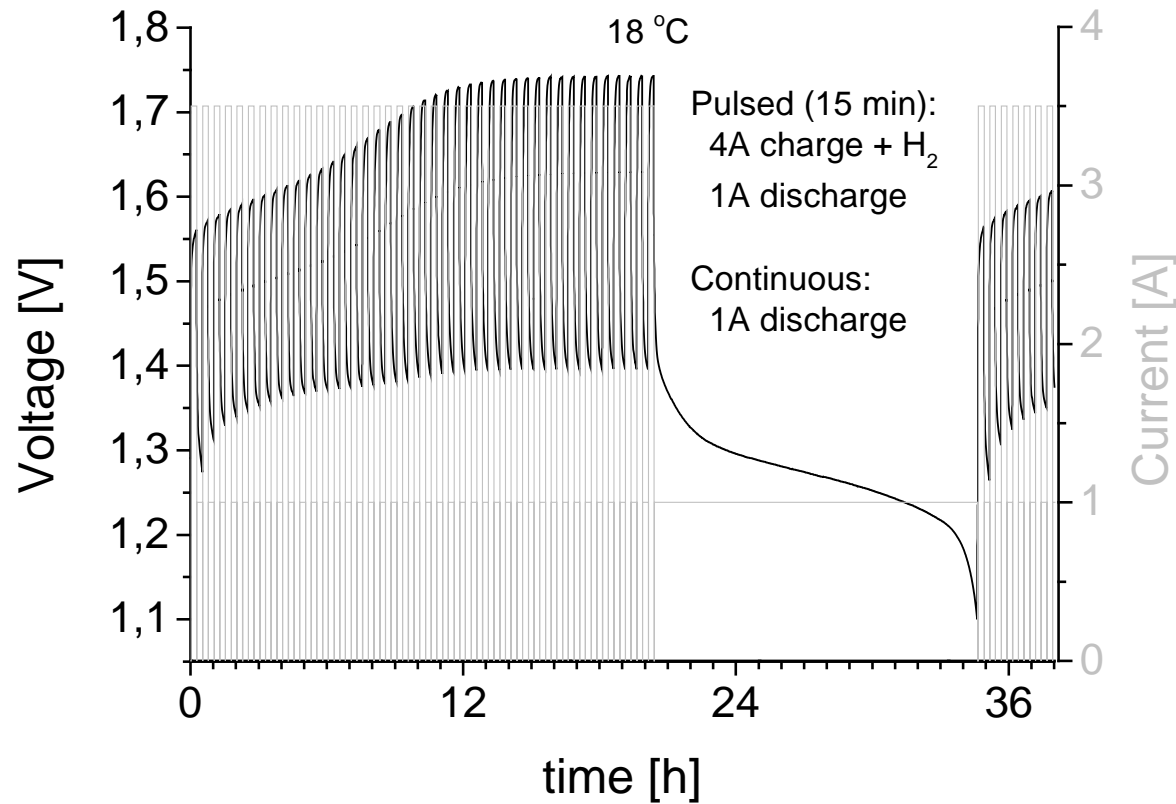
Voltage: that is the voltage that results when using these currents

Several cycles with constant (left) or increasing (right) current insertion.



Flexible operation: one can choose amount of charge insertion

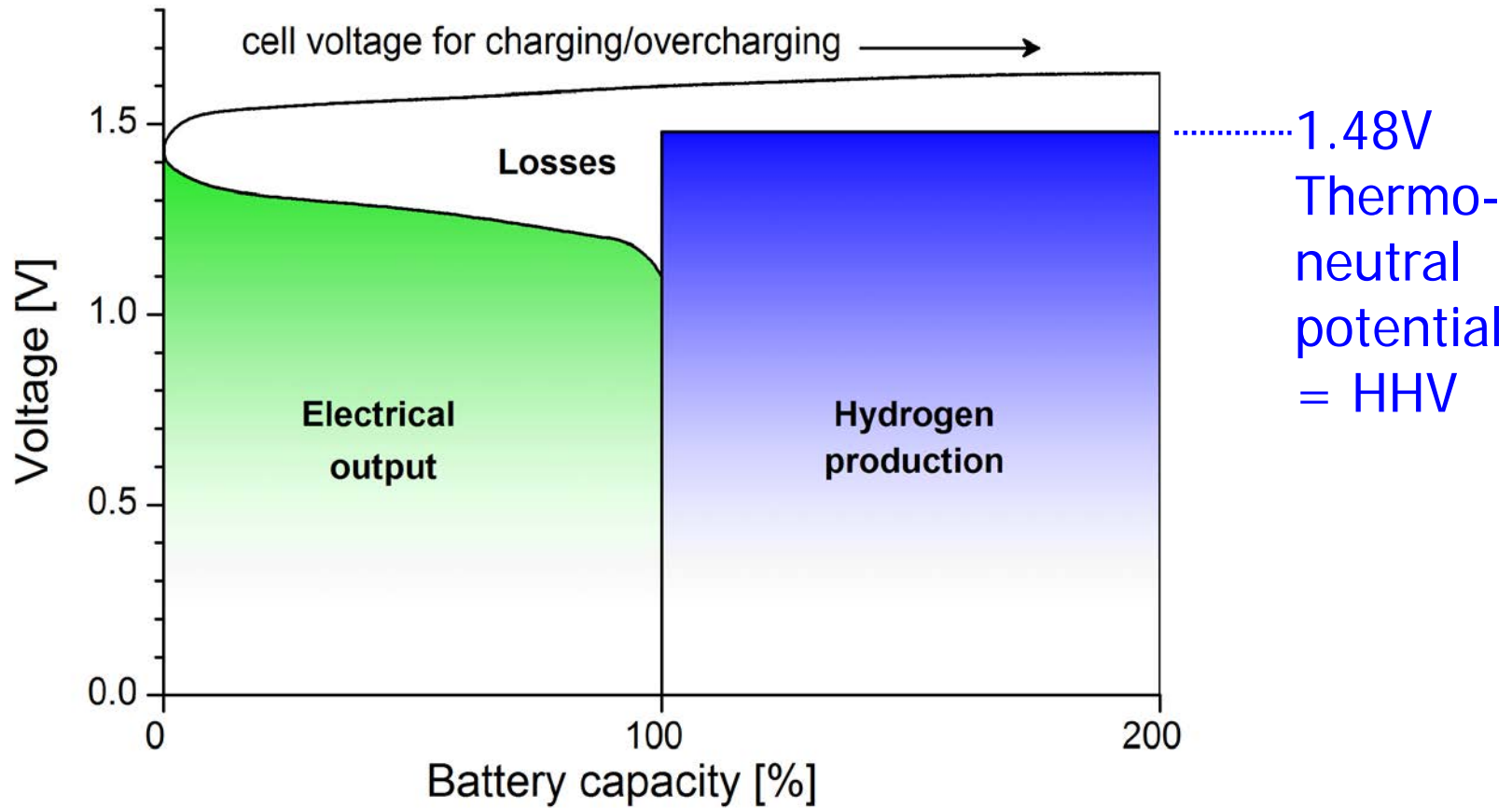
Charge and discharge switching capabilities

