Closing the Carbon Cycle with Air Capture

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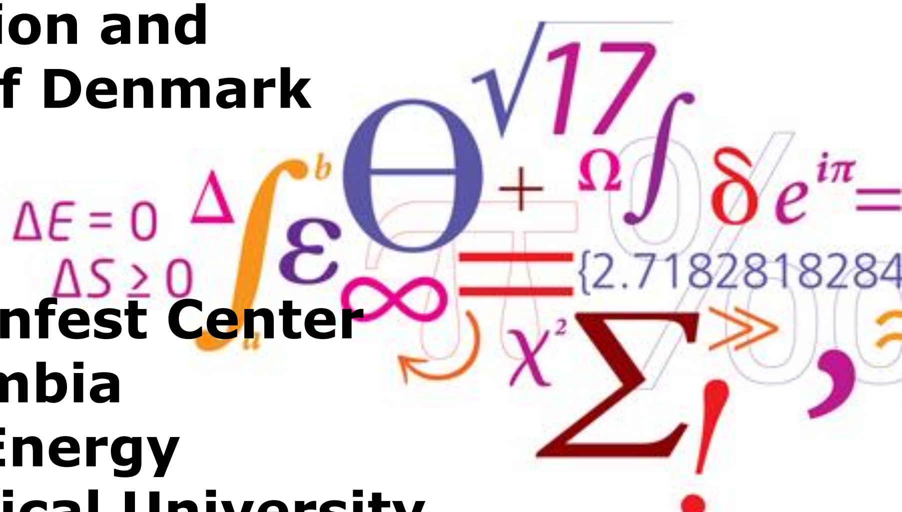


Annual Conference between Lenfest Center for Sustainable Energy at Columbia University and Department of Energy Conversion and Storage, Technical University Denmark (DTU), NY, April 14th, 2014.

DTU Energy Conversion = Department of Energy Conversion and Storage, Technical University of Denmark

- Sustainable technologies for energy conversion and storage
- Located on two campuses near
  Copenhagen, Denmark: Lyngby and Risø at Roskilde
- Ca. 240 employees
- Our research span from fundamental investigations to component manufacture
- Focus on industrial collaboration and industrially relevant processes
- Head quarter is at DTU Risø Campus

