Energieopslag in brandstoffen: processen en procesintegratie uitdagingen

e-Refinery
Towards sustainable production of chemicals and fuels

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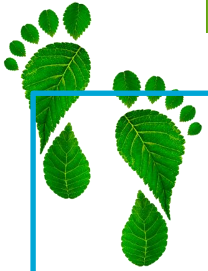
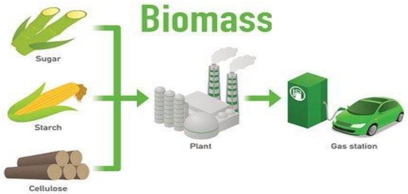
Large Scale Energy Storage section



'Biomass route'



Prof. dr. Wiebren de Jong

'Indirect route'

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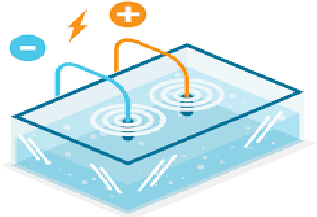

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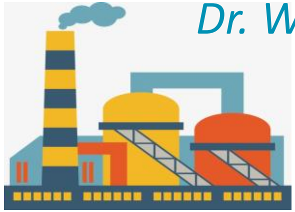

Dr. Wim Haije

Renewable power based

'Direct route'

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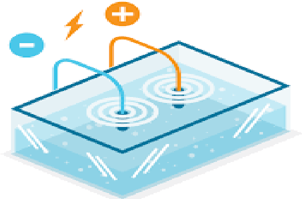

Dr. Ruud Kortlever

Renewable power based

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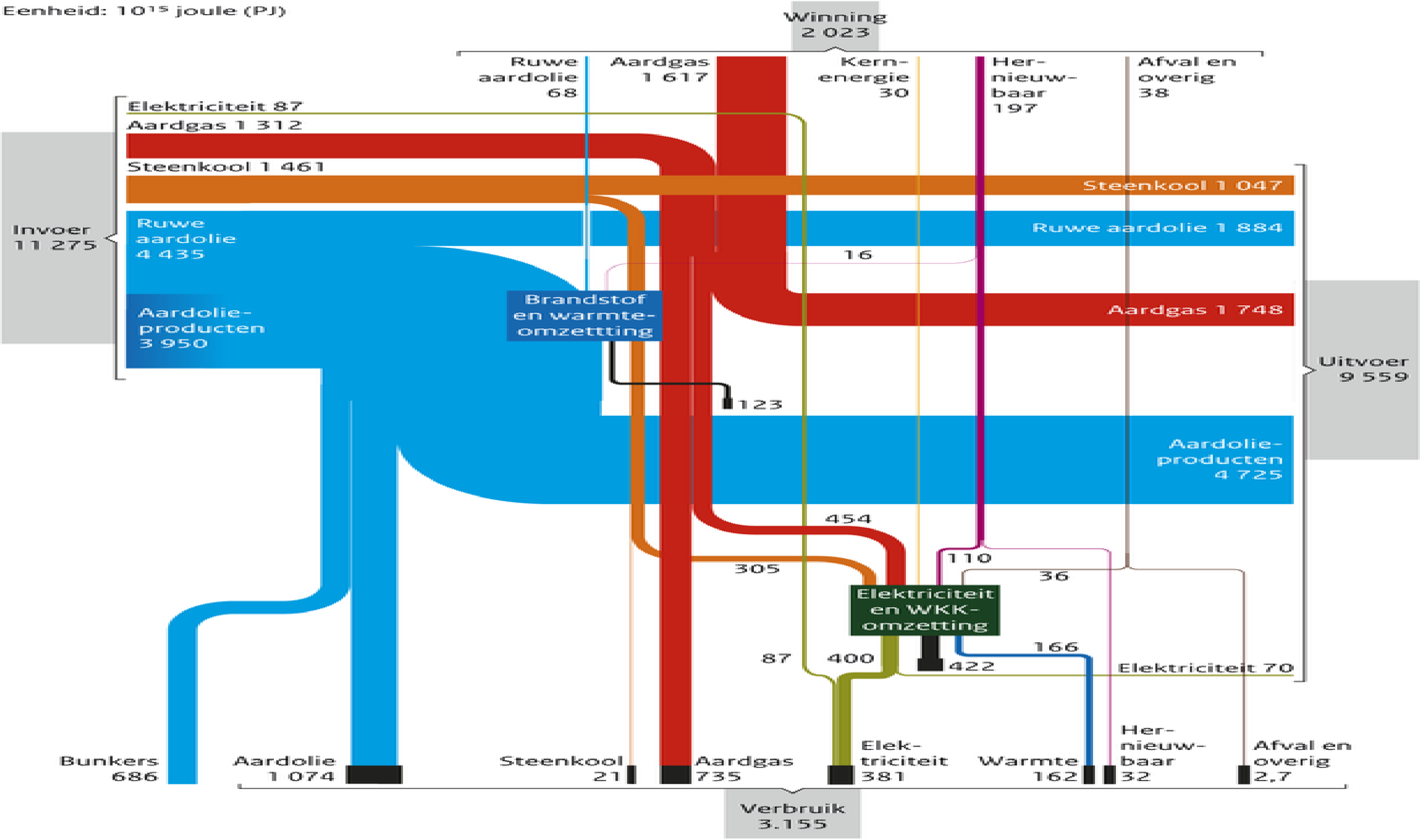
Dutch energy supply, mainly fossil based

Energiestromen, 2016**

Eenheid: 10^{15} joule (PJ)



N.B. De som van de zwarte blokjes is het totale energieverbruik (finaal verbruik en saldi omzetting). In deze figuur zijn verschillende details verwaarloosd.

Bron: CBS

CBS/feb18
www.clo.nl/nl002012

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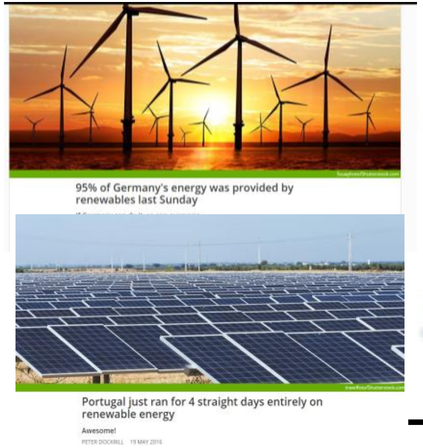
Wind/solar energy supply is intermittent…



Timescales

<~15-30 min

~12 h

days

weeks-
months

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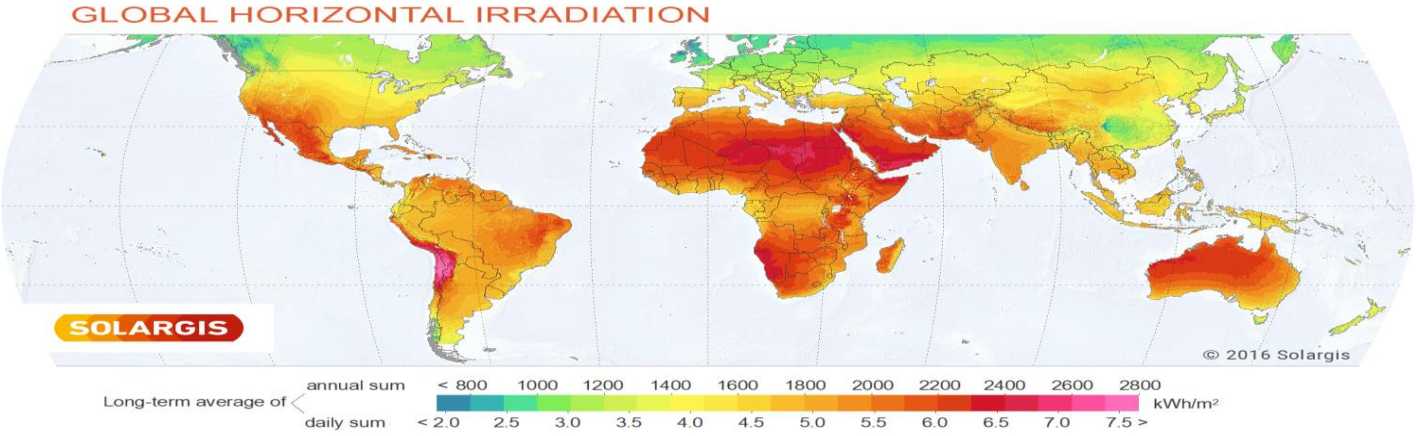
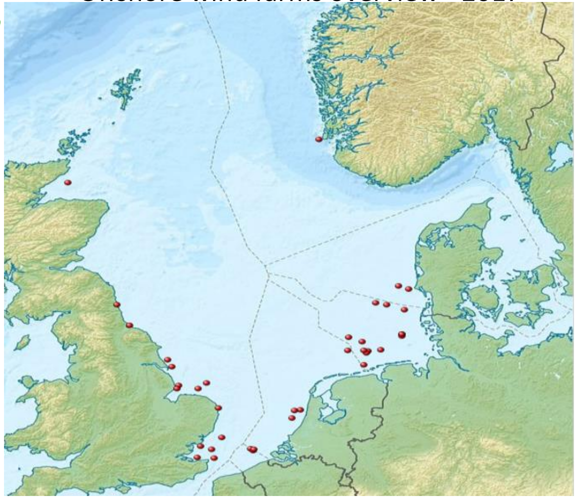
Geographic mismatch demand/supply