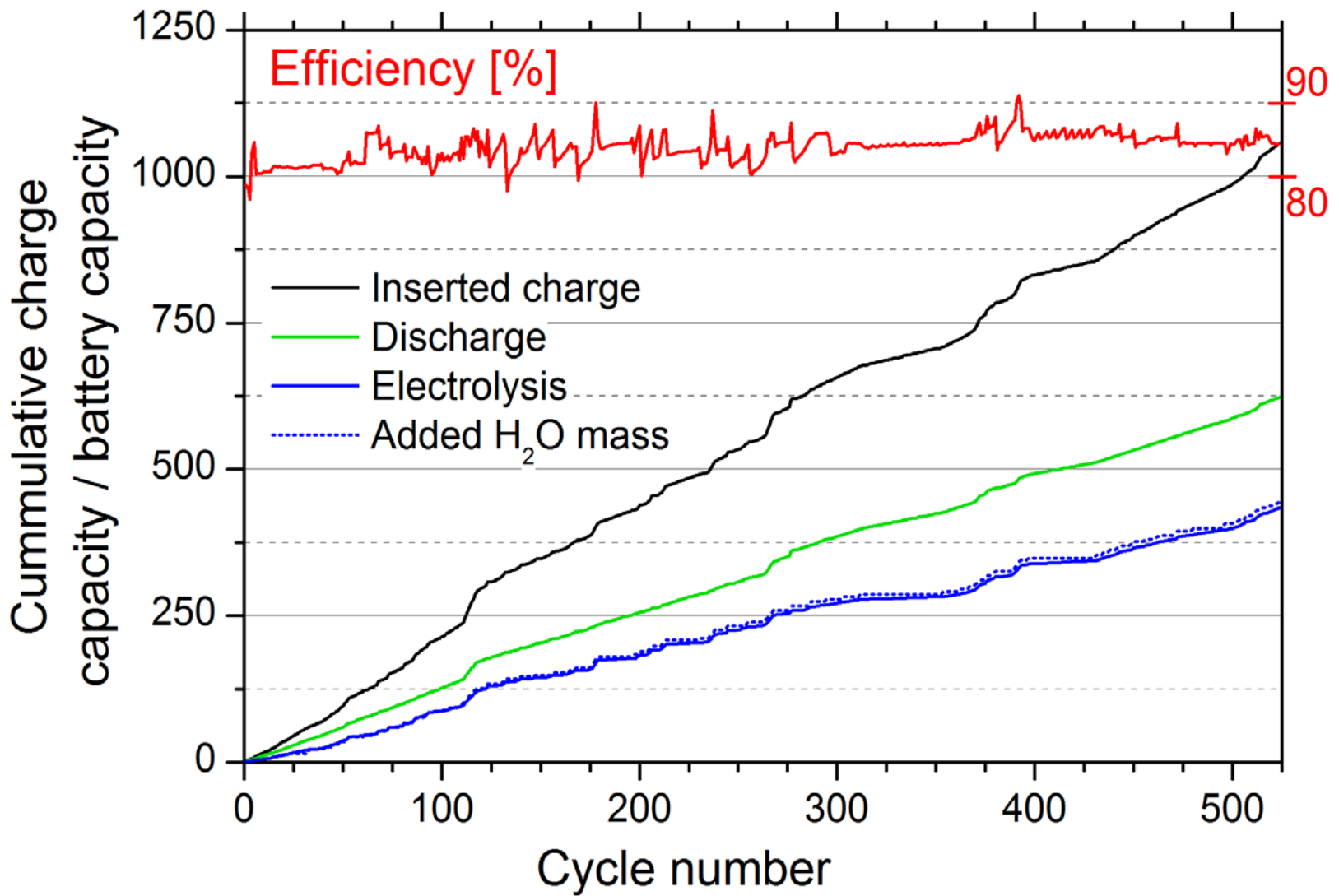


15 minute switching

Compatible with 15 minute electricity
market time slots

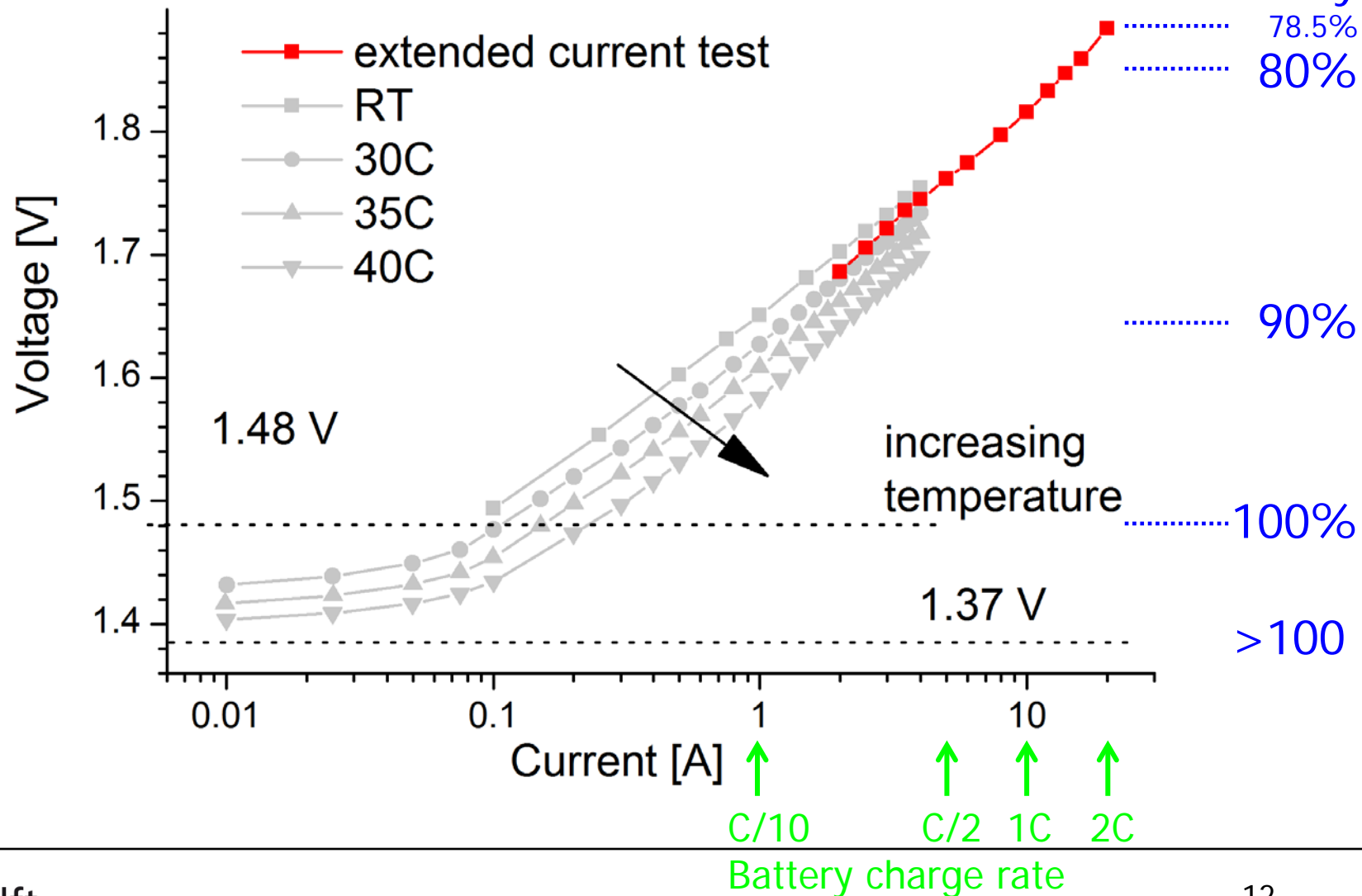
Energy efficiency:

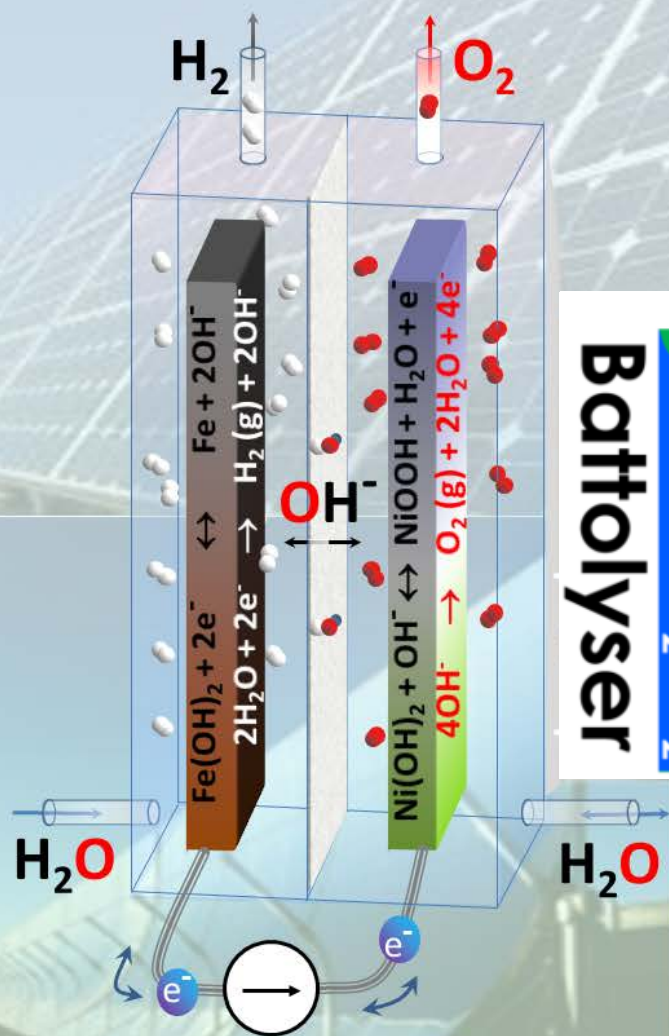




Electrolysis potential versus current.

Higher T lower V, better efficiency

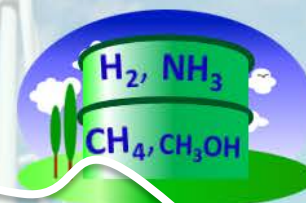




Battolyser

$2\text{H}_2 + \text{O}_2$

$\text{H}_2/\text{EV}/\text{PH}_2\text{EV}$



Energy & Environmental Science 2017

HOT paper

P2A: Power to ammonia



A power plant as a super-battery

Nuon and Delft University of Technology are willing to use gas-fired power plants as storage facilities for renewable energy. They aim to do so by producing ammonia from renewable