The energy revolution: how to reach a climate neutral industrial sector

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The energy revolution: how to reach a climate neutral industrial sector

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17 March 2016

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Never waste a crisis

Great Horse Manure Crisis (1894)

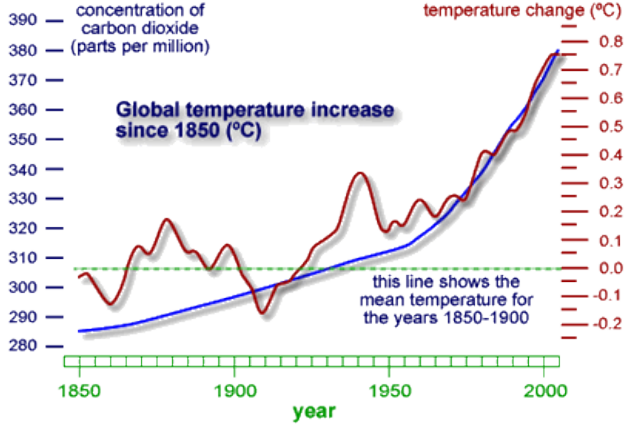
MORTON STREET, CORNER OF BEDFORD, LOOKING TOWARD BLEECKER STREET, MARCH 17, 1893.

The London Smog disaster (1952-53)

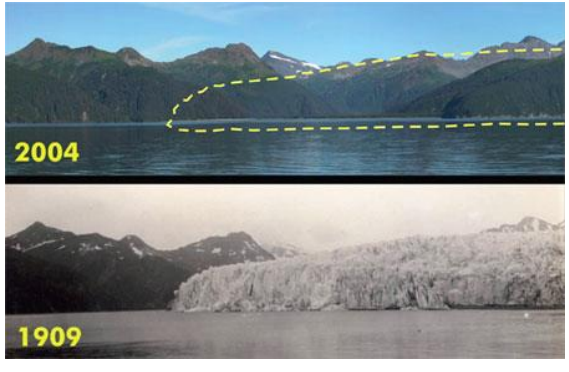
Acid Rain (1970s)

The crisis of today

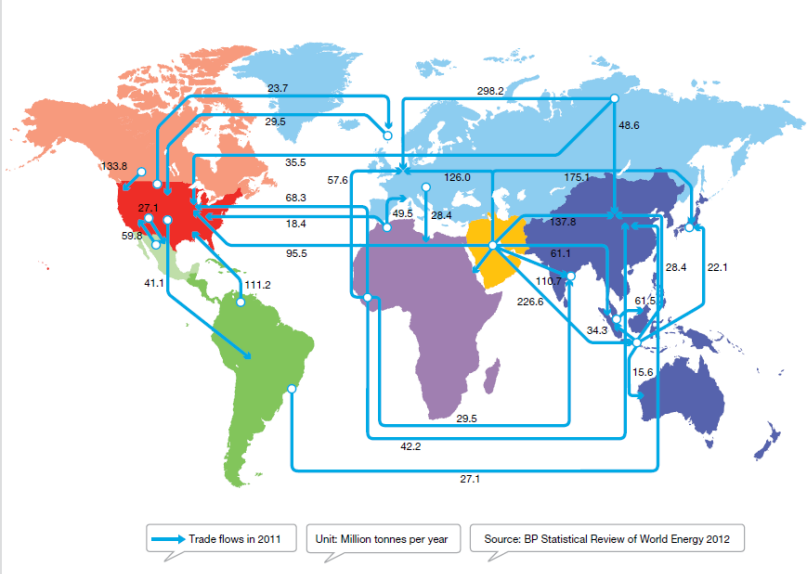
Global Warming



Source: ClimateChoice.org.uk



Security of Supply

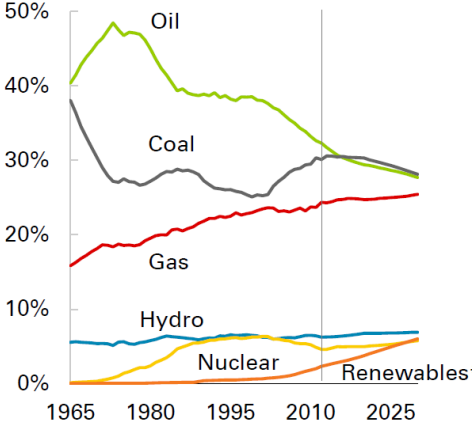


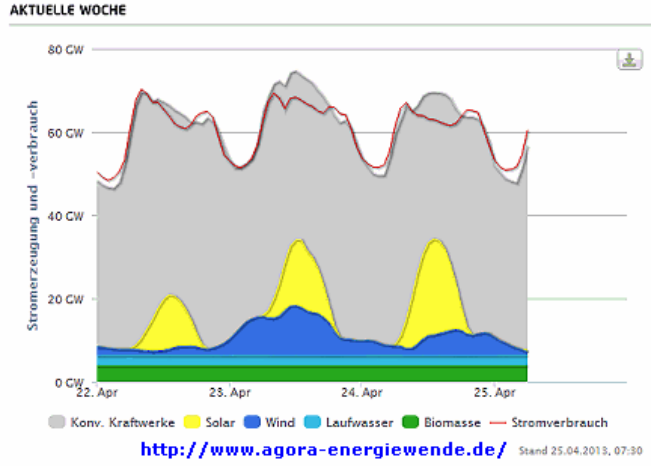
Source: BP Statistical review 2012

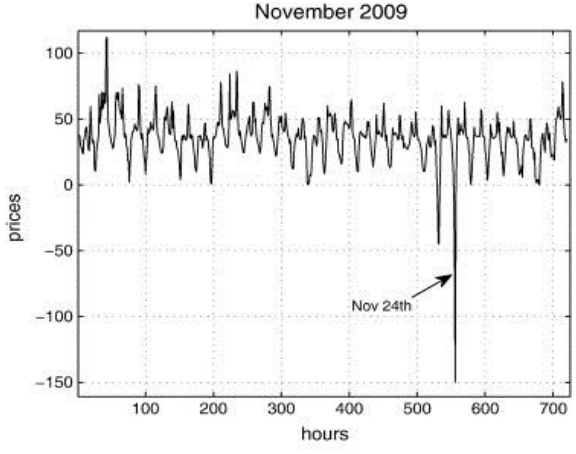
The electricity sector

The electricity sector is changing…

- Rapidly increasing **renewable electricity** *(wind and solar).*
- Local production of *fluctuating electricity leads to* ***inbalance****.*