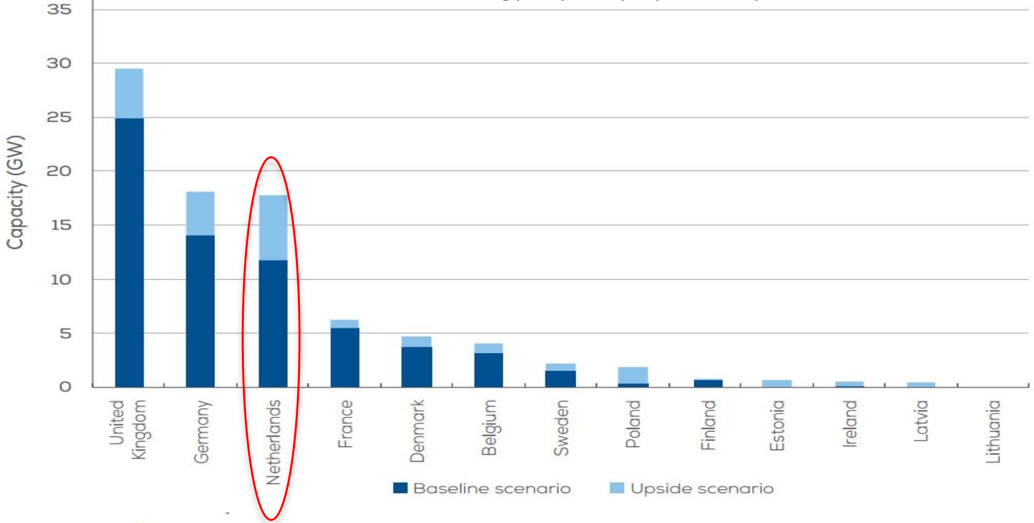


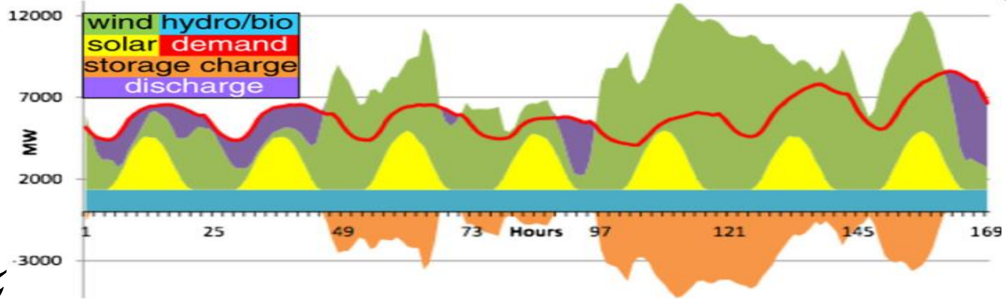
Need for energy storage, NL context

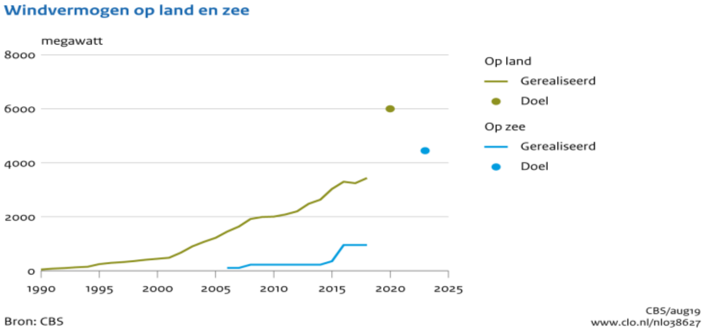
Offshore wind farms overview - 2017



Cumulative installed wind energy capacity by country in the end of 2030







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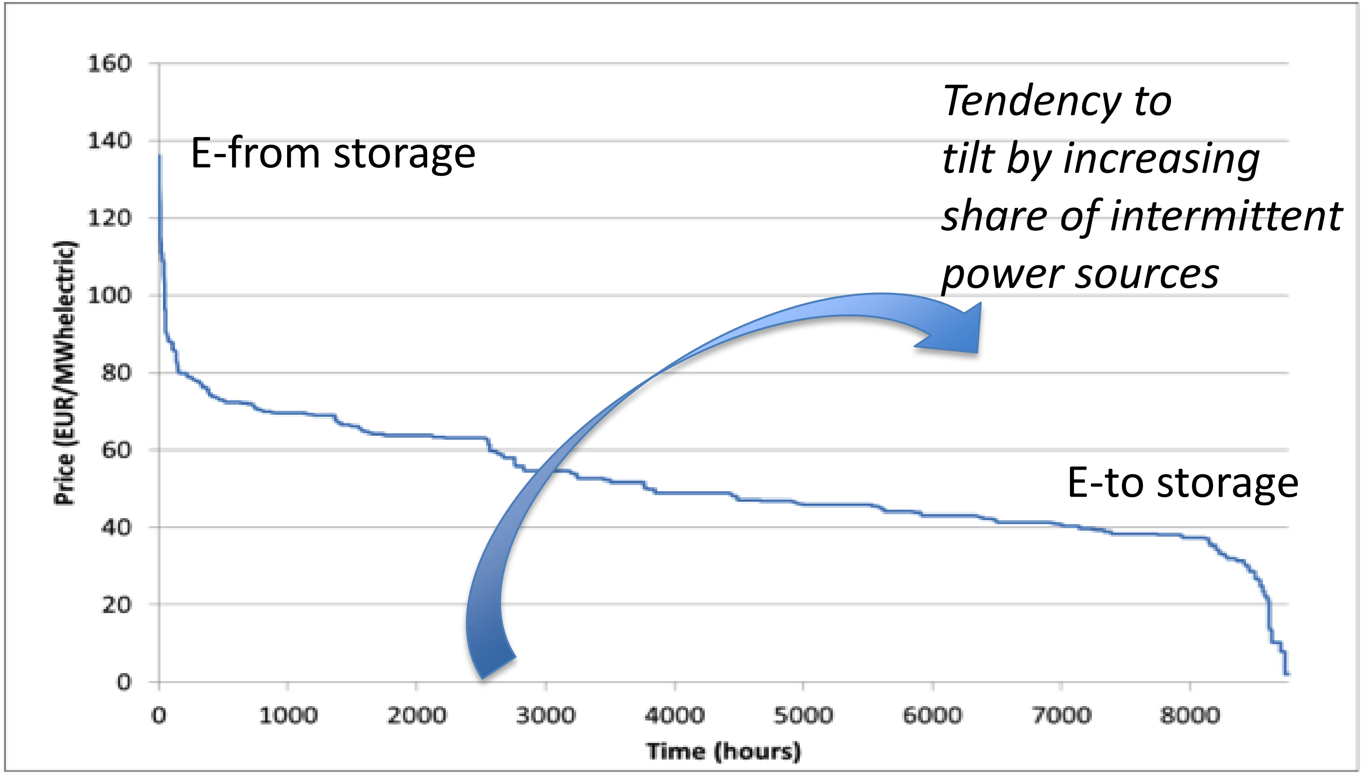
Possible scenario for power price-duration curve 2030