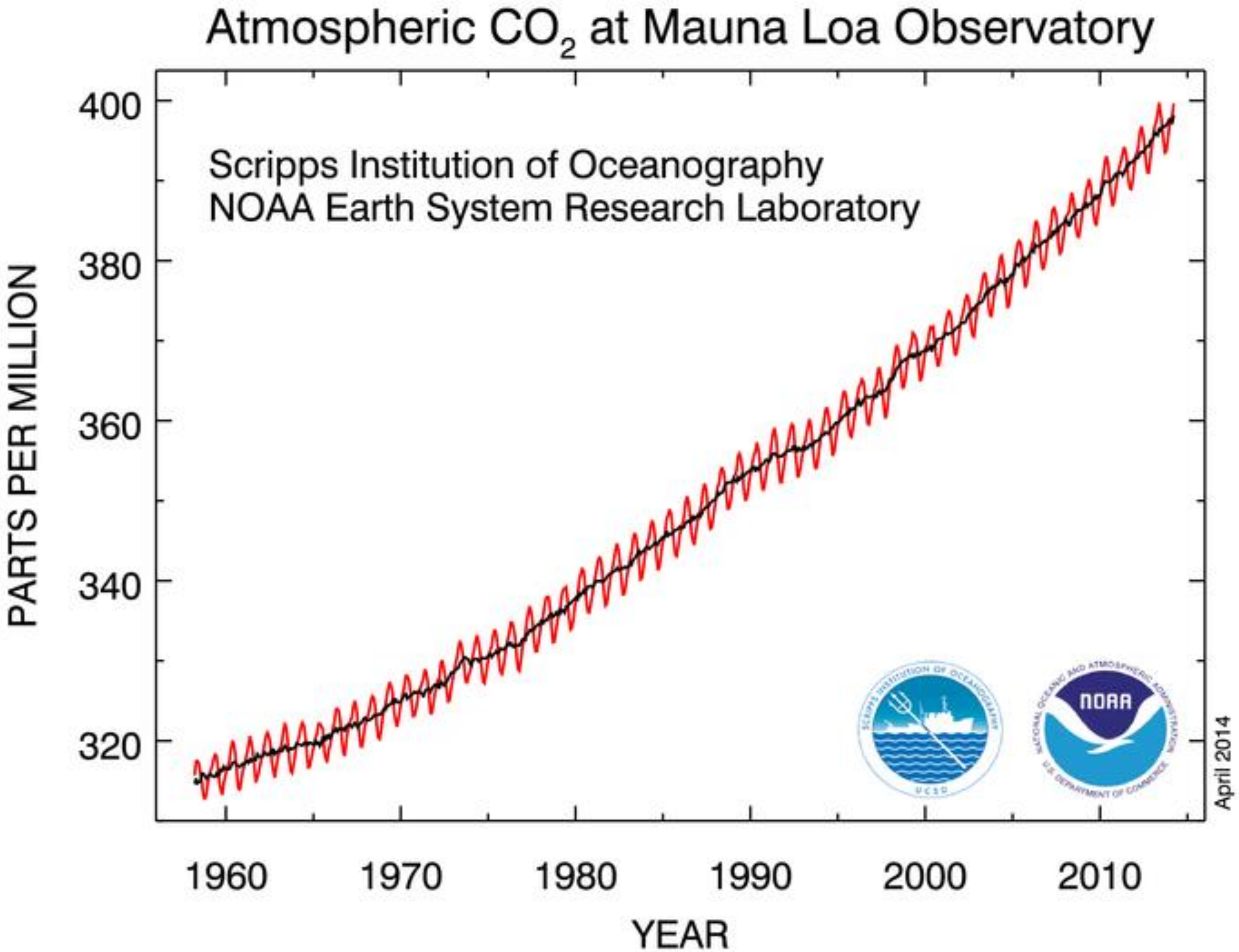
Introduction

There are clear reasons to look for means of recycling CO_2 using renewable energy:

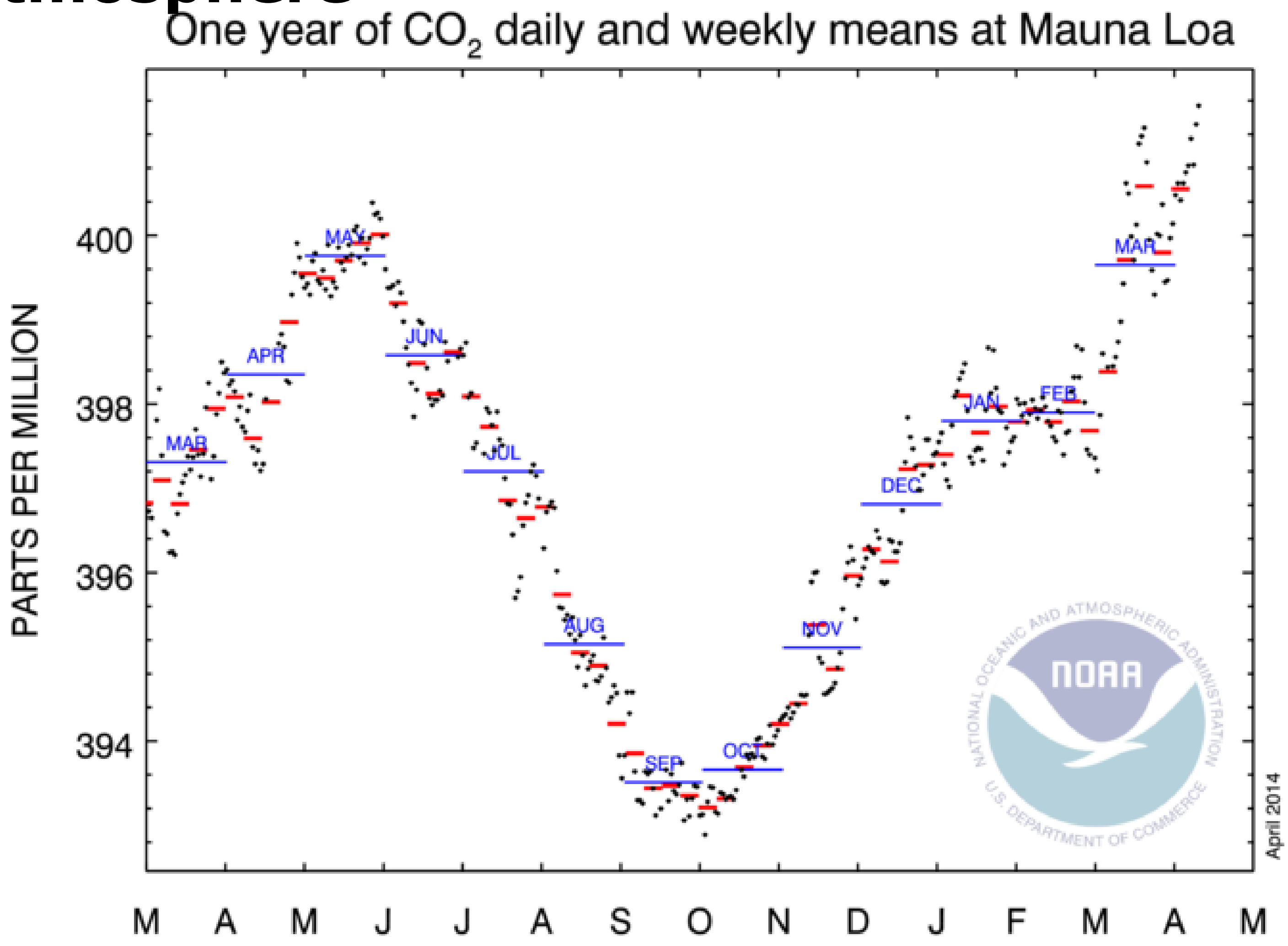
- **Probable anthropogenic climate change by CO_2 emissions**
- **Limited supply of cheap fossil fuel resources in the long term**
- **Security of supply and geopolitical consequences of unequal distribution of resources**