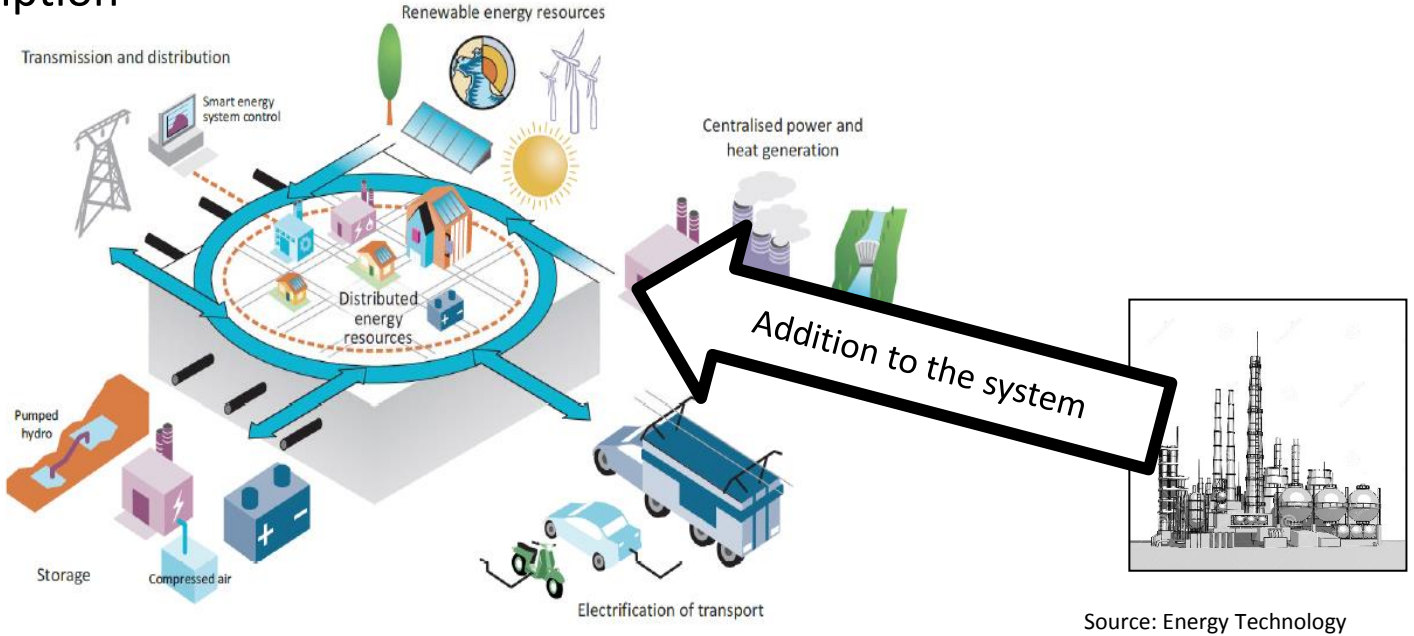


Source: BP Energy outlook 2013

Note: Worldwide renewable electricity capacity, excl. hydro, will increase from 4% (2011) to 12% (2030)

… demanding for a new Energy System

- Electricity will play an increasingly important role in energy systems
- Sustainable generation, smart distribution, and smart end-use consumption



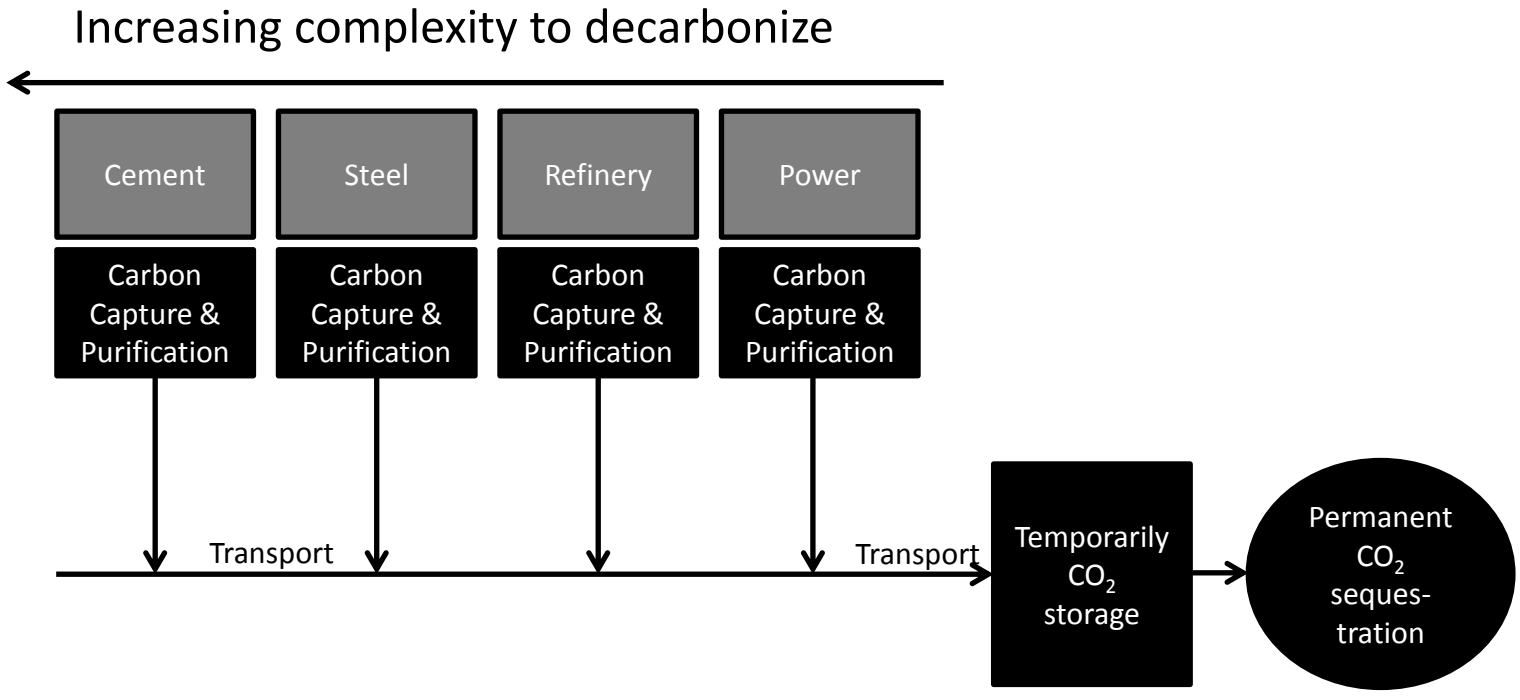
Source: Energy Technology Perspectives 2014 - Harnessing Electricity's Potential.

