Recent trends in E-fuels / Power2X

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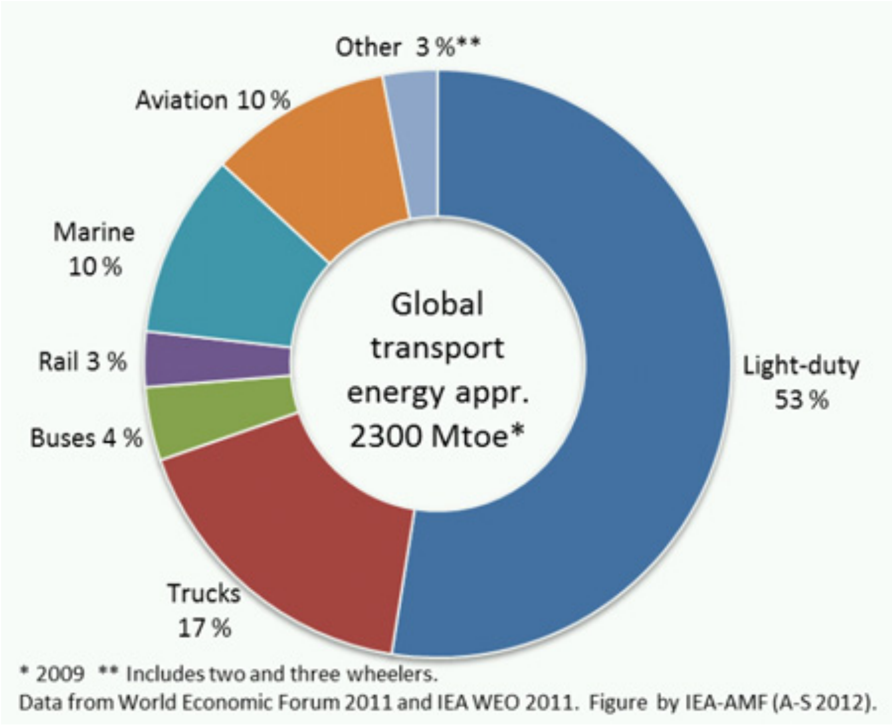
Outline

- Electrofuels
  - What are they
  - What activities are ongoing?

- Carbon dioxide sources

- The road ahead for E-fuels?