Source (adapted): http://www.voltachem.com/news/when-why-power-2-heat

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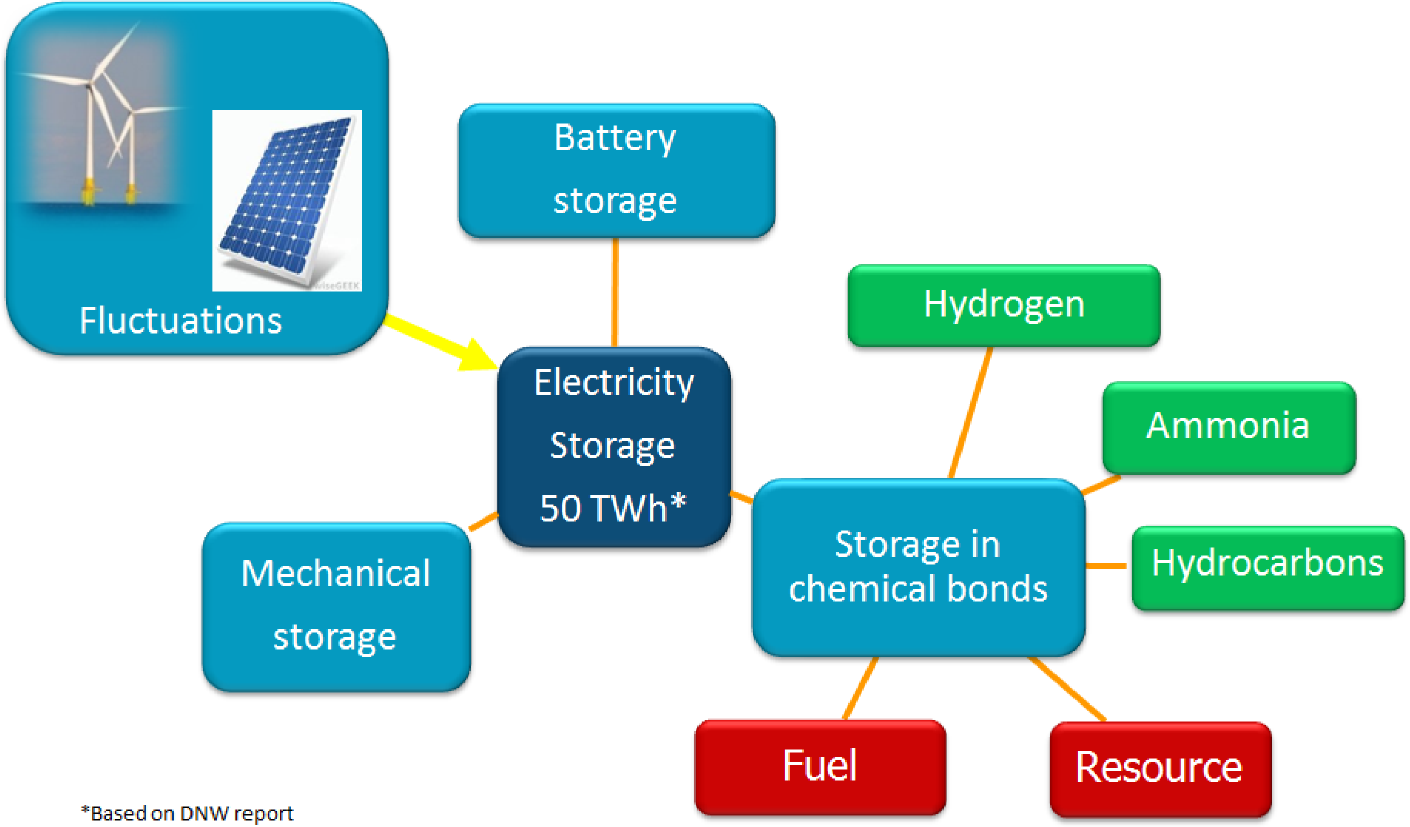
Modes of energy storage



*Based on DNW report

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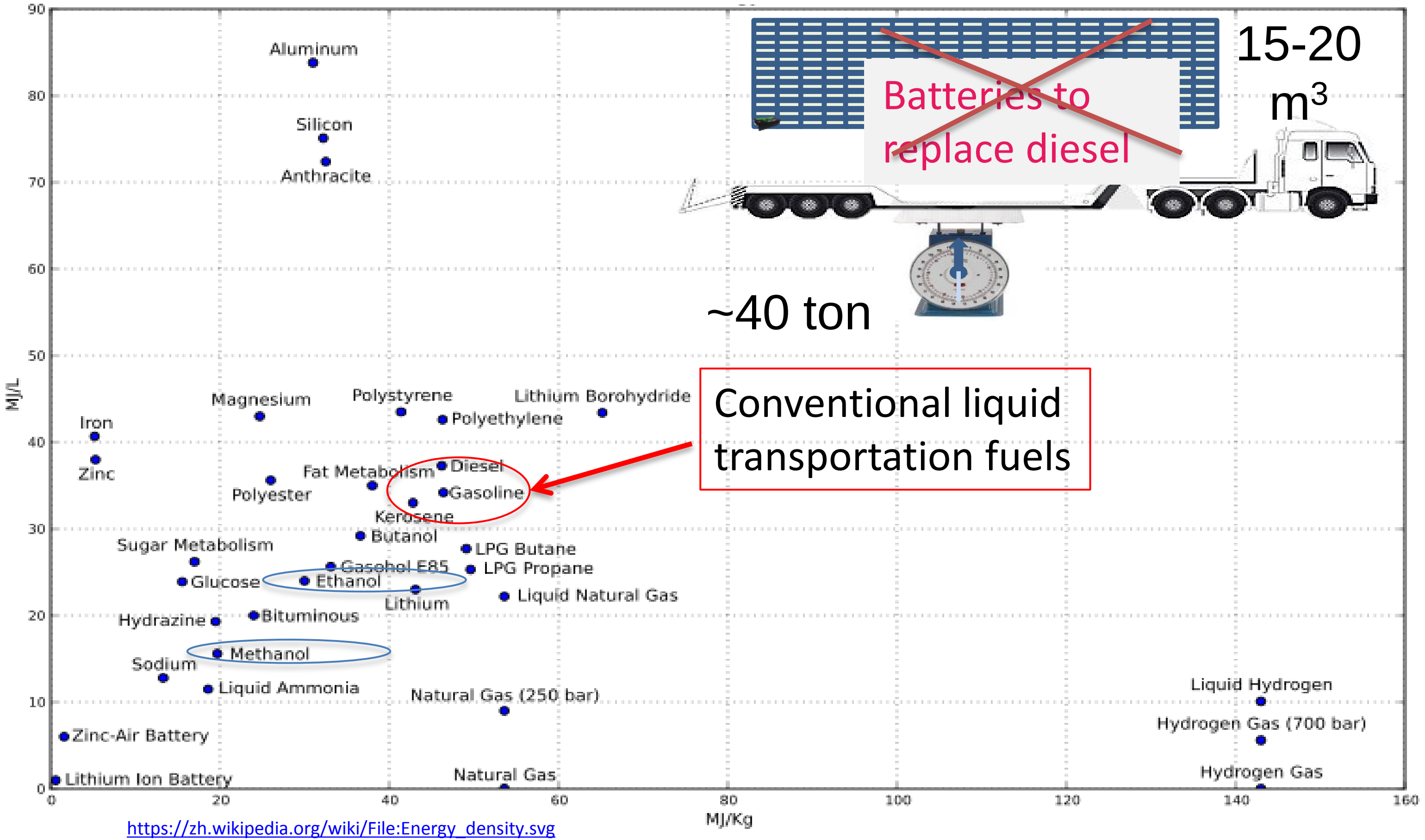
Energy density of several fuels