Role of CO_2 in a climate neutral society

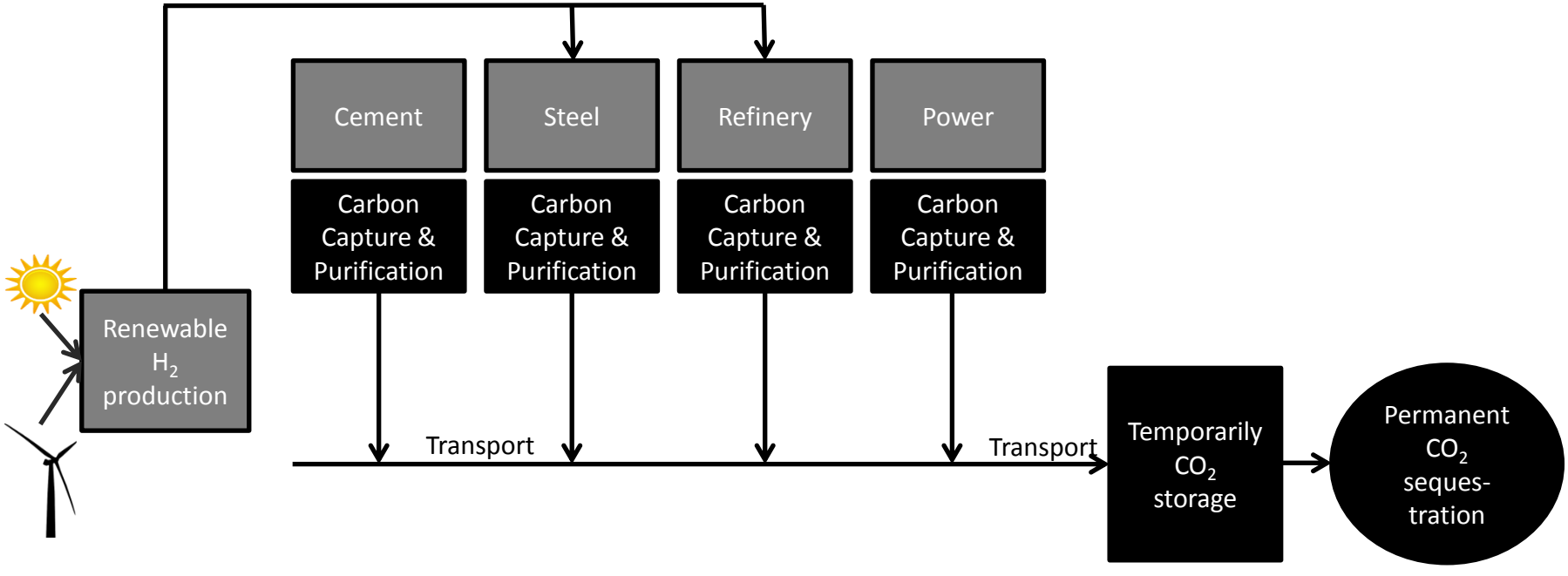
Thoughts and assumptions

- The economy is likely to be carbon based, even if the energy supply is dominated by intermittent renewable electricity generations
- Liquid carbonous fuels remain dominating for shipping, long haul trucking, air transportation
- Some major industrial sectors will continue to produce CO/CO_2, even well beyond 2050
  - Cement industry
  - Steel industry
  - others
- Most carbon in the feed stocks does not end up in the final product (ratio 1:18 or so)
  - Main use is for the energy content, other than the chemical energy required to make a reaction.
  - Significant non energetic uses include
    - As a reductant (bauxite to aluminum, iron ore to iron)
    - Decarbonization of limestone to CaO
    - Etc
- But all carbon ends up in CO_2 at one stage….

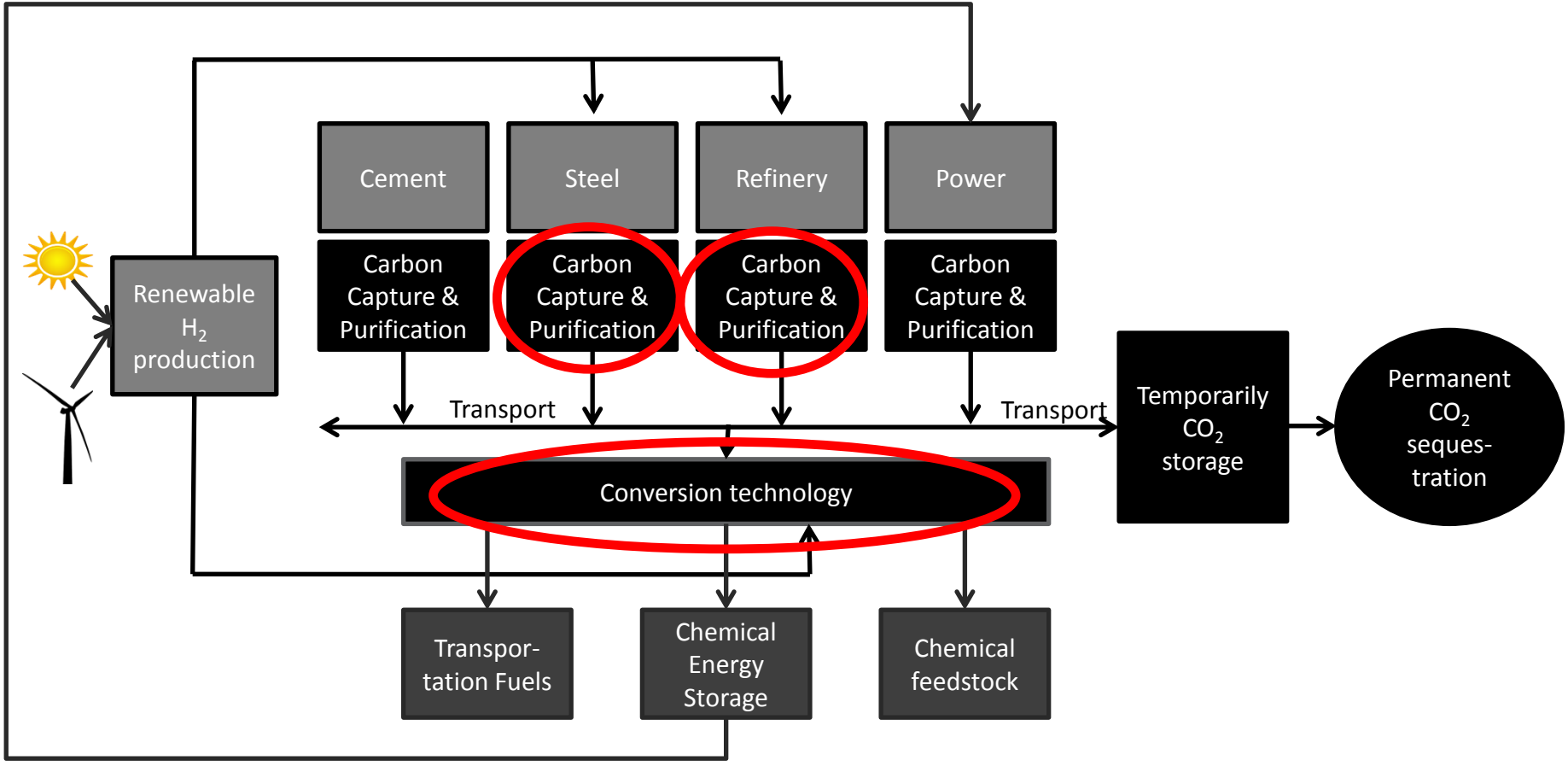
Conventional Carbon Capture and Sequestration