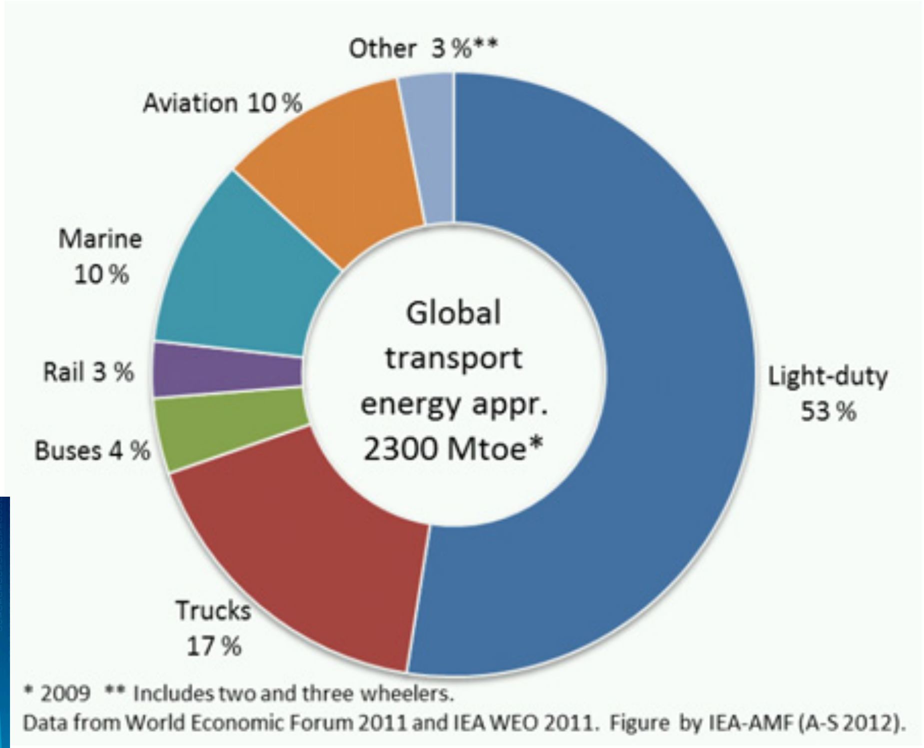


Decarbonization of the aviation sector

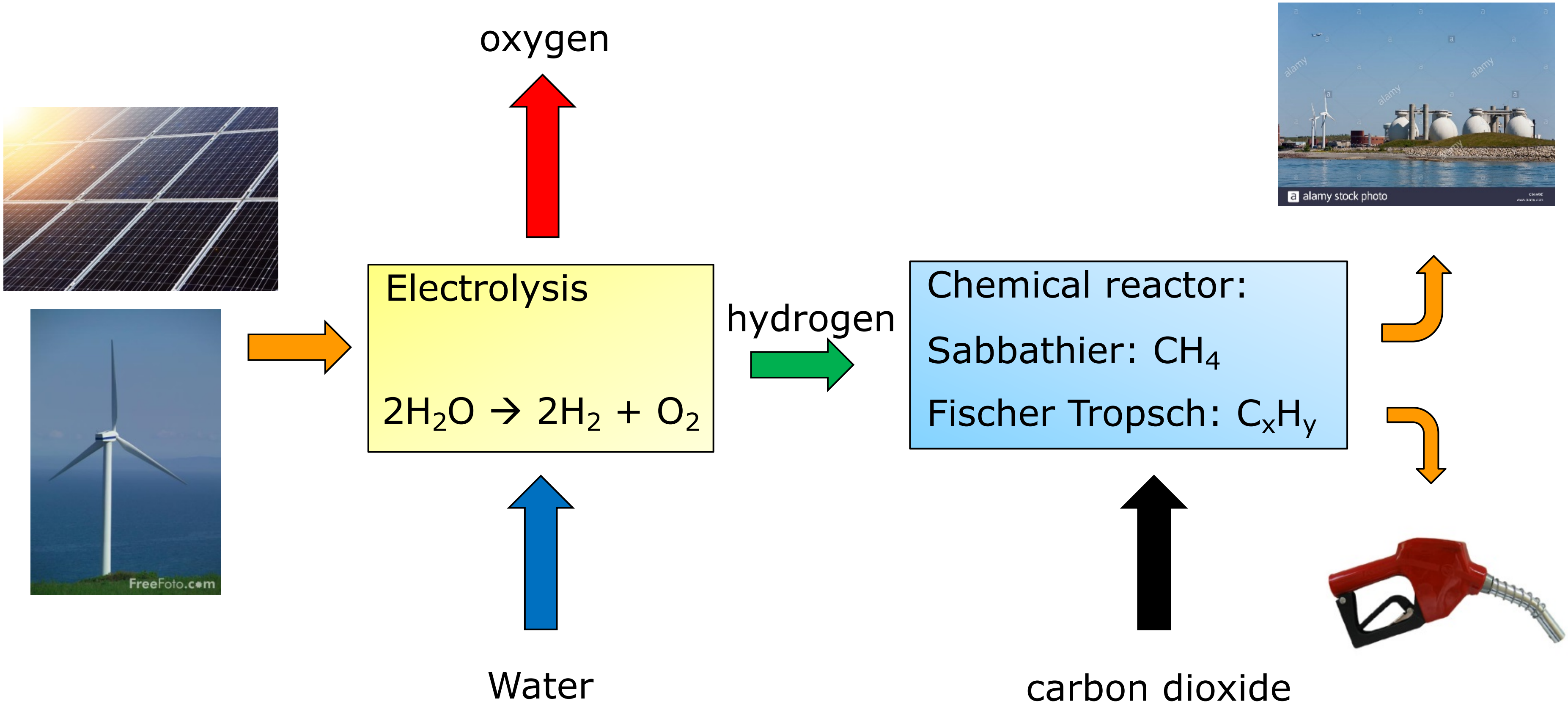
- Is a goal in RED II
  - Sustainable transport fuels

- A small share of the energy system

- Conclusions from report
  - engine technology: marginal
  - Bio based fuels: only partly
  - Electro fuels:
    - possible
    - CO_2 cycle

