Energy to X

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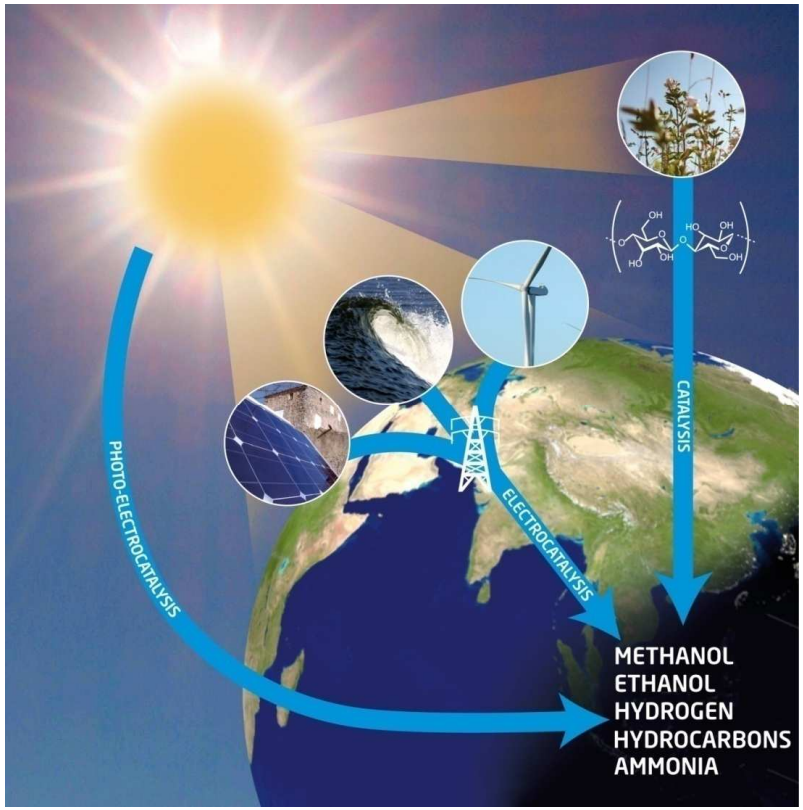


The fossil (20th) century

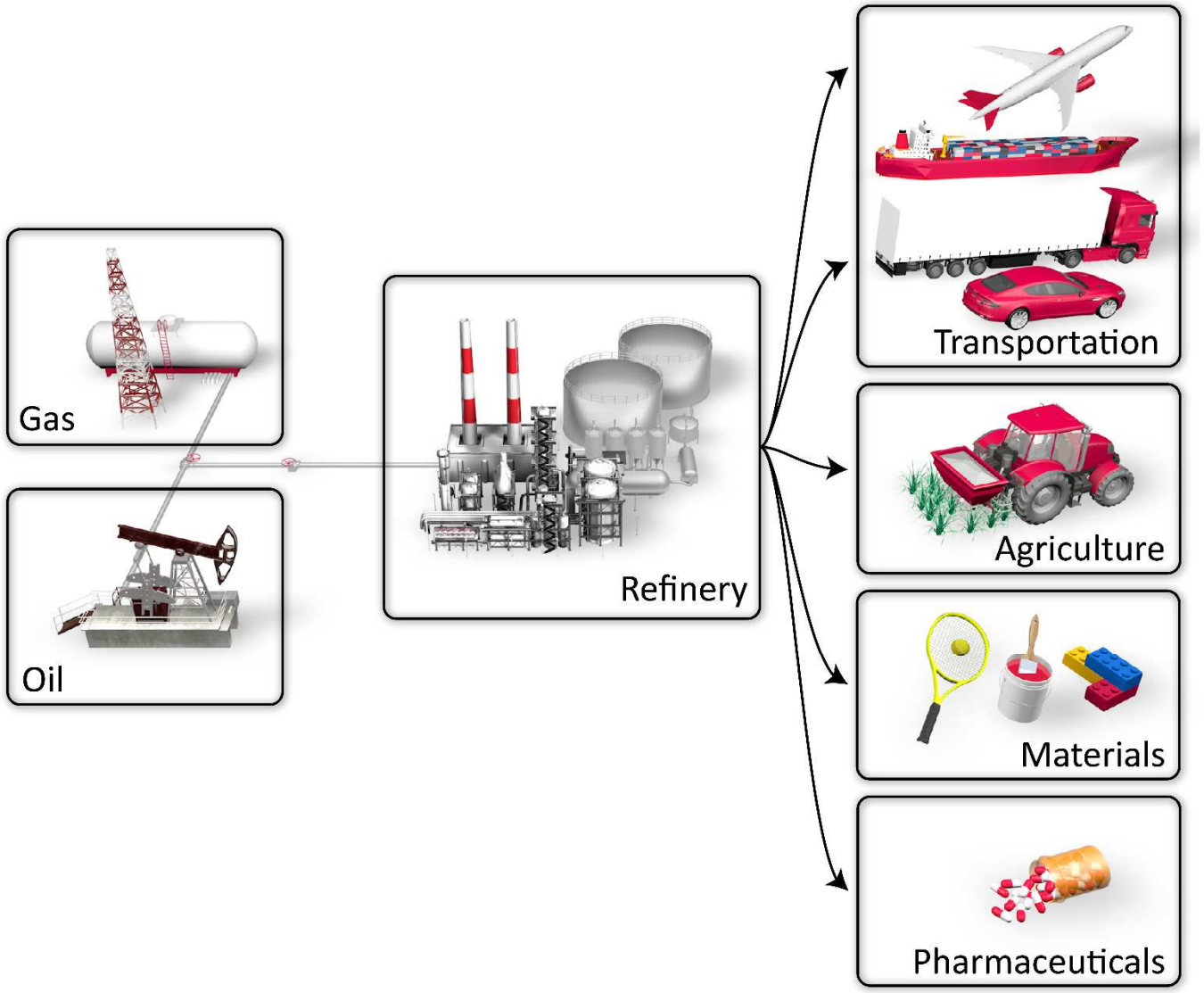
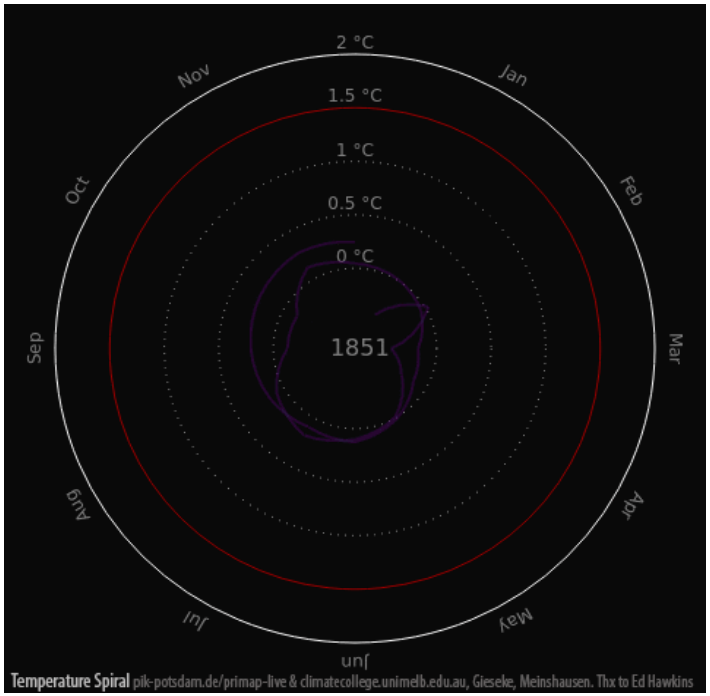