Increasing renewable electricity

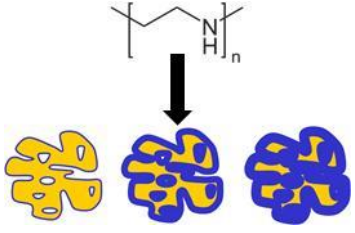
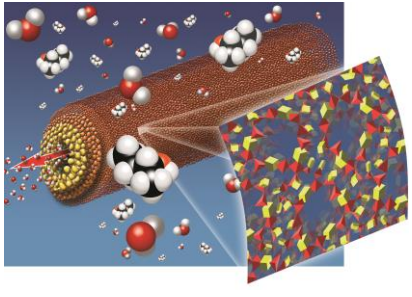


Renewable electricity dominates the energy market



Gas Phase Processing

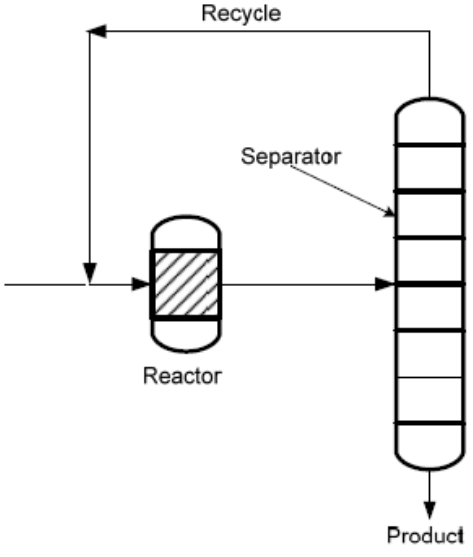
Industrial gases
Membranes and sorbents

	T ≤ 150 °C	T ≥ 300 °C
Advanced sorbents	 Immobilized amines	 Alkasorb®
Advanced membranes	 HybSi®	 HySep®

Thermodynamic limitations

- Conversions hindered chemical equilibria
  - Large recycle streams
  - Complex separator
  - Low conversions
  - Mediocre single pass yields
  - Poor energy efficiency
  - High costs

- Solution: *in-situ* removal of one of the products



Ammonia – Methanation – Water-Gas Shift – Reverse Water-Gas Shift – Methanol – Steam Reforming – Condensation Reactions - Dehydrogenation

