Uden brændstof ingen fremtid – perspektiver for elektrofuels

Recent trends in E-fuels

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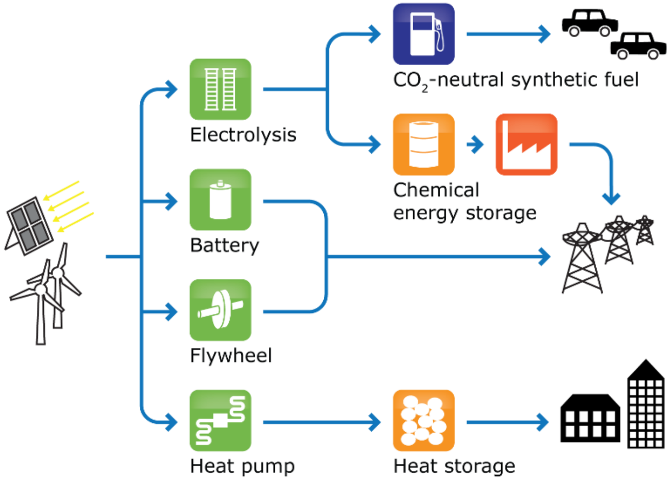
DTU Energy
Department of Energy Conversion and Storage

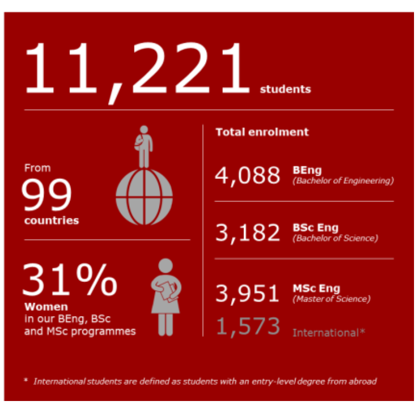
Outline

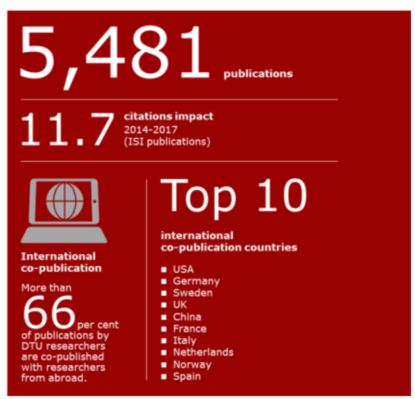
- Intro to DTU Energy
- The political framework
- Electrofuels
  - What are they
  - What kind of activities are ongoing?
    - Selected Demonstration projects
- Carbon dioxide sources
- Future related research

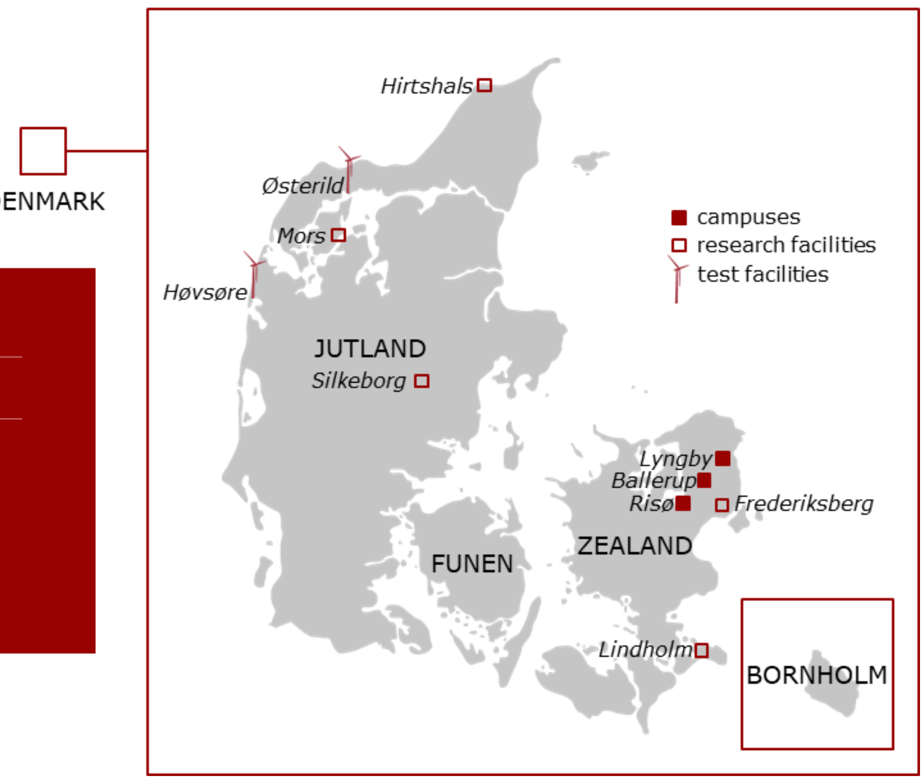


Technical University of Denmark
- founded in 1829 by Hans Christian Ørsted

Locations





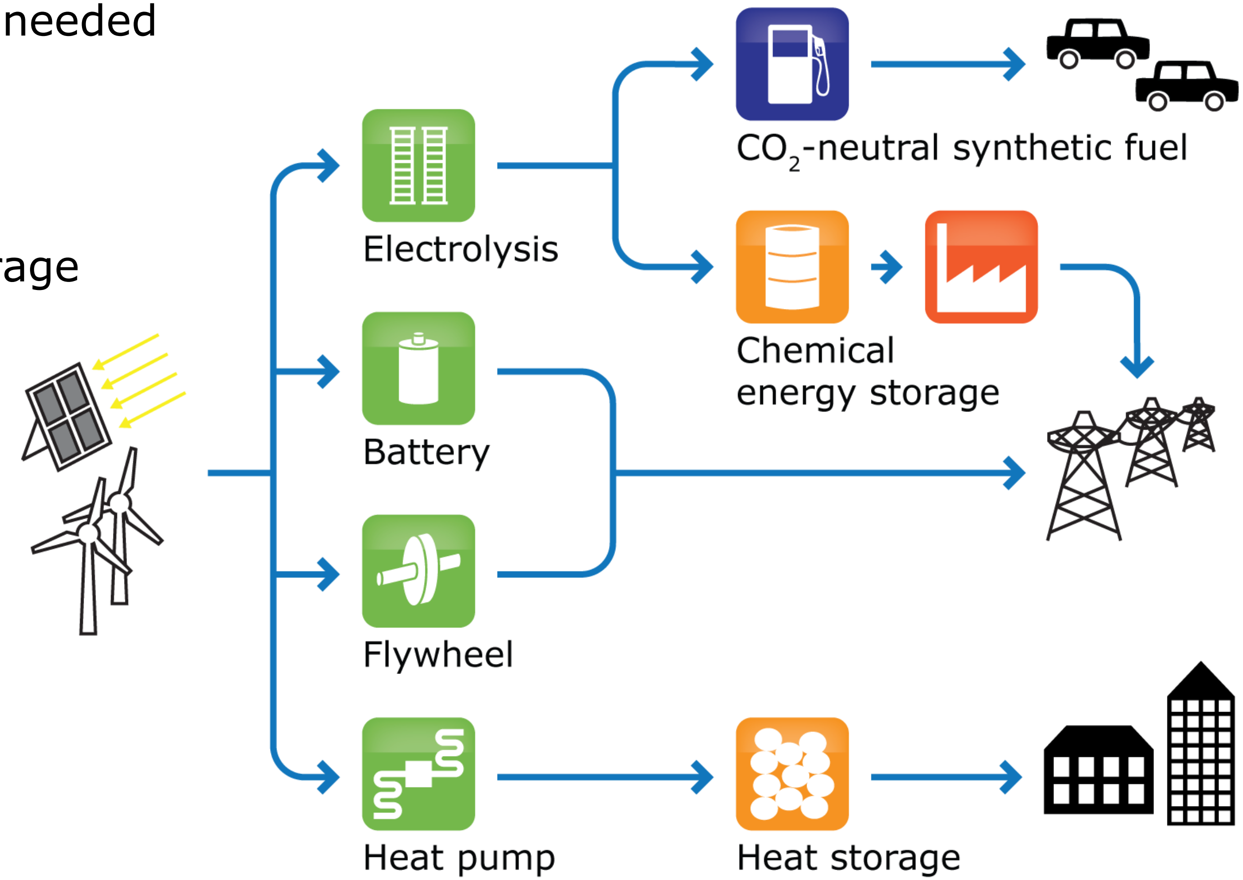


DTU Energy in brief

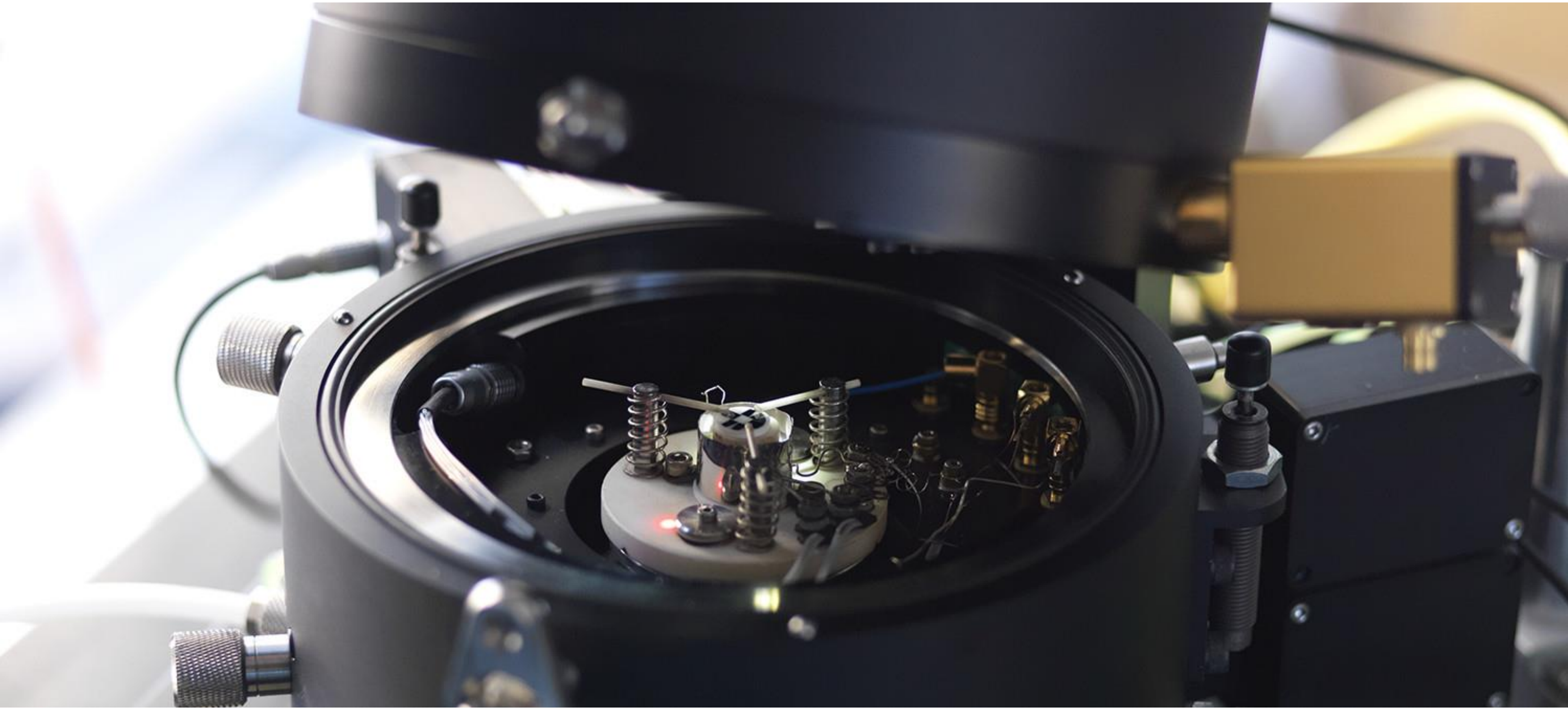
- Sustainable technologies for energy conversion and storage
- 230 researchers, technicians and PhD students
- Research spanning from fundamental investigations to component and prototype manufacture
- Focus on industrial collaboration and industrially relevant processes
- Created 2012 from research groups at
  - Risø DTU National Laboratory for Sustainable Energy
  - DTU Chemistry
- Located on two campuses: Risø and Lyngby

