The key role of CO_2 in the energy transition

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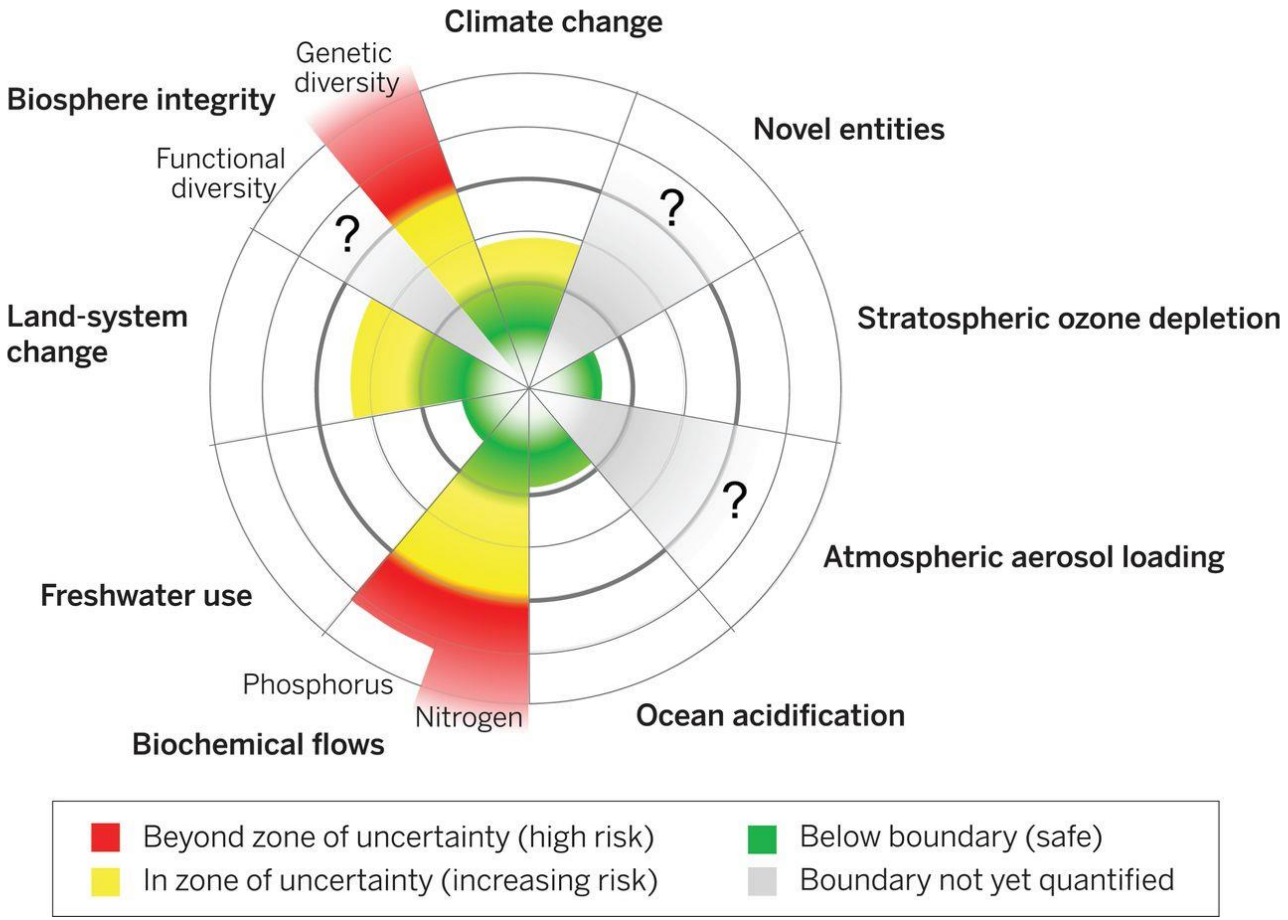
Outline

1. Context
2. Carbon capture
3. Storage & Re-Use
4. Conclusions and perspectives

Sustainable development

- How to keep a safe ecosystem?