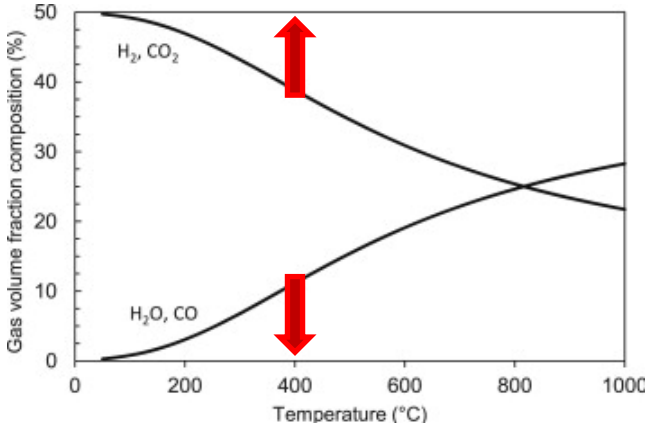
Separation promoted Water-Gas Shift

- Applications in Carbon Capture and hydrogen production

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H = -41\ kJ/mol$$

In situ removal of ONE reaction product

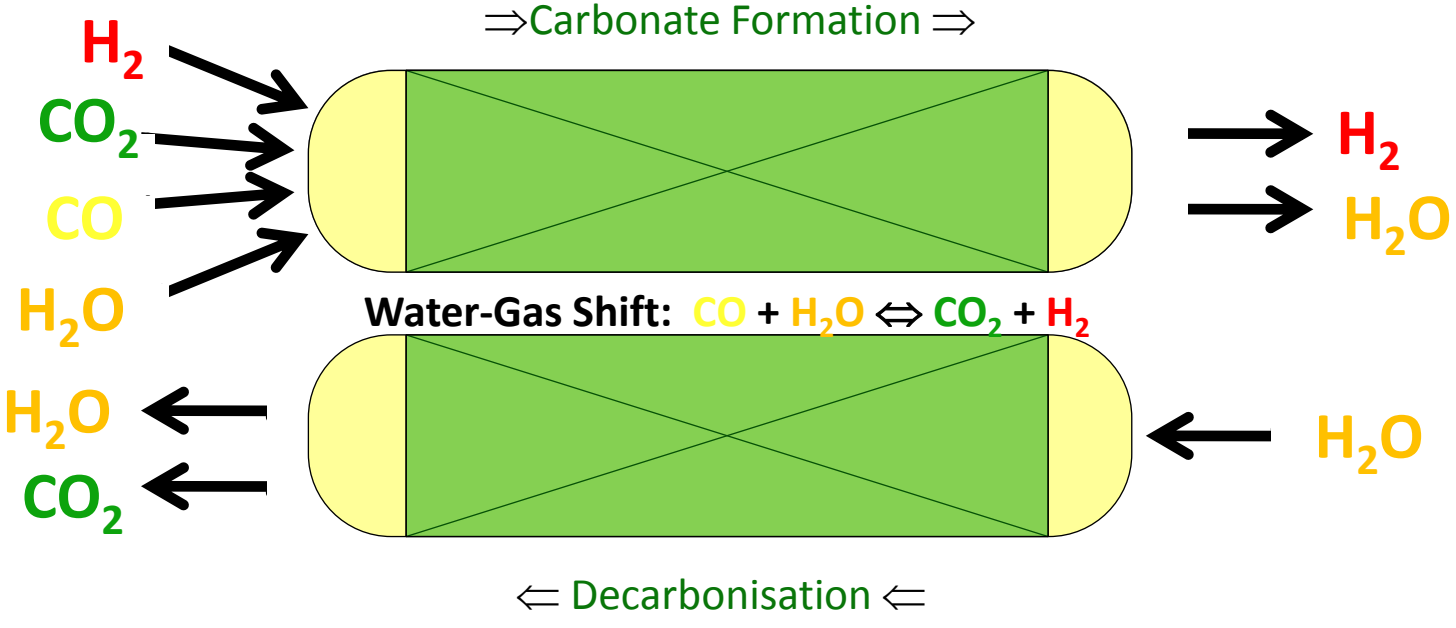
- Normal Reaction Conditions
  - Two stage conversion of CO
    - 12% → 3% → 0.5%
    - 350-400°C → 180-250°C
  - 20-30 bar



Sorption Enhanced Water Gas Shift reaction for carbon capture

The Intensification Step

- Combines the Water-Gas-Shift reaction with sorbent material to simultaneously produce H_2 at high temperature whilst also capturing CO_2



Testing and development on multiple scales

- Facilitating testing of new material and new conditions
- Scaling-up for manufacturing and full process simulations

8 x 2g

High Throughput Comparative Testing

10g

Adsorption Isotherms Realistic Conditions

2kg

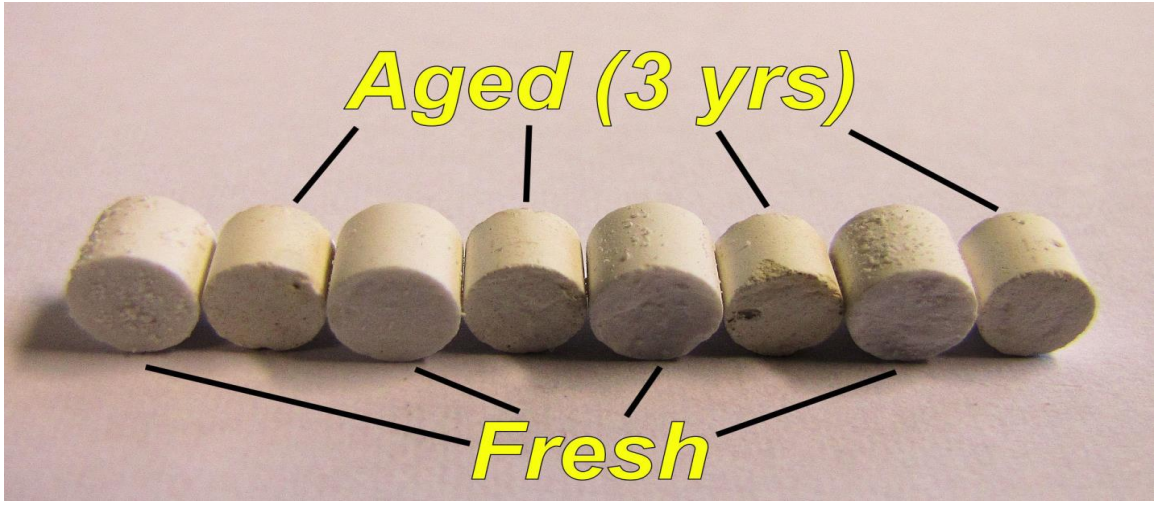
Industrially Relevant Materials

100kg

Pre-pilot Full-Cycles

Sorbent “stress test”