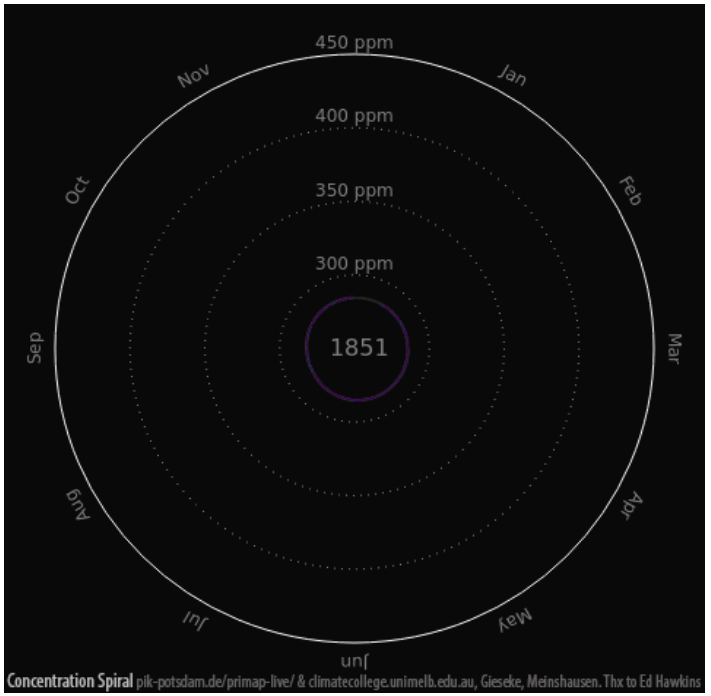
Image: Jakob Kibsgaard

The climate challenge

Temperature increase



CO_2 level

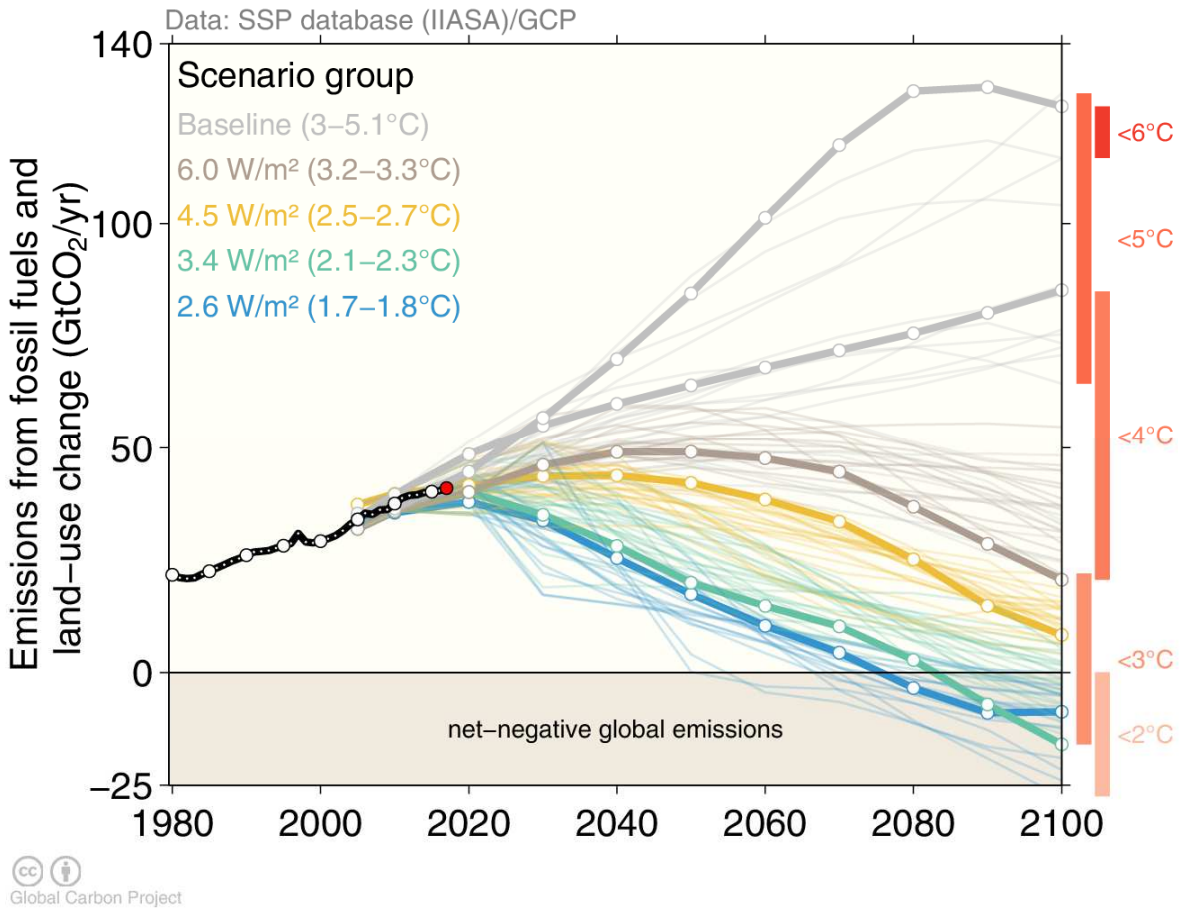


Morice, C. P. *et al*., Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 dataset, J. Geophys. Res.

