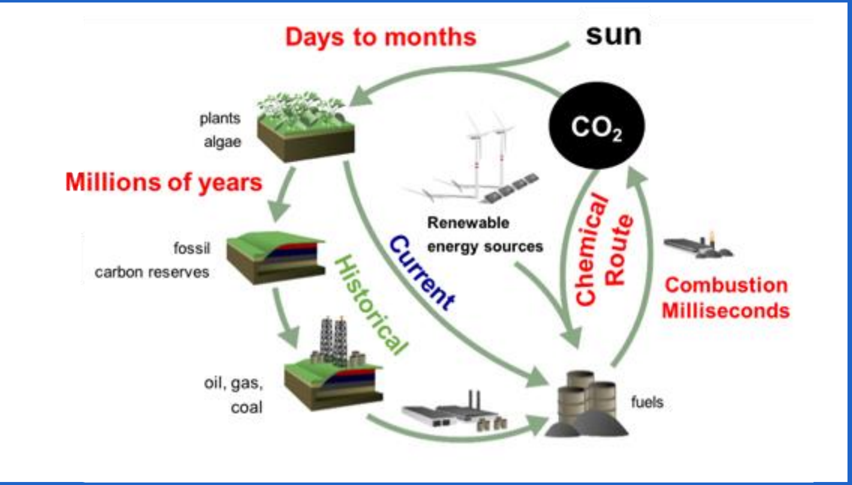
Thoughts on CCS/U



Mark SAEYS, Laboratory for Chemical Technology, Ghent University

Grégoire LEONARD, Department of Chemical Engineering, University of Liège

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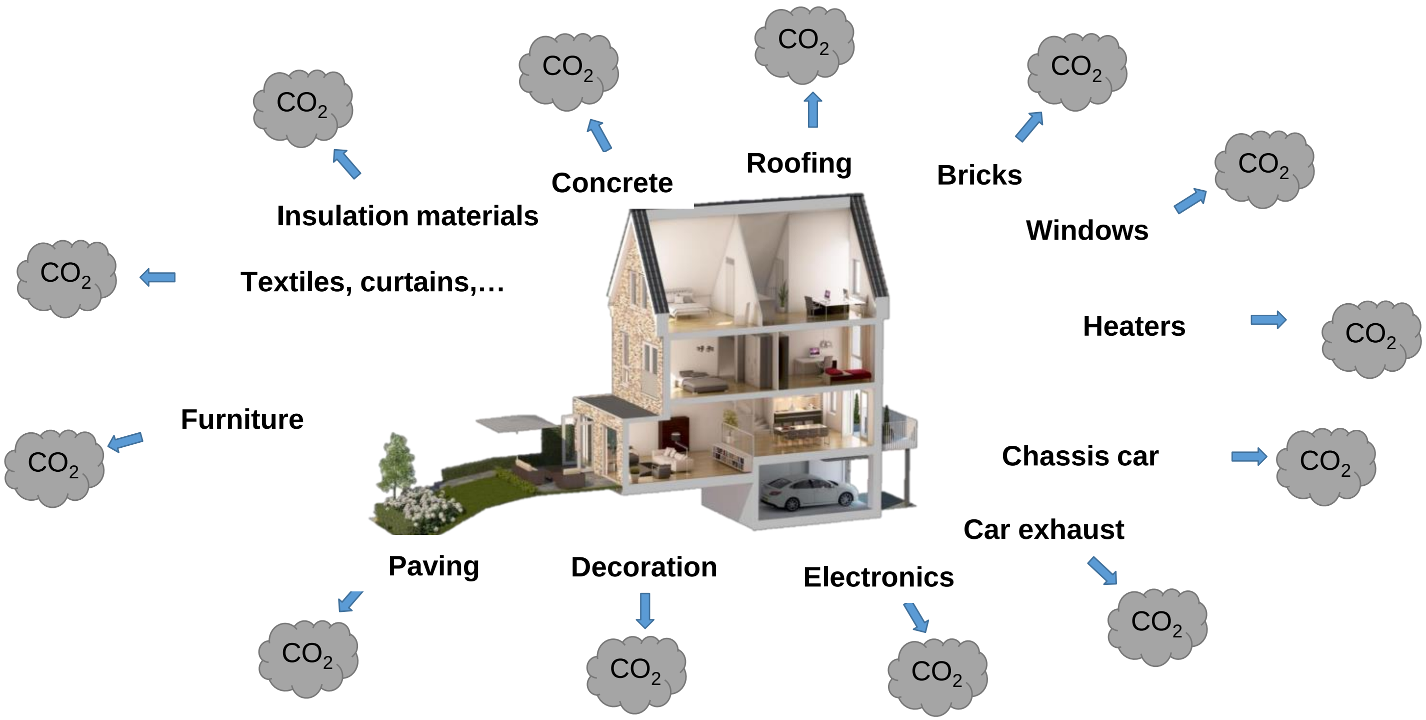
Carbon-based Society



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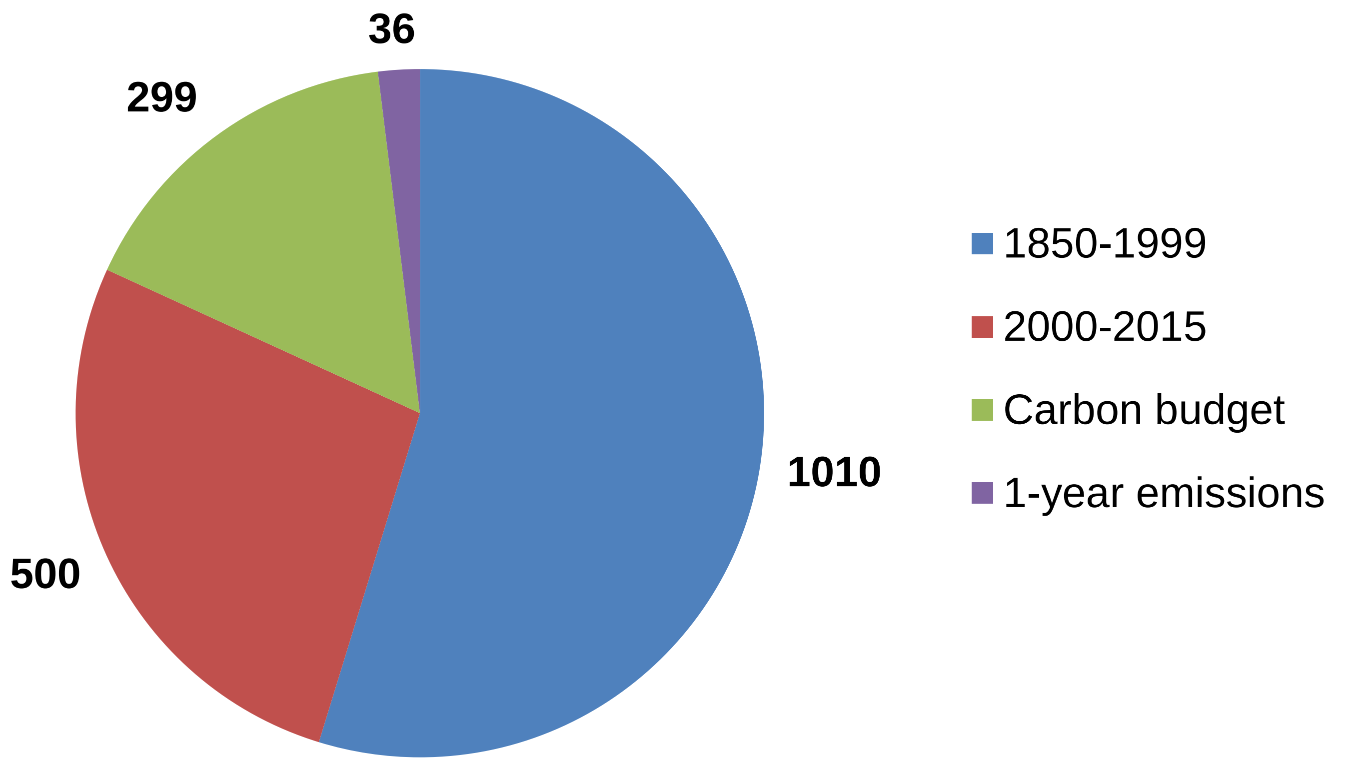
CO_2 Budget

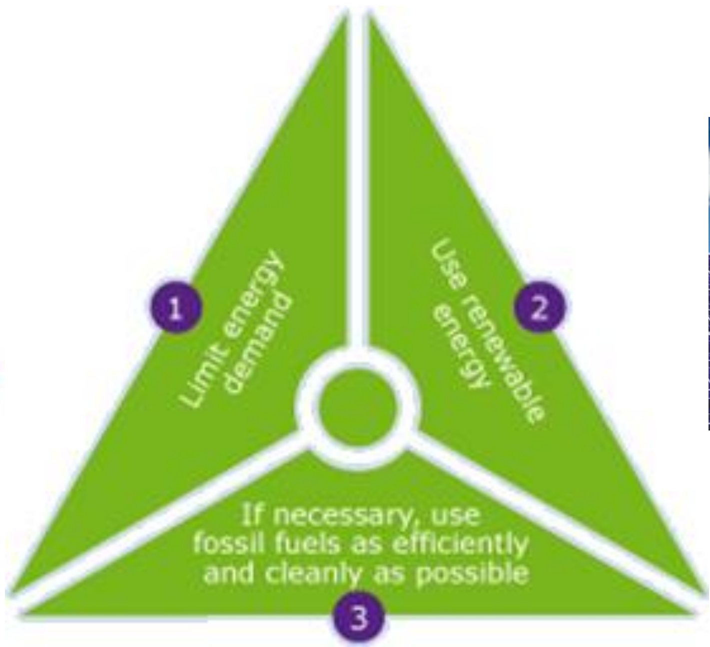
Budget by 2050 for having 80% chances to stay below 2°C



Note: Values in Gt CO_2 eq

IPCC, SR15 (2018).

Possible answers: Trias Energetica



Lysen E., The Trias Energica, Eurosun Conference, Freiburg, 1996

CCUS = Carbon Capture, Utilization and Storage

- Carbon capture and storage
  - Sources usually contain CO_2, N_2, H_2O, H_2, CH_4, O_2 …
  - CO_2 concentration varies between 0.04% and almost 100%
  - => fluid separation process
  - Mature & flexible, but cost only!