The key challenge: Energy conversion and storage

- Mankind have abundant sources of energy, but not in the form needed
- Forms of energy
- The problem of storage

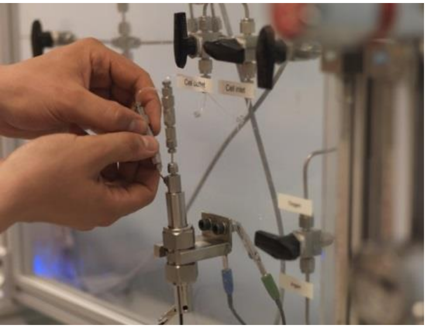
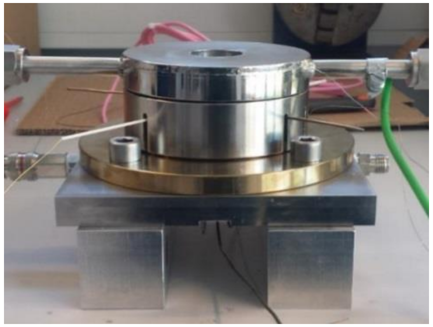


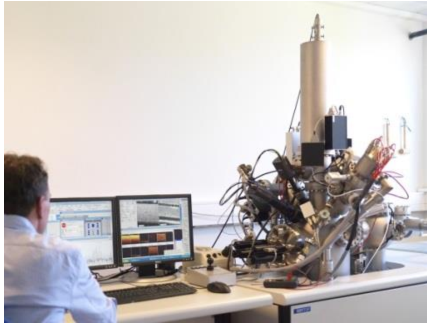
Section for Electrochemical Materials and Interfaces



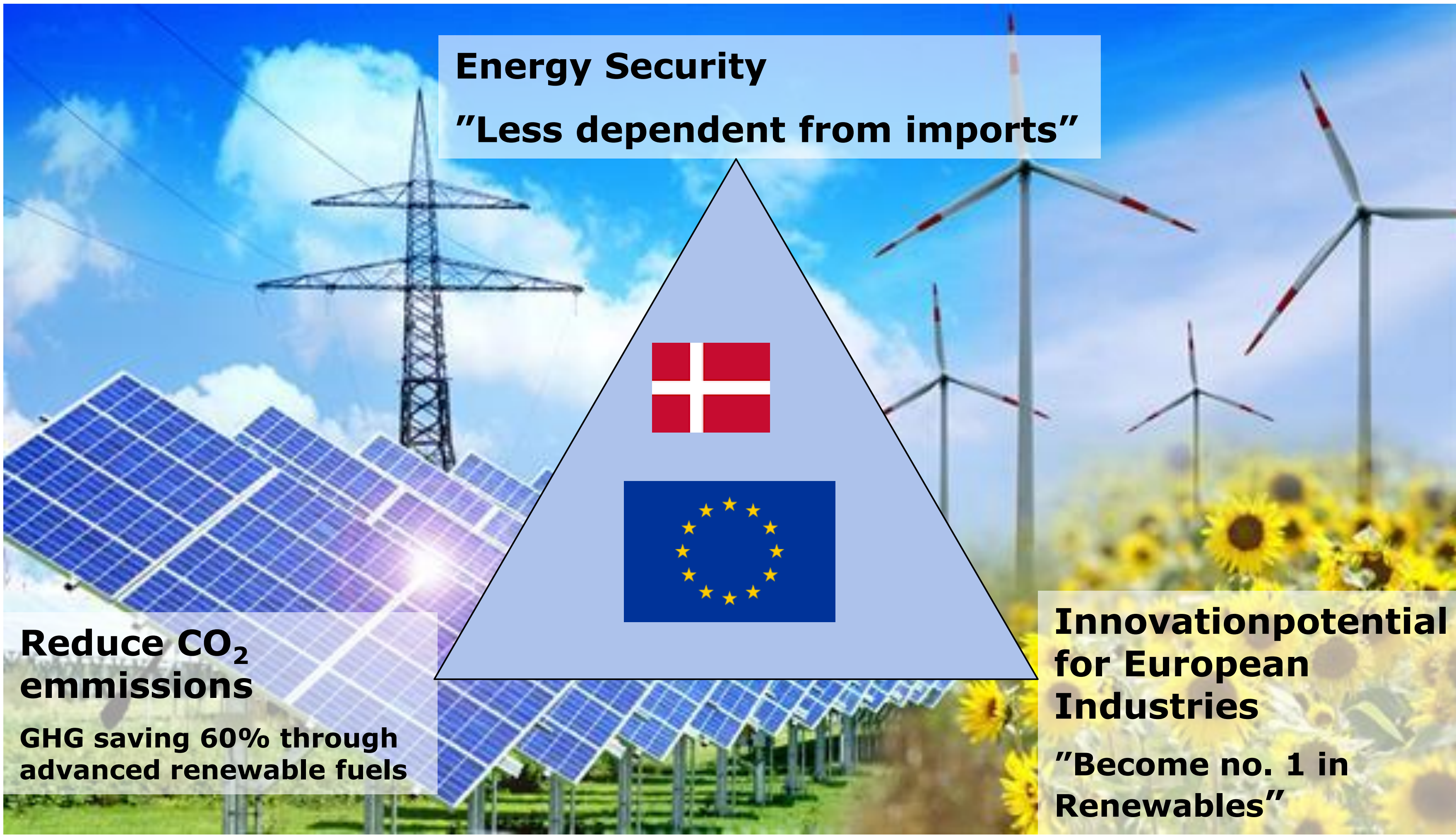
Section for
Electrochemical Materials and Interfaces

- Electrochemical properties of solids
- Advanced *in situ* and *in operando* characterization methods
- Electrocatalysis and nanostructured electrodes
- Novel battery materials



Drivers for ”Sustainable/ renewable fuels”



EU SET-Plan

Energy Union and SET Plan priorities

Energy Union R&I core priorities	SET Plan 10 Key Actions
N° 1 in renewables	1. Develop highly performant renewables
	2. Reduce cost of key renewable technologies
Smart EU energy system with consumers at the centre	3. Create new technologies and services for energy consumers
	4. Increase the integration, security and flexibility of energy systems
Efficient energy systems	5. Increase energy efficiency for buildings
	6. Increase energy efficiency in industry
Sustainable transport	7. Become competitive in the battery sector for e-mobility and stationary storage
	8. Strengthen market take-up of renewable fuels and bioenergy
Carbon capture storage / use	9. Step-up R&I activities and commercial viability of CCS/U
Nuclear safety	10. Increase nuclear safety

European Commission

EU Directives & Goals

- Renewable Energy Directive (RED) 2009
  - 20% of all energy usage in EU from renewabl sources
  - 10% of energy in all road transport
- Fuel Quality Directive:
  - road transport mix 6% less carbon intense tha fossil fuel

- Revised Renewable Energy directive 2017
  - > 27% renewables in the final energy consumption
  - Increasing share of renewable electricity
  - Options to increase low carbon and renewable energy in the transport sector:
    - Advanced renewable transport fuels (including advanced biofuels)
    - alongside a reduction of food based biofuels
  - incorporation obligation for **aviation** and maritime renewable fuels

EUROPEAN COMMISSION

Brussels, 23.2.2017
COM(2016) 767 final/2

2016/0382 (COD)

CORRIGENDUM
This document corrects document COM (2016) 767 final of 30.11.2016
Concerns only EN version.
The text shall read as follows:

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

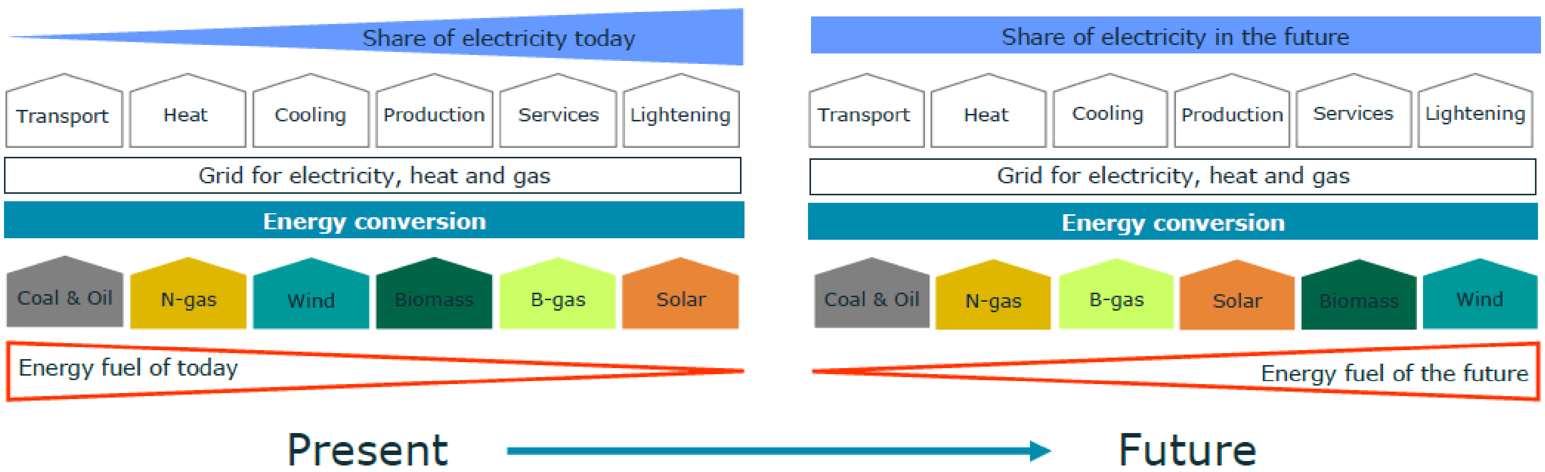
on the promotion of the use of energy from renewable sources (recast)

https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive

The energy system – shift of paradigm

- Coherent energy systems
- Electricity the primary energy carrier for the future
- Flexible demand must follow flexible production