M. Meinshausen *et al*., "Historical greenhouse gas concentrations", Geoscientific Model Development Discussions, 2016

CO_2 emission scenarios

IPCC Sixth Assessment Report



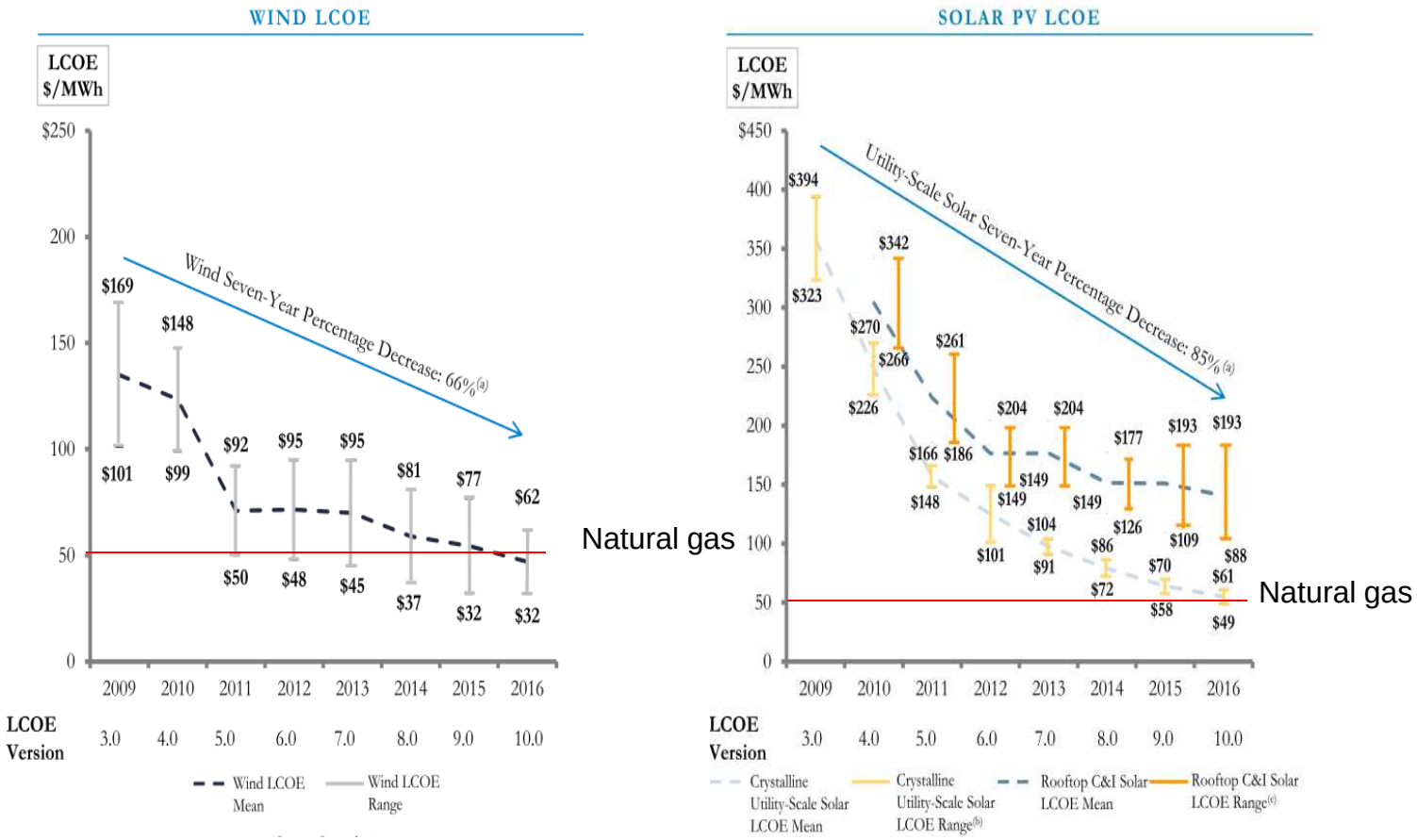
GLOBAL CARBON PROJECT

Five Shared Socioeconomic Pathways (SSPs) have been developed to explore challenges to adaptation and mitigation. Shared Policy Assumptions (SPAs) are used to achieve target forcing levels (W/m^2).

Source: Riahi et al. 2016; IIASA SSP Database; Global Carbon Budget 2017

Some good news …….