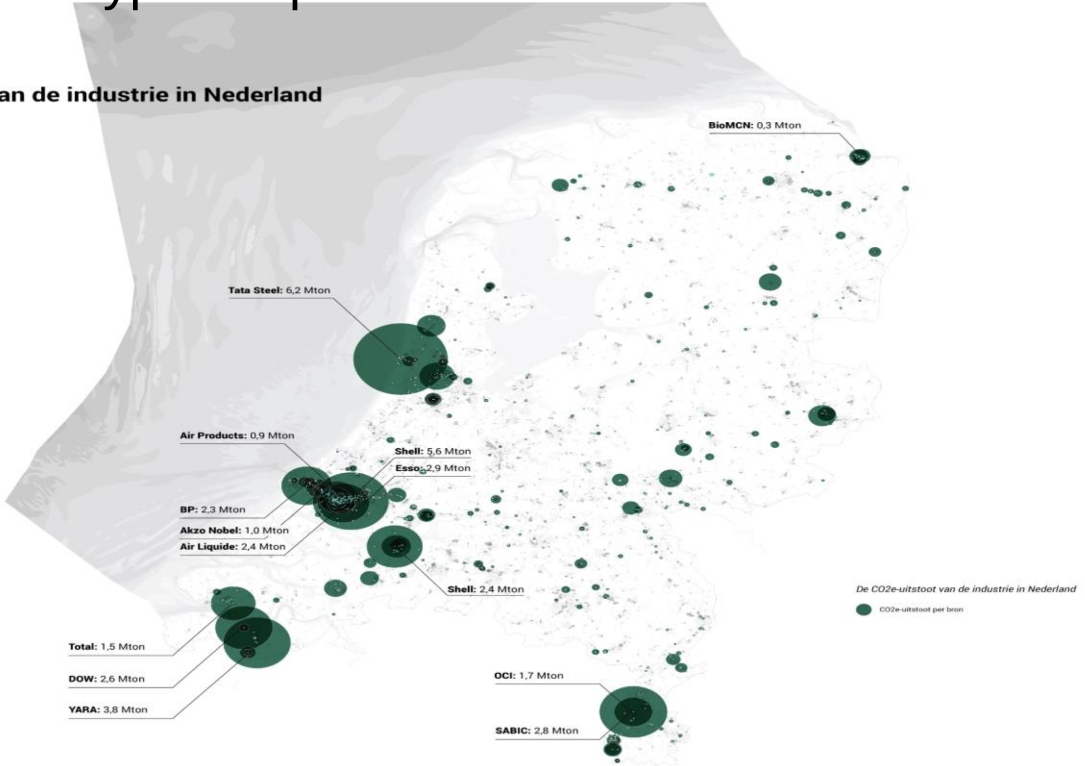


https://zh.wikipedia.org/wiki/File:Energy_density.svg

Picture truck, courtesy prof. Philip de Goey (TU Eindhoven)

Dutch industry CO_2 reduction

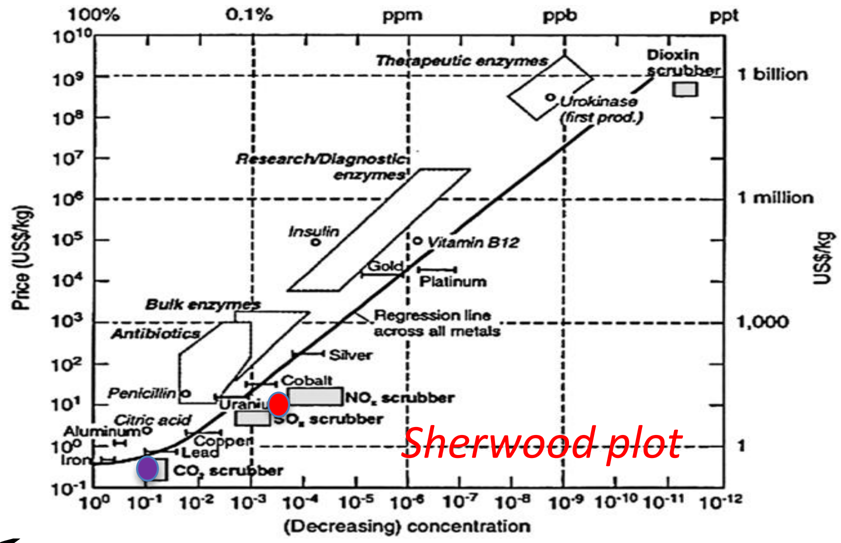
- Reduction by 14.3+5.1 Mton/yr (2030) from 55.1 Mton/yr (2015)
- All different types of point sources

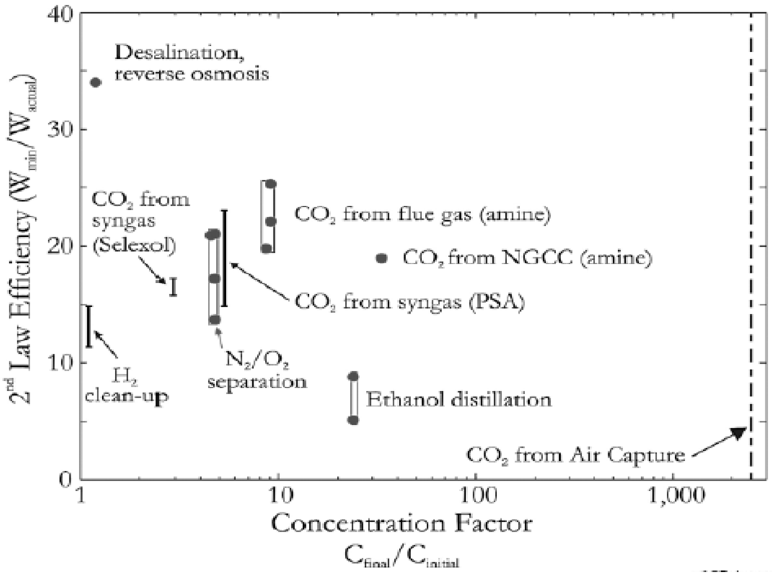


http://marcovermeulen.eu/projecten/selectie/177/klimaatakkoordsectortafelindustrie/

CO_2 sources

- Advantageous to use concentrated CO_2 streams *first*
  - Minimum work increases when more dilute $\Delta G^o = -RT_o \ln y_{CO_2} \approx 0.5 MJ.kg^{-1}$
  - High 2nd Law of thermodynamics efficiency
  - Costs increase substantially for decreasing concentration





- CO_2 capture from air ~400 ppm_v
- CO_2 capture from post-combustion flue gas ~10 vol.%

Figures adapted from
House et al. (2011) PNAS 108(51),20428-33

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Scenario's for future production of chemicals and fuels

'Conventional'

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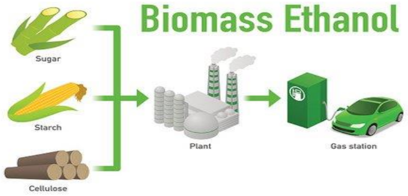

e-Refinery

'Direct route'

Renewable power based

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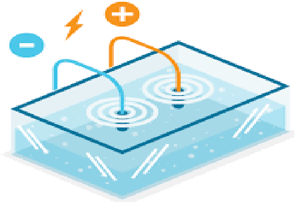

'Indirect route'

Renewable power based

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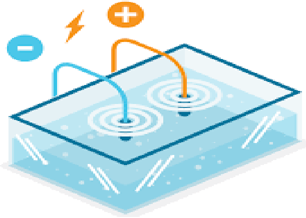

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Indirect power-to-X route to methane

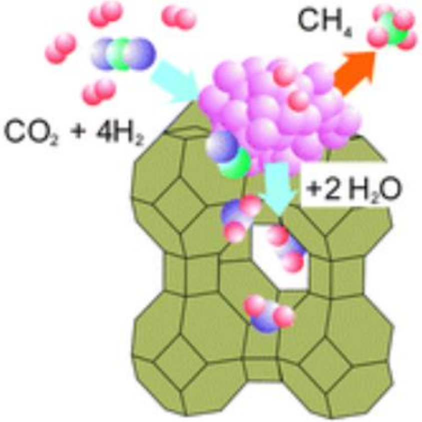
- Sabatier reaction (1902!):

$$CO_2 + 4\,H_2 \overset{cat}{\leftrightarrow} CH_4 + 2\,H_2O + \text{heat} \; (1)$$

- Shift of the equilibrium by sorption:

$$\text{sorbent}_{(dry)} + H_2O \leftrightarrow \text{sorbent}_{(wet)} + \text{heat} \; (2)$$

- Dry (=regenerate) sorbent with heat (1)



Sorption-enhanced equilibrium

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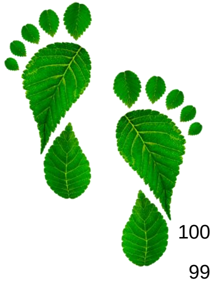
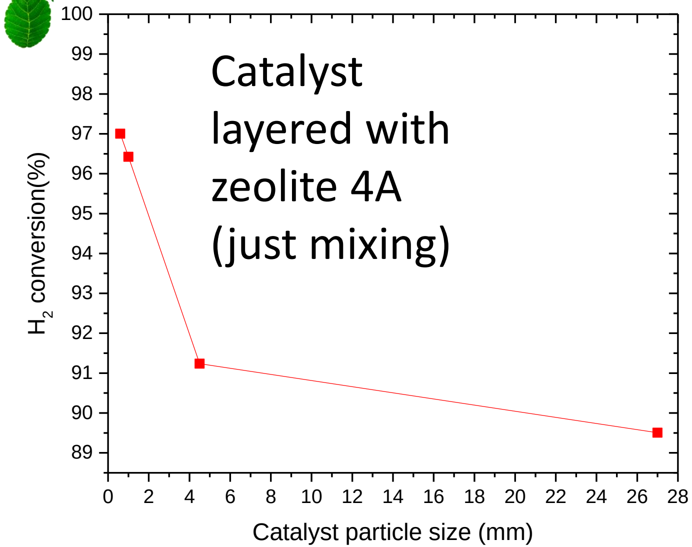
Picture zeolite, source: Borgschulte et al. (2013) *Phys.Chem.Phys.* **15**, pp. 9620-9625
Picture Sabatier, source: https://nl.wikipedia.org/wiki/Paul_Sabatier