- Storage and re-use already existing
  - Pure storage: ~ 5 Mtpa
  - Re-use: ~ 250 Mtpa in 2016 (15% EOR, 50% Urea, 35% others)

Global CCS Institute 2017

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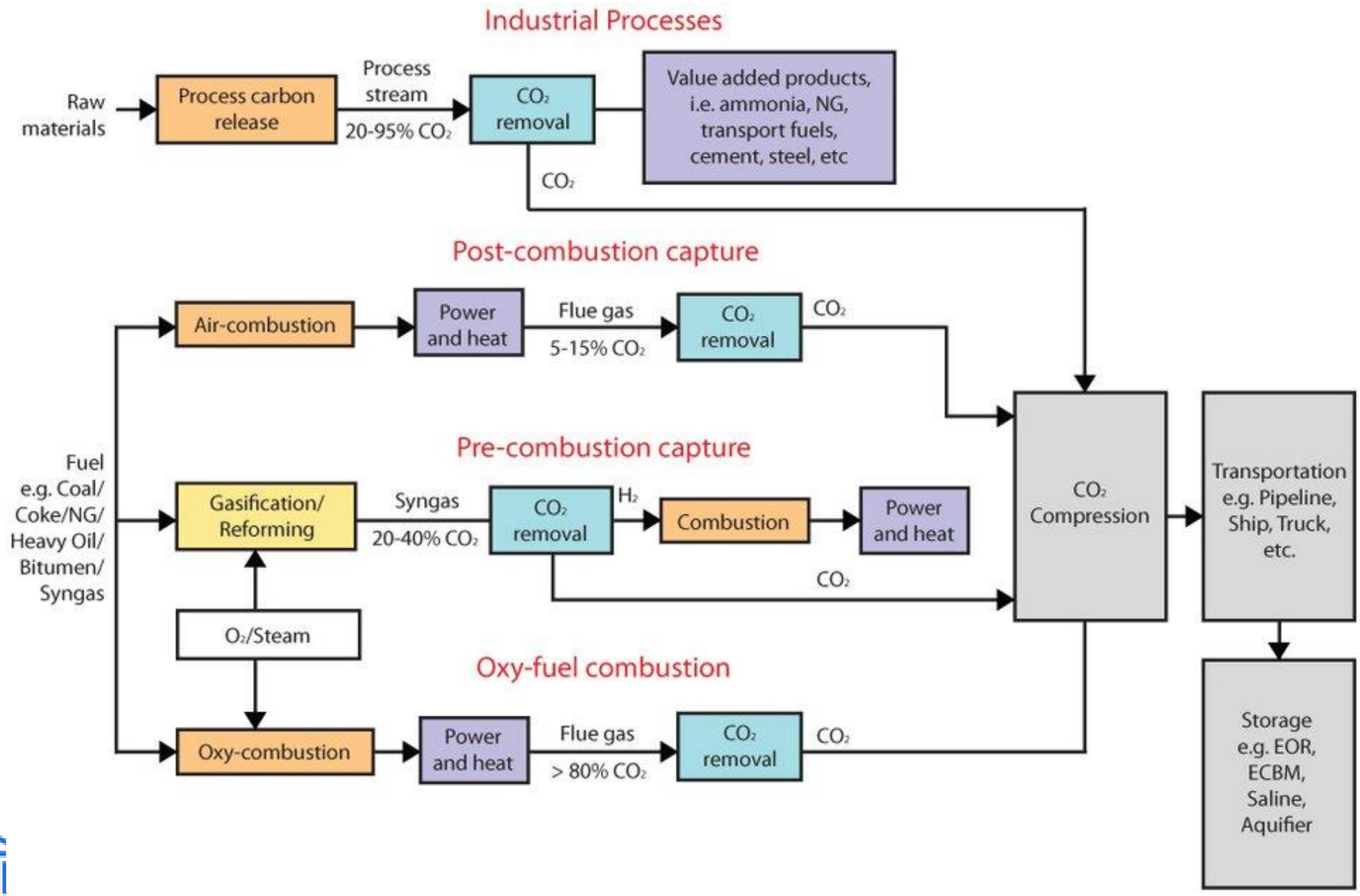
CO_2 capture

CO_2 capture configurations



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CO_2 capture: Pros and cons

Pros:

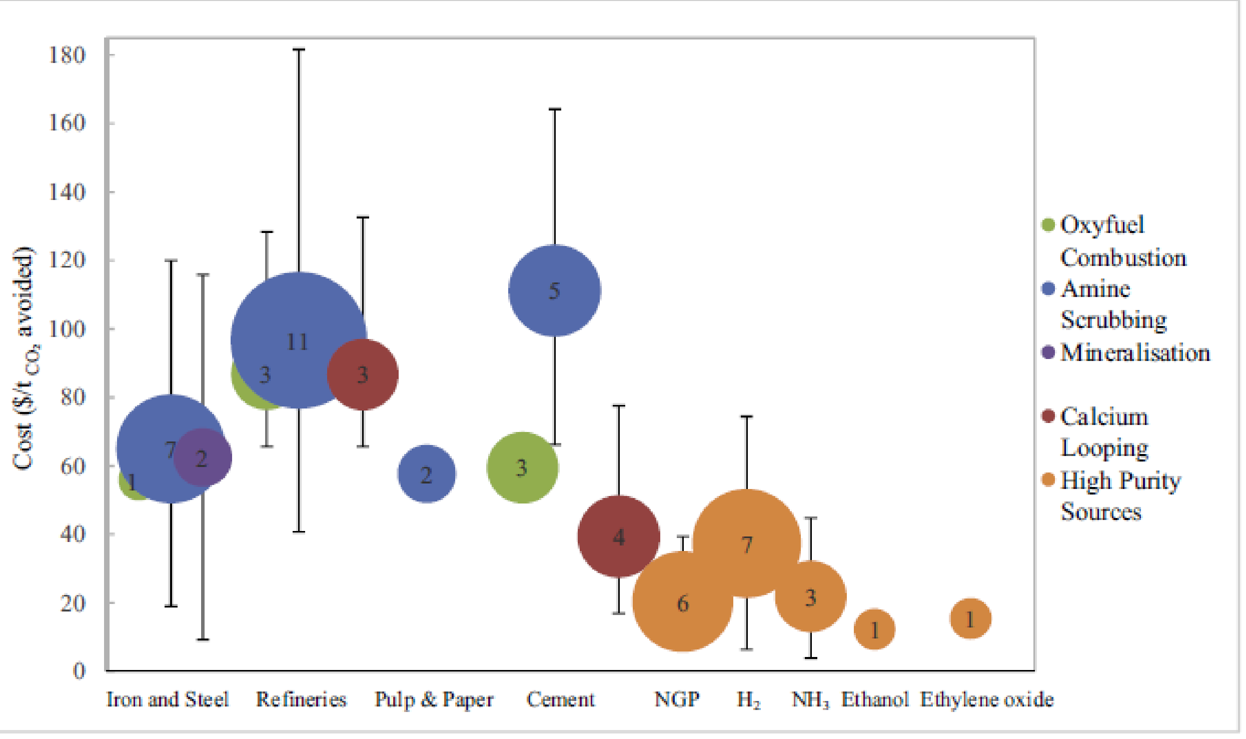
- Rapidly scalable for different industries (end-of-pipe)
- Fast and flexible dynamics
- Retrofit possible on existing units

Cons:

- Large initial investment
- Significant operating costs (efficiency drops by ~10-40%)
- Secondary emissions
- Technologies mature or close to maturity but not yet commercial

Cost of CO_2 capture – laws of thermo

- Estimated cost for different industries
- Largest cost: energy penalty (~38% of total Capex and Opex)



Leeson et al, 2017, DOI: 10.1016/j.ijggc.2017.03.020
Abu-Zahra M., 2009. Carbon dioxide capture from flue gas. PhD Thesis at the Technical University of Delft, The Netherlands

CO_2 market

- European Emissions Trading System (ETS)
- CO_2 price now reaches 25 €/t!

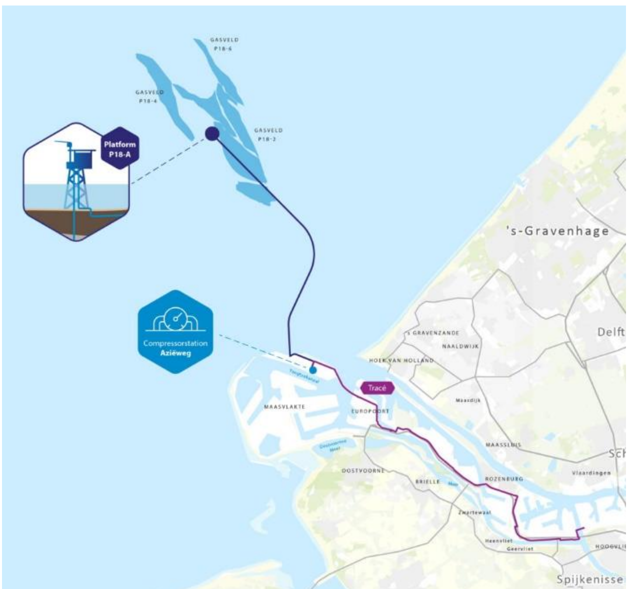
https://ember-climate.org/data/carbon-price-viewer/

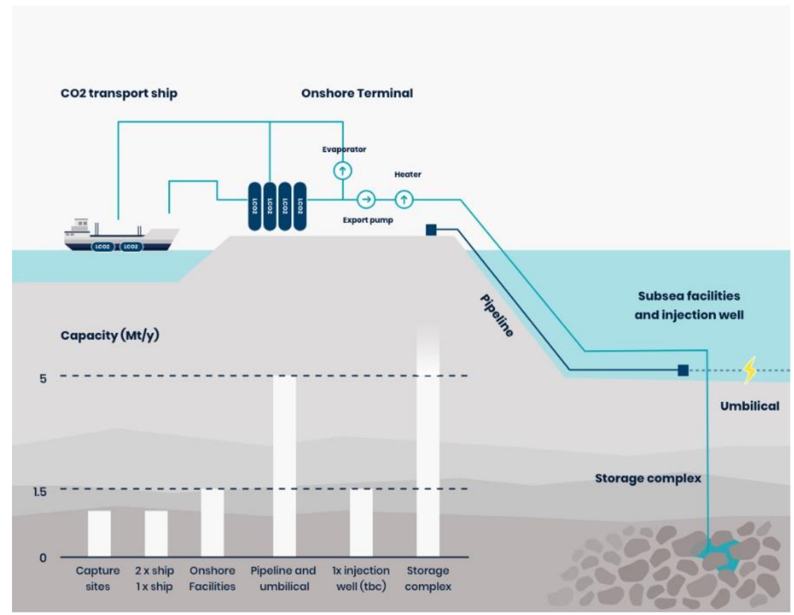
CO_2 storage

CCS: Permanent Storage

Porthos: **P**ort **o**f **R**otterdam CO_2 **T**ransport **H**ub and **O**ffshore **S**torage : 2.5 Mton/y