Synthetic fuels – CO_2 neutral green fuels - seem particularly benign to replace the fossil fuels.

Increasing CO_2 concentration in the atmosphere



Increasing CO_2 concentration in the atmosphere



The solution is synthetic green fuels based on hydrogen and carbon

- **Green fuel** is here defined as CO_2 neutral hydrocarbons: **amount of CO_2 emitted** by using the fuel ≤ **amount of CO_2 used** making the fuel.

- **Biomass or "captured CO_2 + renewable energy for electrolysis"** or at least "CO_2 free electricity" e.g. nuclear).

- **Chemically they may be expressed as $H_xC_yO_z$ – gas, liquid or solid in principle.**

Visions

Synfuels from electrolysis of steam and carbon dioxide

1. **Big off-shore wind turbine parks coupled to a large SOEC – produce CH_4 (synthetic natural gas, SNG) - feed into existing natural gas net-work (in Denmark).**

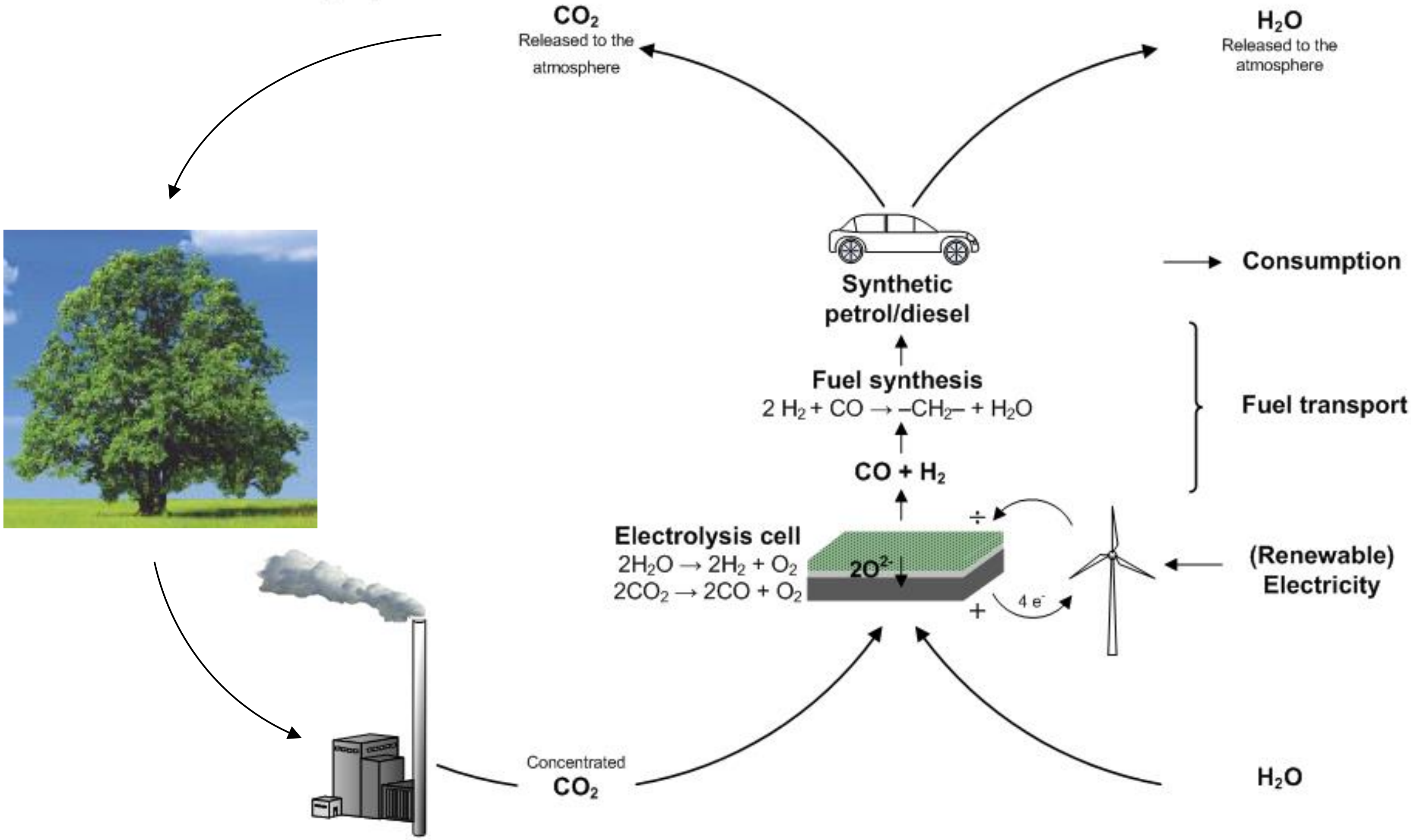
2. **Large SOEC systems - produce DME, gasoline and diesel - Island, Canada, Greenland, Argentina, Australia ... geothermal, hydro, solar and wind.**

3. **First target market: replacement of natural gas and <u>liquid fuels for transportation</u>**