energy whenever there is a surplus. Ammonia is easy to store on a long-term basis. The ammonia can then be used as fuel in gas-fired power plants at times when there is a shortage of renewable energy.

Wind and solar energy are not available on demand...

Sometimes too much is produced...

The supply of wind and solar energy exceeds the demand.

Now:

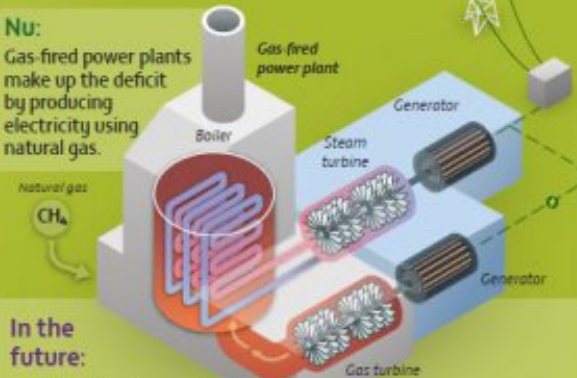
The surplus is sold at very low prices and consumed elsewhere.

...while at other times there is a shortage

Demand is greater than the production of renewable energy at that moment.

Nu:

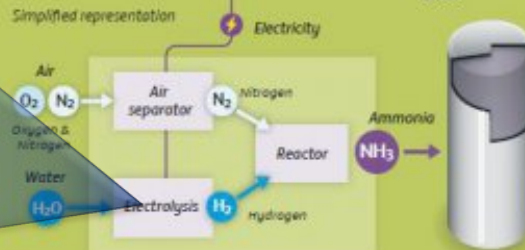
Gas-fired power plants make up the deficit by producing electricity using natural gas.