- Electricity the primary energy carrier for the future
- Wind and biomass an primary energy ressource
- Flexible demand must follow flexible production



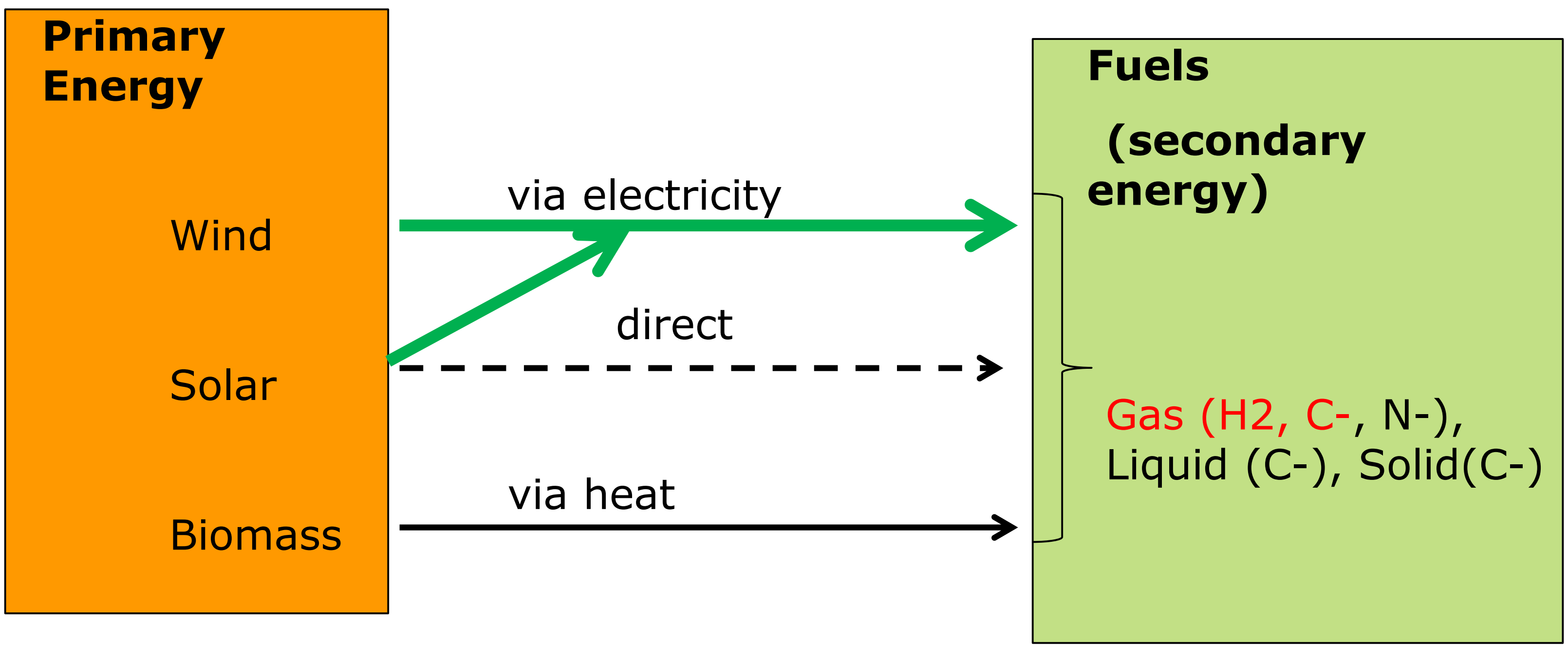
Denmark;

- 2011 – 25 % wind power in the electricity supply
- 2020 – 50 % wind power - equals 18 TWh wind power a year for Denmark alone

But 50 % wind power is just a step stone – The Danish goal is non-carbon energy supply

- 2035 – 100 % RE in the electricity supply – calls for storage of electricity as gas (P2G)
- 2050 – 100 % RES in the energy supply – calls for substantial electrification

Synthetic fuel perspective (DK2050)

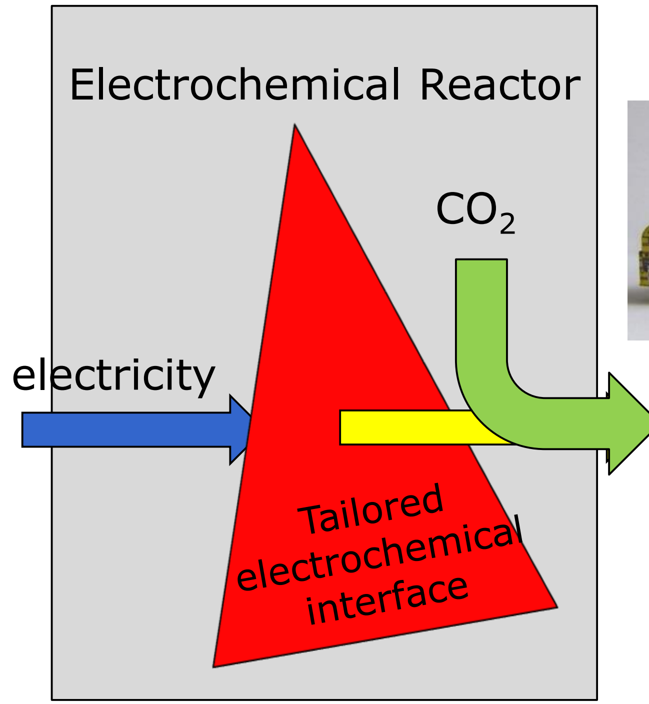


Use of other synthetic fuels derived from electricity might depend on degree of electrification of the transport sector.

Biomass might become the preferred source for transport fuels.

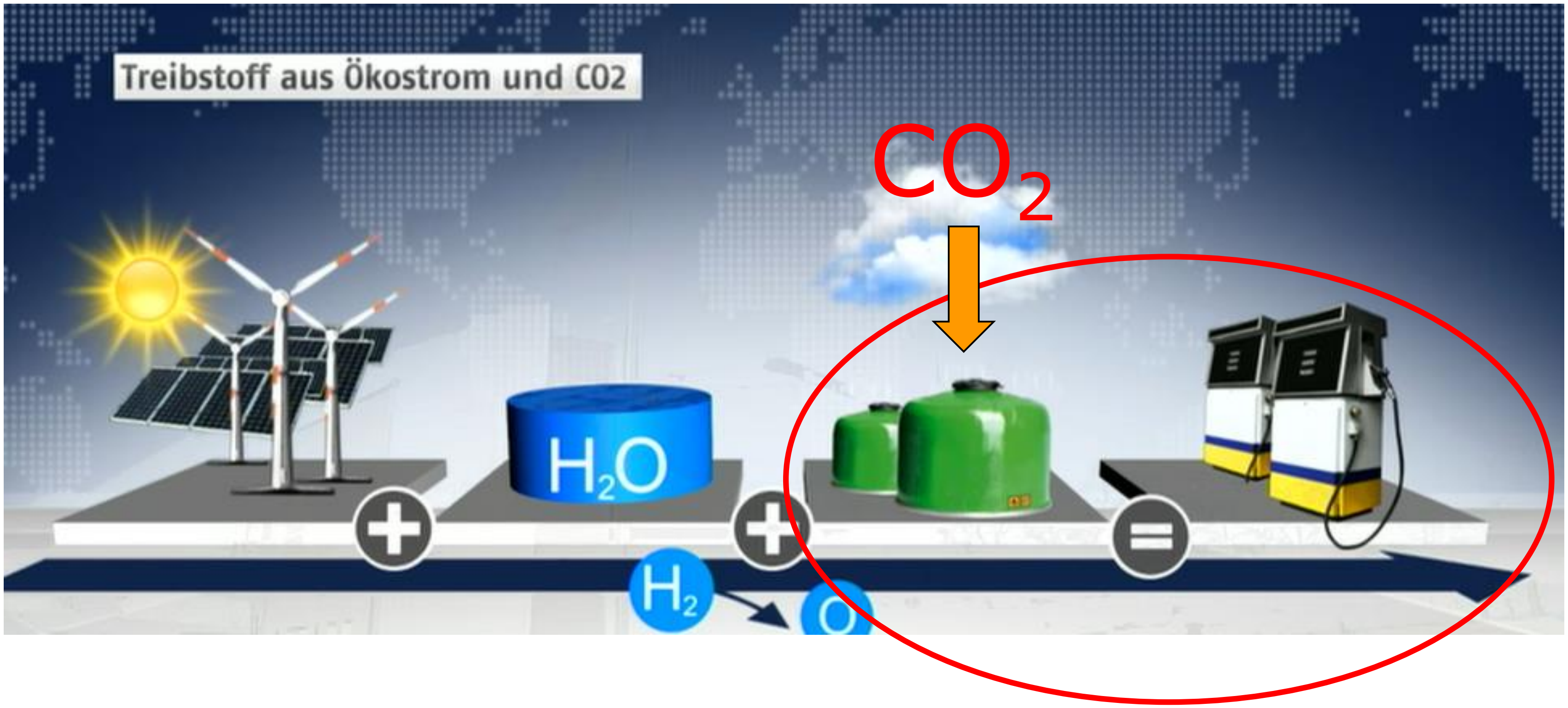
Evtl Picture batteries

Electrofuels



Sustainable Fuels

Power-to-Hydrogen-to-Fuels



Principle Power to X

oxygen

Electrolysis

$2H_2O \rightarrow 2H_2 + O_2$

Water

hydrogen

Chemical reactor:

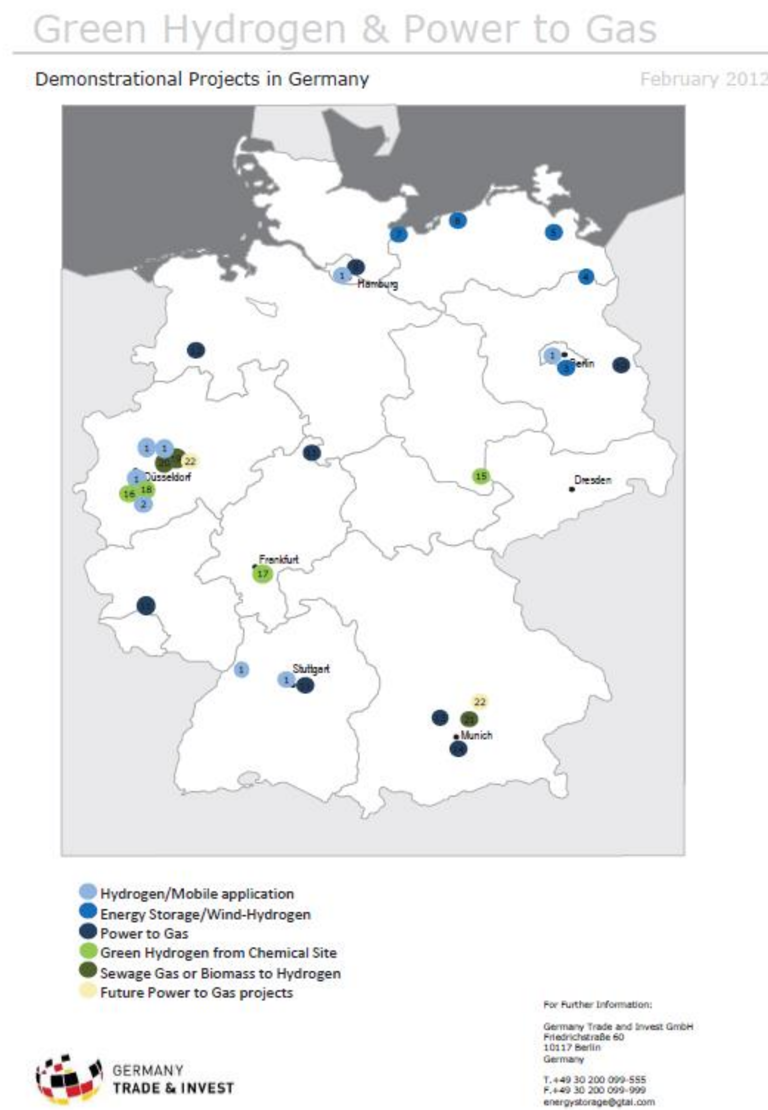
Sabbathier: CH_4

Fischer Tropsch: C_xH_y

carbon dioxide

Power-to-gas activities around DK

- Germany: already in the commercials in TV
  - Hydrogen
    - Falkenhagen (2MW)
    - Eon Hamburg
    - Thüga Munich
  - Methane
    - Fraunhofer Stuttgart (250 kW)
    - Fraunhofer Werlte (6,3 MW ??)
    - Erdgas Schwaben
    - Audi (e-gas ??)
    - Falkenhagen
- NL
  - NaturalHy: H2 feed