Northern lights: 5.0 Mton/y (Phase 2)





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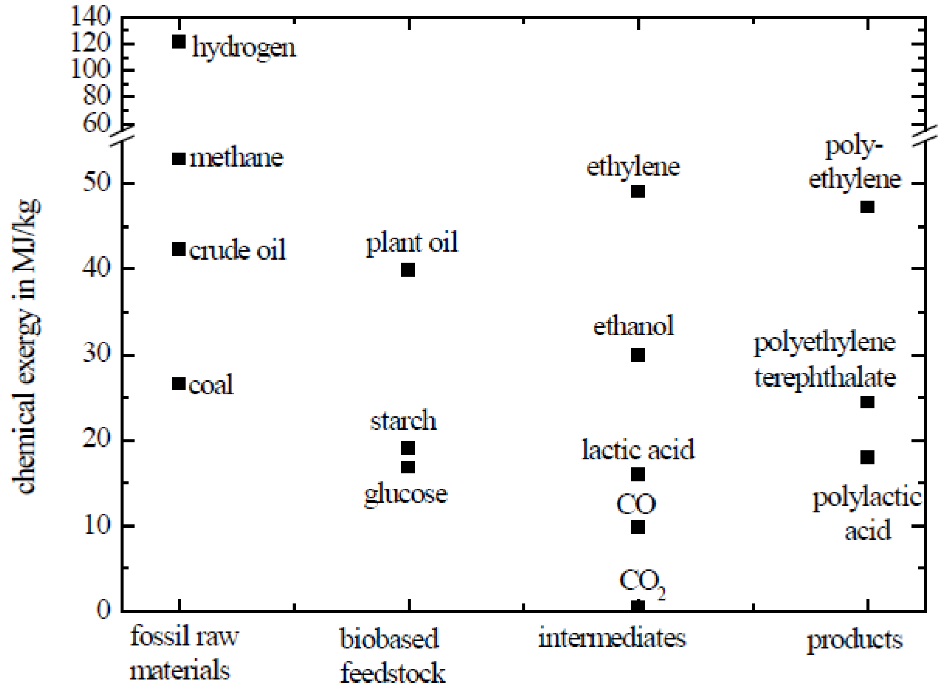
CO_2 re-use

Main CO_2 re-use pathways

- Direct use, no transformation
- Biological transformation
- Chemical transformation
  - To lower energy state
    - Carbonatation
  - To higher energy state
    - Fuels
    - Chemicals
    - …



=> At large scale, need to make sure that energy comes from renewables!

Frenzel et al, 2014. Doi:10.3390/polym6020327

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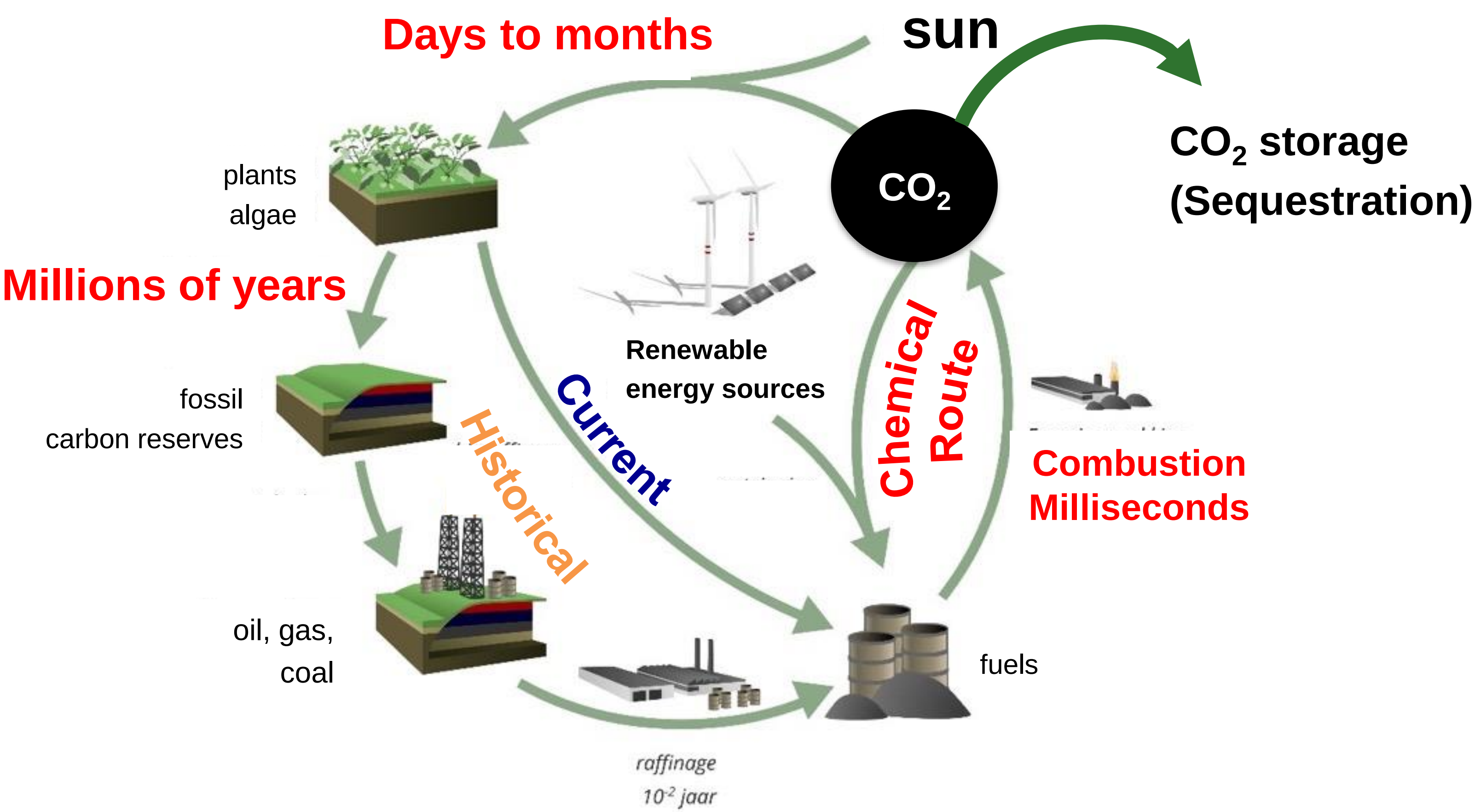
CO_2 Cycle: Kinetic / Catalytic challenge



Martens, Saeys et al., (2017) The Chemical Route to a CO_2-neutral world, *ChemSusChem* and (2015), De chemische weg naar een CO_2-neutrale wereld, Standpunt KVAB

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Storage of Solar Photons/Electrons

SOLAR ENERGY + CO_2 + H_2O

↓ **CATALYSIS**

SOLAR FUELS and CHEMICALS

Molecule	Heat (kJ/mol C)	H_2 eq.	Fraction H_2 energy stored
Hydrogen	-240		100
Methanol	-680	3	94
Diesel	-640	3	89
Glucose	-450	2	94

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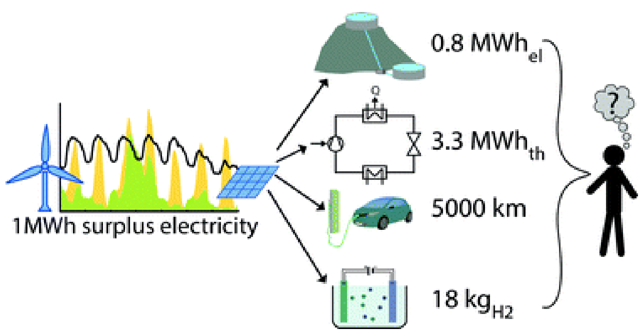
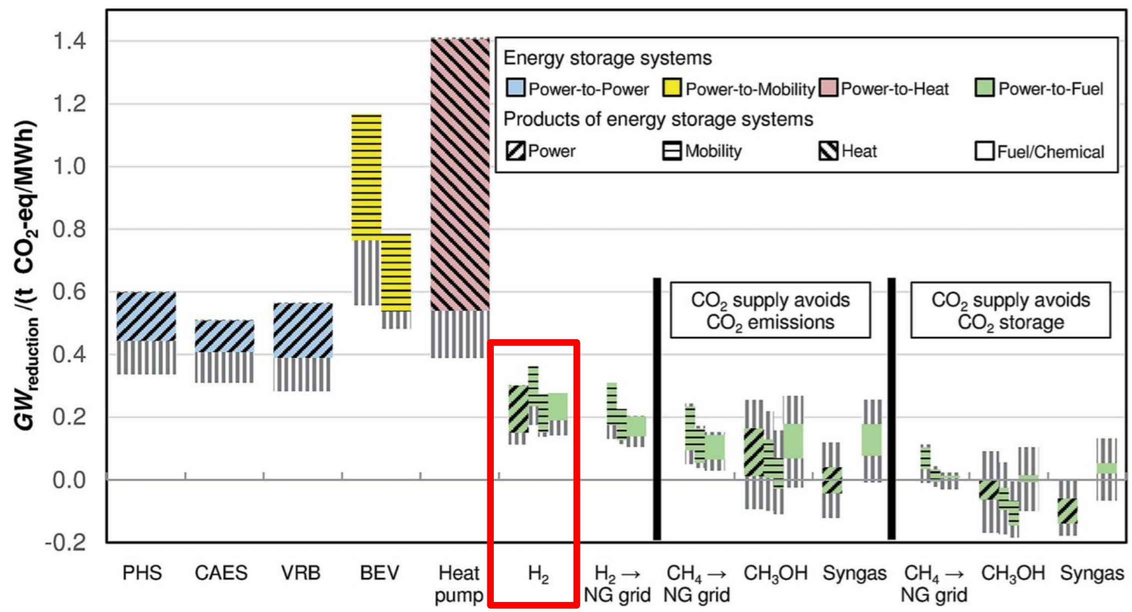
CCU and Renewable Electricity

Power-to-What?