In the future:

1 The energy surplus will be converted into ammonia.

2 The ammonia will be stored in liquid state.



In the future:

1 The stored ammonia will be used as fuel instead of natural gas.

2 No CO₂ will be released when ammonia is burned.



NUON

News: Upscaled battolyser at Magnum powerplant Eemshaven, planned 2019



VATTENFALL

About Vattenfall

Sustainability

Investors

Press and media

Careers

About energy



News

Media bank

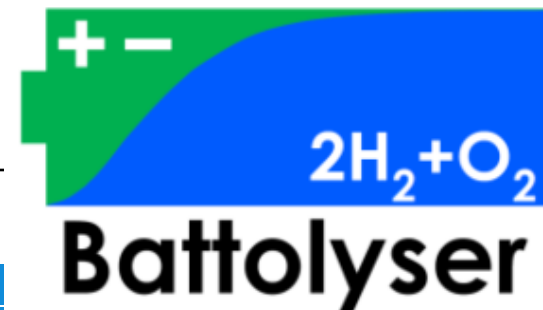
Contacts

News

Vattenfall/Nuon takes another step towards fossil-free gas power production

Builds combined electricity storage and hydrogen production facility at Dutch gas power plant.

2018-06-12



If you have H₂ you can 'clean'
many processes in industry

- Steel
- Ammonia
- Cement
- Methanol

IEA 2017:

INTERNATIONAL ENERGY AGENCY
INSIGHTS SERIES 2017

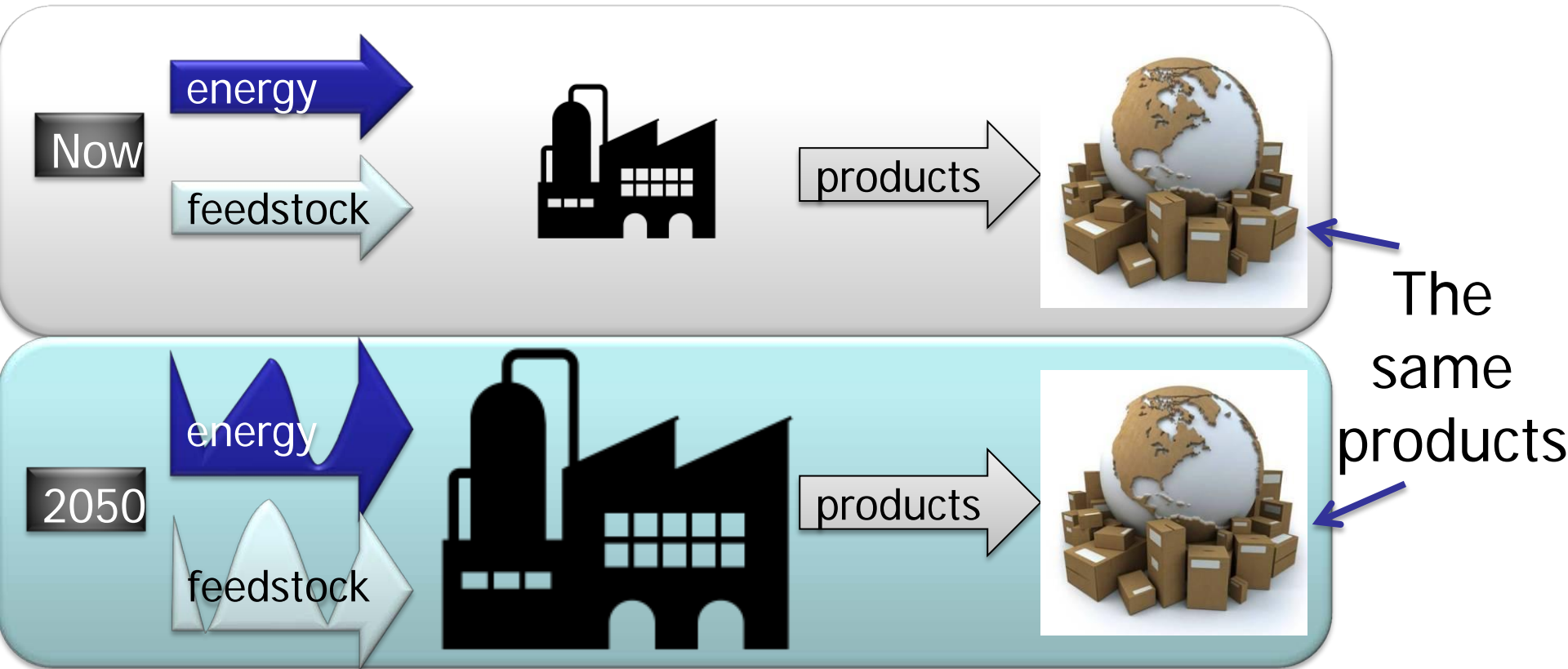
Renewable Energy for Industry

*From green energy to green
materials and fuels*

Cédric Philibert

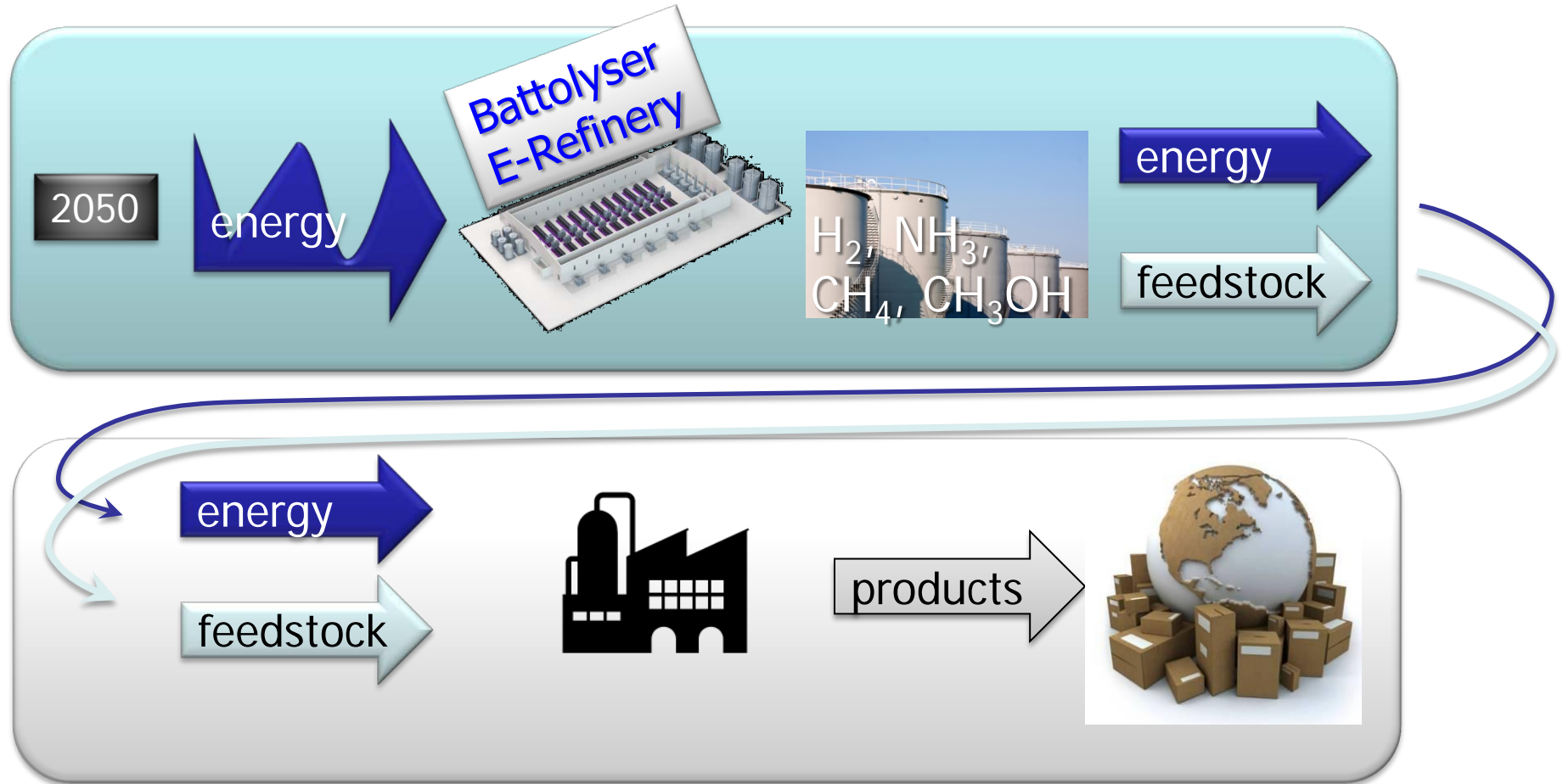
The views expressed in this paper do not necessarily reflect the views or policy of the International Energy Agency (IEA) Secretariat or of its individual member countries. The paper does not constitute advice on any specific issue or situation. The IEA makes no representation or warranty, express or implied, in respect of the paper's content (including its completeness or accuracy) and shall not be responsible for any use of, or reliance on, the paper. Comments are welcome, directed to cedric.philibert@iea.org.

➤ Energy & feedstock transition:



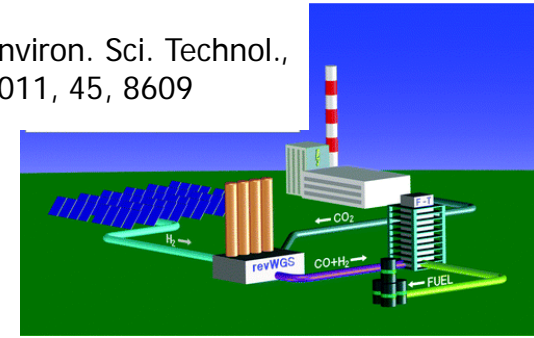
Larger capacity to handle
intermittency, lower capacity factor?

➤ Greening of energy and feedstock supply



H₂ Feedstock & power

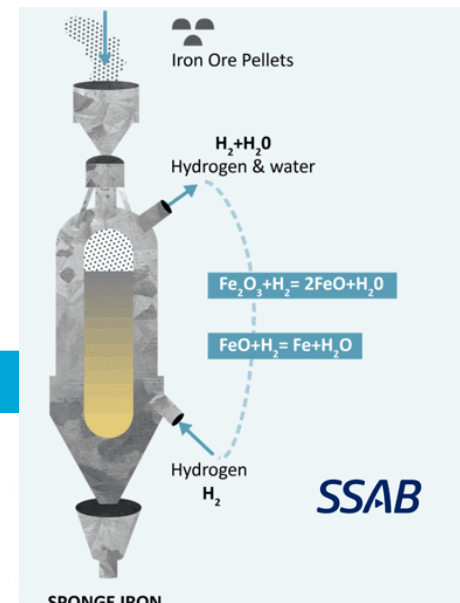
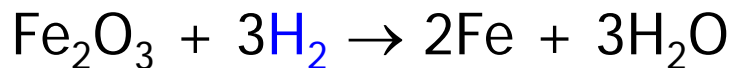
Environ. Sci. Technol.,
2011, 45, 8609