Falkenhagen

- Operator Uniper (Eon)
- 2 MW Hydrogen
- 2017 Methanation unit
  - 57 Nm^3/h SNG
  - Ca 600 kWh
- Heat utilization
  - in local industry

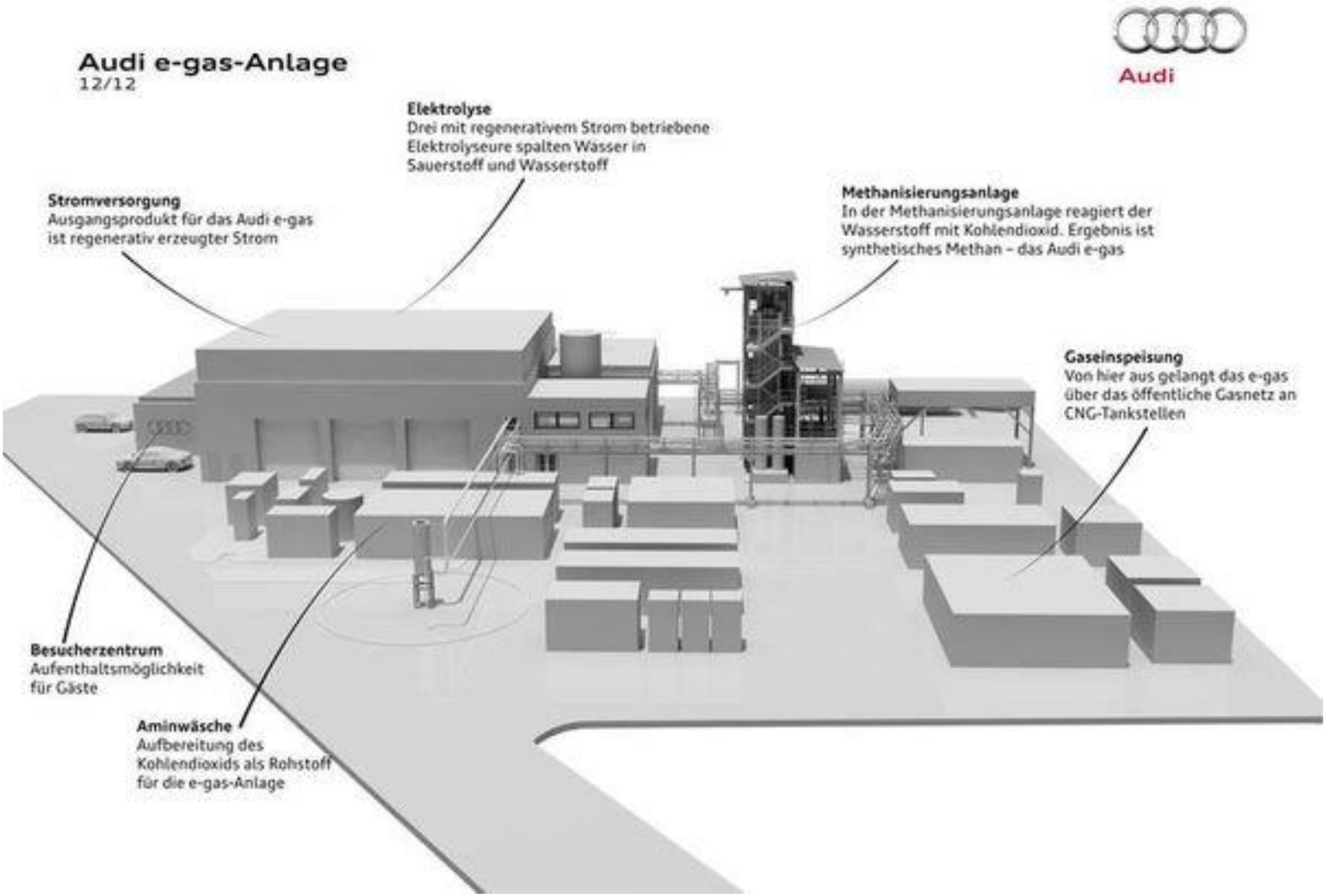
https://www.euwid-energie.de/uniper-erweitert-power-to-gas-anlage-in-falkenhagen-um-methanisierungseinheit/

Audi E-gas

- **Location**
  - Werlte, Niedersachsen
- **Inauguration**
  - 25.06.2013
- **Electrical power input**
  - 6.000 kWe
- **H_2-Production**
  - 1.300 m^3/h
- **SNG-Production**
  - 300 m^3/h.
- **CO_2-Source**
  - Biogasplant EWE AG
- **Heat utiliztaion**
  - In biogas plant for hydrogenation and balance of plant

Efficiency ca 50% power to methane

http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/audi-e-gas-projekt/

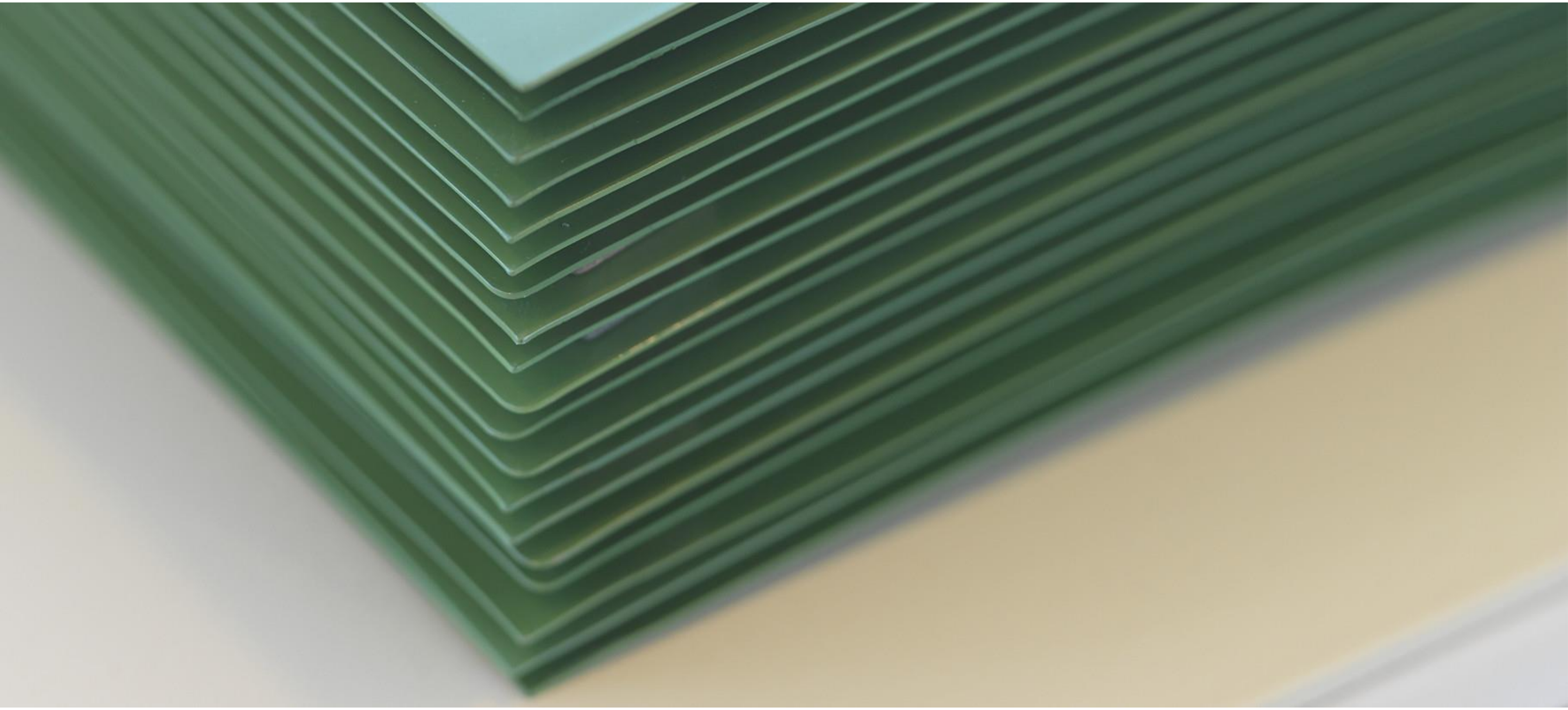

Audi e-gas-Anlage
12/12
Audi
Elektrolyse
Drei mit regenerativem Strom betriebene Elektrolyseure spalten Wasser in Sauerstoff und Wasserstoff
Stromversorgung
Ausgangsprodukt für das Audi e-gas ist regenerativ erzeugter Strom
Methanisierungsanlage
In der Methanisierungsanlage reagiert der Wasserstoff mit Kohlendioxid. Ergebnis ist synthetisches Methan – das Audi e-gas
Gaseinspeisung
Von hier aus gelangt das e-gas über das öffentliche Gasnetz an CNG-Tankstellen
Besucherzentrum
Aufenthaltsmöglichkeit für Gäste
Aminwäsche
Aufbereitung des Kohlendioxids als Rohstoff für die e-gas-Anlage