Where should we use renewable electricity first?





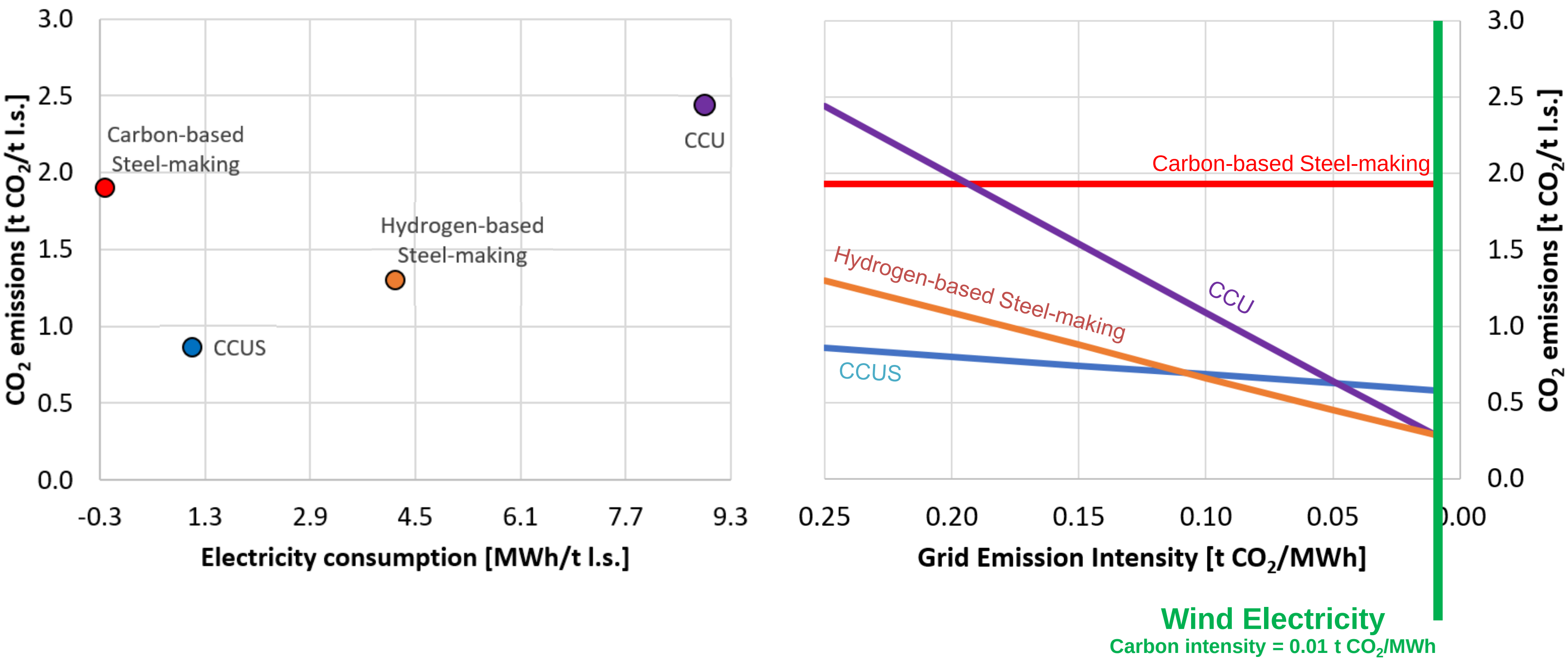
Global warming (GW) impact reduction.

Sternberg, Bardow et al. (2015). Power-to-What? *Energy & Environmental Science*

SAPEA report (2018): Novel carbon capture and utilisation technologies

Renewable Electricity in the Steel industry

Comparison of several scenarios for the steel industry



Flores-Granobles, Saeys (2020), Minimizing CO_2 emissions with renewable energy, *EES*

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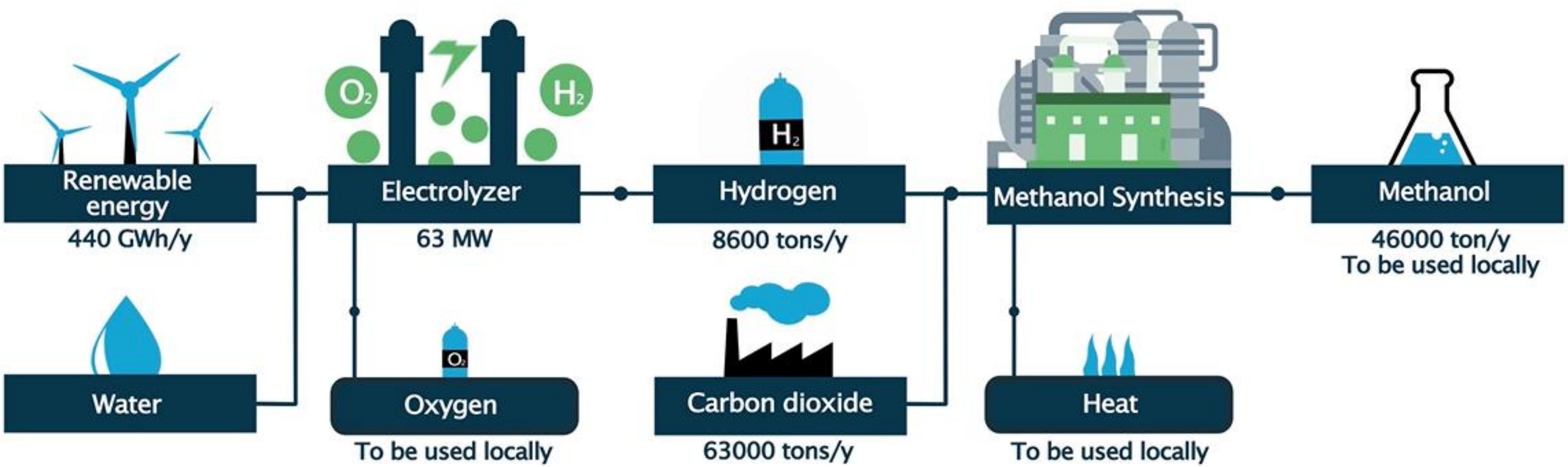
Recent announcement - Methanol

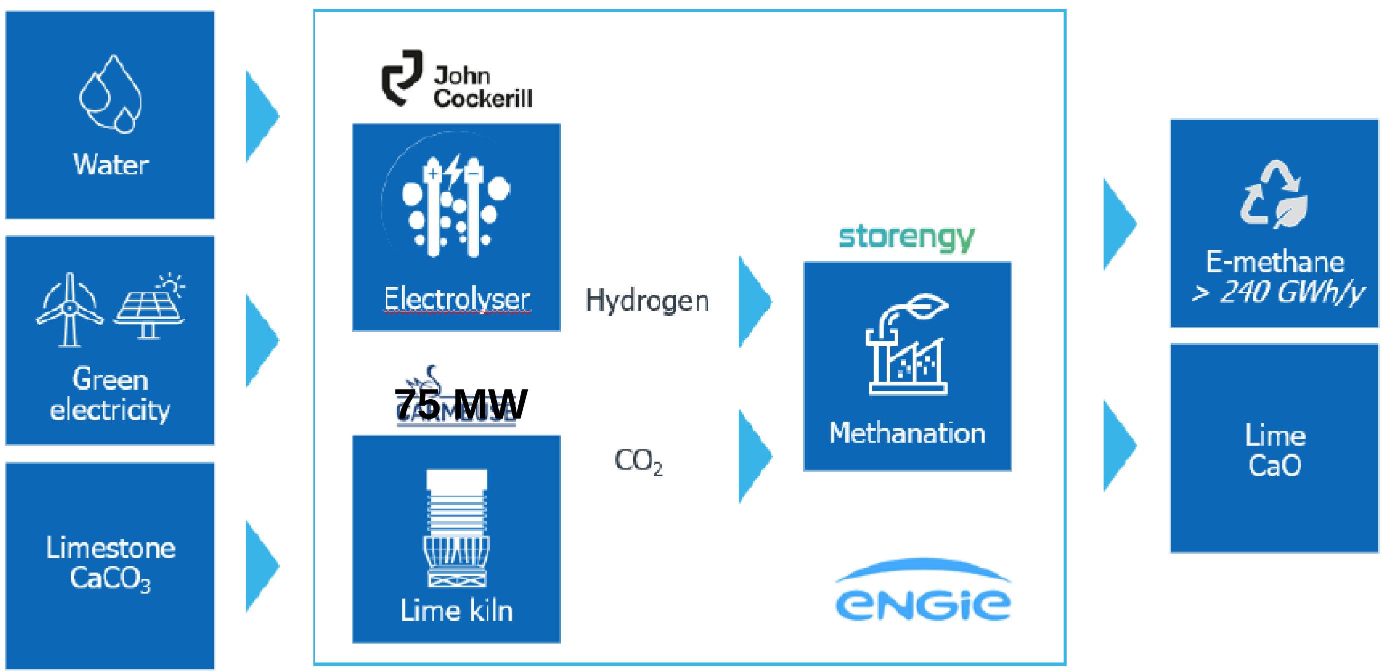
https://northccuhub.eu/



Antwerp: power-to-methanol: 8000 ton/y

Recent announcement - Methane

CARMEUSE John Cockerill ENGIE storengy



Jupiter1000 in Marseille,…

Greiner et al., (2020) Early decarbonisation of the European energy system pays off, *Nature comm.*