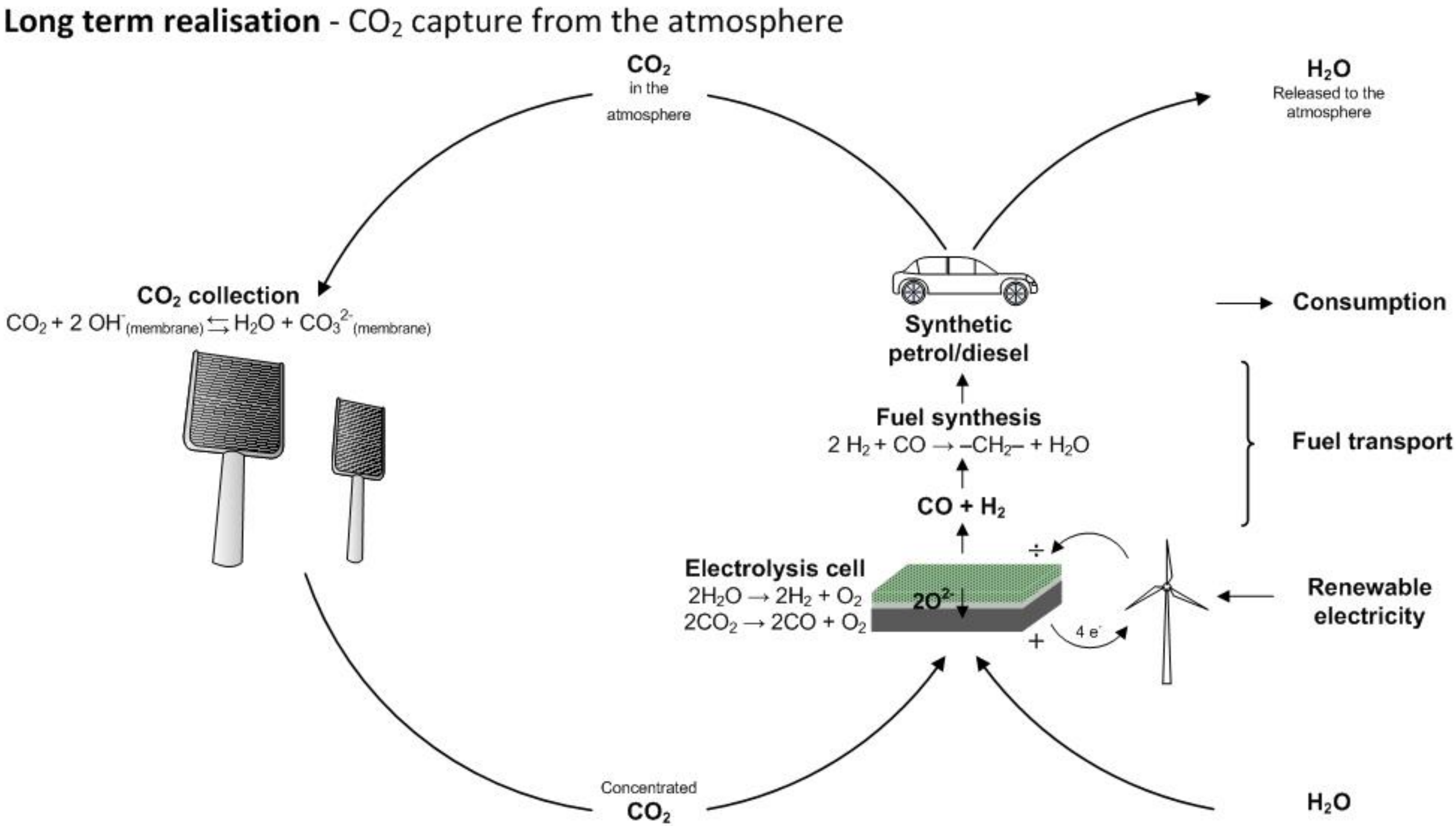
4. **All the infrastructure exists!!**

Biomass CO_2 recycling

Short term realisation - CO_2 capture from industrial sources



Capture of CO_2 from air + co-electrolysis



Many methods – all need support

- **Several chemical systems for air capture**
- **Biomass of various kinds**
- **Chemical looping of oxygen for coal combustion (not air capture – for CCS)**

- **Electrolysis of H_2O followed by reaction of CO_2 with H_2**
- **Co-electrolysis of CO_2 and H_2O**
- **Chemical looping of CO_2 into CO**

- **Artificial photosynthesis of fuel (photo-electrochemical conversion of CO_2 and H_2O) into hydrocarbons**

Concluding remarks

1. **We have cycles that can provide green synthetic hydrocarbon fuels**

2. **We wish to make them more affordable. About 2 - 6 % of GNP to change to 100 % renewable according to some models.**

3. **We can do it – let's do it!**

4. **Today we will hear about <u>how we can do it</u>.**

Acknowledgement

We acknowledge support from our sponsors

- **Danish Energy Authority**
- **Energinet.dk**
- **EU**
- **Topsoe Fuel Cell A/S**
- **Danish Programme Committee for Energy and Environment**
- **Danish Programme Committee for Nano Science and Technology, Biotechnology and IT**
- **The work of many colleagues over the years**

Thank you for your attention!