Power-2-Gas activities in Denmark

- Power-to-Gas via Biological Catalysis (P2G-BioCat) 1 MW 27.6 MDKK, **ForskEL**
  - Electrochaea, Low temperature elelctrolysis
  - http://www.electrochaea.com/technology/:
- Foulum DK: precommercial project
  - http://www.electrochaea.com/technology/
- EL upgraded biogas
  - Haldor Topsøe, **EUDP**
  - 10 Nm3 Hydrogen, 40 kW High Temperature, Solid Oxide Electrolysis
- CO2 electrofuel project
  - **Nordic Energy Research**
- Synfuel
  - DTU Energy, **Innovationsfonden** (DSF) 2015-2019
  - Gasification of Biomass and electrolysis
  - reuse of oxygen in gasification
- Wind2H: coupling windpower and hydrogen production
  - DTU Energy, **Innovationsfonden**
- Cryogenic Carbon Capture and Use C3U
  - Aalborg University, **EUDP** 2017-2019

https://energiforskning.dk

Technology Track:
Solid Oxide Electrolysis Cells



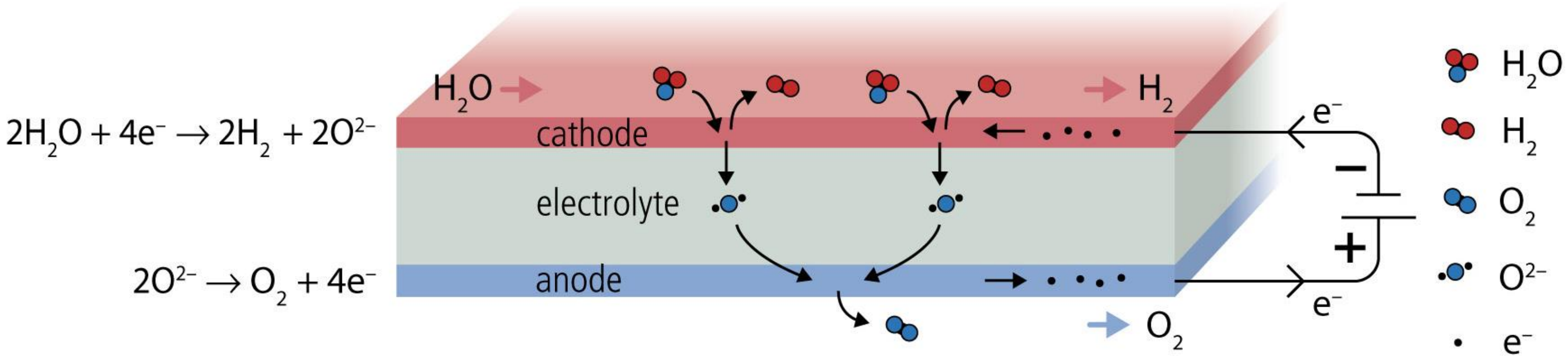
Technology Track:
Solid Oxide Electrolysis Cells

- Very similar to the corresponding fuel cells (SOFC)

- High operation temperature (approx. 800 °C), very high efficiency

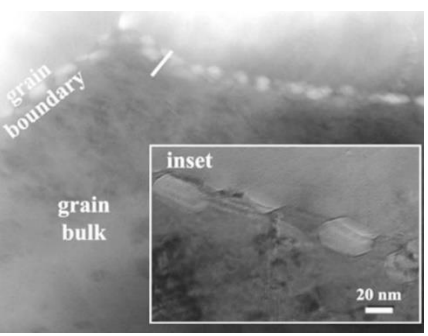
- Conversion of electricity to chemical energy, either by electrolysis of water or CO_2

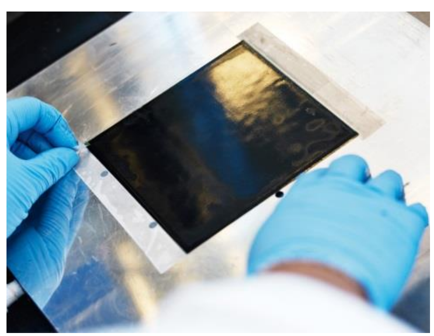
- Synthetic fuels

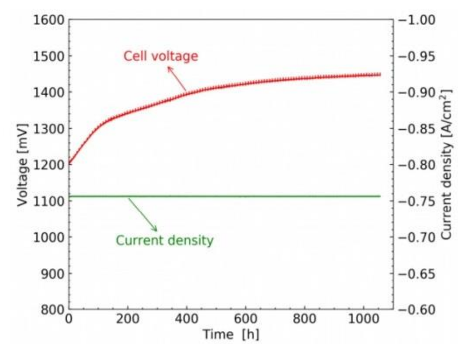


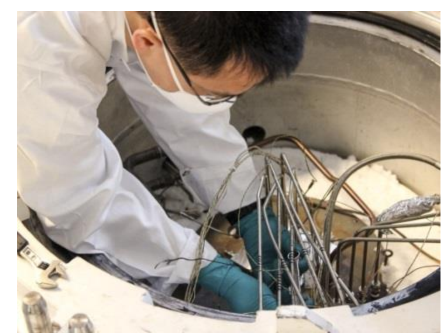
Technology Track:
Solid Oxide Electrolysis Cells

- Fundamental investigations of materials
- Development of materials, cells, stack components and stacks
- Test and characterization (high pressure, dynamic operation, etc.)
- Co-electrolysis (conversion of H_2O + CO_2 to H_2 + CO)

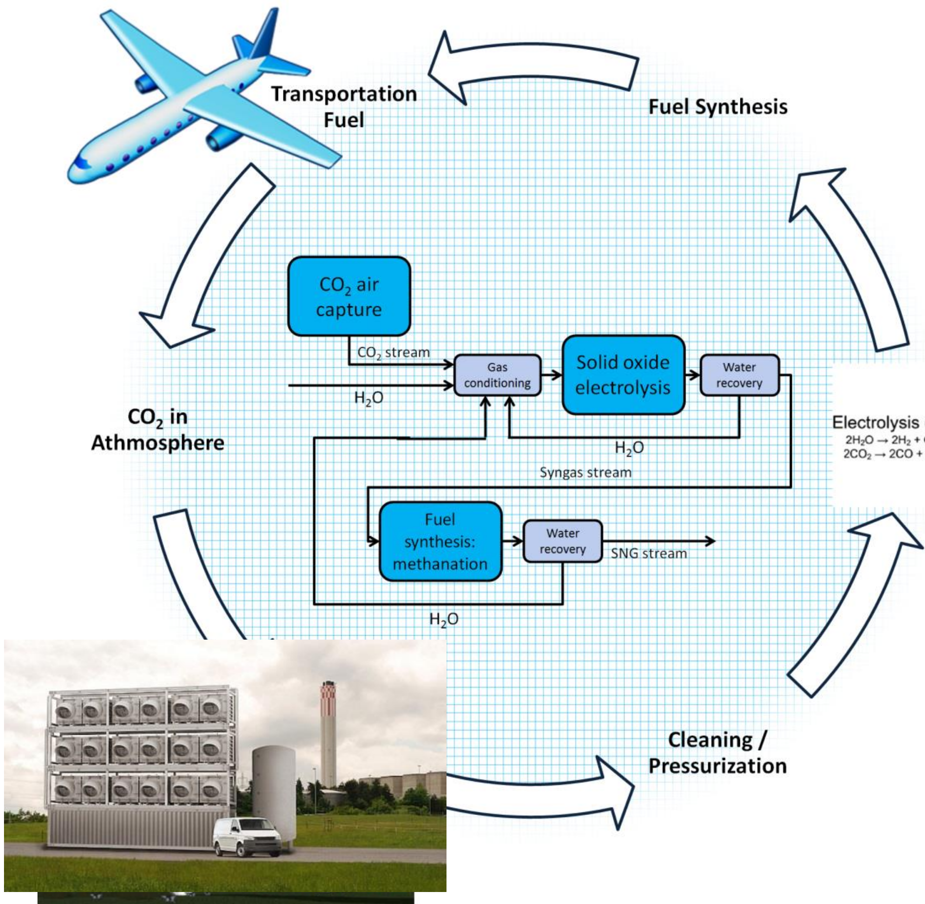


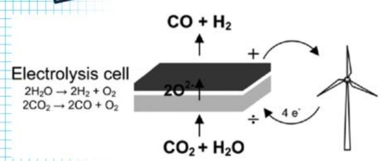






Closing the carbon cycle?





Sources:
Kilimanjaro Energy
Ebbesen, S.D., Graves, C., Mogensen, M., International Journal of Green Energy, **6**, 646-660, 2009
Graves, C., Ebbesen, S., Mogensen, M., Lackner, K.S., Renewable and Sustainable Energy Reviews 15 (2011) 1–23