Electricity cost from solar and wind is rapidly decreasing

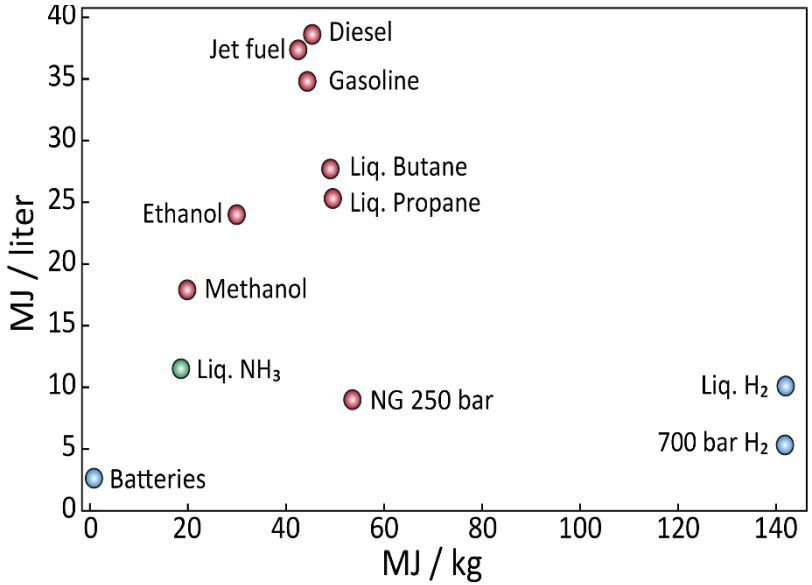


LAZARD'S LEVELIZED COST OF ENERGY ANALYSIS—VERSION 10.0

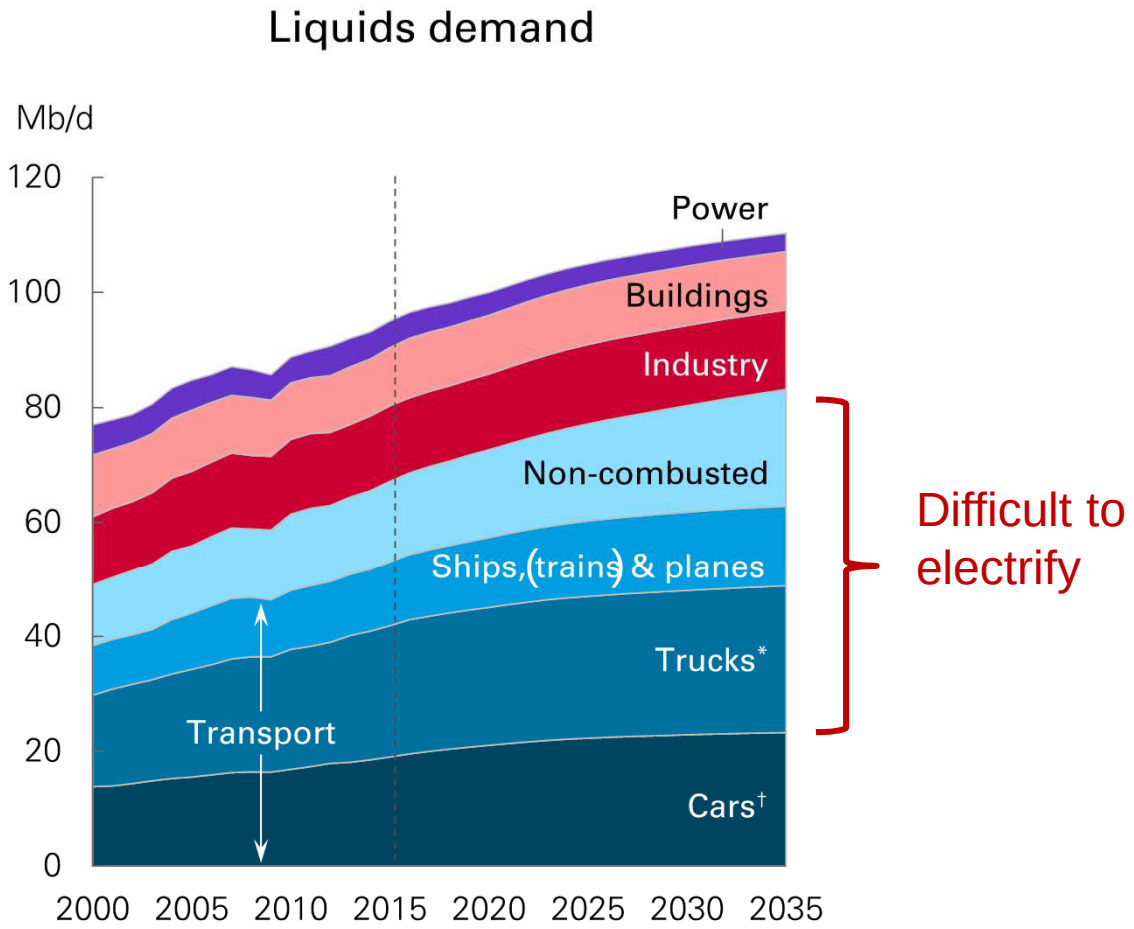
U.S. Energy Information Administration | AEO2016 Levelized Costs

The challenge: Energy storage

- Batteries
  - \+ Exisiting technology
  - \+ High efficiency
  - – Low energy density
  - – New infrastructure needed
- Synthetic fuels
  - \+ High energy density
  - \+ Exisiting infrastructure
  - \+ Basis for sustainable chemical industry
  - – Low efficiency