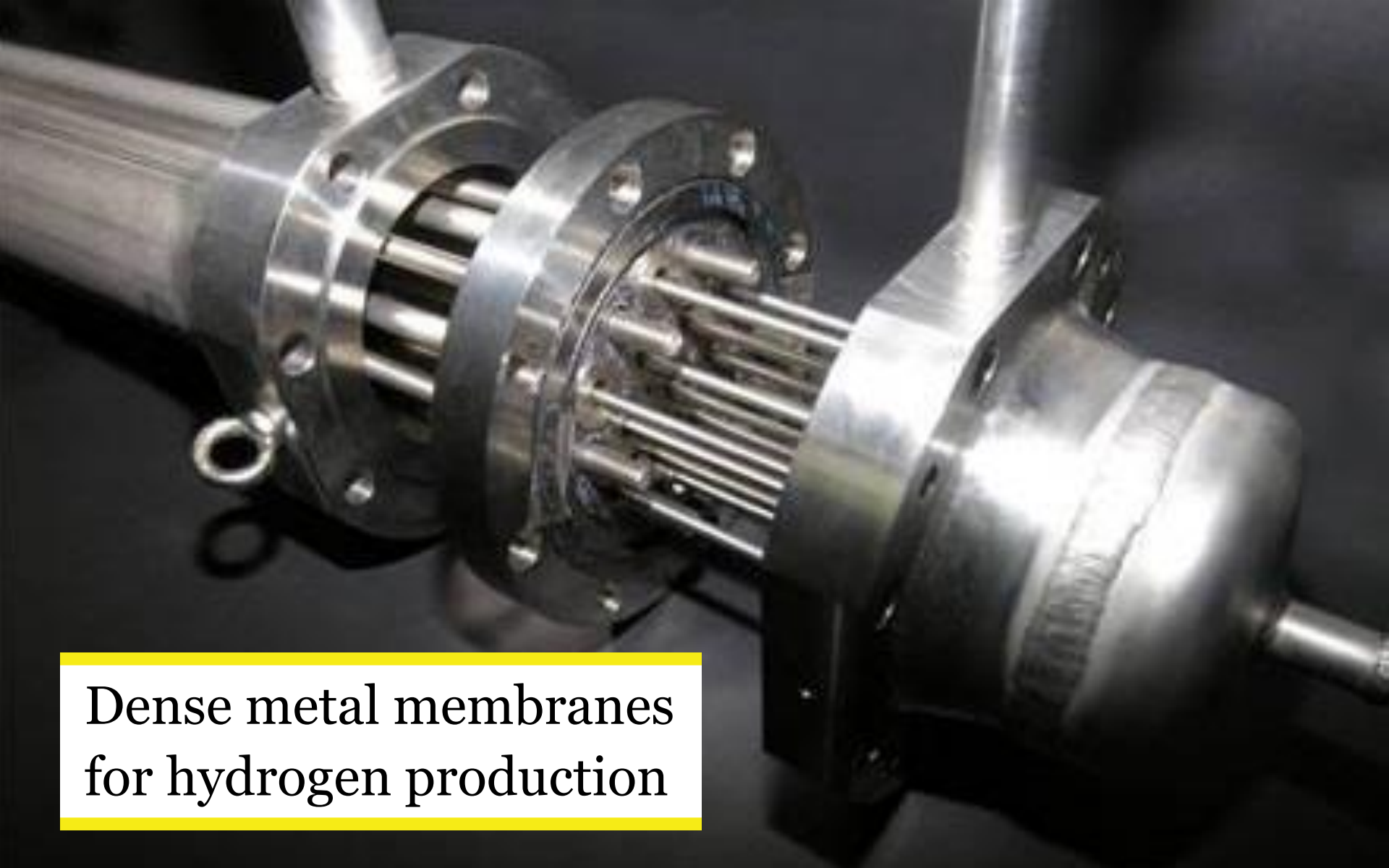
- Stability of the CO_2 sorbent ALKASORB
  - Combined adsorbing and catalytic activity of material for more than 5000 cycles
  - No deterioration was observed



Building now

- At ECN laboratory
- 100 kg of sorbents

- In the steel industry
- 14 ton CO_2/day



Dense metal membranes for hydrogen production

Methane steam reforming at pre-pilot scale

Hydrogen membrane reactor

- Hydrogen production : 2 Nm^3/h
- Methane conversion increase > 30%
- 1000 hour long term testing at 7 bar

- Ambition
  - Continued testing at high pressure to increase methane conversion to >90%

HYSEP®
Hydrogen Separation Modules

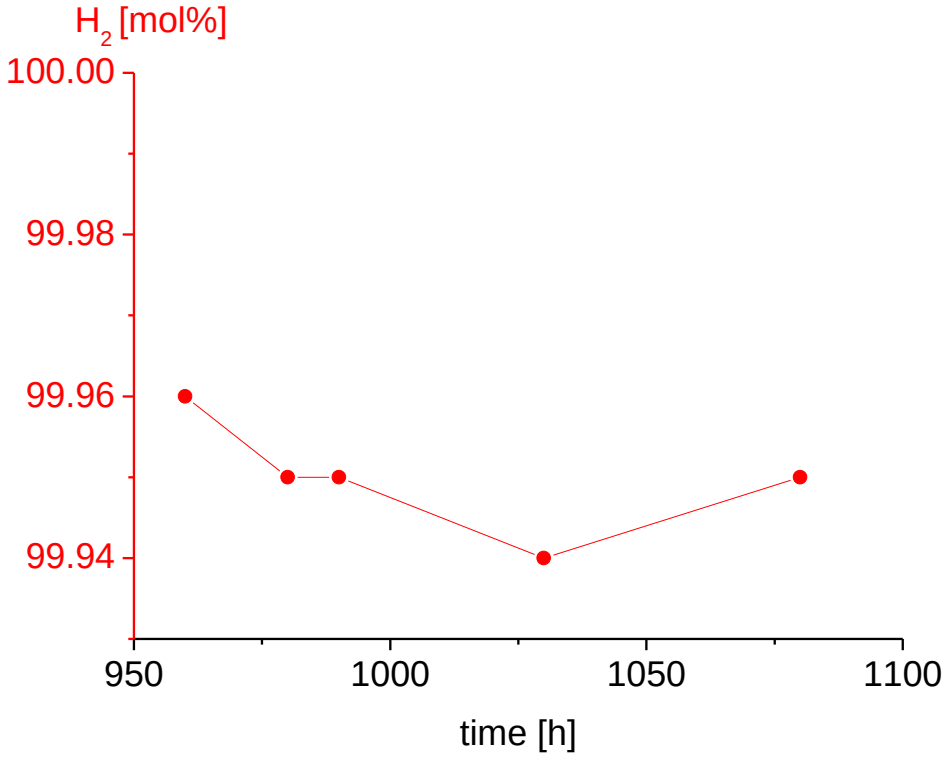
Pre-Pilot membrane testing

- Hysep module 1308
- Membrane area = 0.4 m^2
- 13 membranes, 26 seals, L = 70 cm

Designed parameter	Value
H_2 production[$Nm^3 \cdot h$]	4-6
H_2 max. recovery [%]	30
H_2 purity[%]	>95
T [°C]	450
P_{feed} [bar]	21