Why liquid synthetic fuel? The power density argument

- **Gasoline (33 MJ/L) filling rate of 20 L/min equivalents 11 MW of power and means it takes 2½ min to get 50 l = 1650 MJ on board**

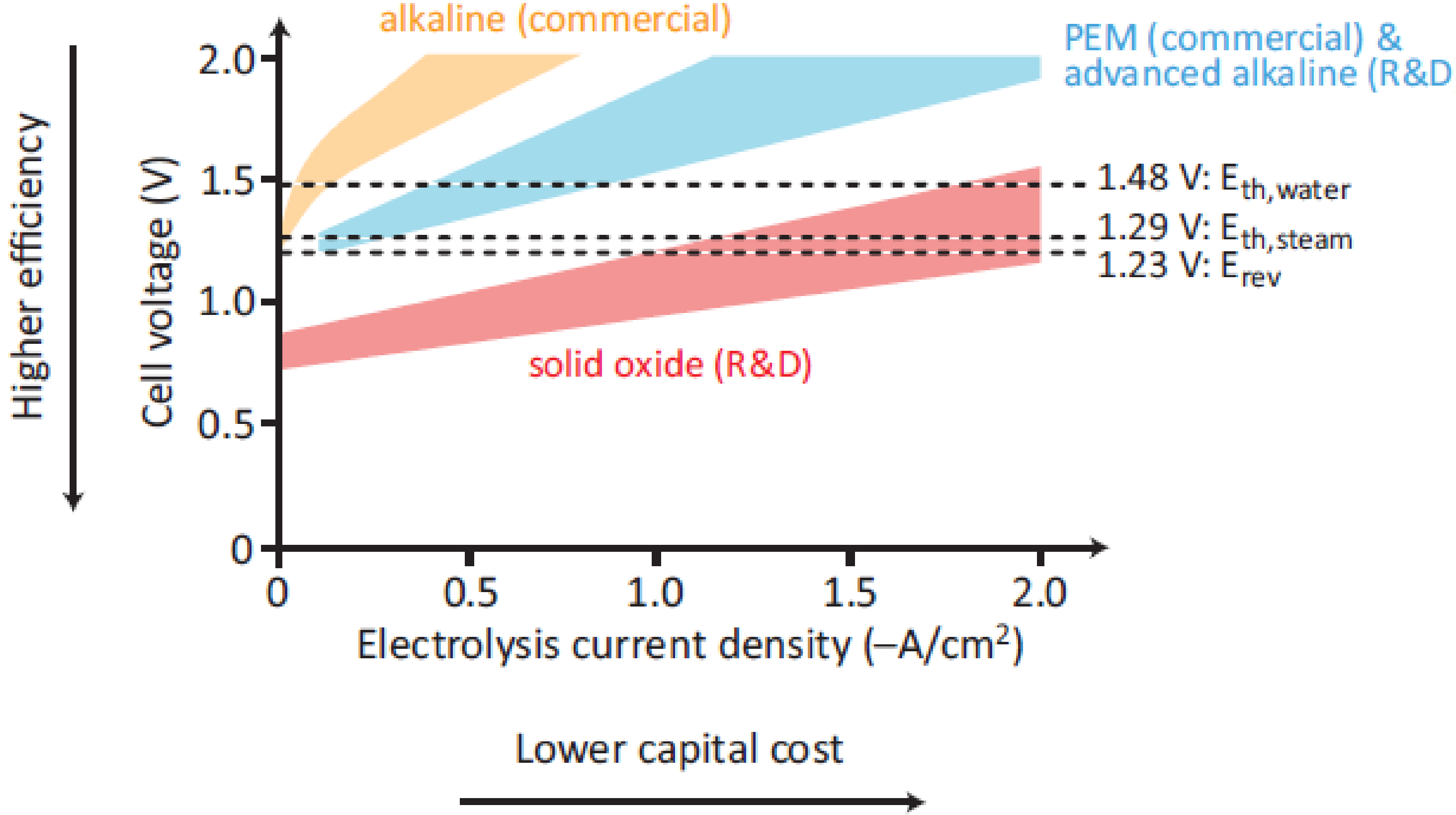
- **For comparison: Li-batteries usually requires 8 h to get recharged. For a 300 kg battery package (0.5 MJ/kg) this means a power of ca. 3.5 kW i.e. it takes 8 h to get 150 MJ on board.**

- **The ratio between their driving ranges is only ca. 5, because the battery-electric-engine has an efficiency of ca. 70 % - the gasoline engine has ca. 25 %.**