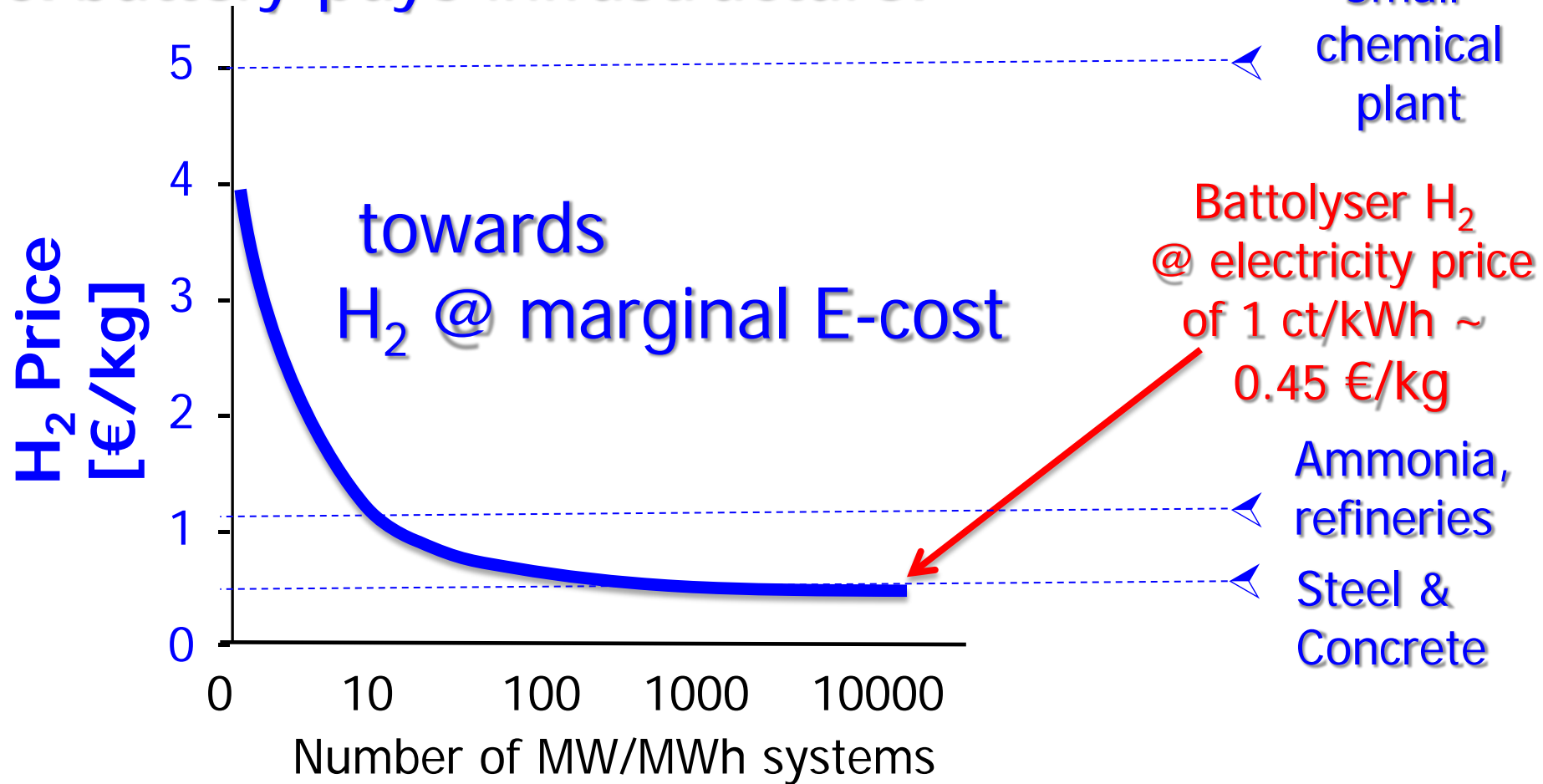
- H₂, power and N₂ for NH₃ synthesis
- H₂, power and CO₂ for Sabatier or Fischer-Tropsch process
- H₂ & power for concrete production and CO₂ harvesting



- H₂ & power for fossil free iron reduction

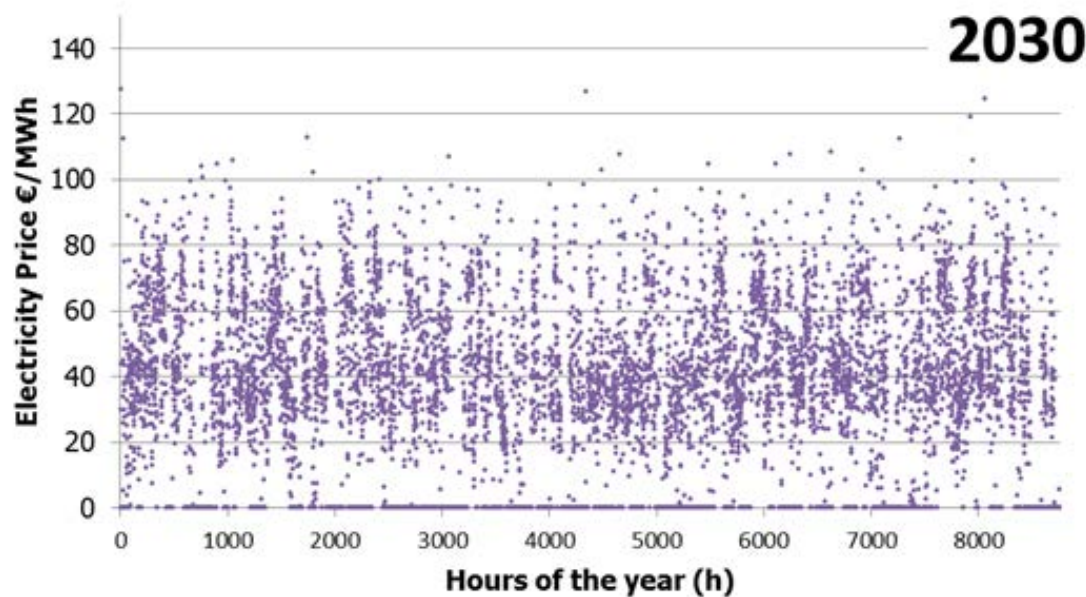
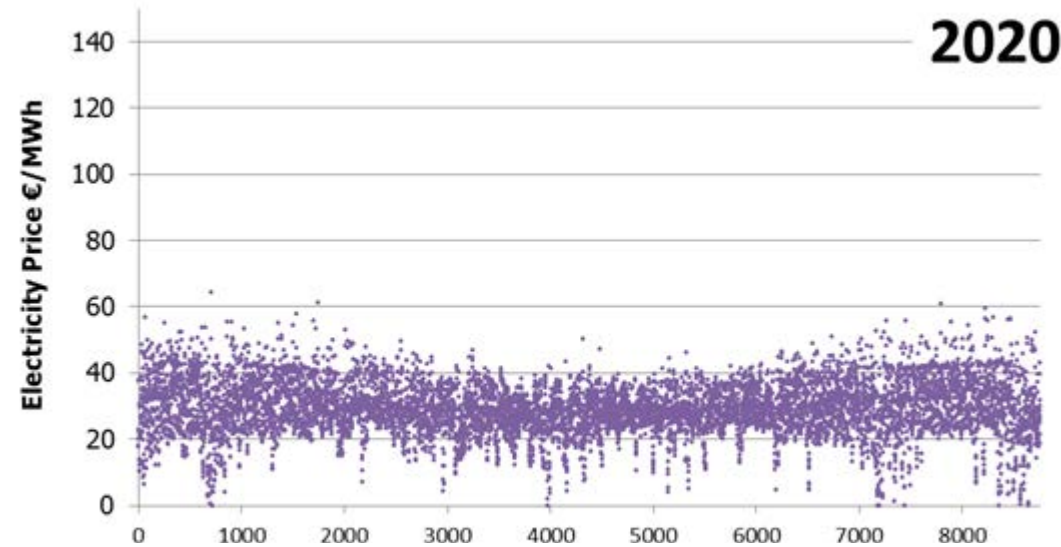