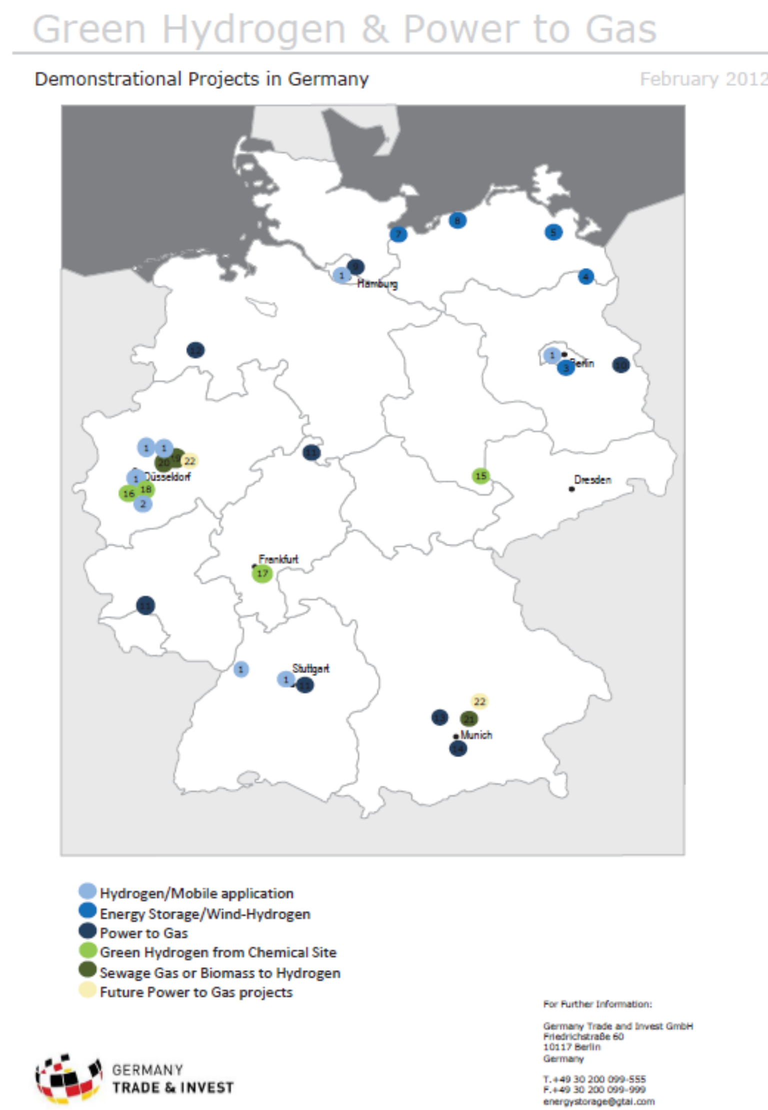


Principle Power to X



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) 6 MW (3 MW CH4)
    - Falkenhagen (2017 0.6 MW (CH4)
- 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

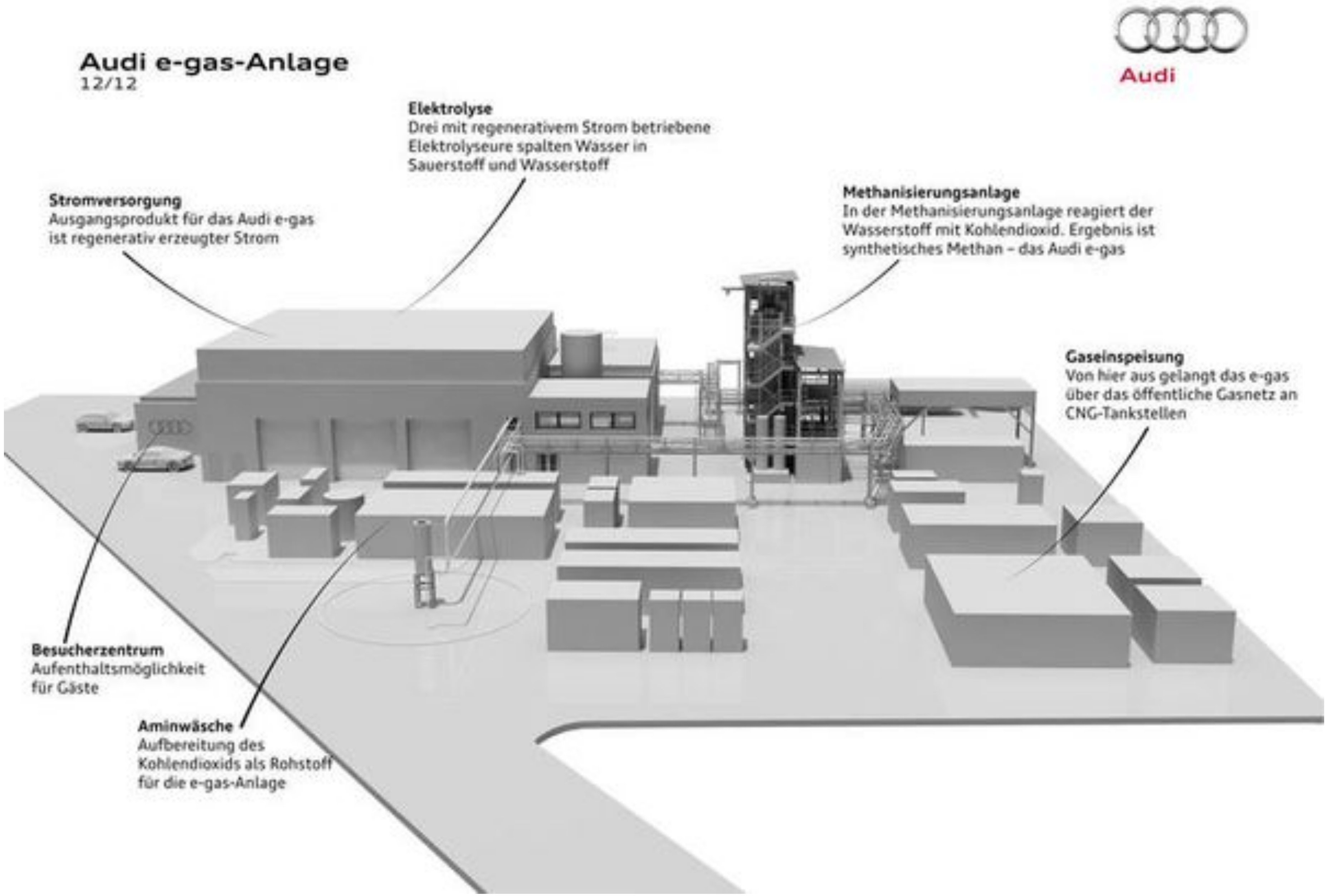
https://www.euwid-energie.de/uniper-erweitert-power-to-gas-anlage-in-falkenhagen-um-methanisierungseinheit/