HYSEP®
Hydrogen Separation Modules

From 32% to 99.95% H2 purity

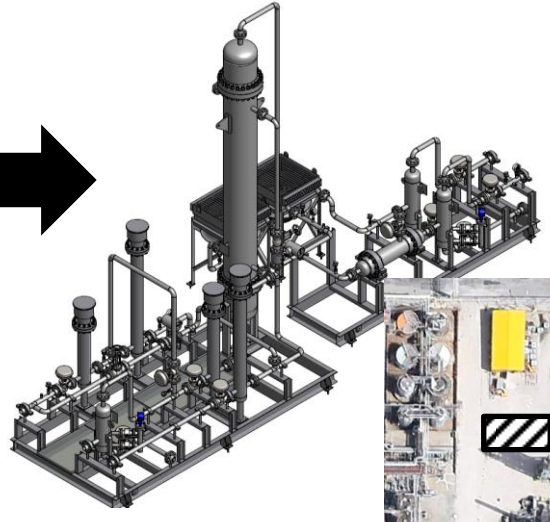


Feed

CO_2 ~ 6 mol%
CO ~ 2 mol%
H_2O ~ 50 mol%
H_2 ~ 32 mol%
CH_4 ~ 10 mol%

HYSEP® Hydrogen Separation Modules

Near future ambition



HYSEP®
Hydrogen Separation Modules

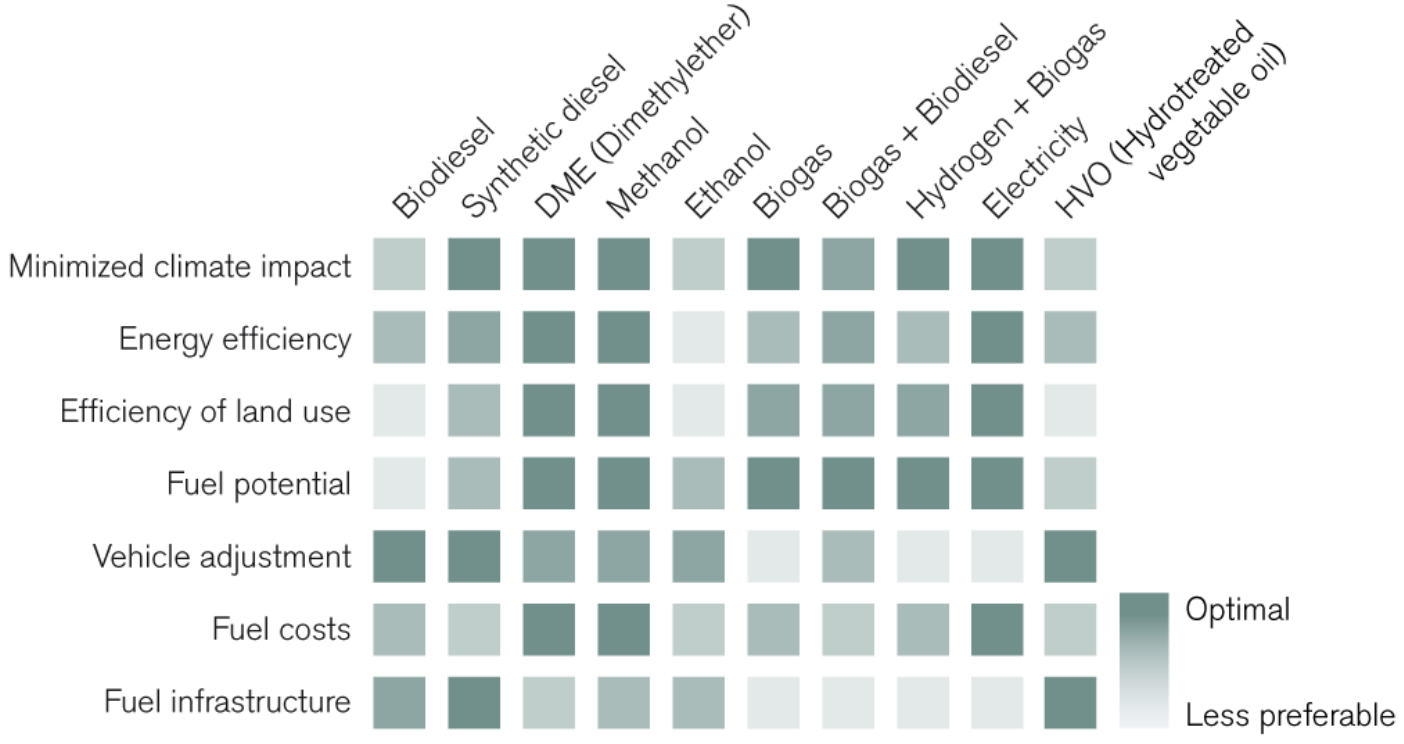
- Purposed built pre-pilot
- 4 Nm^3/h H_2

- Full on-site pilot,
- 50 Nm^3/h H_2

DME the new fuel from renewable sources

Photo: Volvo Trucks

Evaluation of fuel pathways



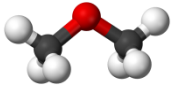
Source Volvo Sustainability report 2013

DME- Highlights

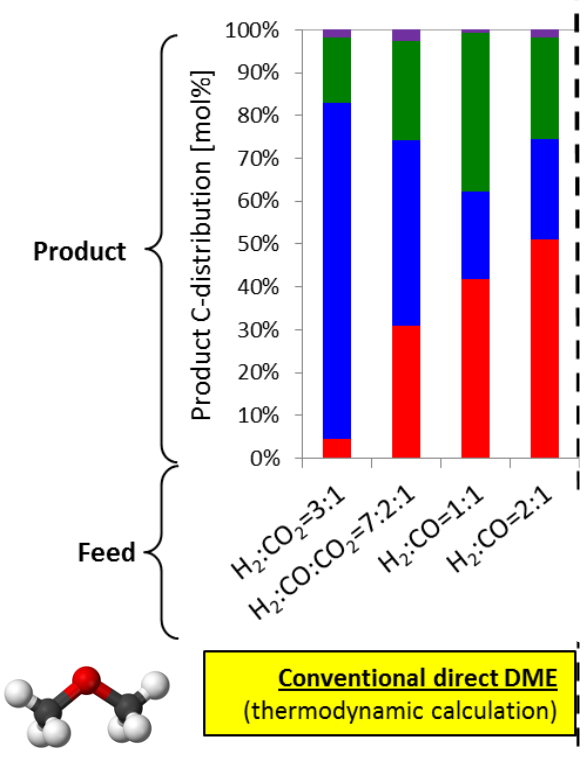
Main reasons behind interest in DME

- One of the most promising fuels from GHG, efficiency and cost perspective on a Well To Wheel basis
- Can in principle be applied in most applications
- Potential for simple exhaust after-treatment due to absence of soot