Abundant renewables, scaling up & battery pays infrastructure:



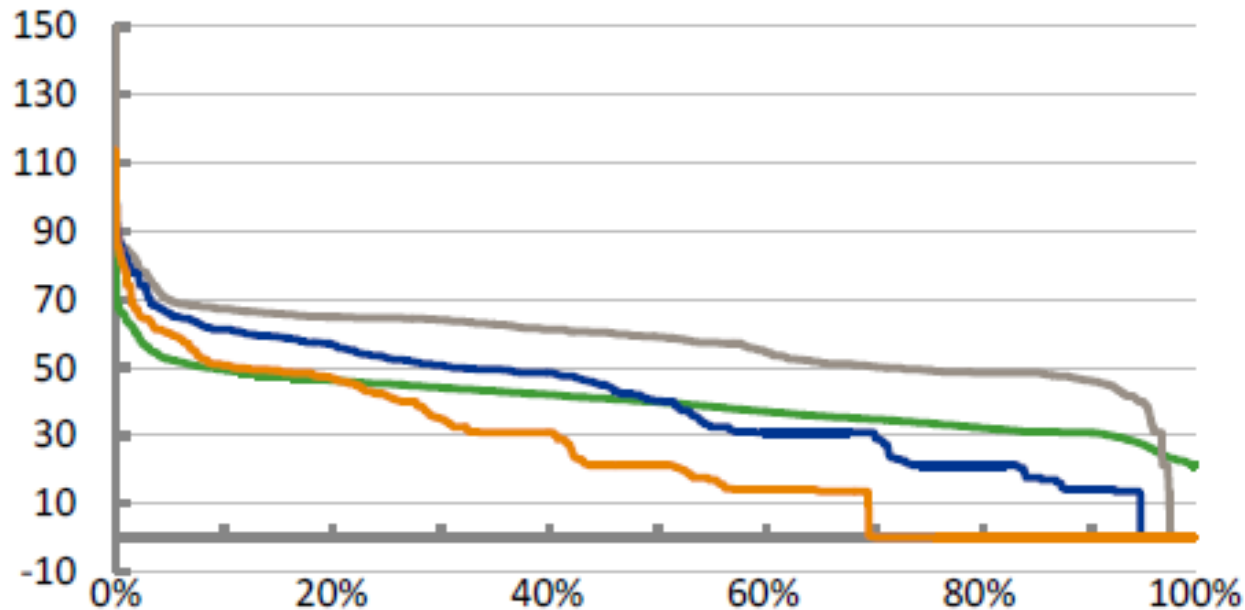
Power 2 Ammonia project with ISPT and partners

Simulations day-ahead
market of CE Delft



Larger price differences:
Many low & many high
price hours: storage
opportunity

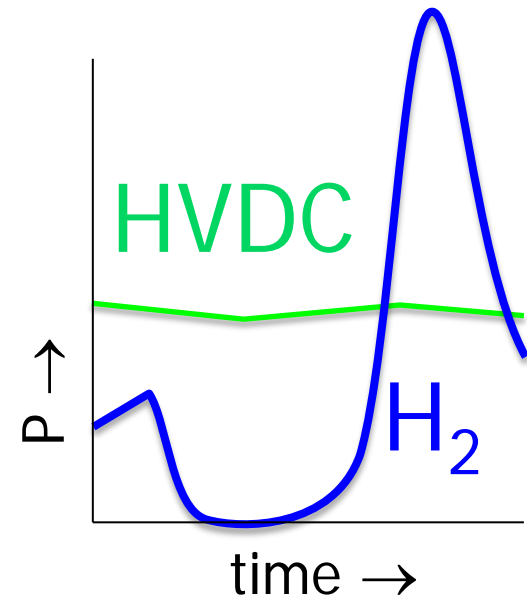
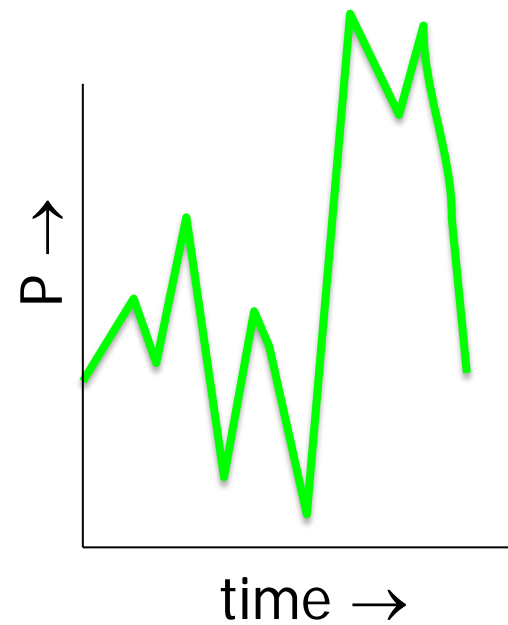
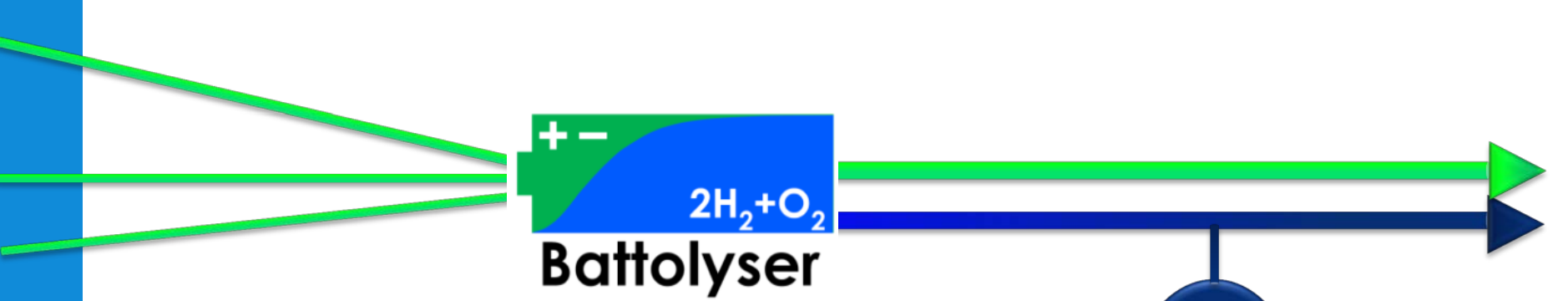
Netherlands (2030)



High renewables:
Many low price
< 1ct/kWh
hours, curtailment

— 2012 — 2030 - Low RES — 2030 - Base — 2030 - High RES Source: DNV GL

ENTSO-E Vision4 scenario 2014,
not high in RES any more today...