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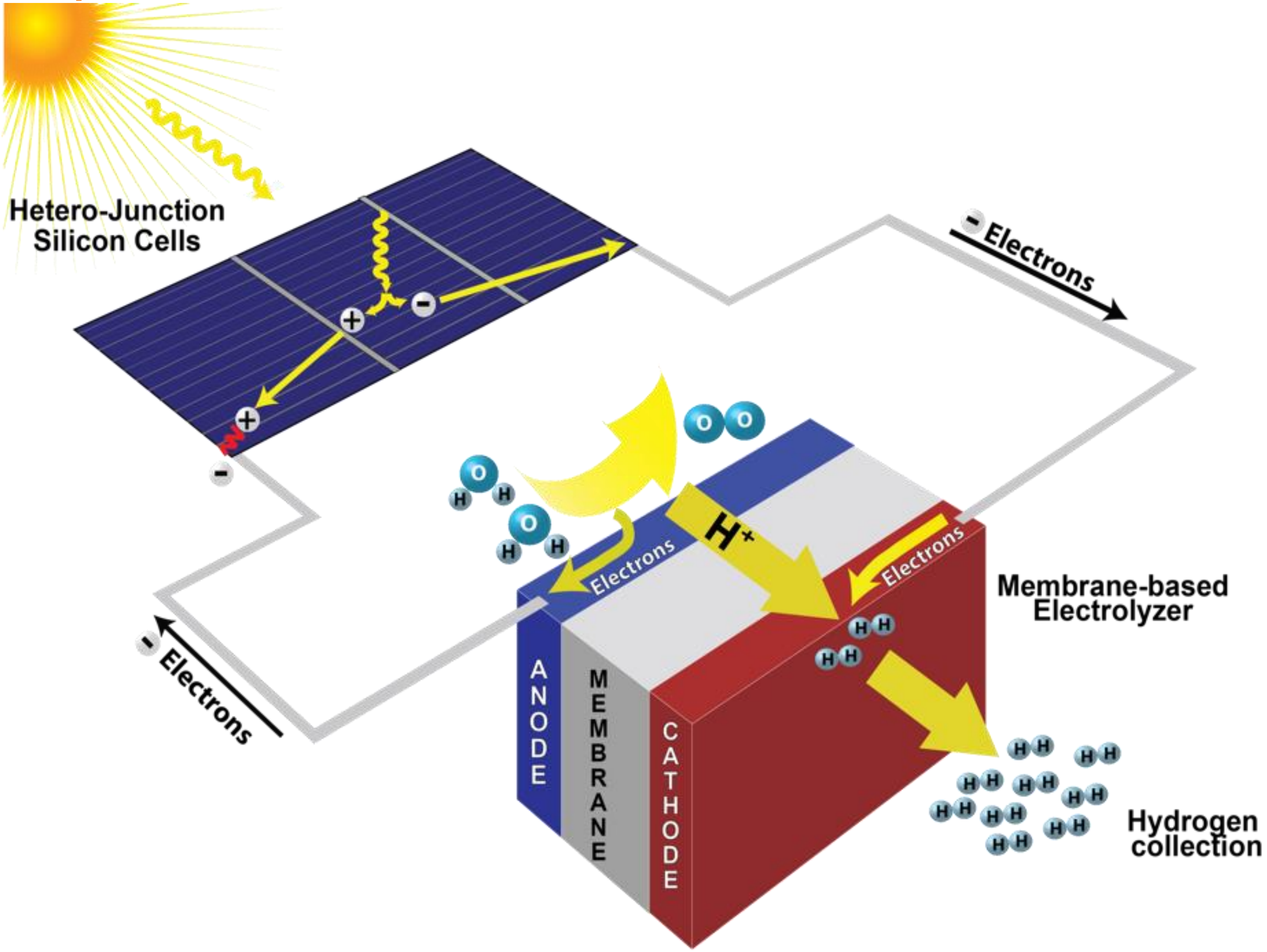
Solar-to-Hydrogen: Optimistic study



Cost of materials

Electrolyzer: 10%

Si PV: 90%

Total: 0.75 €/kg H_2

-> 0.15 €/l solar fuel

Market: 0.25 €/l

See: **H-Panels** of Johan Martens, KU Leuven

Modestino et al., *Ener. Env. Sci.*, **2014**

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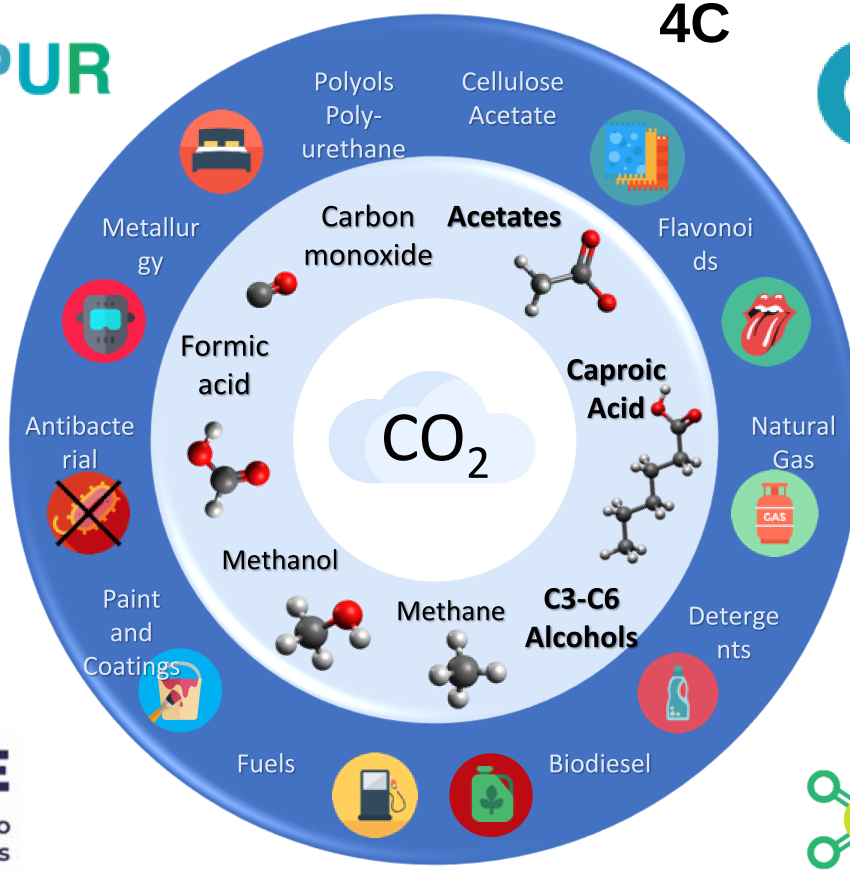
What can we do with CO_2- UGent portfolio

Carbon4PUR

MOT – SDR
MOT – D2M

4C



Project EnOp
- Improving our lives -

FLANDERS INDUSTRY INNOVATION MOONSHOT

CO2PERATE

CAPTURE

ENERGY X

capaa

CATCO$_2$RE
Catalytic CO_2 Reduction to Solar Fuels and Chemicals

BIOCON-CO_2

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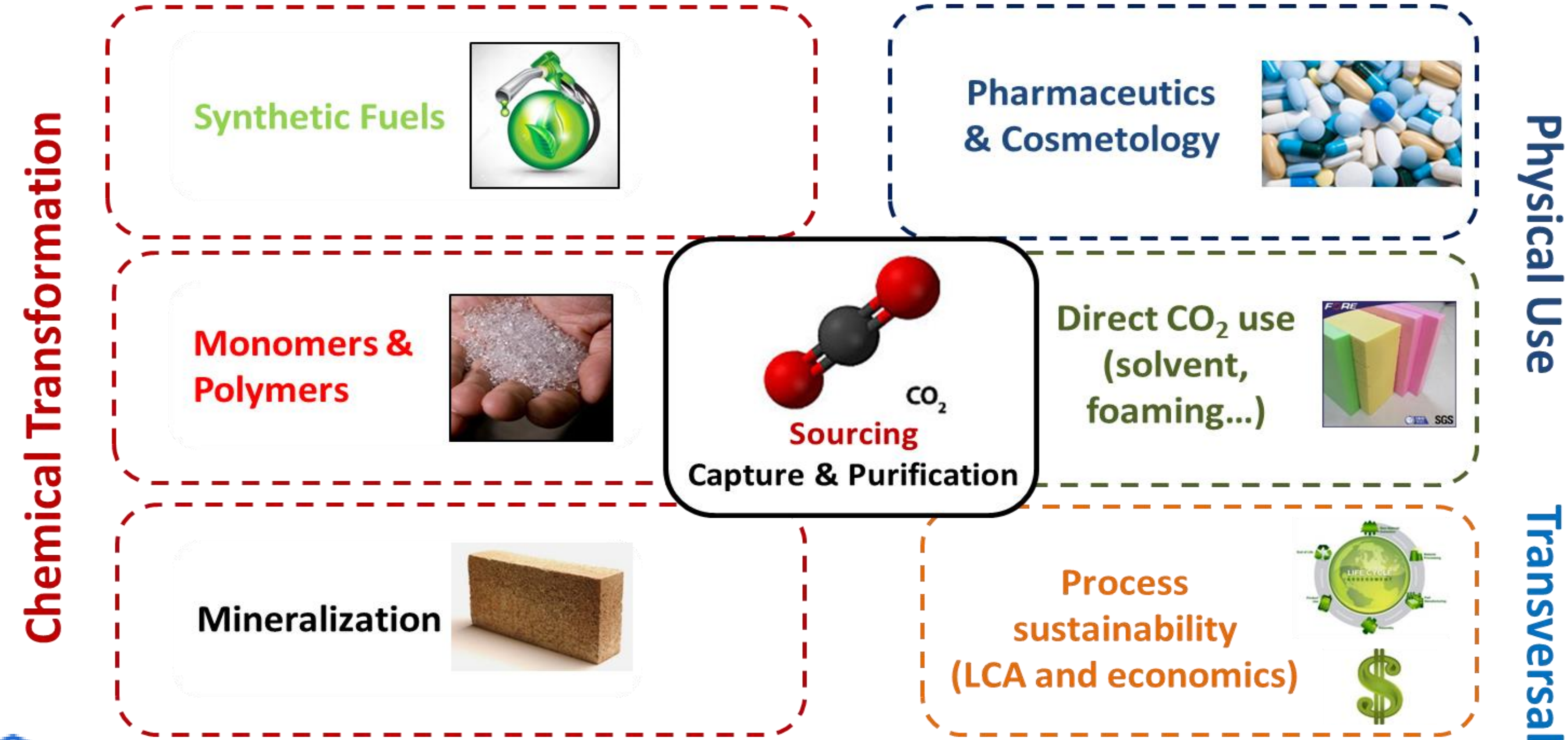
Perspective ULiège: FRITCO$_2$T platform

Federation of Researchers in Innovative Technologies for CO_2 Transformation



Conclusion: State of technologies CCUS

- Capture of CO_2
  - Mature but not commercially applied yet
  - Improvements needed to lower costs & energy penalties, extend lower limit for CO_2 concentration in stream for capture
  - Current estimates *circa* \$50-100/t CO_2