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/

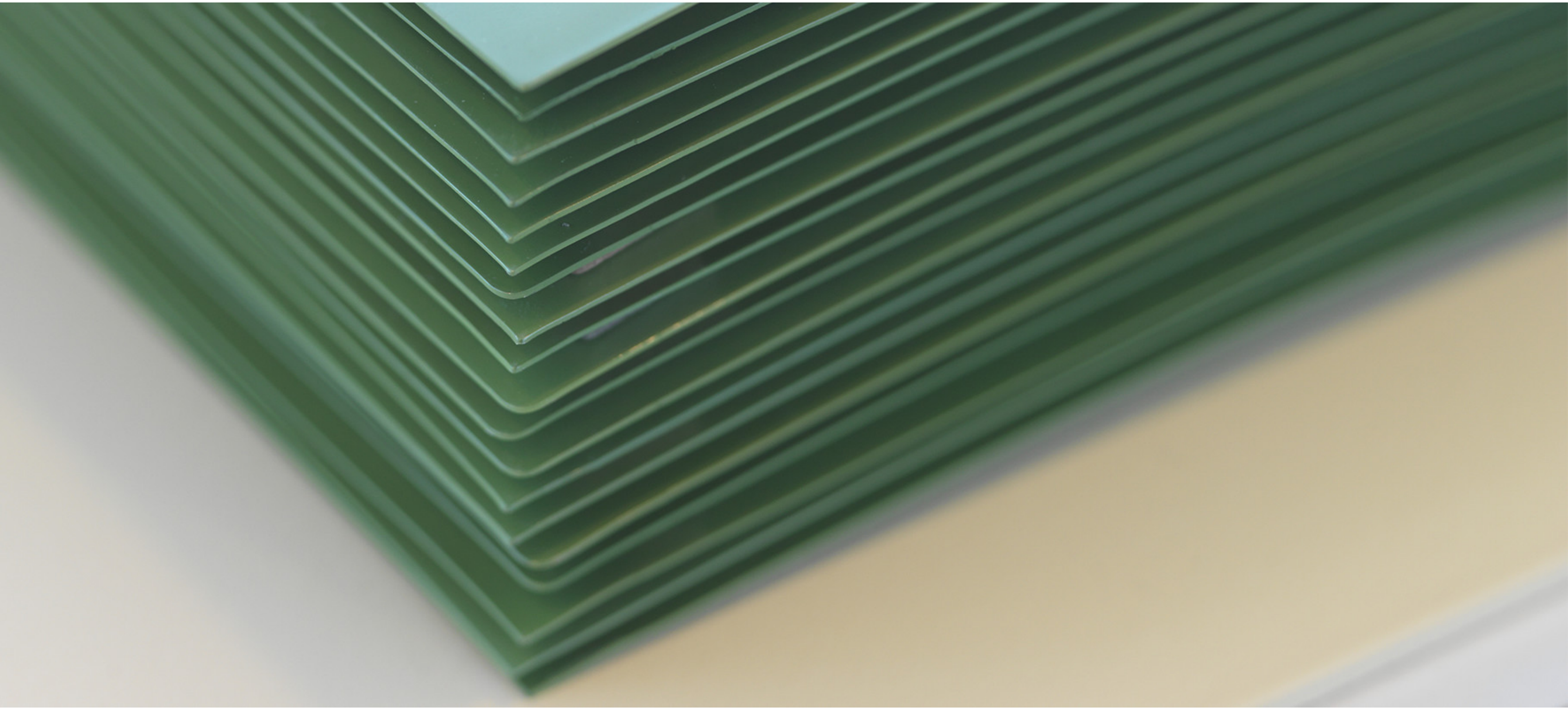

Audi e-gas-Anlage
12/12
Audi
Elektrolyse
Drei mit regenerativem Strom betriebene
Elektrolyseure spalten Wasser in
Sauerstoff und Wasserstoff
Stromversorgung
Ausgangsprodukt für das Audi e-gas
ist regenerativ erzeugter Strom
Methanisierungsanlage
In der Methanisierungsanlage reagiert der
Wasserstoff mit 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 Nm^3 Hydrogen, 40 kW High Temperature, Solid Oxide Electrolysis
- CO_2 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