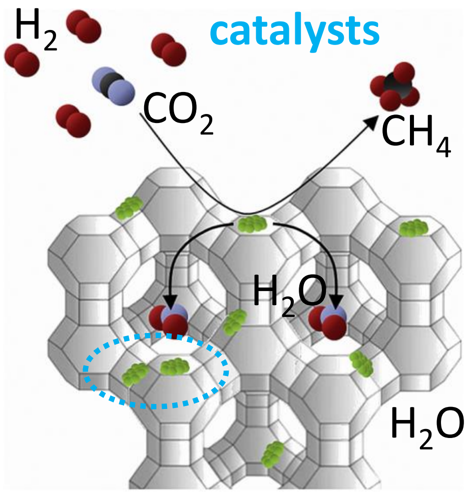
Research towards new catalysts



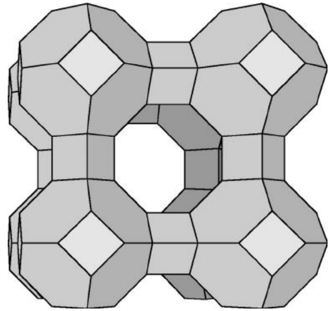


H_2 conversion under the condition of different size catalyst(42g) mixed with zeolite 4A (2.5-5mm, 220 g) at 280 °C, GHSV=2400 h^{-1}.

Different precursors to prepare Ni-zeolite catalysts



Zeolite 13X*



Zeolite 5A

Sorption enhanced CO_2 methanation over a nickel catalyst on zeolite

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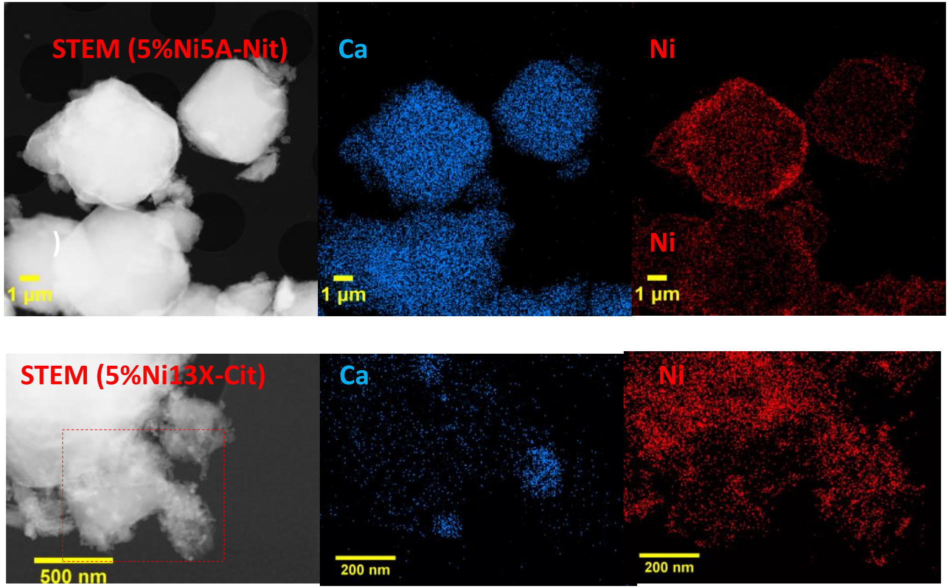
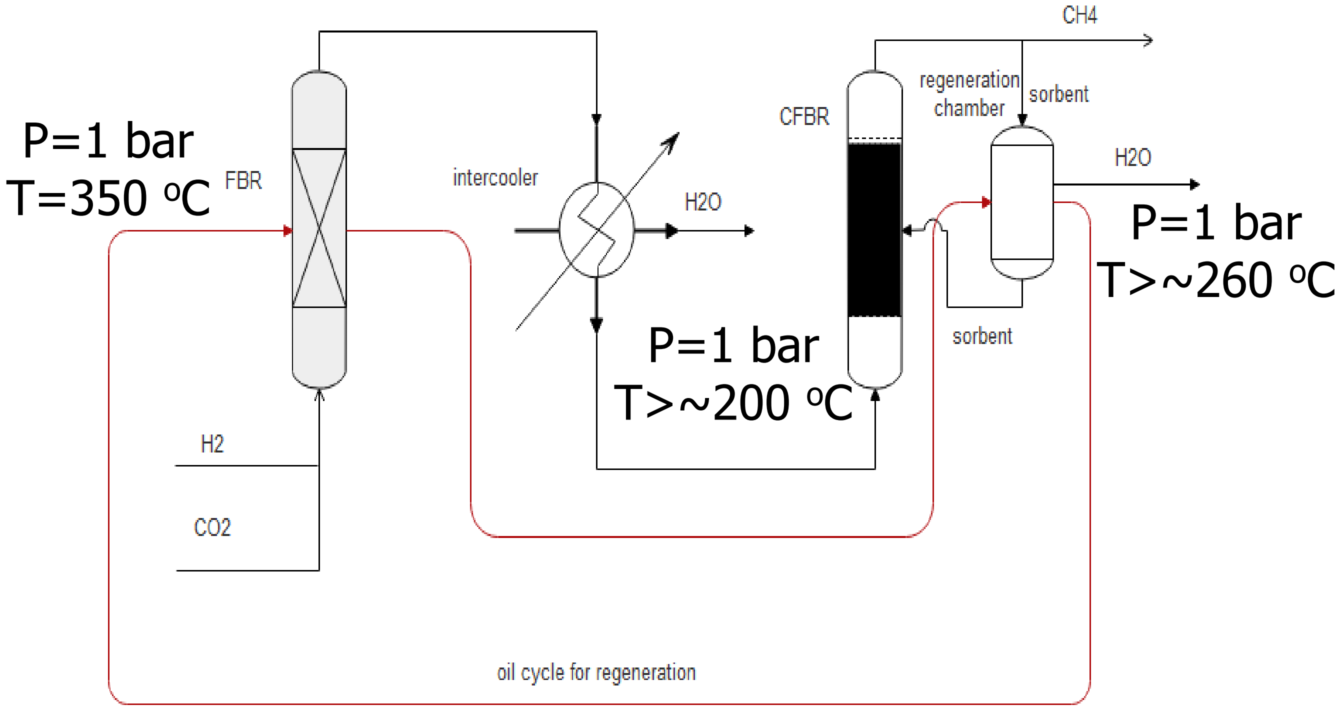
Material preparation, impact on Ni distribution



Towards an Integrated novel process



Challenge: Smart reactor system design including **C**irculating **F**luidized **B**ed **R**eactor with optimal heat integration to regenerate sorbent and to make use of exothermal reaction