    → < **\$40 with further development (~\$0.1 /liter gasoline)**
- Transport of CO_2
  - Commercially applied
  - Pipelines, ships
- Storage
  - Commercially applied, interest rising
  - Risk assessment, monitoring, standards
- Re-use
  - Maturity level depends on the application
  - Business ”profitability” is increasing, but usually strongly dependent on energy cost –> **energy storage**

Back-up slides CO_2 capture

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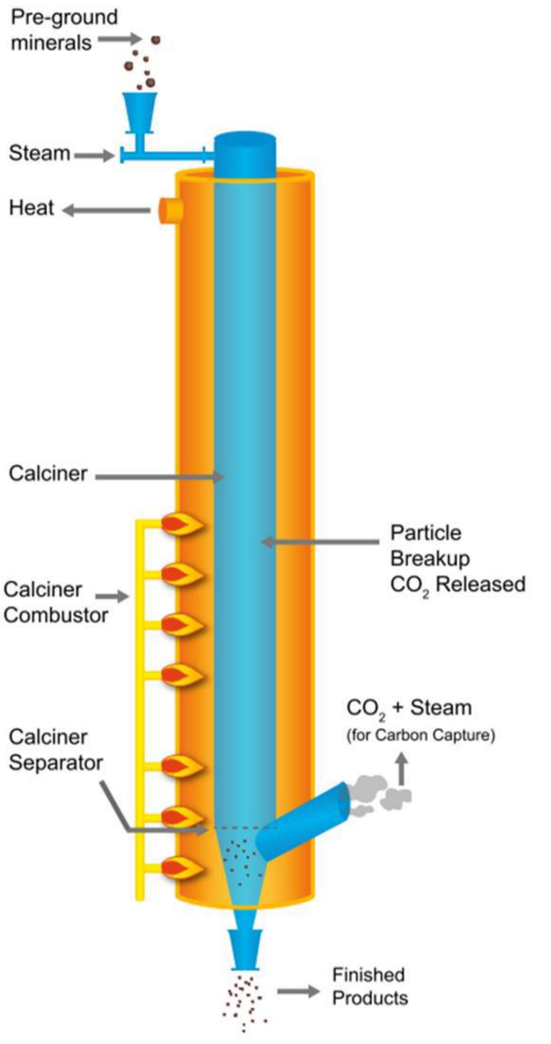
Industrial processes

1. **CO_2 not resulting from combustion**
   - Cement plants
     - $CaCO_3$ → $CaO + CO_2$
     - Potential gain: -60% CO_2
     - High temperature → 1000°C

     - Pilot plant close to Liège
     - End of construction: 2019
     - Investment: 21 M€



https://www.project-leilac.eu/videos

LEILAC public preFEED report, 2016

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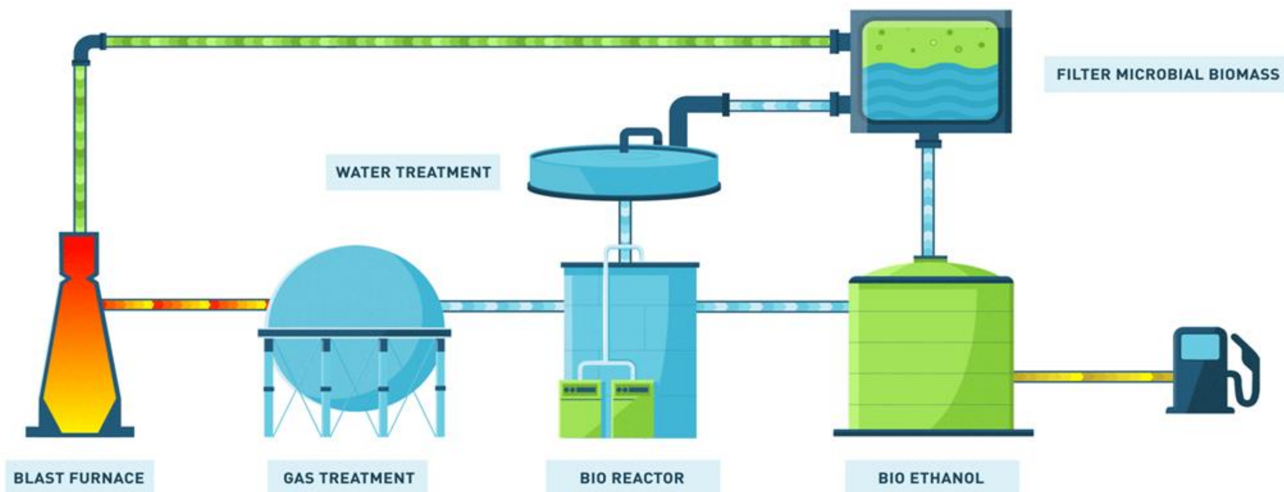
Industrial processes

1. CO_2 not resulting from combustion

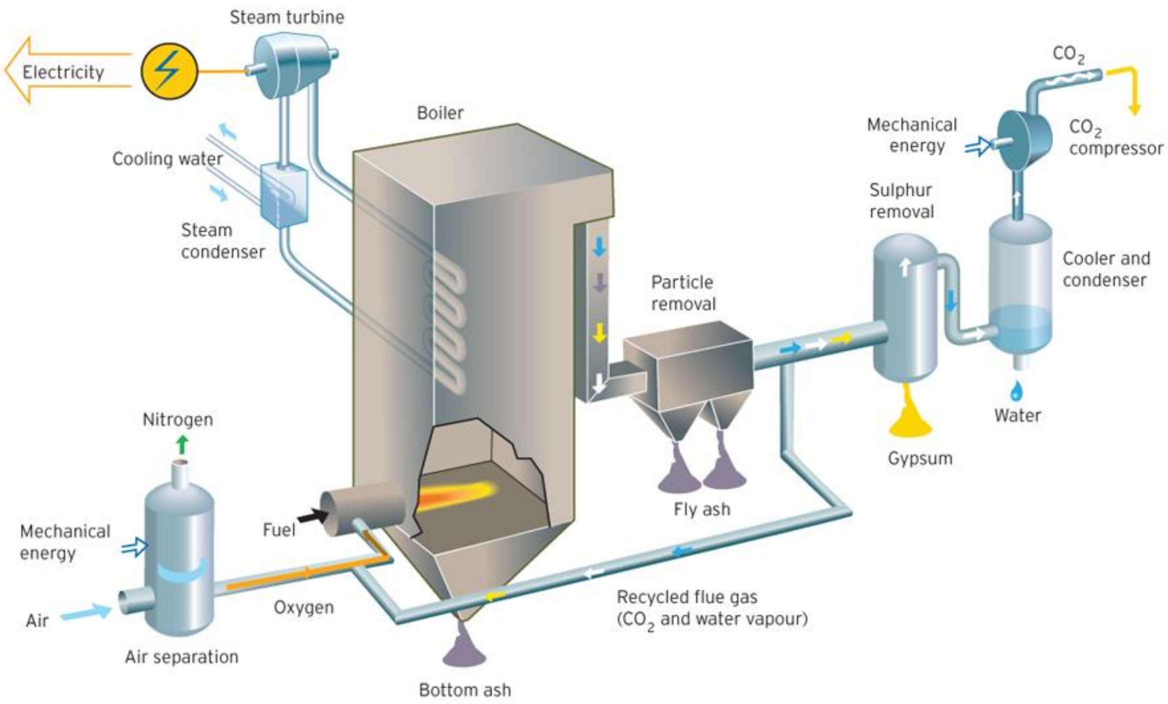
- Steel plants
  - Steelanol project: 87 M€, -70% CO2
  - Partners: Arcelor Mittal (Ghent plant), Lanzatech…
  - Investment in bioethanol production from CO_2 in flue gases
  - LanzaTech's technology recycles the waste gases and ferments them with a proprietary microbe to produce bioethanol



Steelanol project website

Oxyfuel combustion

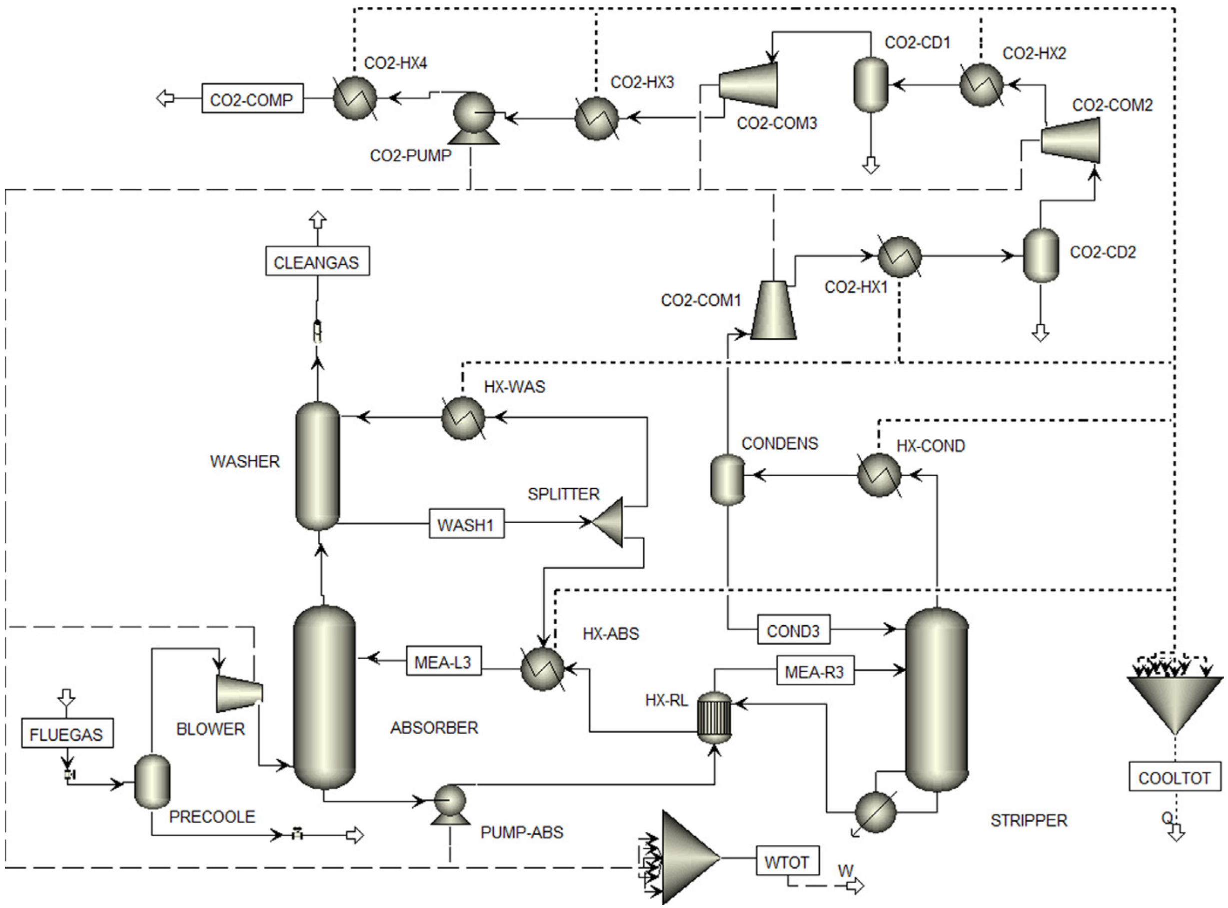
2. **Burn the fuel with pure oxygen**
   - Air separation needed
   - Waiting for large-scale projects