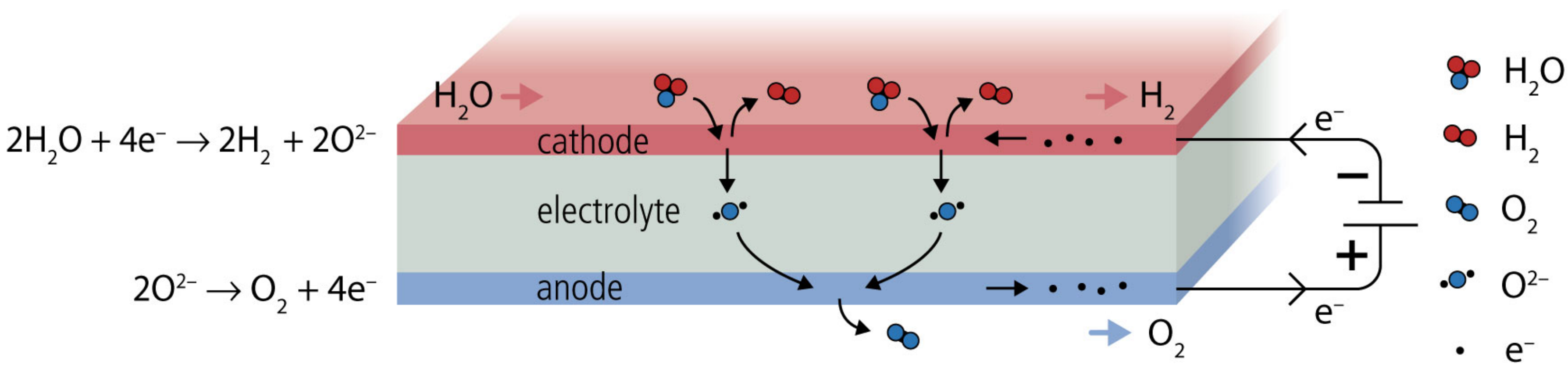
https://energiforskning.dk

DTU Energy: Solid Oxide Electrolysis Cells



Solid Oxide Electrolysis Cells (SOEC)

- Very similar to the corresponding fuel cells (SOFC)
- High operation temperature (approx. 800 ºC), very high efficiency
- Conversion of electricity to chemical energy, either by electrolysis of water or CO_2
  - High efficiency >80%
  - Syngas as feedstock for synthetic fuels



Conclusion on SOEC technology

- European and worldwide development
  - DTU, DLR, Jülich, CEA, ENEA, ….
  - Haldor Topsoe, DK, Sunfire, DE, SolidPower, IT, ….

- Based on solid oxide fuel cell technology
  - Ni- based fuel electrodes
  - Co-electrolysis: syngas composition is defined by reversed WGS equilibrium
  - Other design and materials are possible

- Thermal integration into downstream processes possible

- General conclusions on Electrolysis
  - Highly efficient
  - Area based → material extensive
  - Scaling problem: several 10th of kW units → large scale chemical plants

CAPFUEL project

- Søren Lyng Ebbehøj & Mogens B Mogens

- Modelling based analysis:
  - CO_2 air capture
  - Solid oxide electrolysis
  - Fuel synthesis: methanation

- System and heat integration
  - Plant layout
  - Mass balance
  - Heat integration
  - Energy balance