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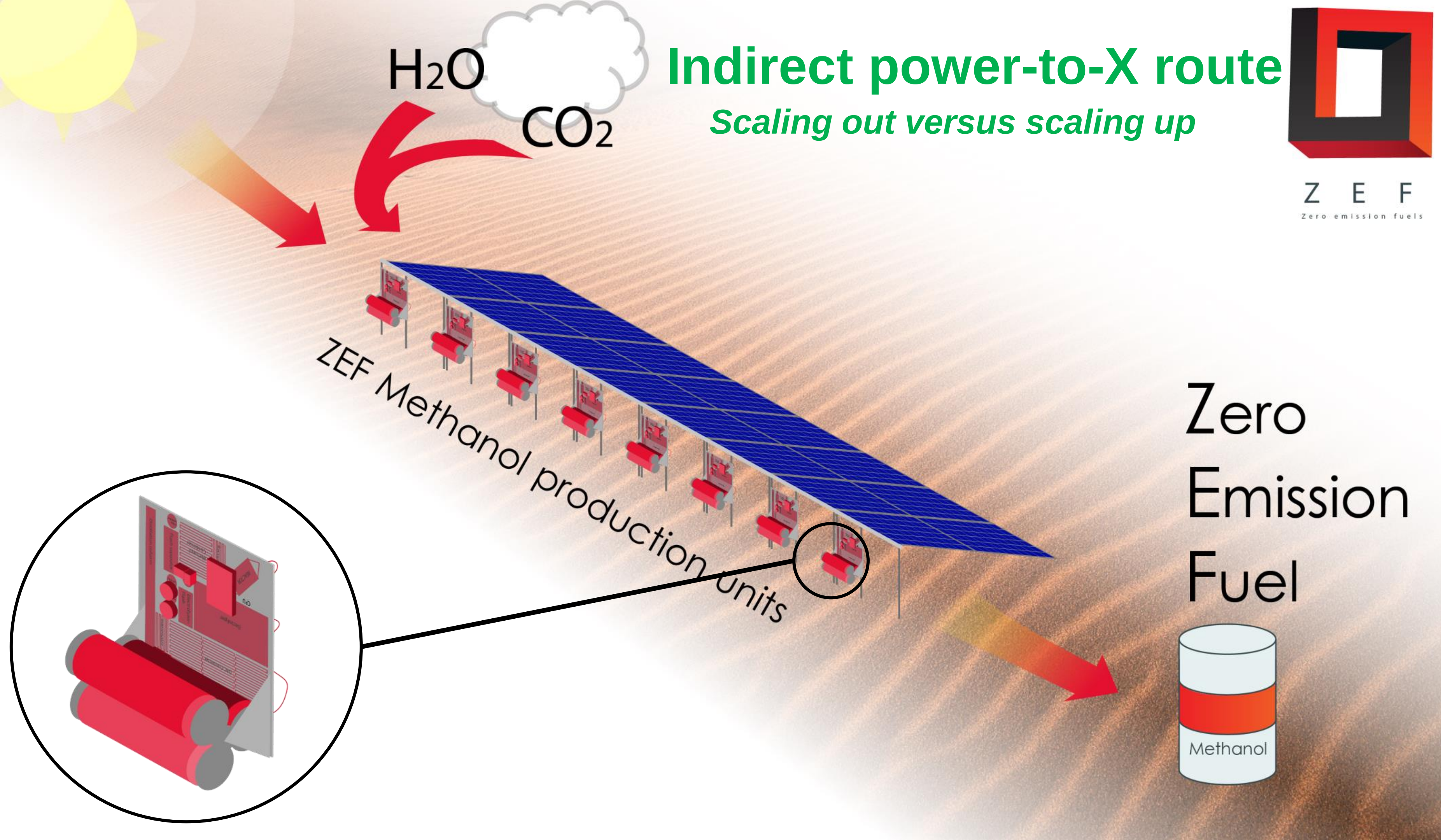
Indirect power-to-X route

Scaling out versus scaling up



Global Methanol production

Methanol produced from gas (80%)

Production cost: 100–300 €/tonne

10 suppliers @ 50% marketshare

70 large production plants globally

Methanol produced from coal (17%)

Production cost: 200 – 350 €/tonne

Mainly in China

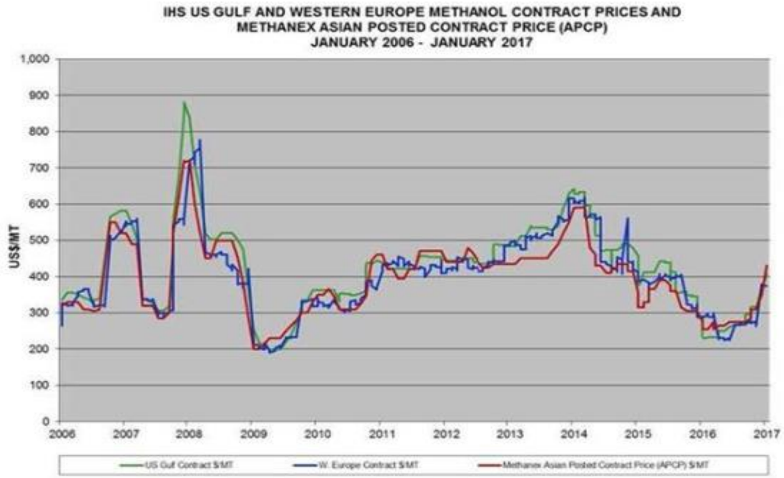
Bio Methanol (< 1%)

Production cost: 500 €/tonne

Premiun sales price: 700 €/tonne

0.18 million tonnes / year

EU directive incentive: double counting in blending



Grey average: **350 €/tonne**
Green premium: 700 €/tonne

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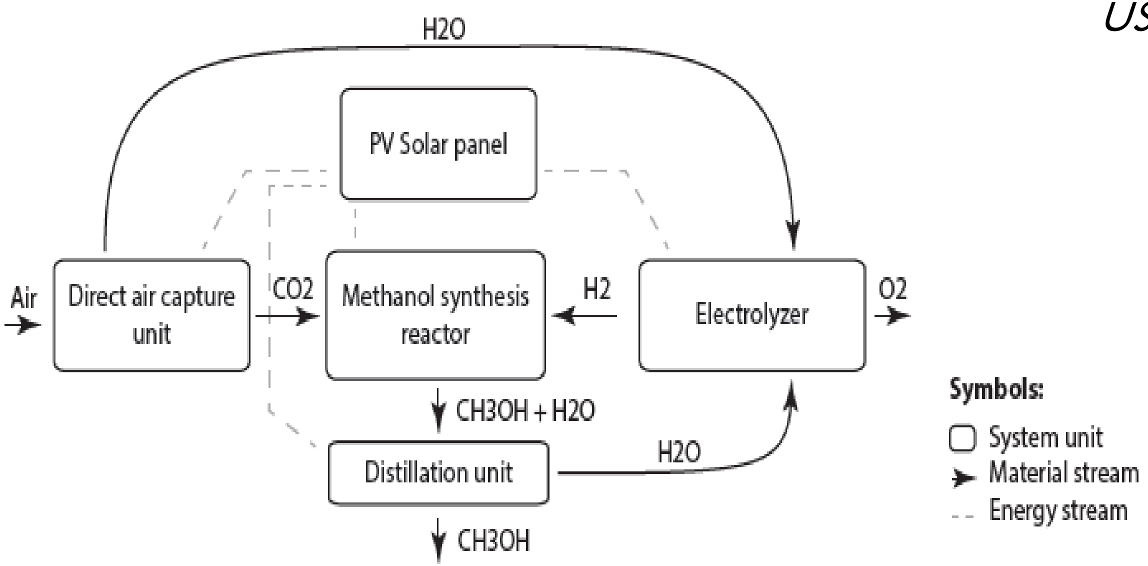
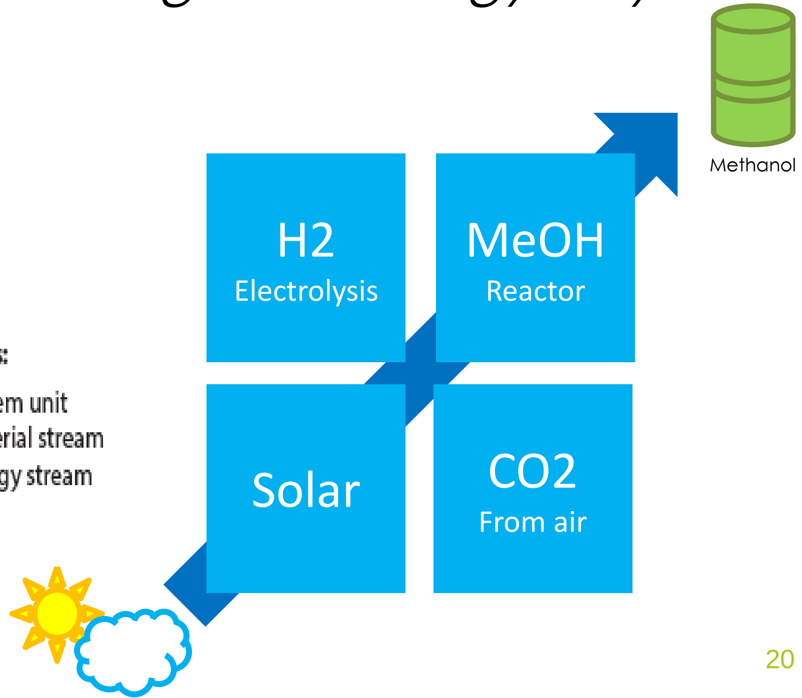
The ZEF pathway

"Capture CO2 from air to produce renewable liquid fuels using solar energy only!"