Post-combustion capture

3. **Capture CO_2 from combustion gases**

- Usually absorption-regeneration loop with chemical solvents



DOI: 10.1016/j.compchemeng.2015.05.003

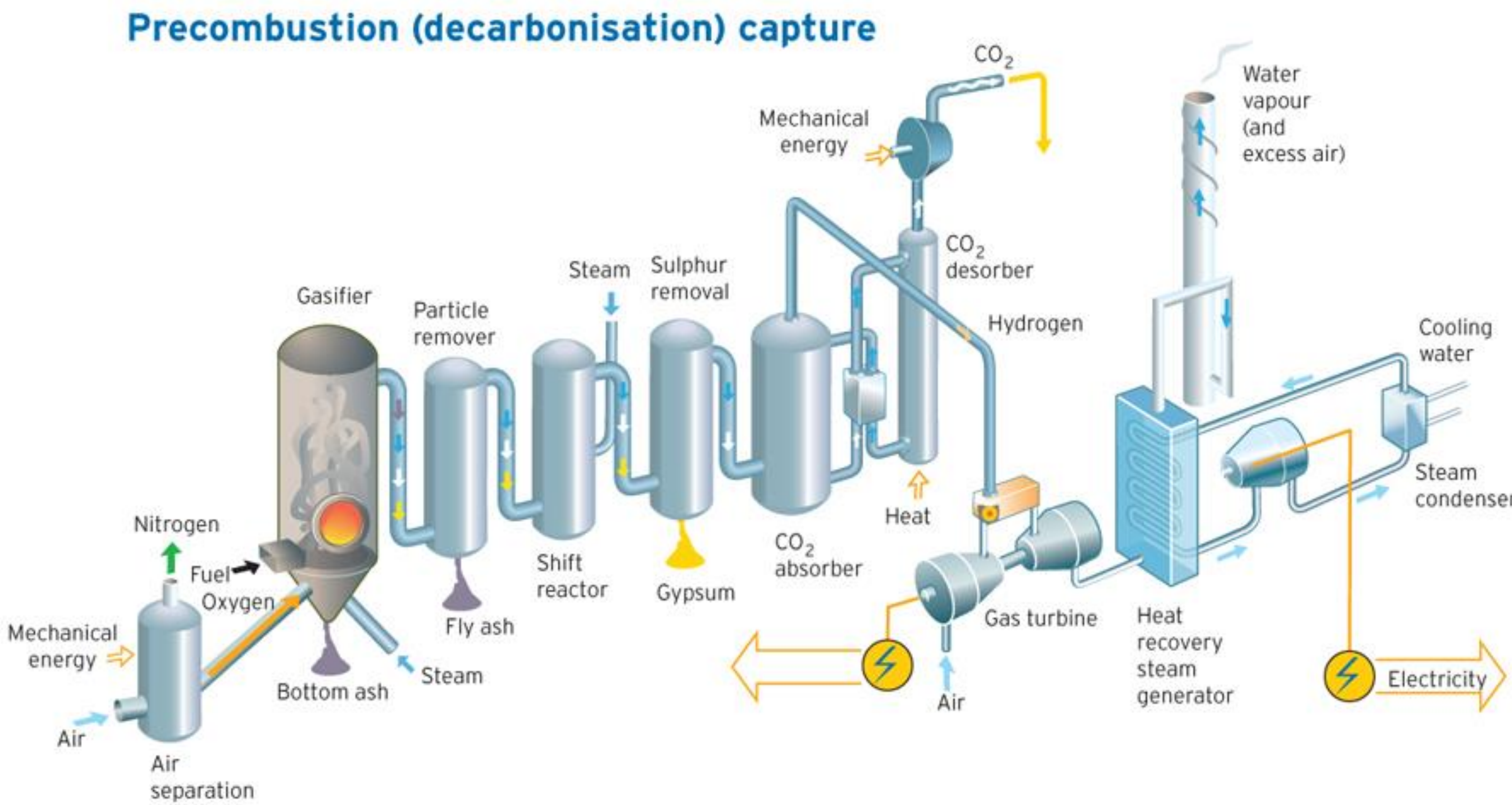
Post-combustion capture

- Commercial scale has been achieved
  - Boundary Dam, Saskatchewan (2014)
    - Coal power plant 160 MWe
    - 2700 tCO_2/day captured (~90% capture rate)

      => Flue gas: 180 Nm³/s ; Solvent: 550 L/s
  - Petra Nova, Texas (2017):
    - 4400 tCO_2/day, 1 milliard US$

Pre-combustion capture

4. Remove C from the fuel by gasification



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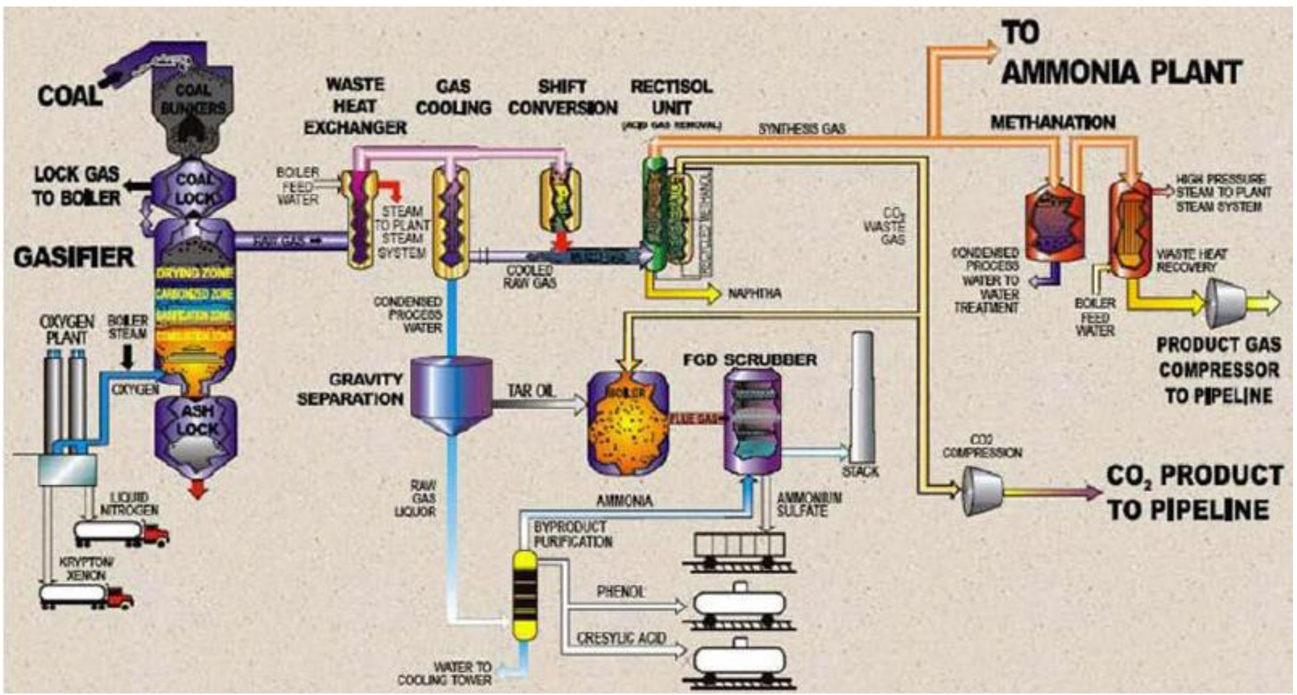
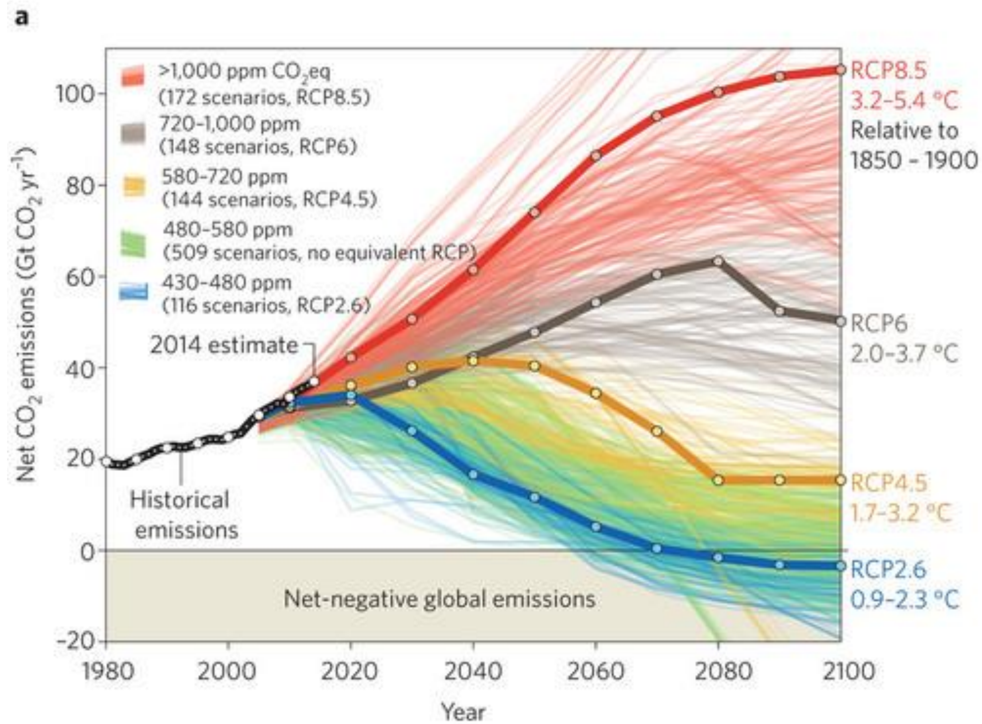
Pre-combustion capture