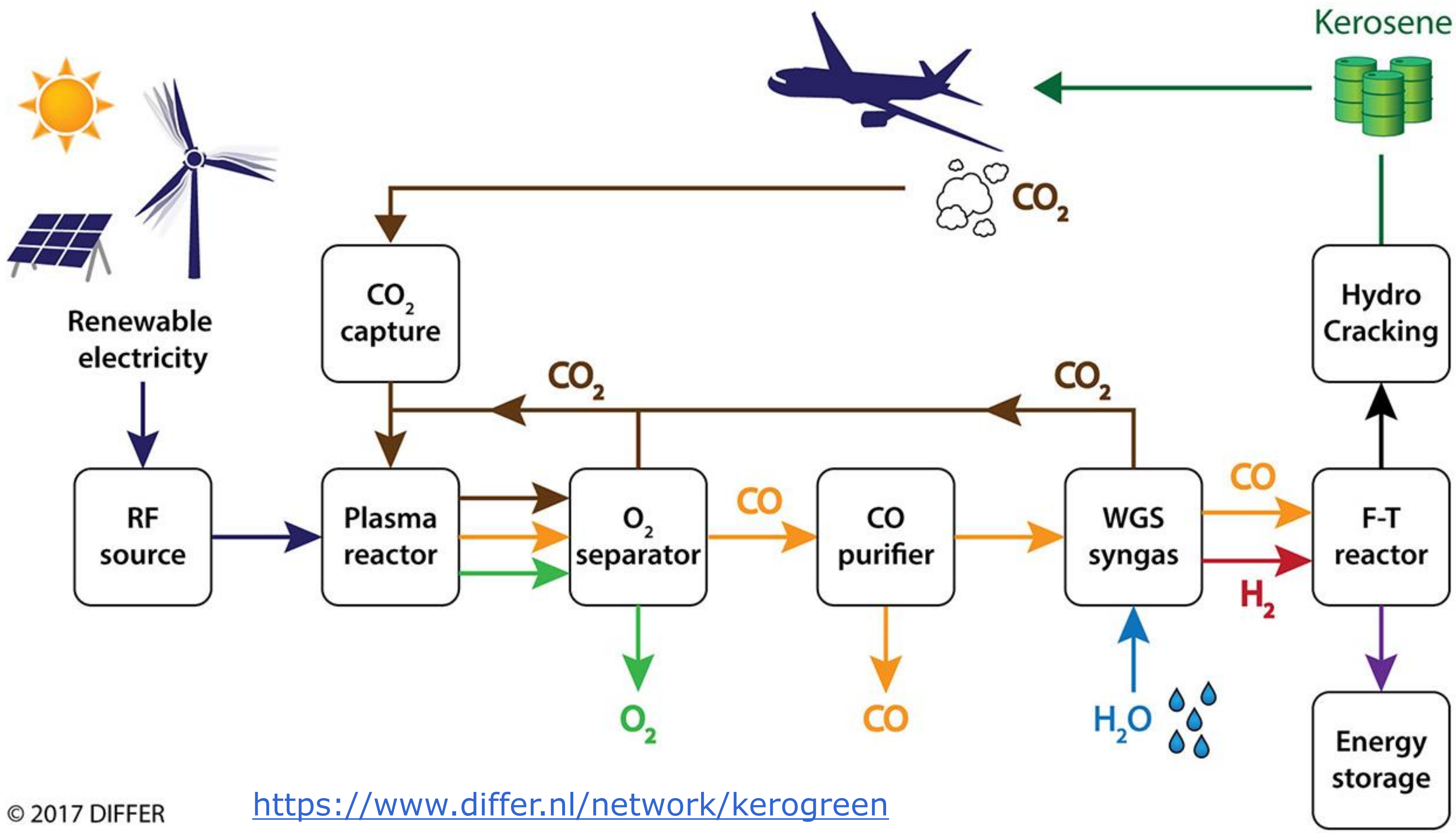
Keragreen project

Demonstration of synthetic Kerosene

1 l/hour

Container size unit

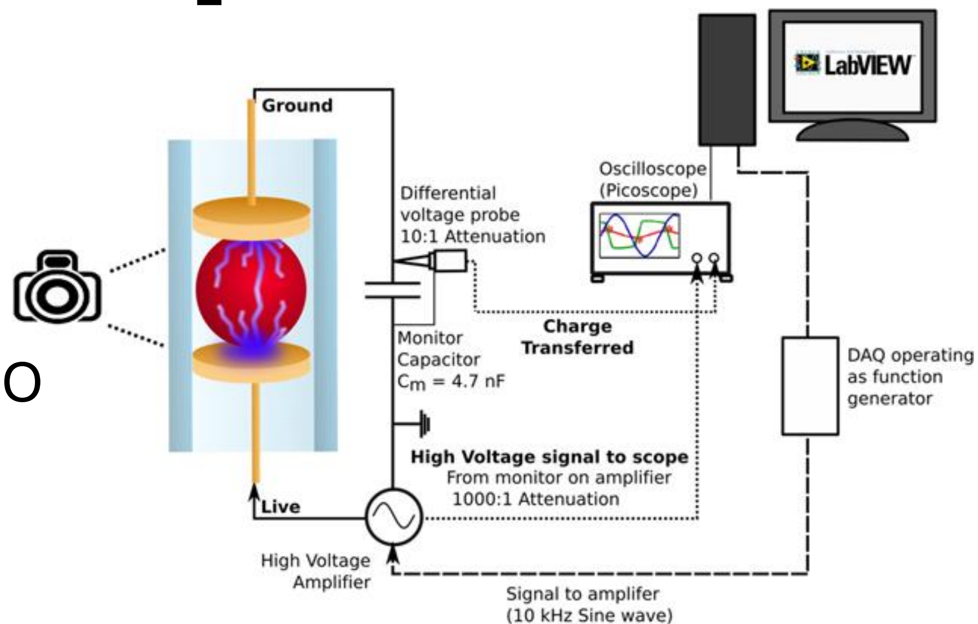
costs +50% of fossil kerosene



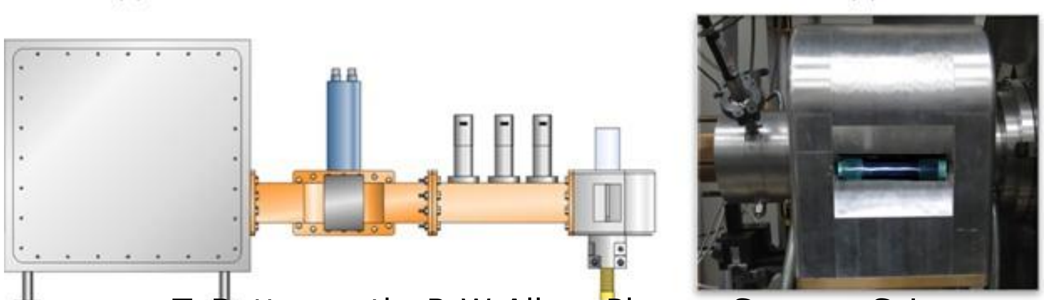
https://www.differ.nl/network/kerogreen

Plasma reactor for CO_2 activation

$$2\ CO_2 \rightarrow O_2 + CO$$



(a) (b)



T. Butterworth, R.W Allan, Plasma Sources Science and Technology 26 (6) 065008

W. Bongers et.al. Plasma processes and Polymers, doi.org/10.1002/ppap.201600126

From Kerogreen project

- Challenges in decarbonizing the aviation sector
  - Low energy density of batteries, hydrogen, hybrids of the two
  - Biofuels: food vs fuel vs flora trilemma

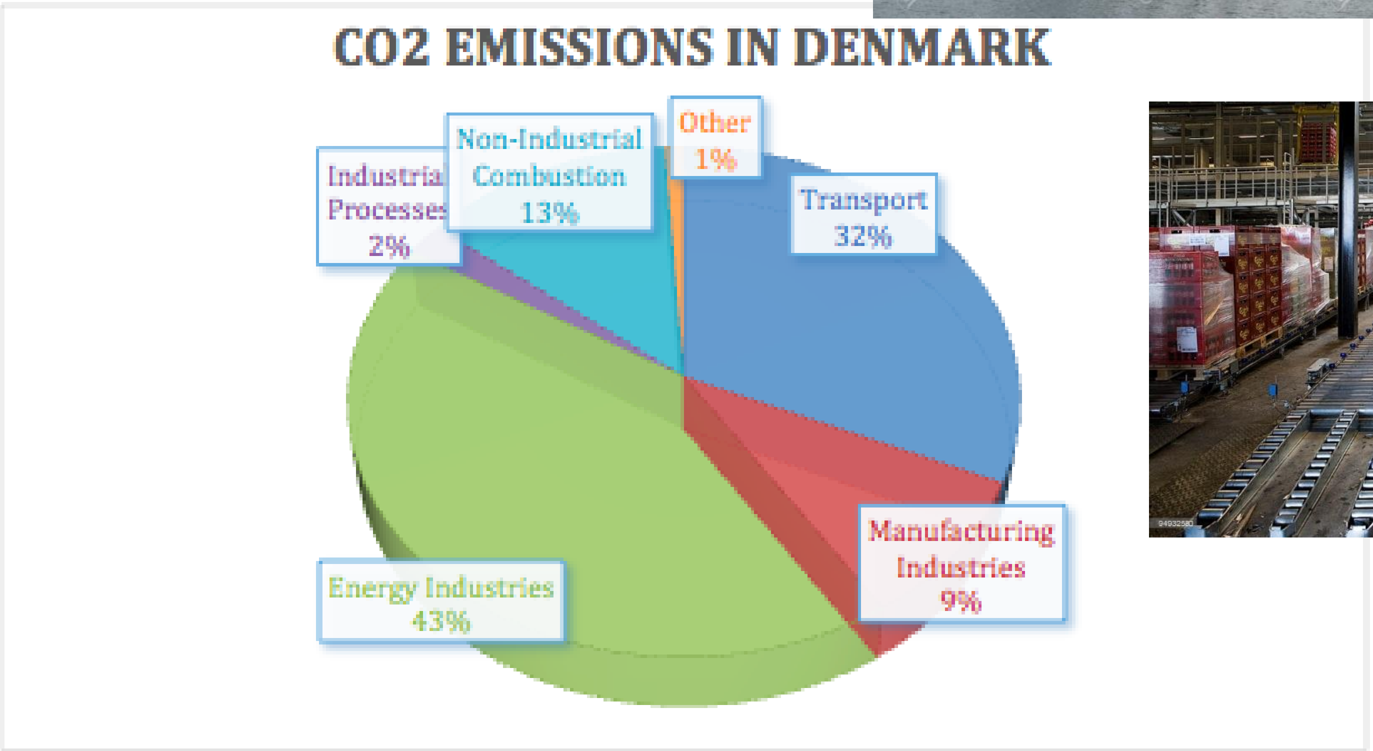
  - Circular economy: closed Carbon cycle, using CO_2 from air to and renwable electricity

- Advantage of green kerosene
  - Existing infrastructure can be kept
    - Storage , transport, filling and jet engine technology
    - Synthetic kerosene emits no sulphur and less soot
    - NOx (I don't understand why this should be lower??)

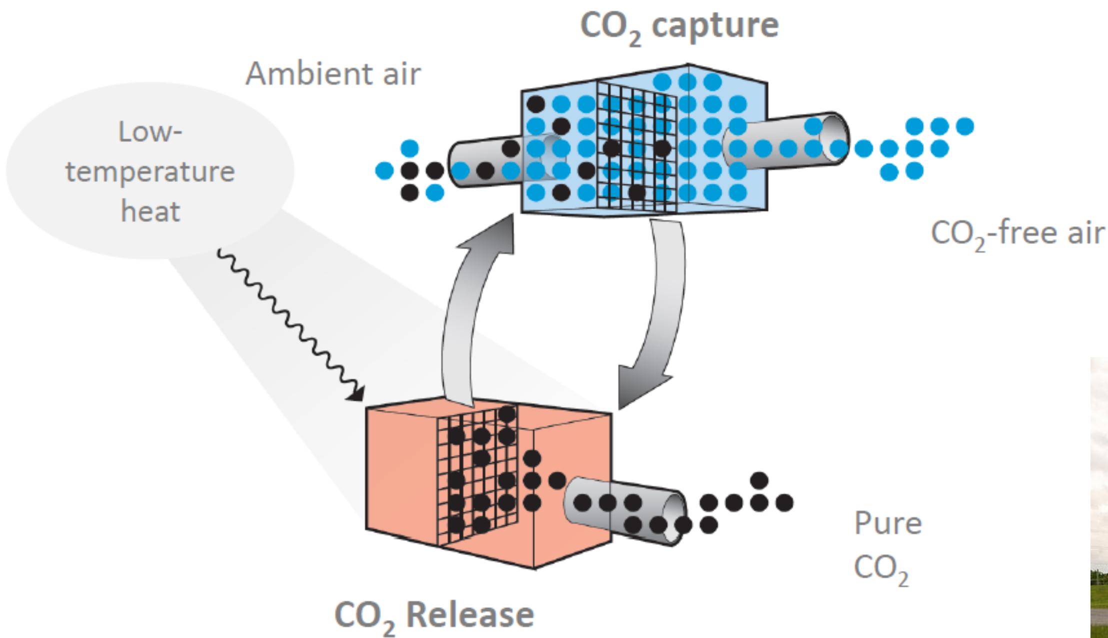
- Aim of Kerogreen: demo with 1 l/ hour: plant size is 10-20 kW?? Container size unit, costs +50% of fossil kerosene,
- Facilitators:
  - ETS, airline CO_2 compensation fund, ICAO regulation, CO as byproduct
- Electrical energy: Plasma and MIEC membrane

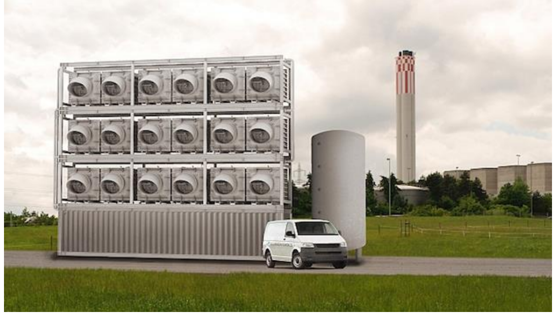
Sources for CO_2

- Short to mid term: Point sources
  - Biogas plants
  - Cement industry
  - Brewery