Battolyser tests

- Energy efficiency > 82-92%
- Scalable, no precious metals
- Highly robust
- Switches instantly
- Competitive with static batteries and electrolyzers

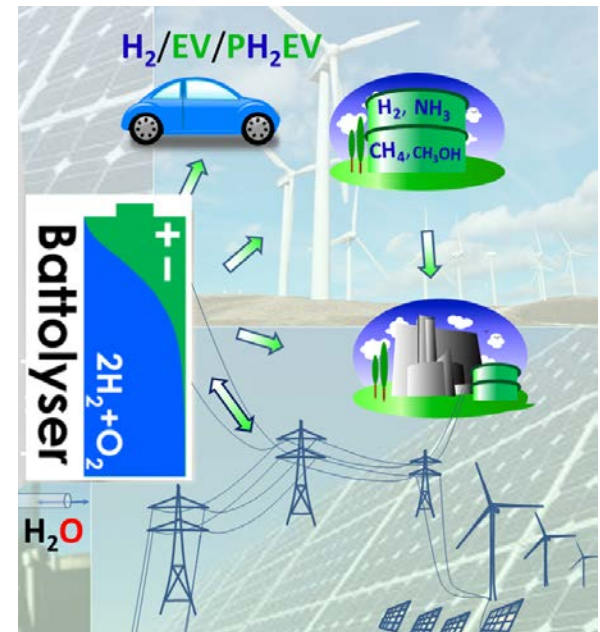


2 FOR 1

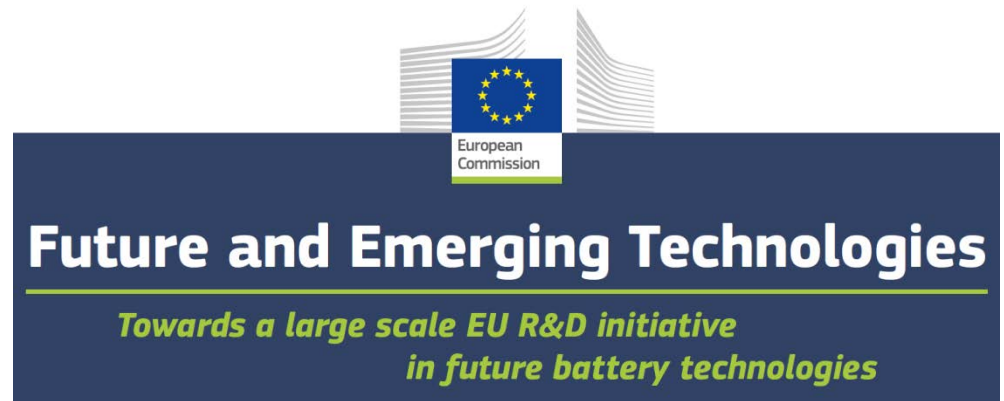
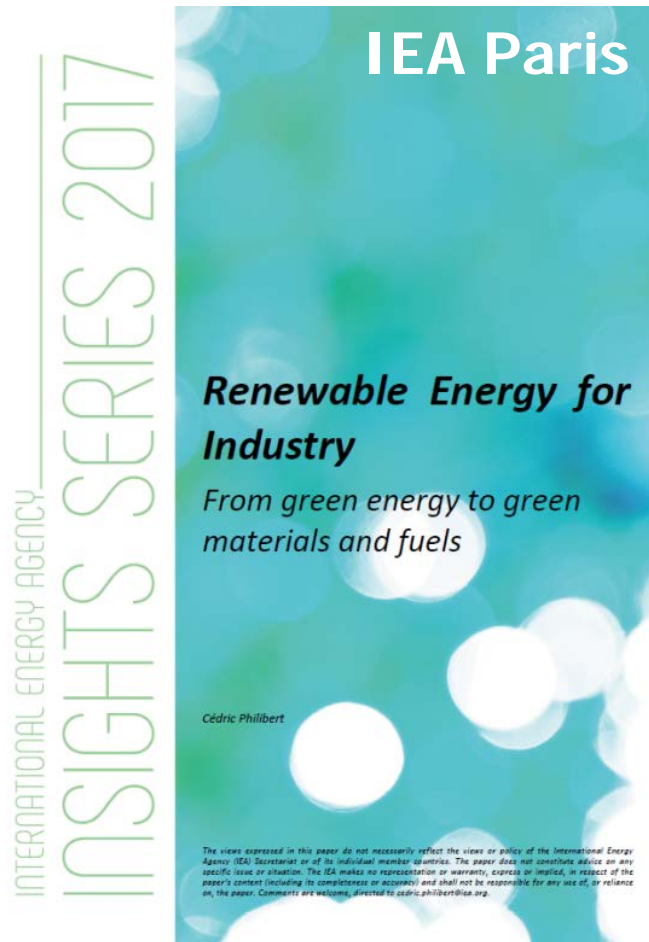


NWO | Applied and
Engineering Sciences

& industrial partners



Battolyser exposure



https://setis.ec.europa.eu/system/files/set_plan_batteries_implementation_plan.pdf

Acknowledgements:

Audrey Iranzo
Jebin James
Joost Middelkoop
Robin Moller-Guland
John Nijenhuis
Frans Ooms
Herman Schreuders
Berhard Weninger
& Industrial partners

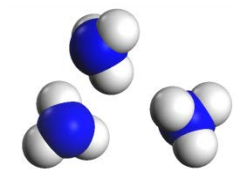


Applied and
Engineering Sciences

P2A



Ammonia NH_3 for large scale energy storage?



Energy future ➤ Renewables implementation needs storage.

Production ➤ based on abundant elements N, H, and cheap catalysts: scalable.
➤ can be produced using abundant renewable electricity and CO_2 free.

Storage ➤ energy density NH_3 : 22.5 MJ/kg (HHV)
➤ liquid at 10bar, 20°C and 1bar, -35°C
➤ current containers can contain 100000 ton NH_3 ~ 625 GWh.

Use ➤ clean use in fuel cell, combustion engine, gas turbine. No CO_2 .
➤ fertilizer industry: CO_2 neutral fertilizers

Acceptance ➤ poisonous, but 100+ yr industrial know-how
➤ current NH_3 production costs >1.5% of world energy use >5 EJ/yr
➤ Bio degradable (fertilizer)