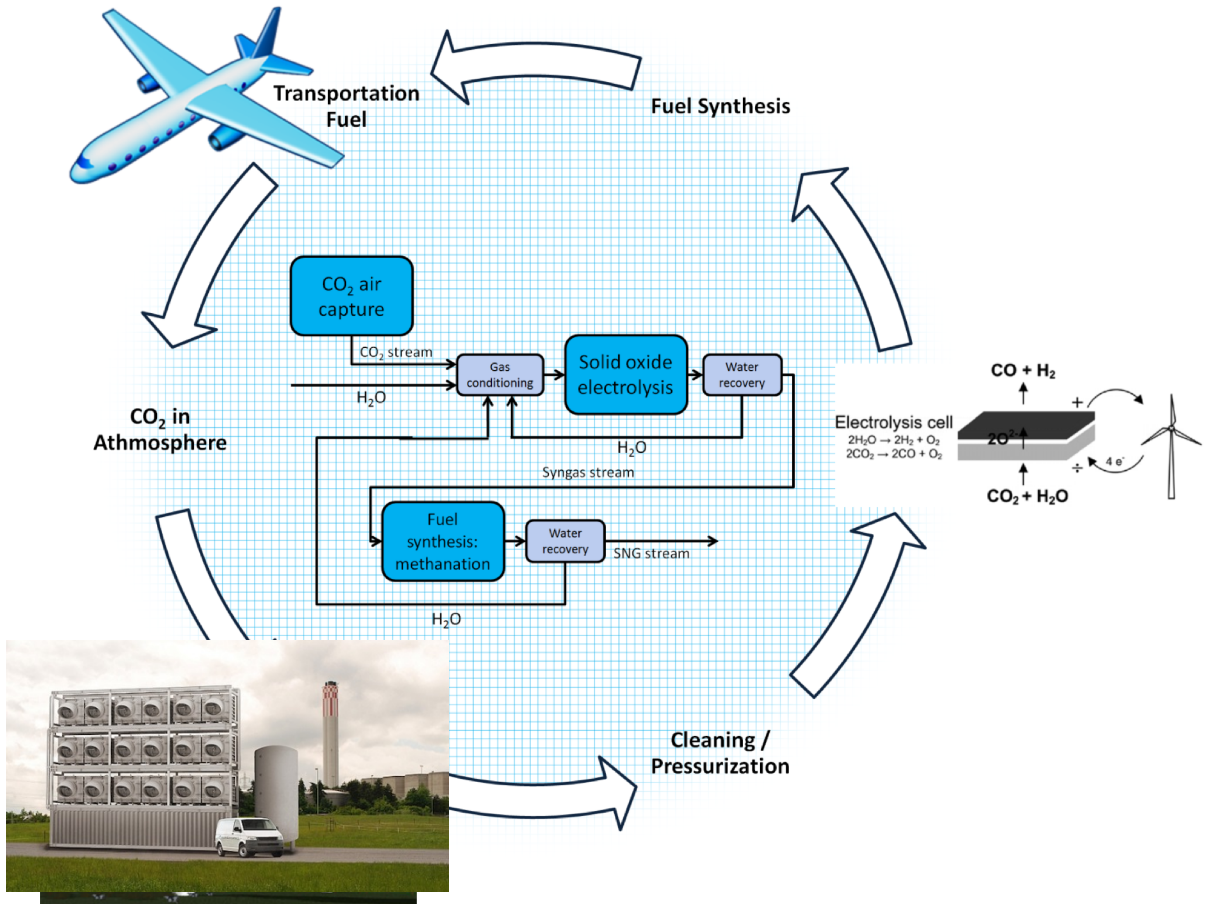
"Integration of CO_2 air capture and solid oxide electrolysis for methane production"
Søren Lyng Ebbehøj

PhD Thesis April 2015

Department of Energy Conversion and Storage

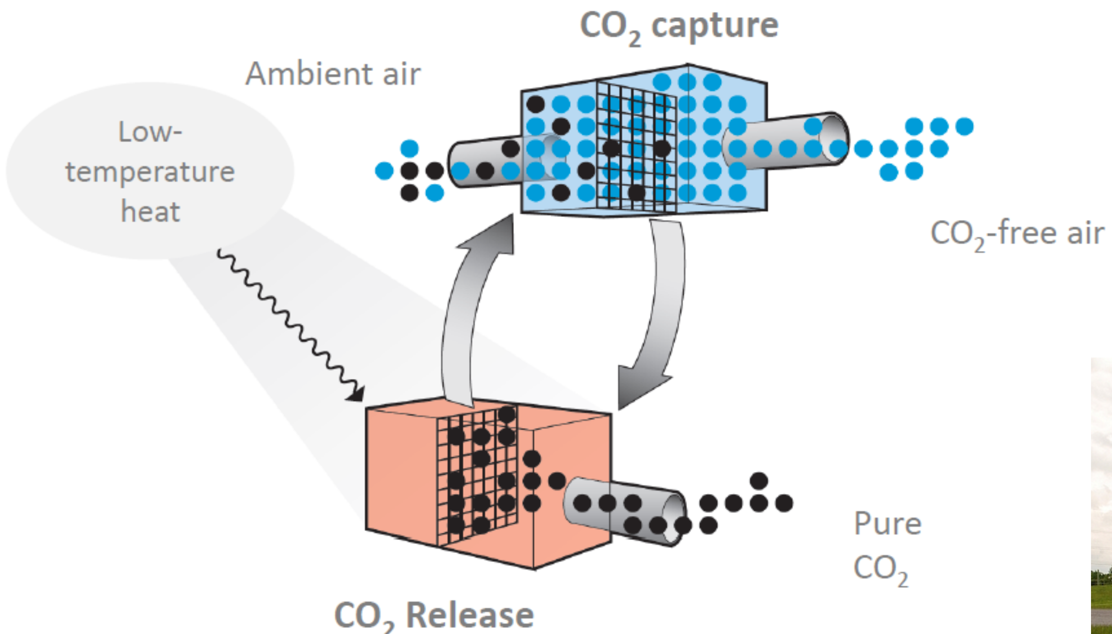
ISBN 978-87-92986-32-0

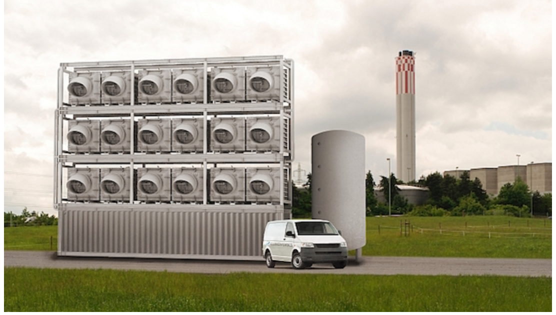
Closing the carbon cycle?