Fuels demand



2017 Energy Outlook (BP)

Synthetic fuels – the carbon cycle

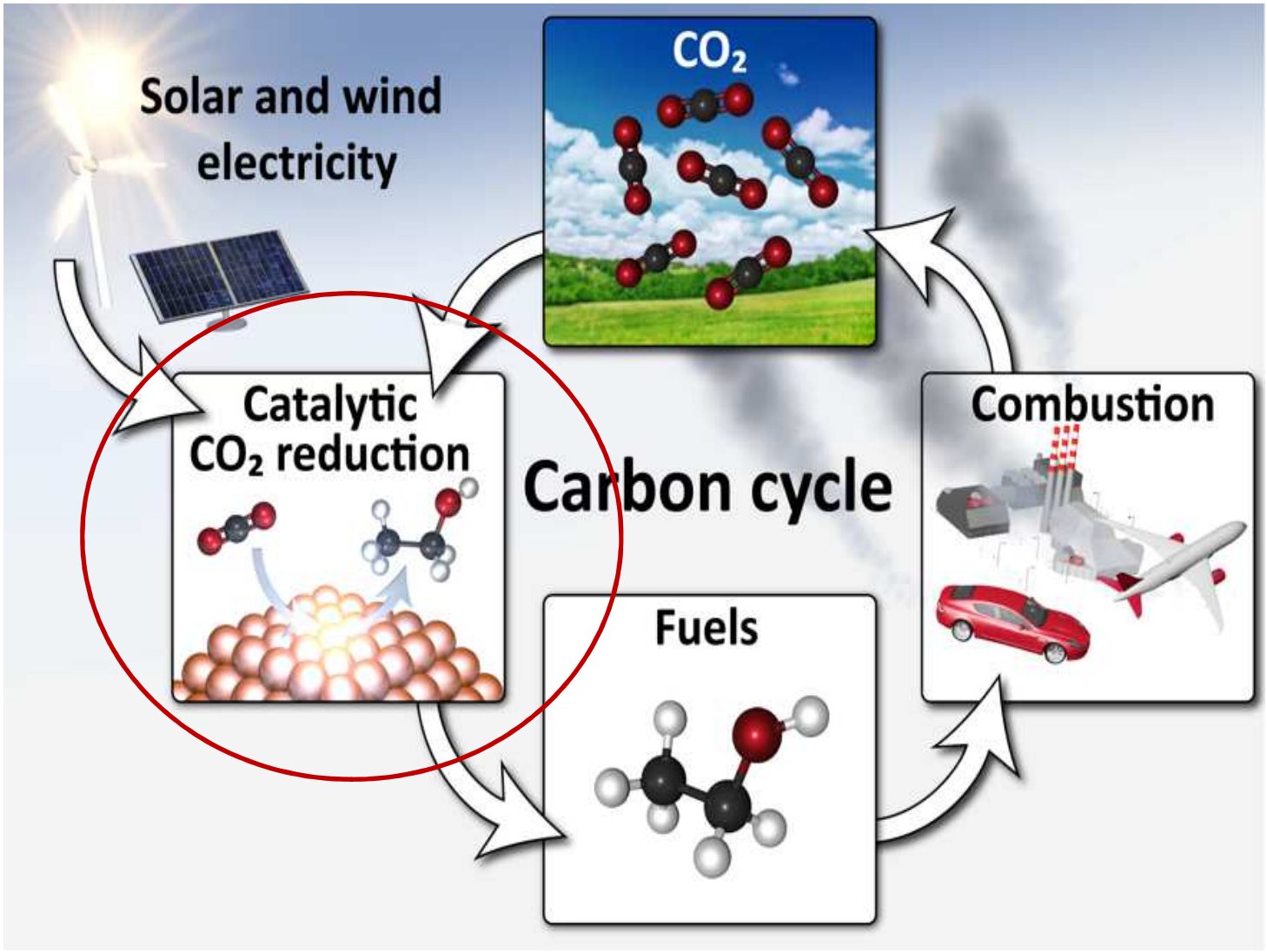


Image: Jakob Kibsgaard