ZEF Micro-plant: numbering up

Dynamic operation

100K Micro-plants
< 150 Components

Fast(er) realization

Scenario's for future production of chemicals and fuels

'Conventional'

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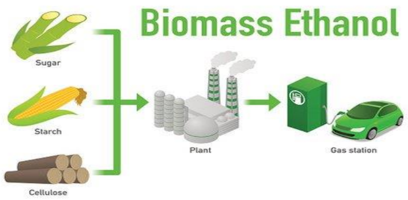

'Direct route'

e-Refinery

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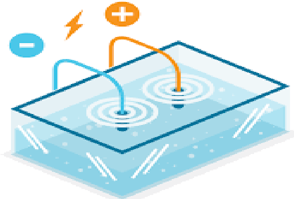

'Indirect route'

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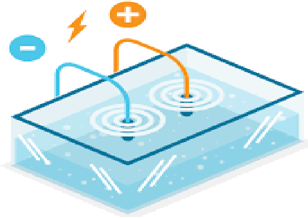

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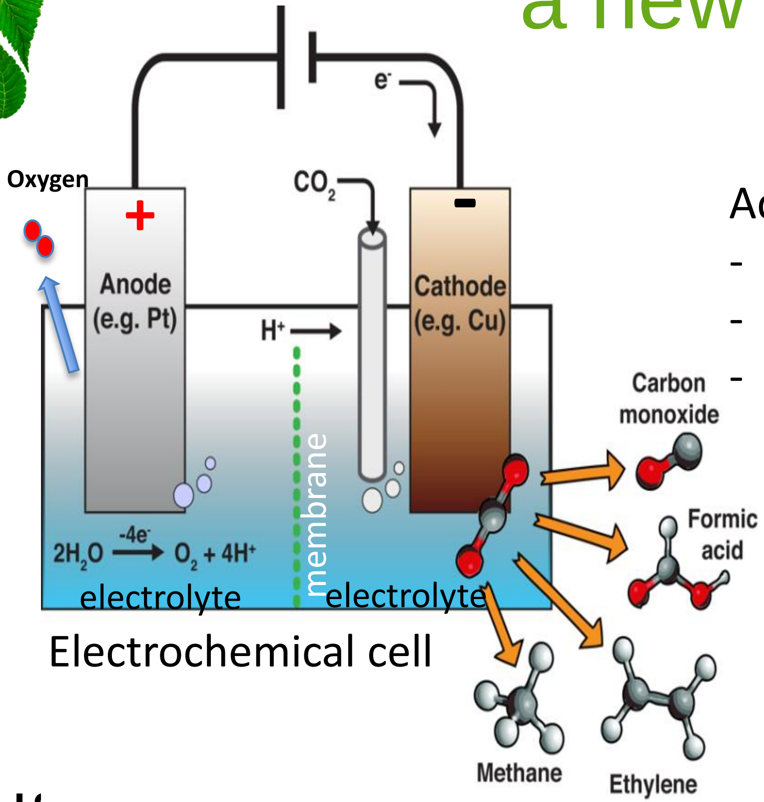
Direct electrochemical CO_2 conversion, a new research area



Electrochemical cell

Advantages of using electrochemical conversion:

- Using DC electricity
- Mild process conditions
- Can be carried out relatively selectively

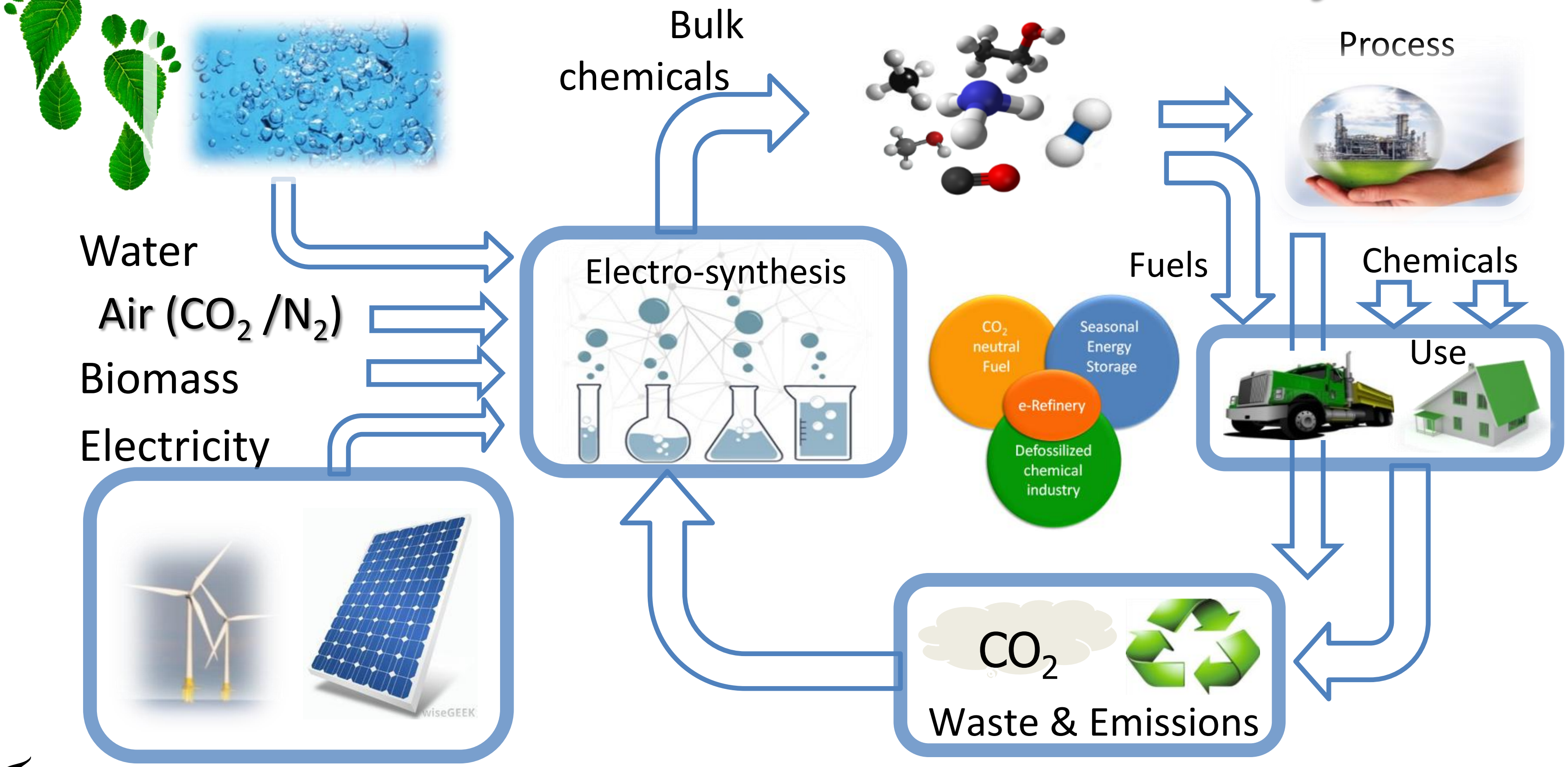
$$\Delta V = \Delta E + \Sigma\eta + IR$$

Equilibrium Potential (thermodynamics)

Overpotentials

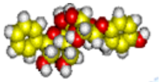
Ohmic (resistance) loss

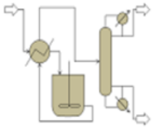
Delft Initiative: "The e-Refinery"