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

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

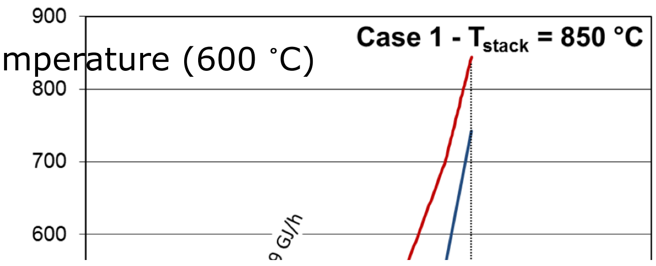
- Estimated CO_2 price: ~100 €/ton (electricity @ 18.6 €/GJ)
- “Second of a kind” (no mass production or learning)

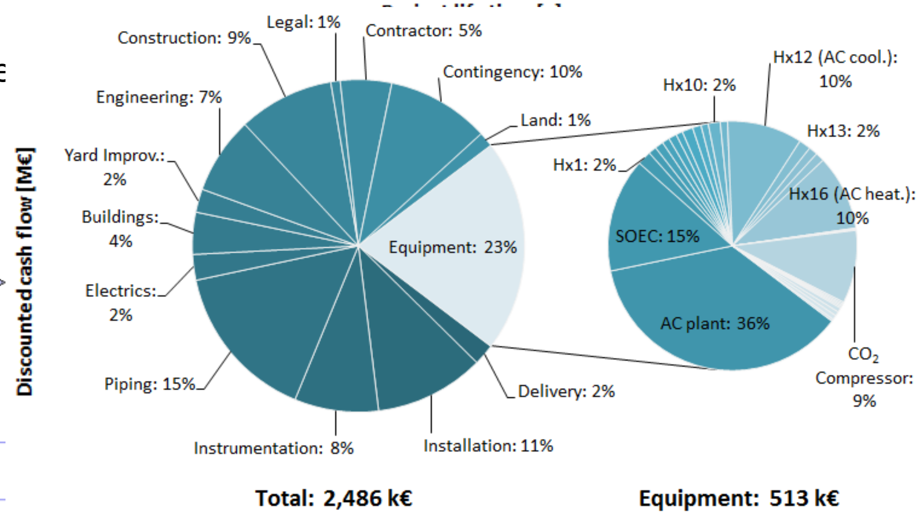
Source: www.Climeworks.com

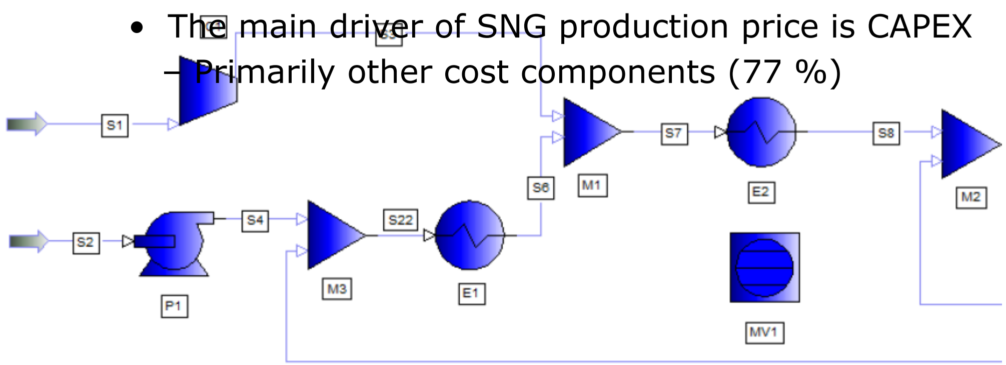
Conclusion

Lessons learned from this study:

- A technological, steady state, thermodynamic SOEC model was developed and operating parameters mapped
- The SOEC and methanation sub-systems integrated well in terms of heat balance but insufficient waste heat is present in the plant to cover the air capture sub-system
- High temperature (850 ˚C) operation is more economic than low temperature (600 ˚C)
- SNG production price was 2.3 times the price of upgraded biogas
- CO_2 quota has negligible impact at 45 $/ton
- Air capture plant costs is the main CAPEX cost drive
- The main driver of SNG production price is CAPEX
  - Primarily other cost components (77 %)