Why synthetic hydrocarbons? The energy density argument

Type	MJ/l	MJ/kg	Boiling point °C
Gasoline	33	47	40 - 200
Dimethyl ether - DME	22	30	- 25
Liquid hydrogen	(10)	(141)	-253
Water at 100 m elevation	10^{-3}	10^{-3}	
Lead acid batteries	0.4	0.15	
Li-ion batteries	1	0.5	

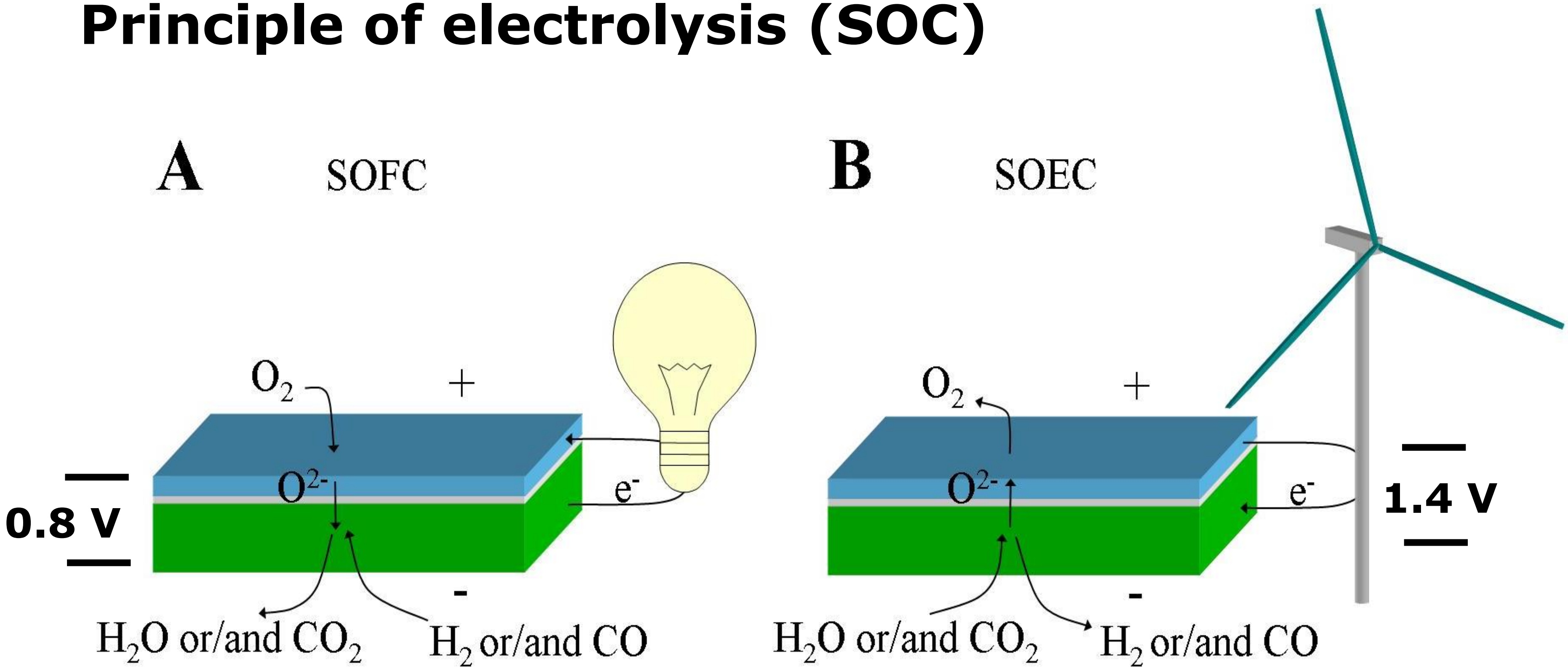
Electrolyser status



Typical ranges polarization ranges for state-of-the-art water electrolysis cells. $E_{th,water}$ and $E_{th,steam}$ are the thermoneutral voltages. E_{rev} is the reversible voltage at standard state.

C. Graves, S. D. Ebbesen, M. Mogensen, K. S. Lackner, *Renew. Sustain. Energy Rev.*, 15 (2011) 1–23

Principle of electrolysis (SOC)



750 - 850 °C EMF ca. 1.1 V

Working principle of a reversible Solid Oxide Cell (SOC). The cell can be operated as a SOFC (A) and as a SOEC (B).