The e-refinery

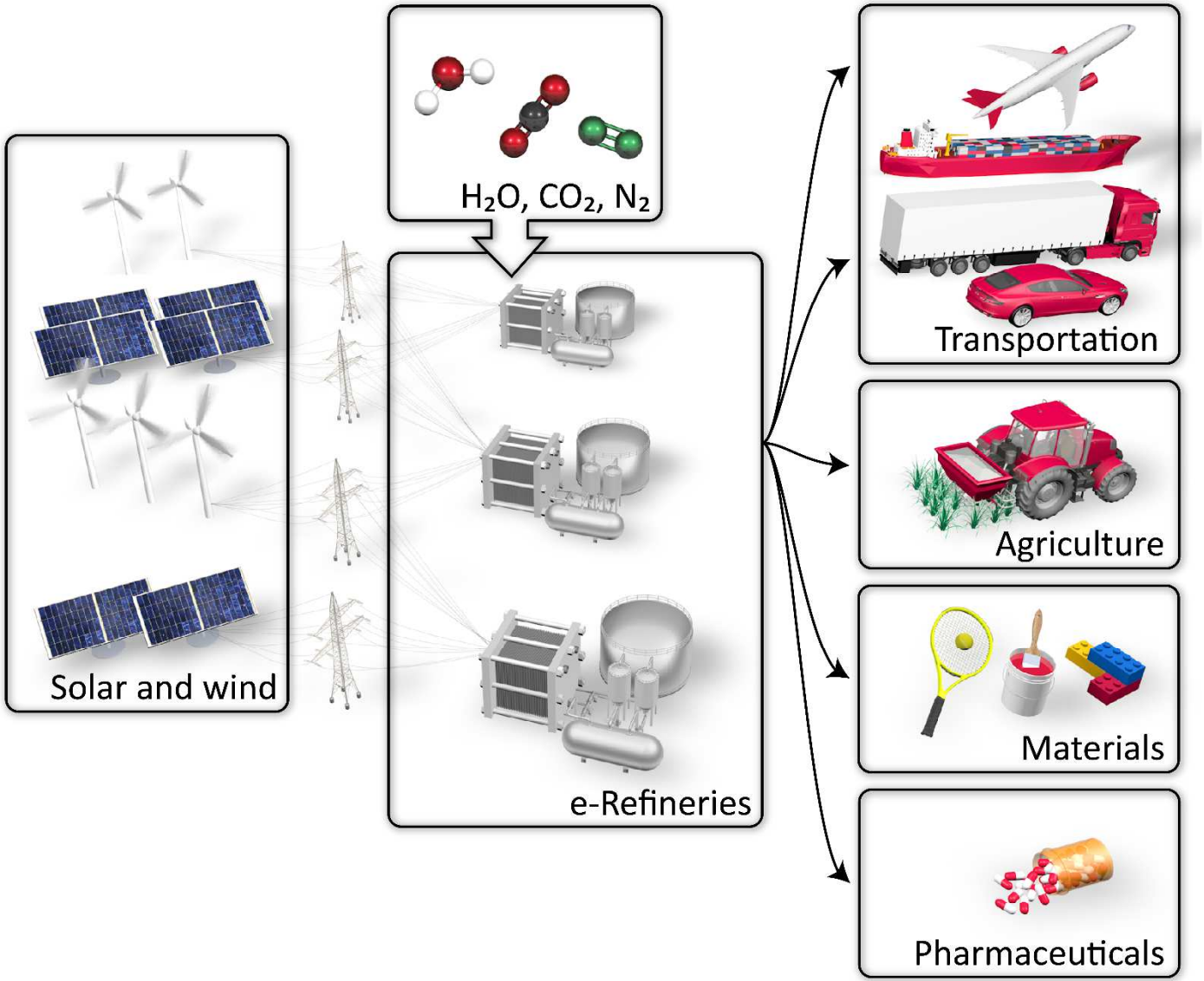
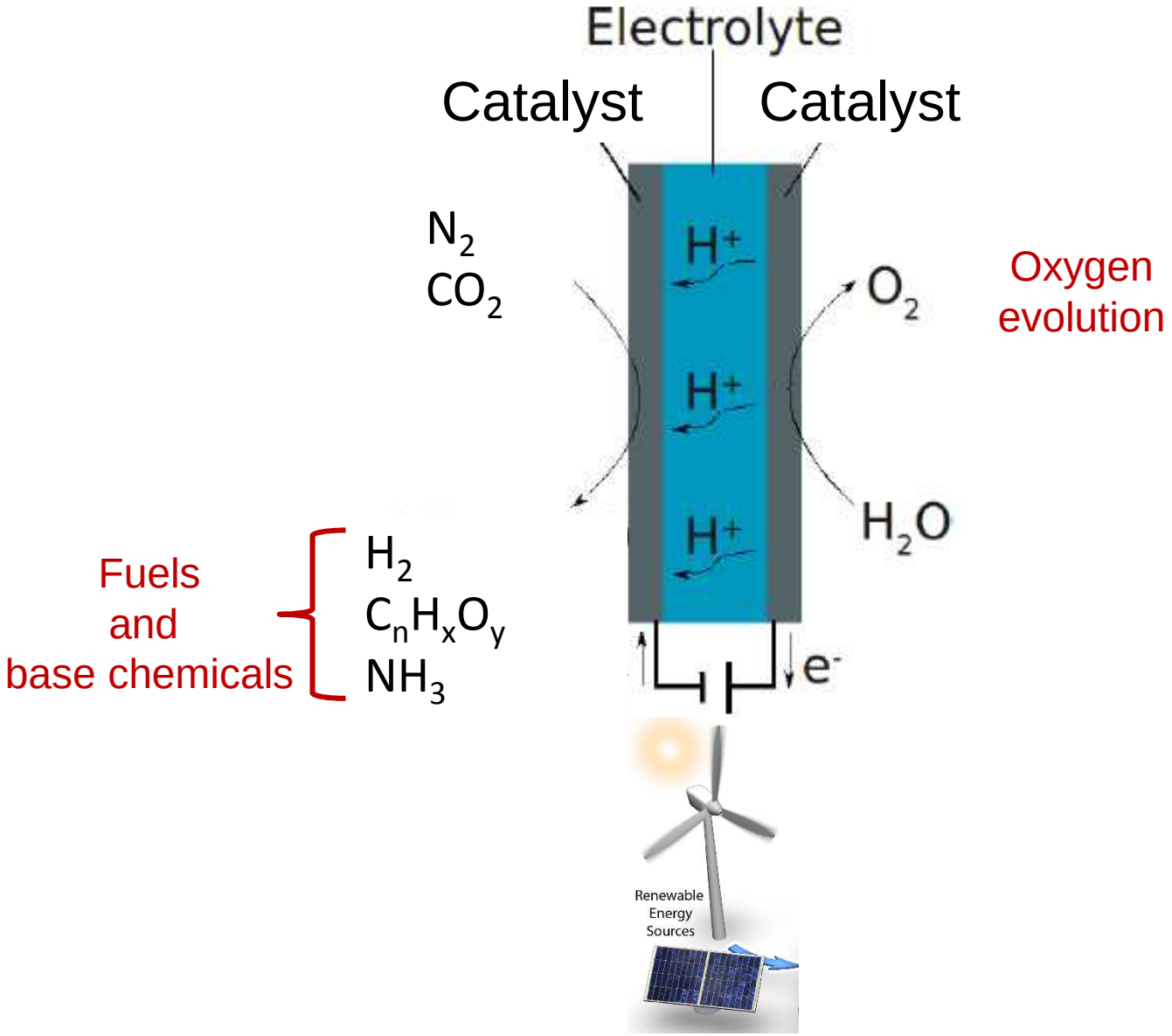
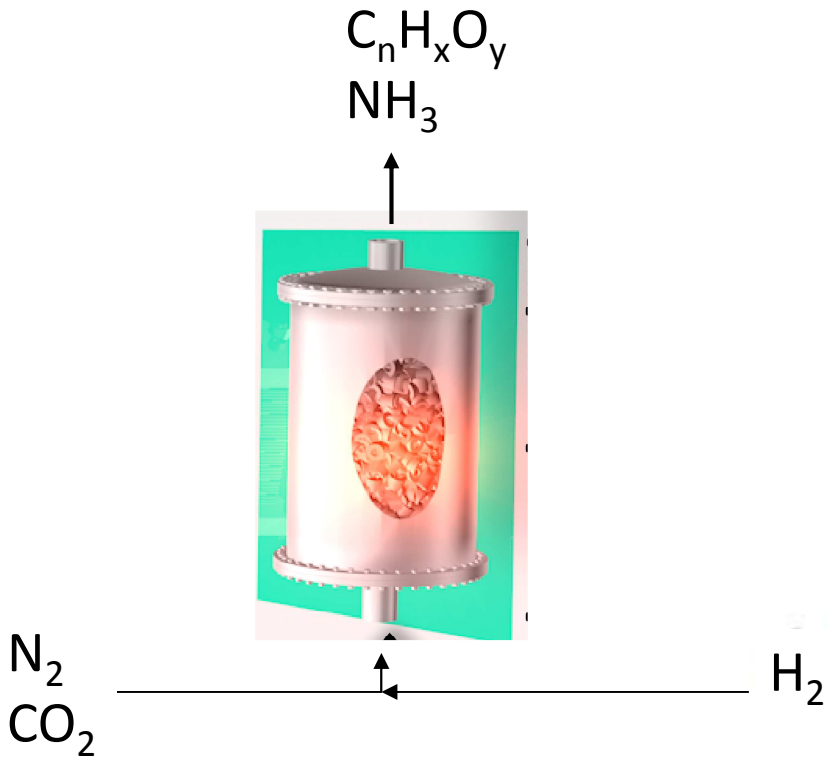