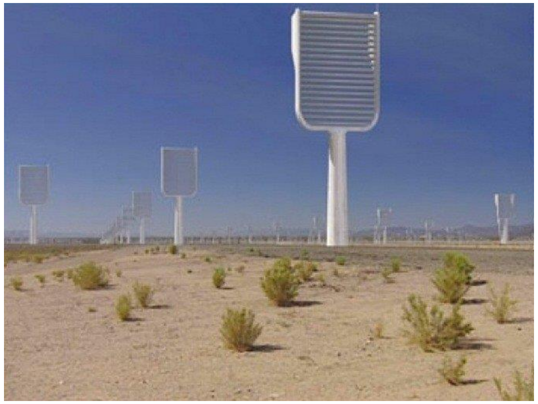
- Great Plains Synfuel Plant, North Dakota (US)
  - Gasification of 16 000 tpd of lignite
  - 8 200 tCO_2/day (~50% capture rate), 3 Mtpa since 2000



Future challenges

- Negative CO_2 emissions





  - Use of biomass with CCS
  - Direct air capture
    - Expected costs vary between 100 and 800 $/ton

Fuss et al, Nature, 2014, doi:10.1038/nclimate2392
K.S. Lackner, CNCE ASU, 2017.

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Direct air capture

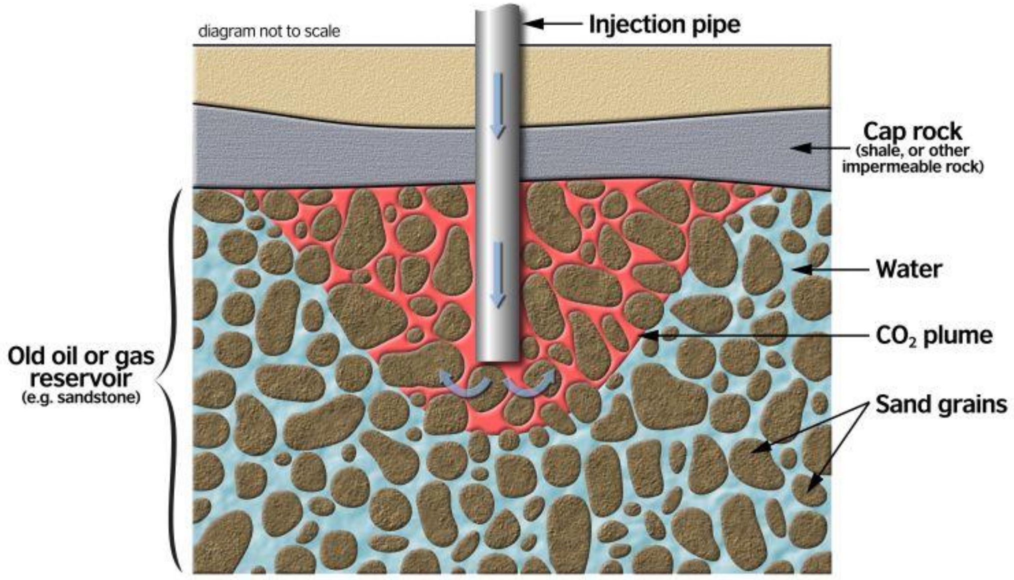
- Direct air capture motivations
  - Compensate for mobile CO_2 emissions: 30 to 50% of current emissions
  - Close the carbon cycle of synthetic fuels
  - Reduce the need for transporting CO_2
    - No Nimby effect, you can go wherever you want, incl. close to use or storage sites
- Compensate for CO_2 leakage from geologic storage
- Long-term considerations: remove C from the atmosphere

www.pnas.org/cgi/doi/10.1073/pnas.1108765109

Back-up slides CO_2 storage

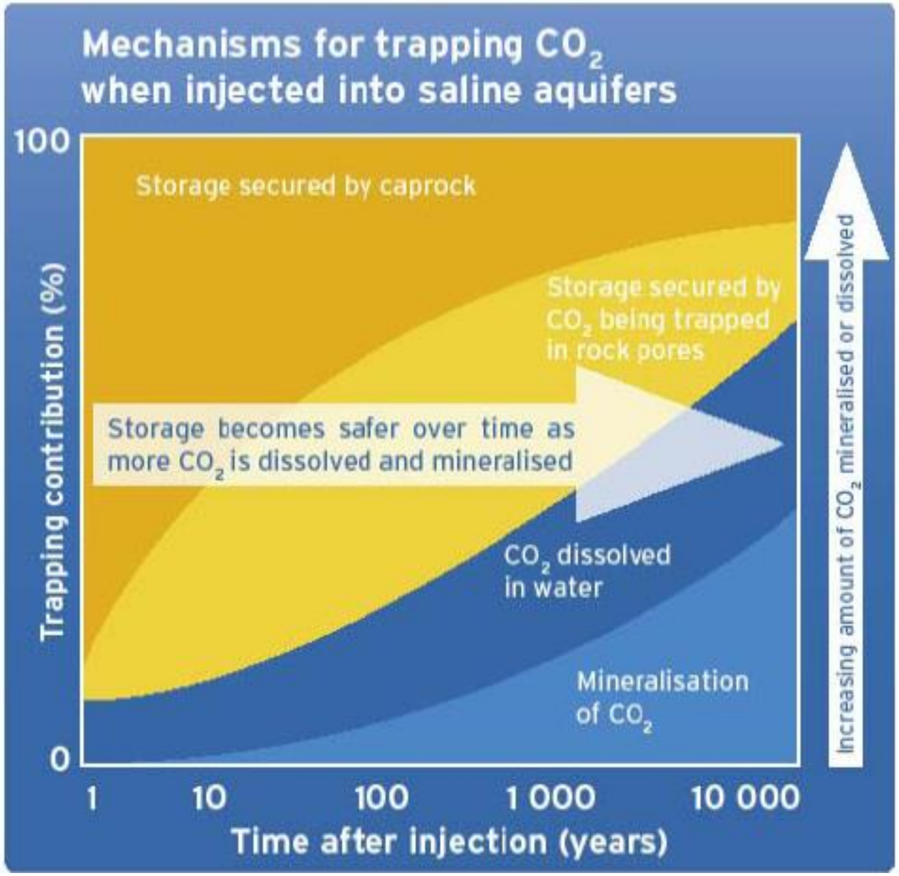
Possible storage sites

- Saline aquifers: large capacity, geology less well-known, reservoir properties under study
- Depleted gas and oil fields: Limited capacity, but geology is well-known, storage safety has been proven
- Coal seams: limited capacity, low permeability, possibility to recover methane



What happens to stored CO_2?

- CO_2 diffuses in the geological formation and is trapped under the cap
- It then get stuck in smaller porosities
- It dissolves and gets mineralized
- Long time-scale!



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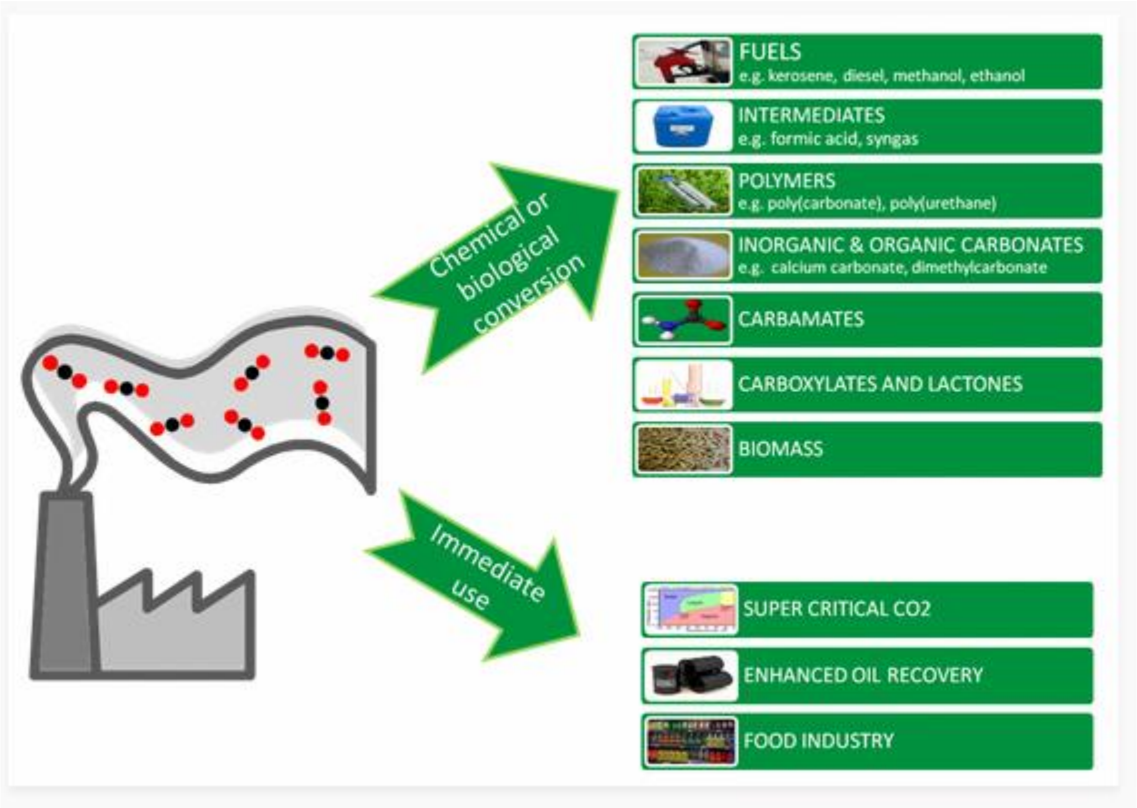
Back-up slides CO_2 re-use

Main CO_2 re-use pathways

Many different products, as CO_2 can be seen as a carbon source => leads to almost all petrochemical products!



Source: CO2Chem