- Can be handled like LPG, in refueling etc
- Behaves like diesel in an engine



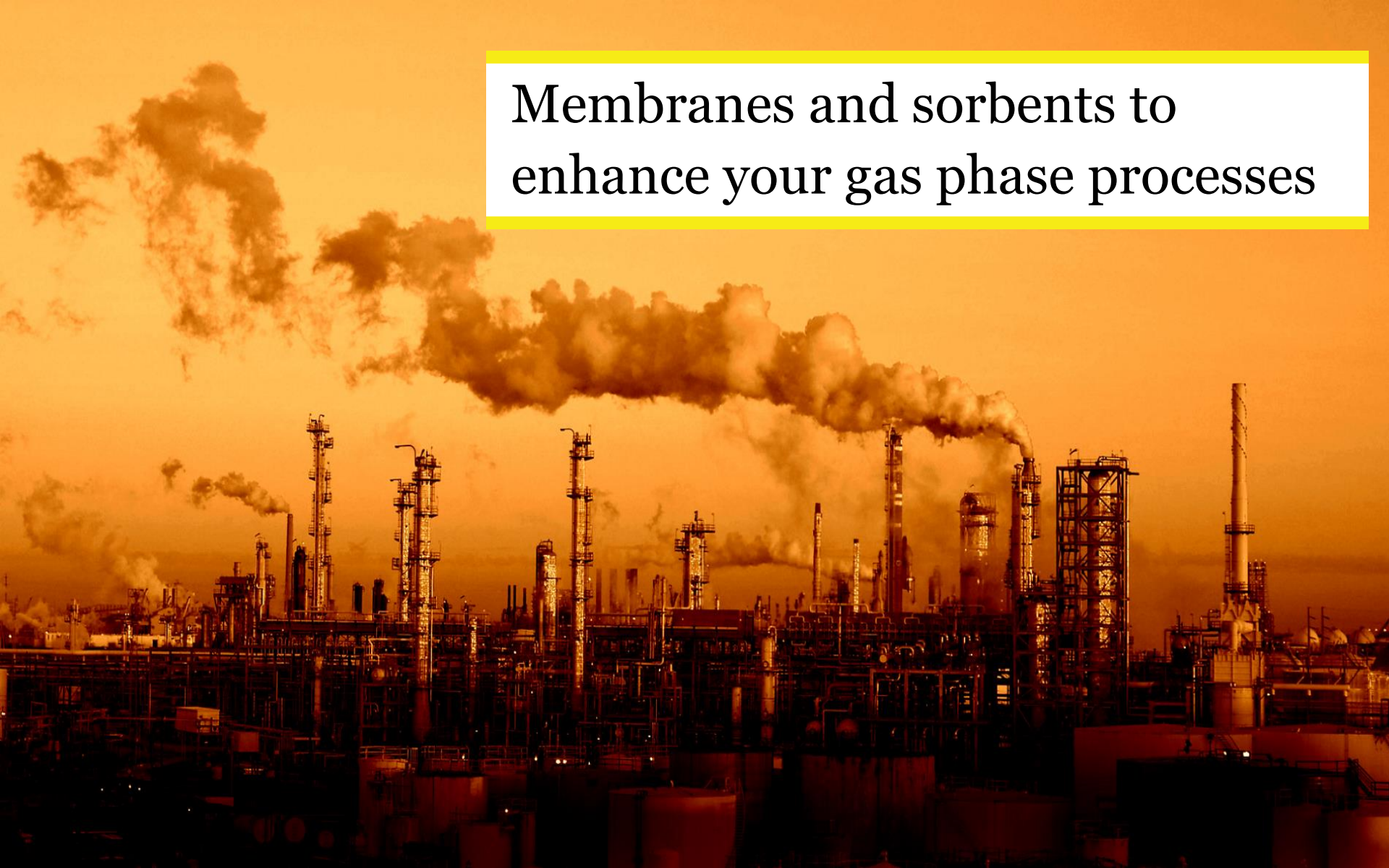
Making DME in the lab



- Major thermodynamic limitations
- Water removal can assist to overcome this!

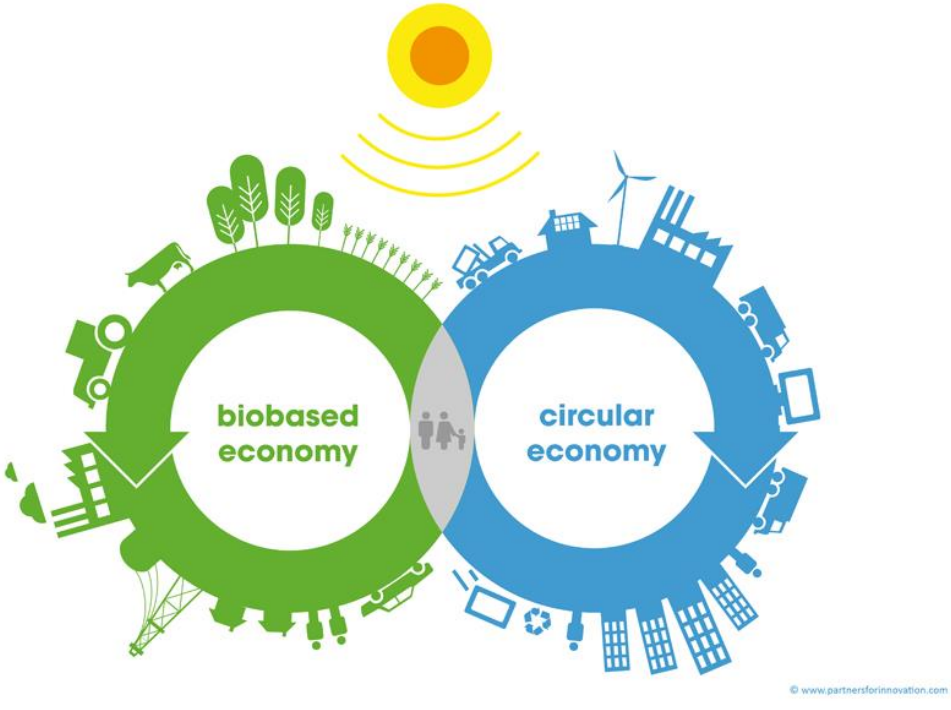
Next steps

- Increase conversions further
- Determine feasibility and profitability
- Scale-up towards continuous production



Membranes and sorbents to enhance your gas phase processes

The dream



- Closing the loop
- Waste free society
- Novel technologies ready to be implemented

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Timber storage in Sweden after “Gudrun” storm, 2005, 1 month fuel for SSAB blast furnace

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