Air Capture via Pressure Swing





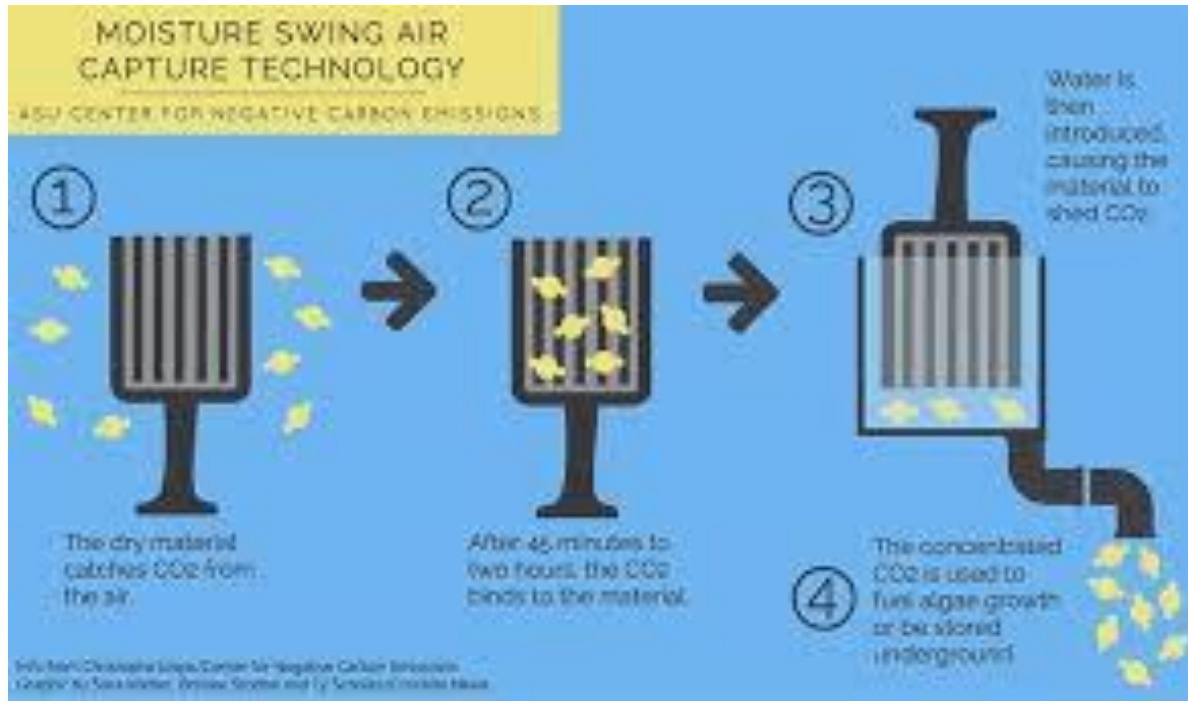
- Batch processes
  - Chemisorbtion of CO_2 unto sorbent, amine based solid
  - Regeneration of sorbent and release of CO_2 by energy input
    - Vaccum–temperature swing process
    - T can be kept below 100 C

www.climeworks.ch

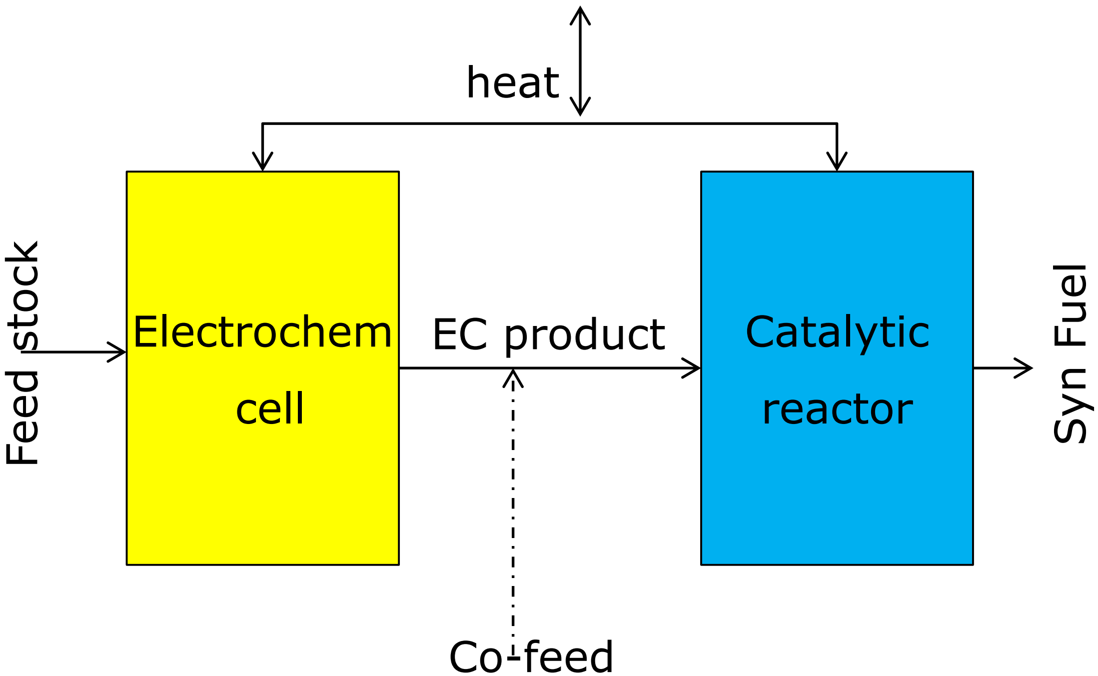
- Estimated CO_2 price: ~100 €/ton (electricity @ 18.6 €/GJ)
- “Second of a kind” (no mass production or learning)

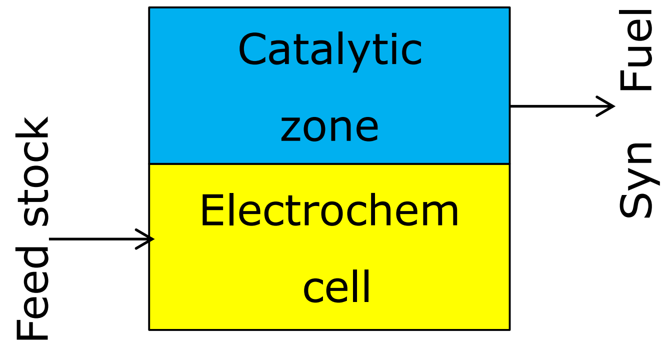
Source: www.Climeworks.com

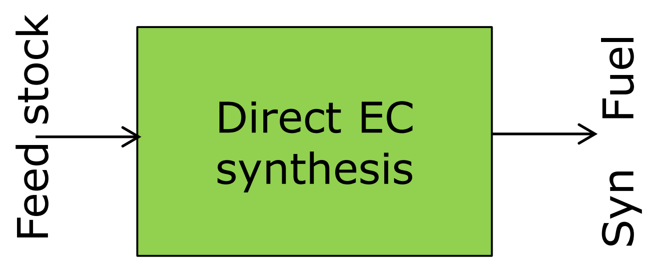
Mimiking Nature: ”Artificial Trees”



Benchmark for EC reactors

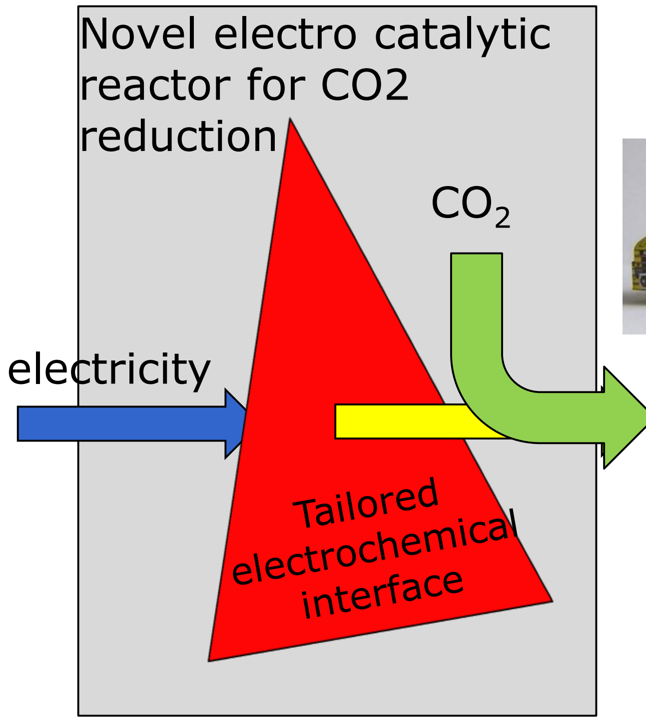






Benchmark: Technology today: H_2 EC (AEC) + Sabbatier

A Dream: direct synthesis from CO_2 ?