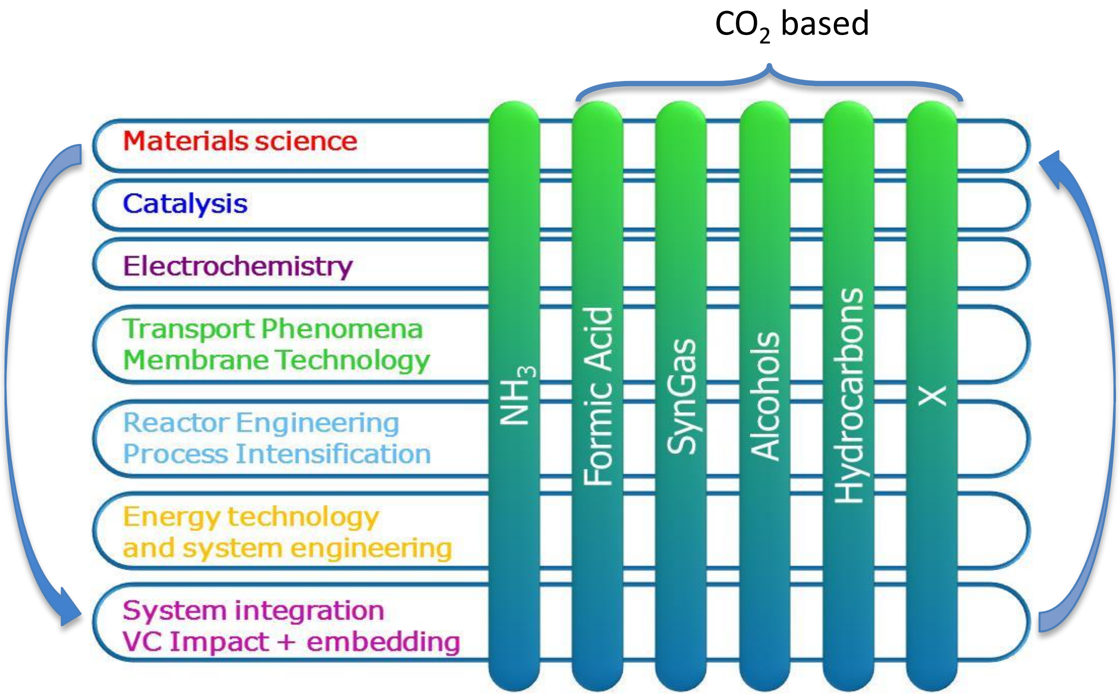


e-Refinery development at TU Delft

Fuels, bulk chemicals







e-Refinery
Towards sustainable production of chemicals and fuels

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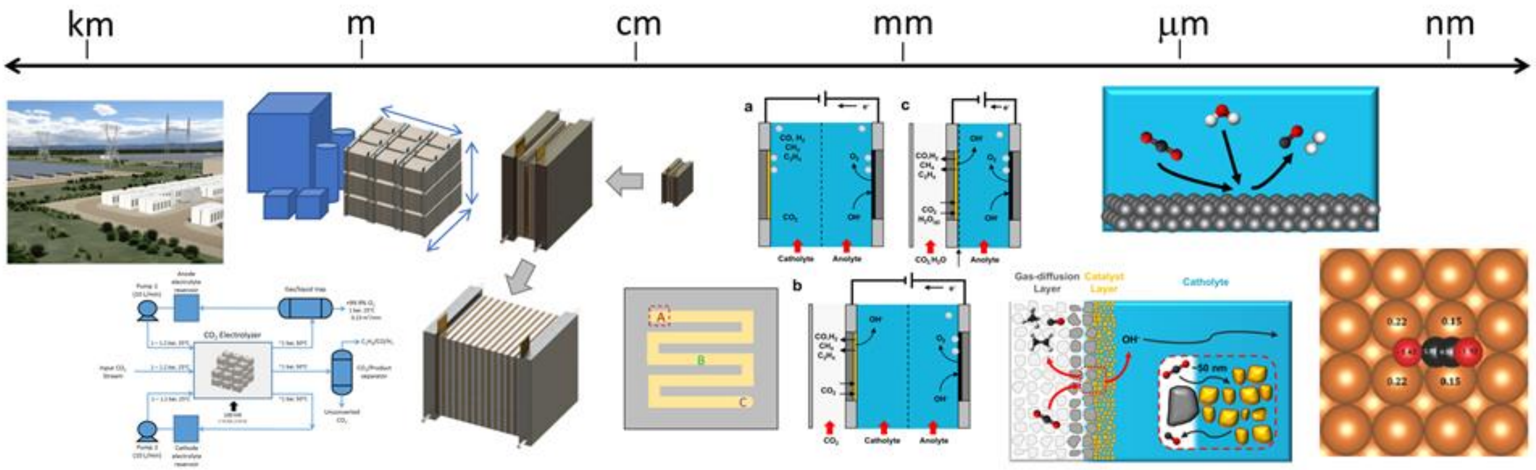
Need for Speed: parallel development together with our industry!

Bridging scales



Current research

Large scale research: high current densities using abundant materials

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Bridging TRL levels: idea to pilots

Electrochemical conversion
Reactor CO_2 to formic acid

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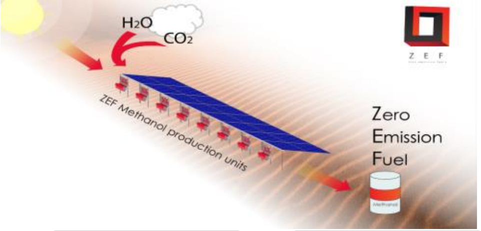
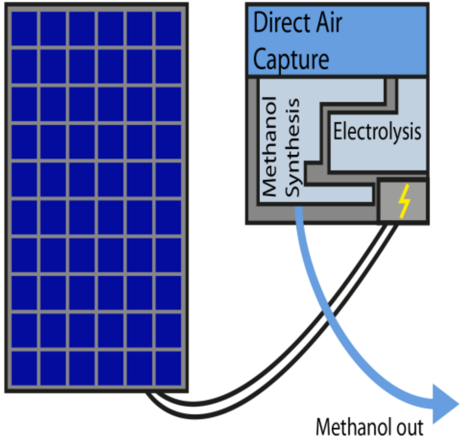




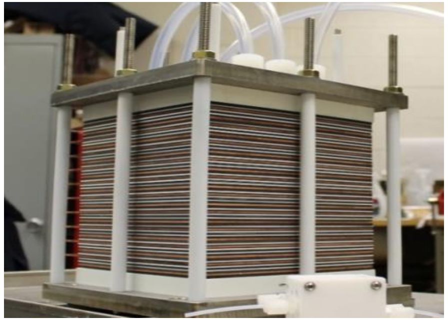
System Integration and
Process Intensification
3D Printing of Components

Validation

Ambition: 100 kW electrolyser for ethylene production by 2025

Operating parameters

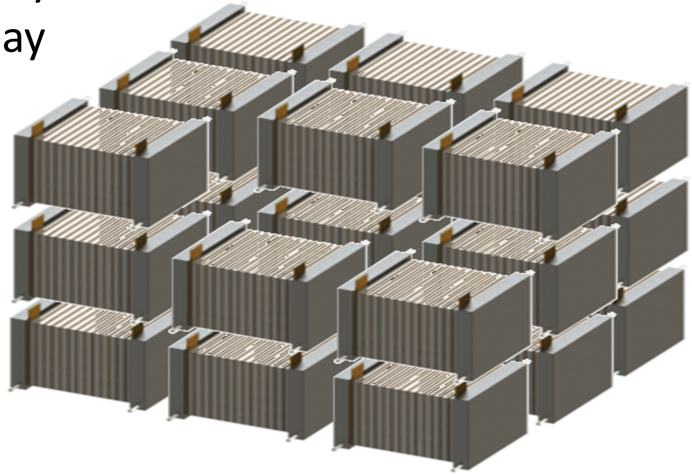
Total amperage:	~31 kA
CO_2 converted:	~143 kg CO_2/day
C_2H_4 Produced:	~45 kg C_2H_4/day
H_2O consumption:	~58 kg H_2O/day
O_2 produced at anode:	~156 kg O_2/day



World production
Ethylene tending to
~200 Mton/yr
-> ~**1200 GW_e** needed

Goals

- Feasibility test
- Find design rules
- Basis for large scale design
- Provide input for LCA



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Further developments

‘Indirect route’ of energy storage

- Improving fuel generation selectivity, via material development (catalyst-sorbent)
- Process integration (heat utilization, reaction-regeneration, system dynamics)
- Scale-up (process simulation & valorization, component development and testing)

‘Direct route’ of energy storage

- Improving, scale-up and implementing gas diffusion electrodes (increase i, lower potential)
- Design of better, stable membranes (high recovery of products)
- Design of stable electrodes (high stability in a range of pH values)
- In-situ separation of products (eliminate downstream steps)
- Use of non-aqueous solvents (easier product recovery)
- Optimize gas and liquid flows (increase concentration)
- Paired electrolysis (anode side alternative products, improved economics of overall process)

Thank you for your attention!

Acknowledgment to current projects at TU Delft:

E2CB NWO Perspectief

TKI-Shell 'ToELS' project