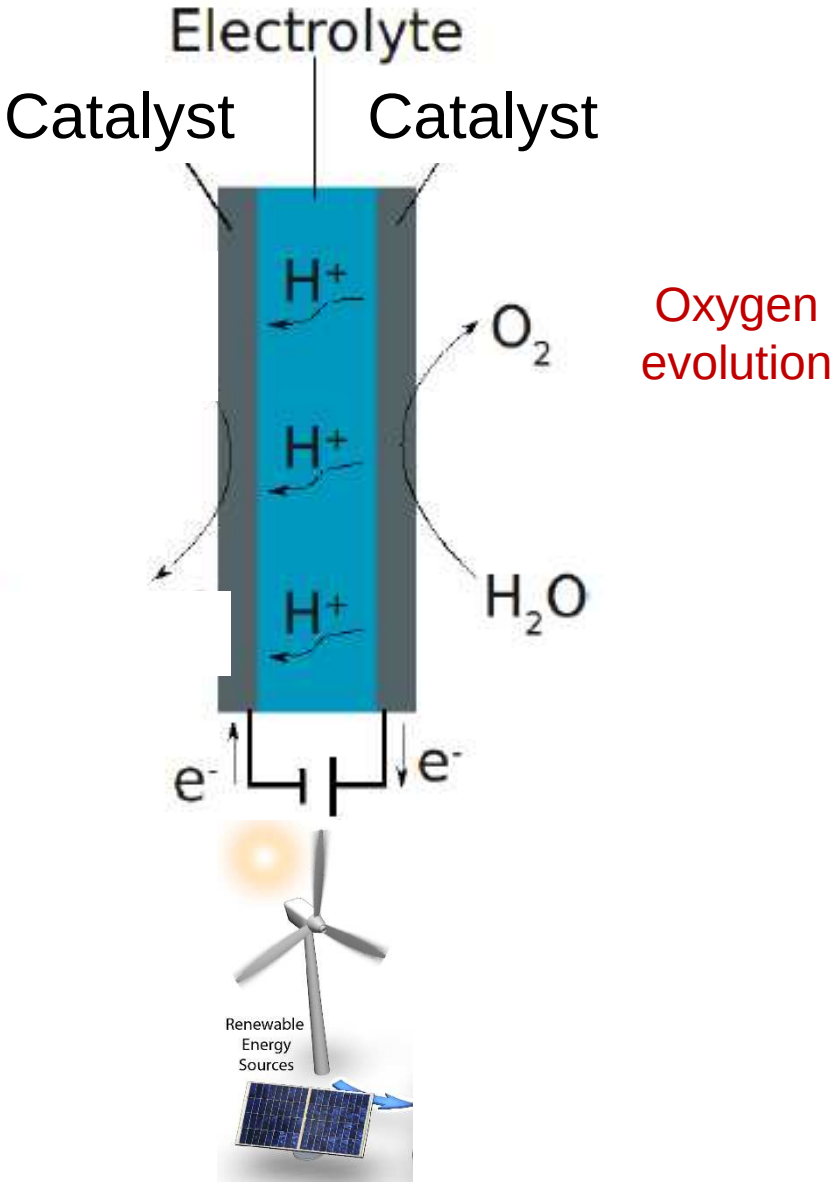
Image: Jakob Kibsgaard

Synthetic fuels I – artificial photosyntehsis



Synthetic fuels II – electrochemical+thermal





Oxygen evolution

Known technology but new challenges

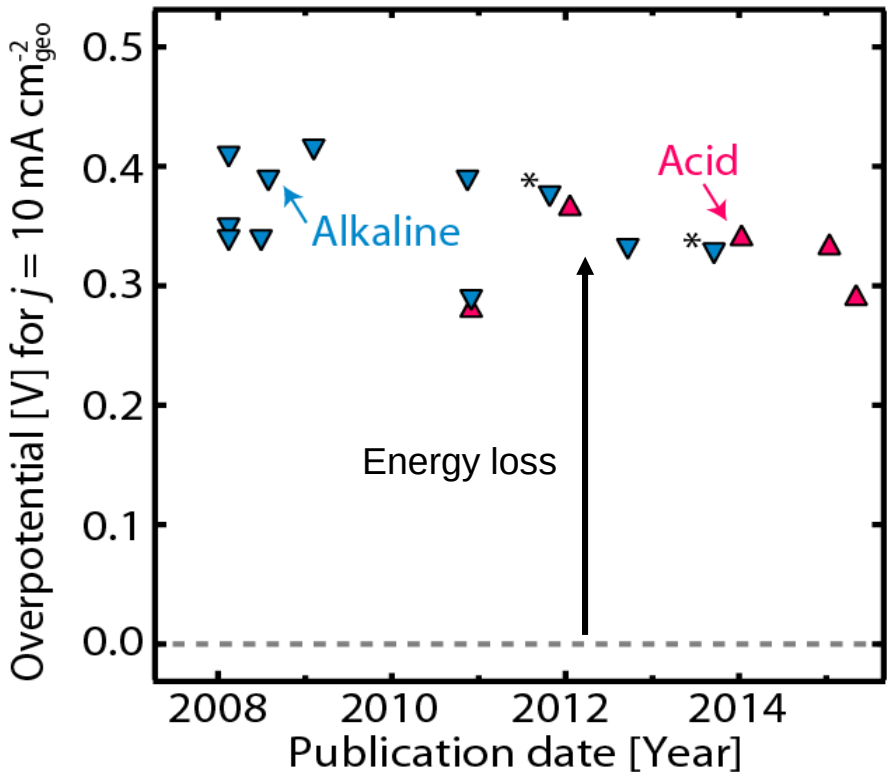
- Lower pressure processes
- Lower temperature processes
- Decentralized production

Challenges to catalysis science, an example

Oxygen evolution:

$2H_2O \rightarrow O_2 + 4(H^+ + e^-)$

Development in overpotential 2008-2017

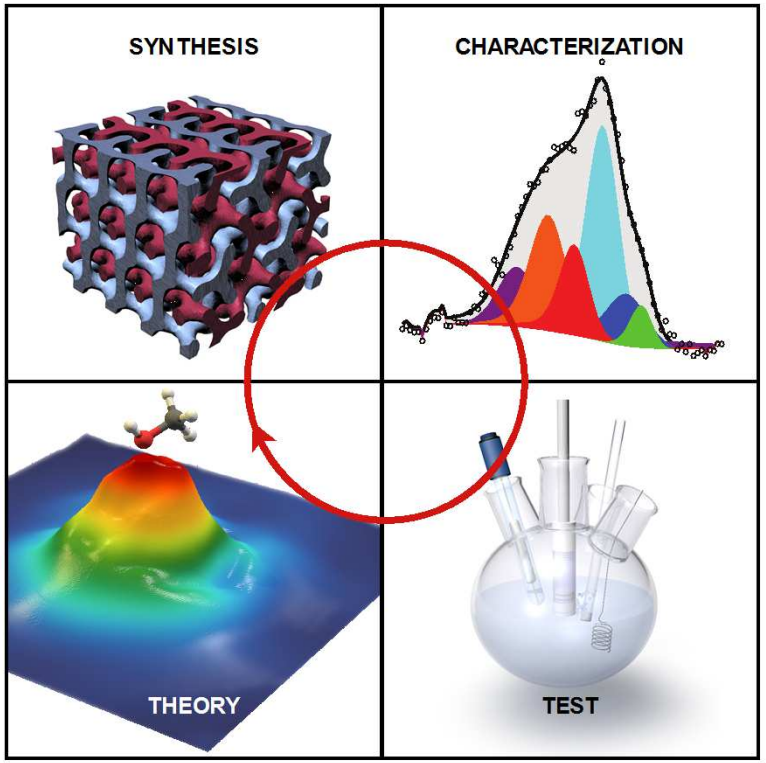


Seh, Kibsgaard, Dickins, Chorkendorff, Nørskov, Jaramillo, Science **355,** 146 (2017)

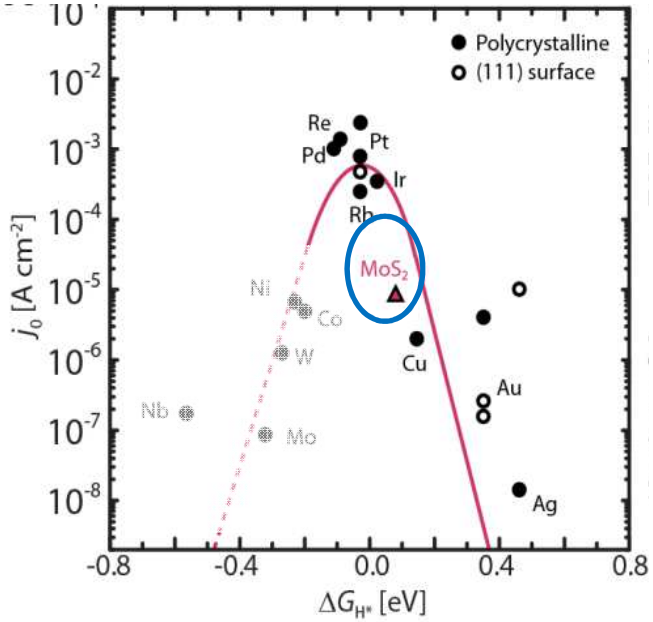
New scientific developments

New paradigm in materials discovery:

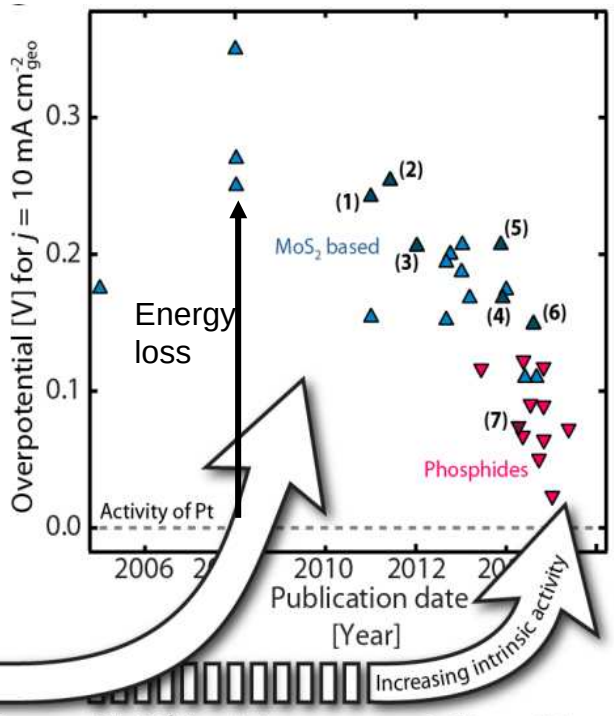
- New synthesis with molecular scale precision
- New advanced characterization methods
- Theoretical/computational materials design
- Data-driven methods and machine leaning

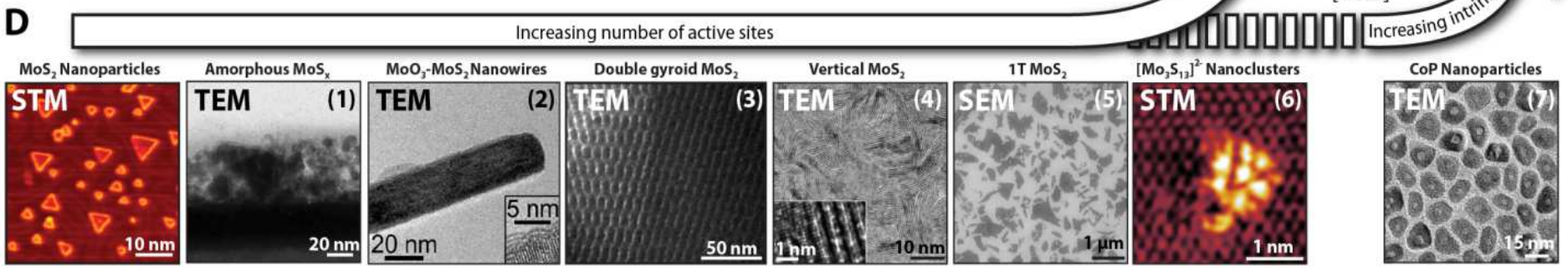


A recent success



$2(H^+ + e^-) \rightarrow H_2$

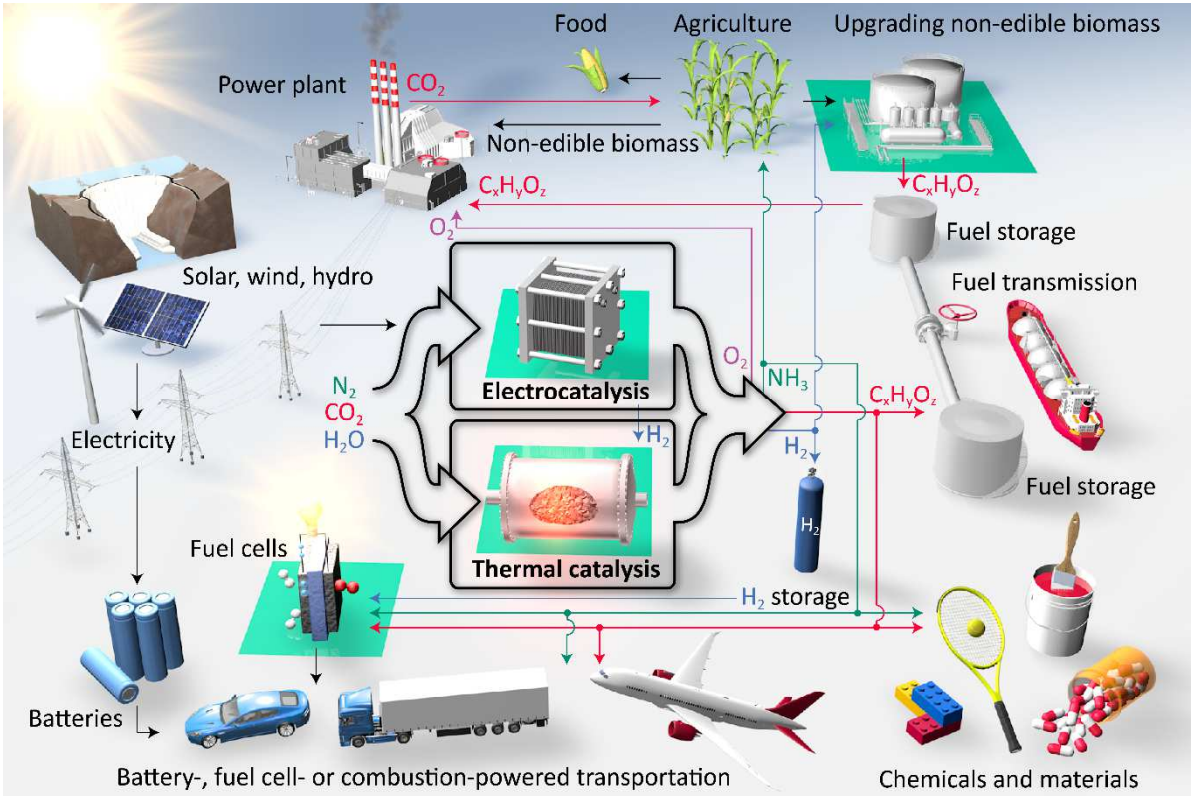




Seh, Kibsgaard, Dickins, Chorkendorff, Nørskov, Jaramillo, Science **355** (2017)

Energy-X – towards a sustainable energy system

https://www.energy-x.eu/



The Energy-X consortium

Nørskov, Chorkendorff, Weckhuysen, Schlögl, Centi, Corma, Gomez, Mougin, Bedel, Perez-Ramirez, Marain, Krtil, Witco, Rutkowska-Zbik, Schmidt, Förster, Bazzanella, Schneider