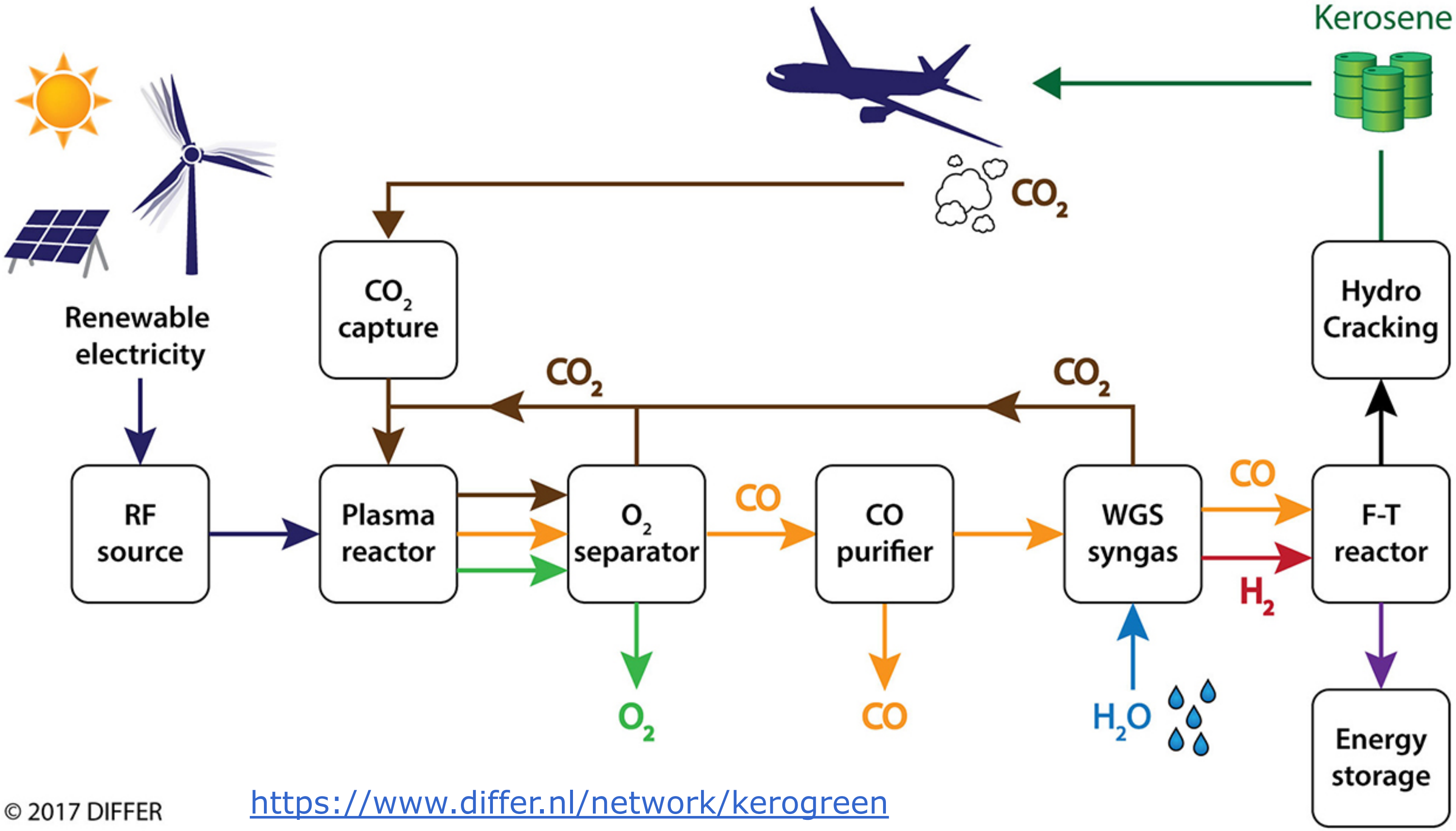




Kerogreen project

Demonstration of synthetic Kerosene

- 1 l/hour
- Container size unit
- costs +50% of fossil kerosene



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

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 CO2 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 (lean combustion)

- 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 CO2 compensation fund, ICAO regulation, CO as byproduct
- Electrical energy: Plasma and MIEC membrane

The road ahead for E-fuels?

- Several pathways exist already today:
  - Power to Hydrogen to X
  - Power to syn-gas to X
  - Power to carbon monoxide to syngas to X

- For classical reactor technology a scaling problem has to be overcome:
  - Several 10th of kW EC reactors vs MW chemical plants
- Microreactor technology can decentralize the down stream processes

- Several research attempts to improve
  - Electrolysis efficieny and Costs:
  - Direct air capture technology
  - Reactor technology

- Shift of paradigm
  - From central production of fuels to local production

The VILLUM Center for the Science of Sustainable Fuels and Chemicals

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KOPERNIKUS PROJEKTE
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Bundesministerium für Bildung und Forschung