Sustainable

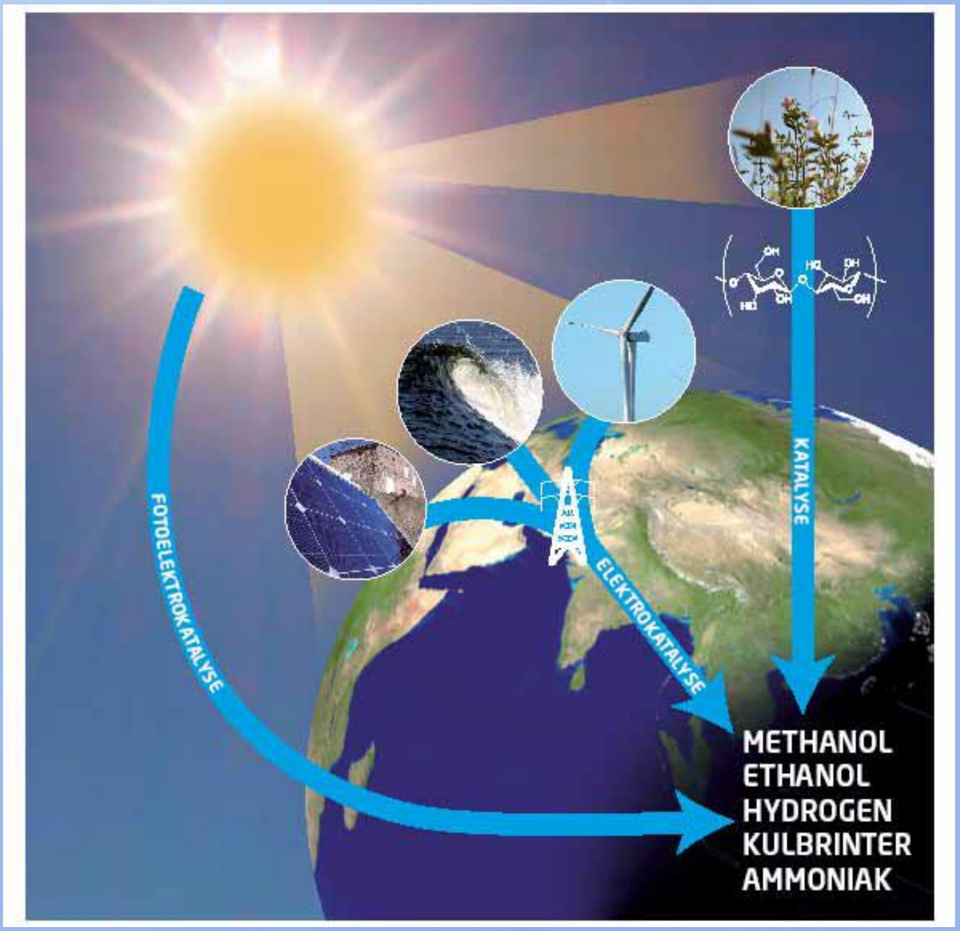
Chemicals

&

Fuels

CASE

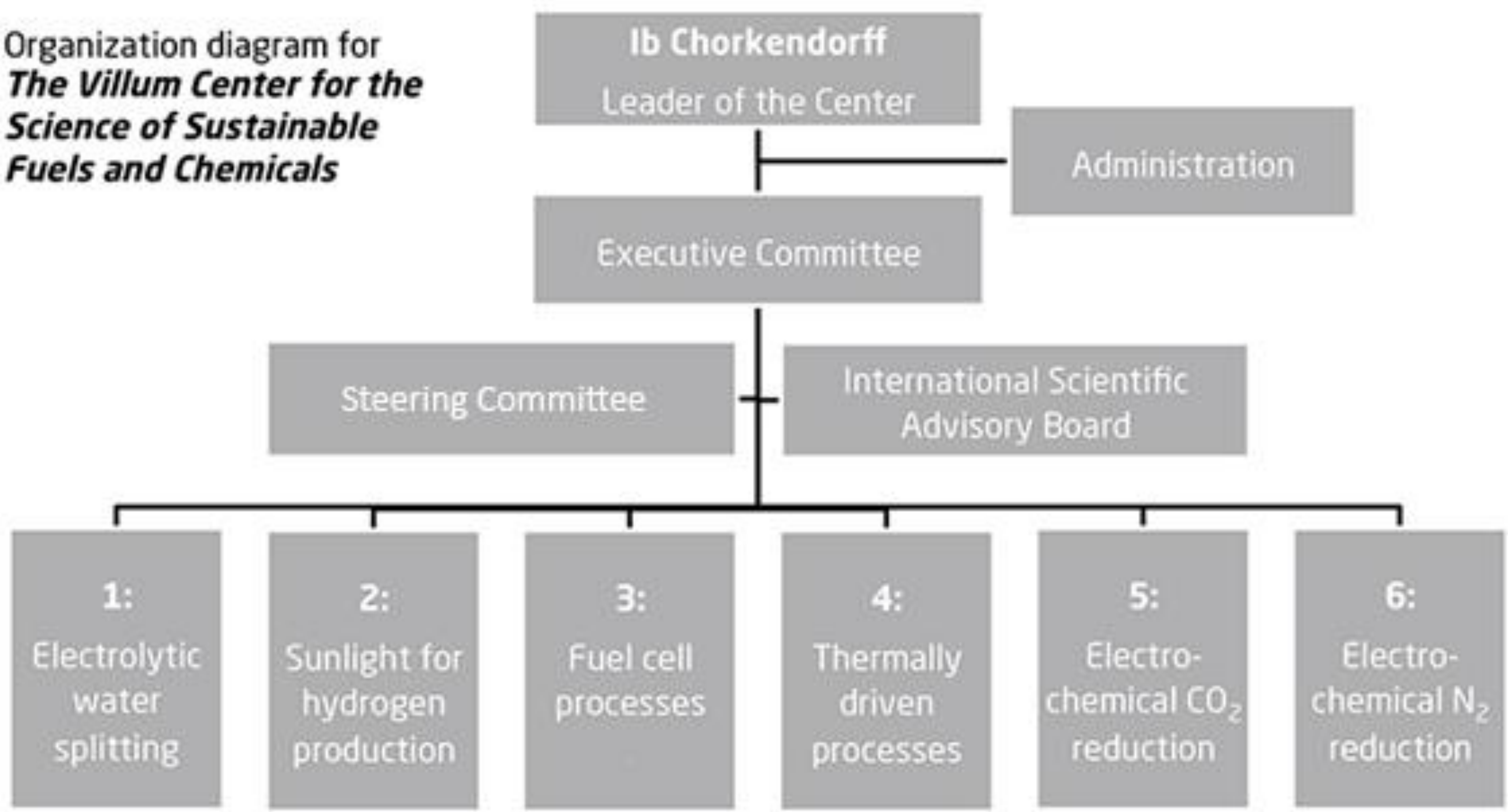
Catalysis for Sustainable Energy



The VILLUM Center for the Science of Sustainable Fuels and Chemicals

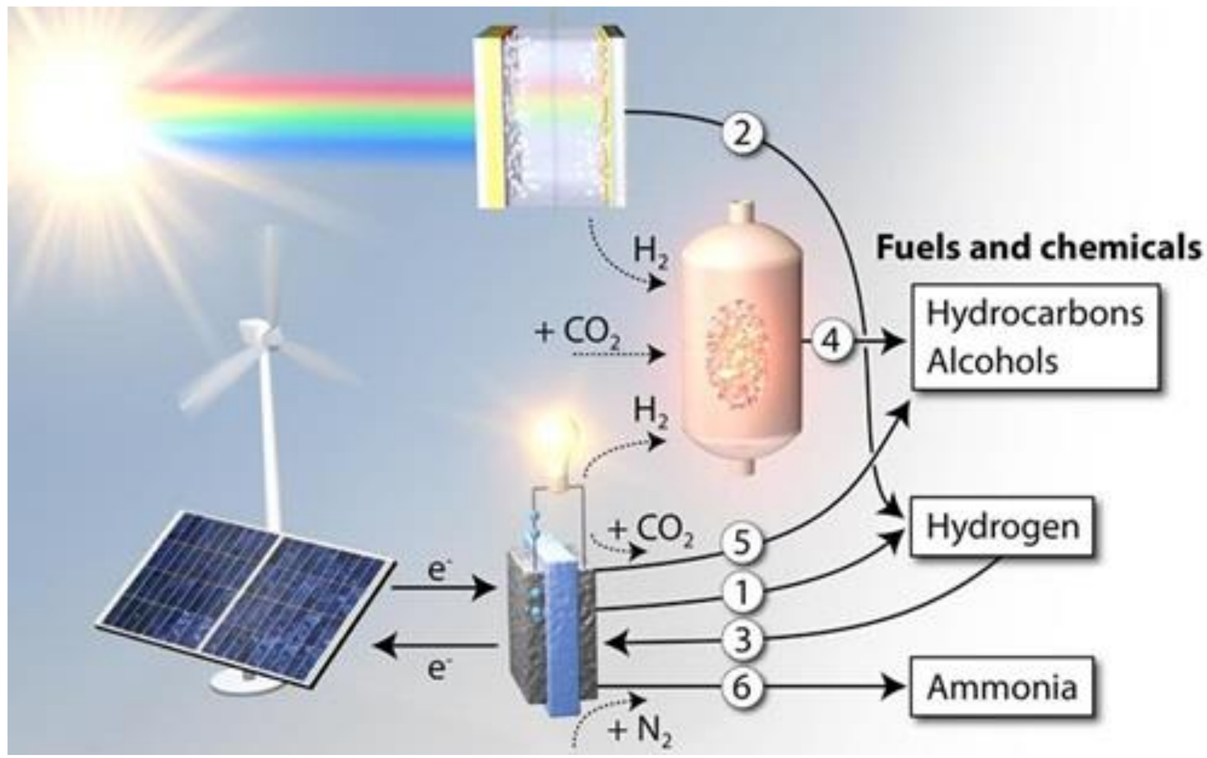
VILLUM FONDEN

Organization diagram for
The Villum Center for the Science of Sustainable Fuels and Chemicals



Reserach topics in the V-Sustain Center

- Electrolytic water splitting
- Sunlight for hydrogen production
- Fuel cell processes
- Thermally driven processes
- Electrochemical CO2 reduction
- Electrochemical N2 reduction



http://www.v-sustain.dtu.dk/

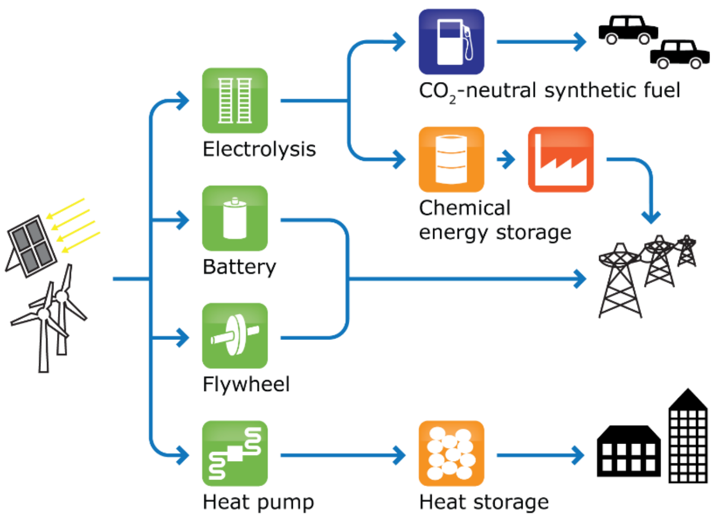
What hinders the deployment of electrofuels?

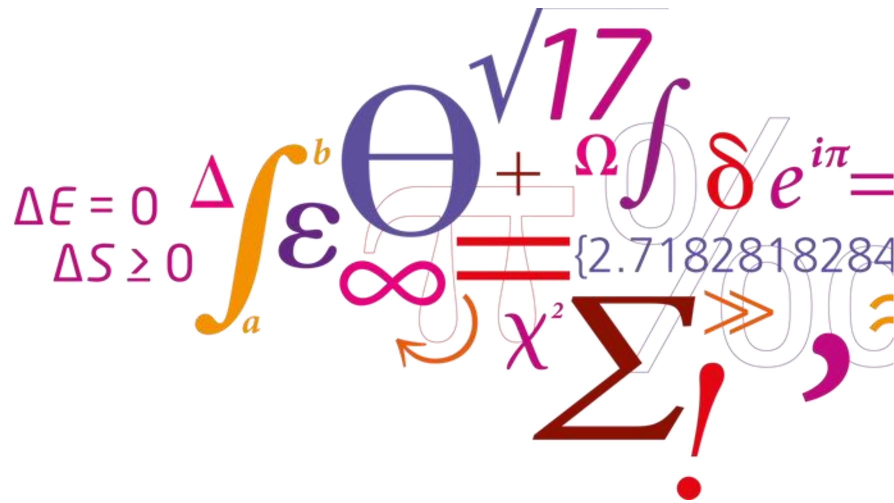
- Electrolysis:
  - Cost of green hydrogen
  - Highly efficient electrolysis units
  - Clever systemintegration into downstream processes

- Catalysis:
  - Challenge: development of catalysts for low pressure / low temperature reactors, compatible (in size/scale) with renewable electricty production (solar/wind)

- Legal frameworks
  - Business models
  - Legislation supporting electrical energy storage
    - Example: avoid double fees: electricity used and fuel provided

Thank You for Your attention





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