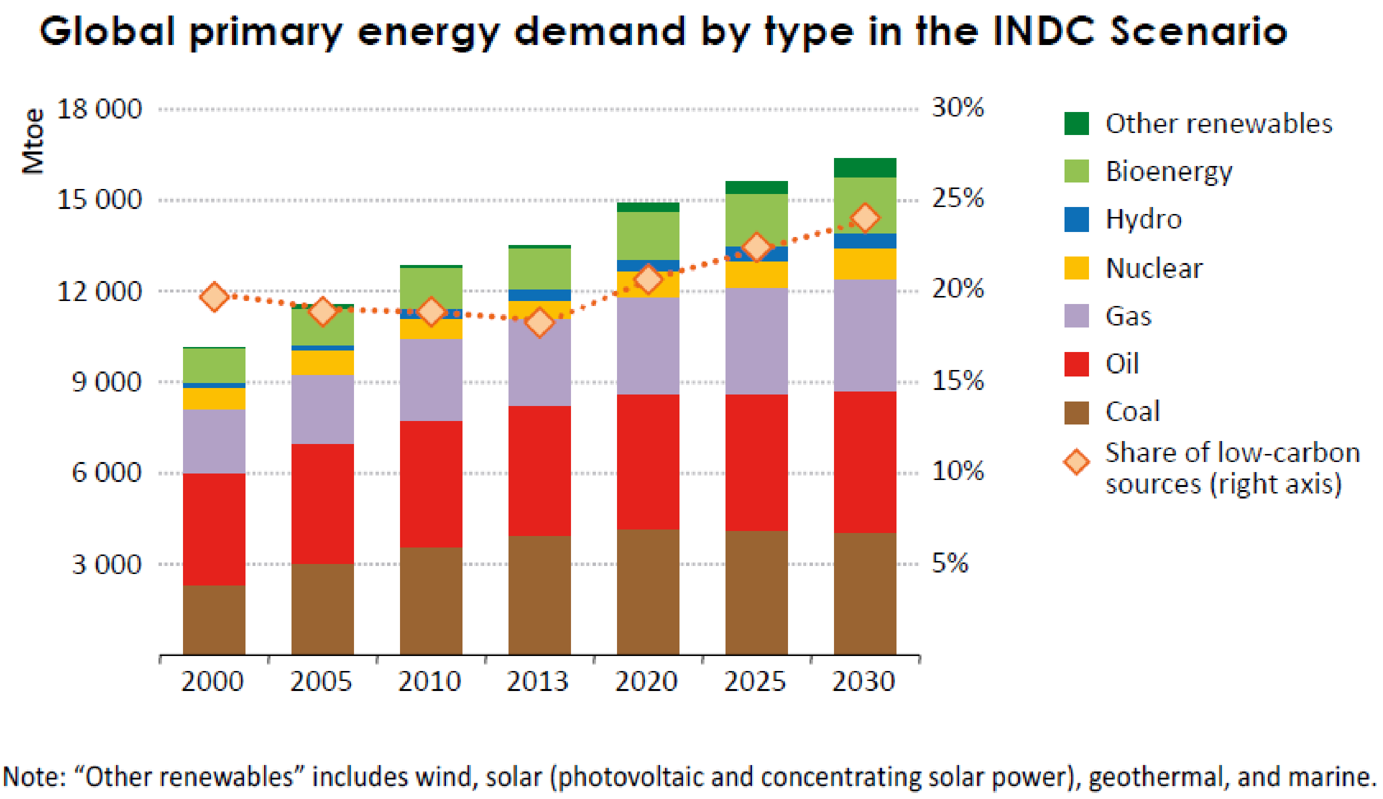
Steffen W. *et al.* (2015), *Science 347* (6223), 1259855.

The energy transition has already started…

But it has to address 2 objectives in contradiction:

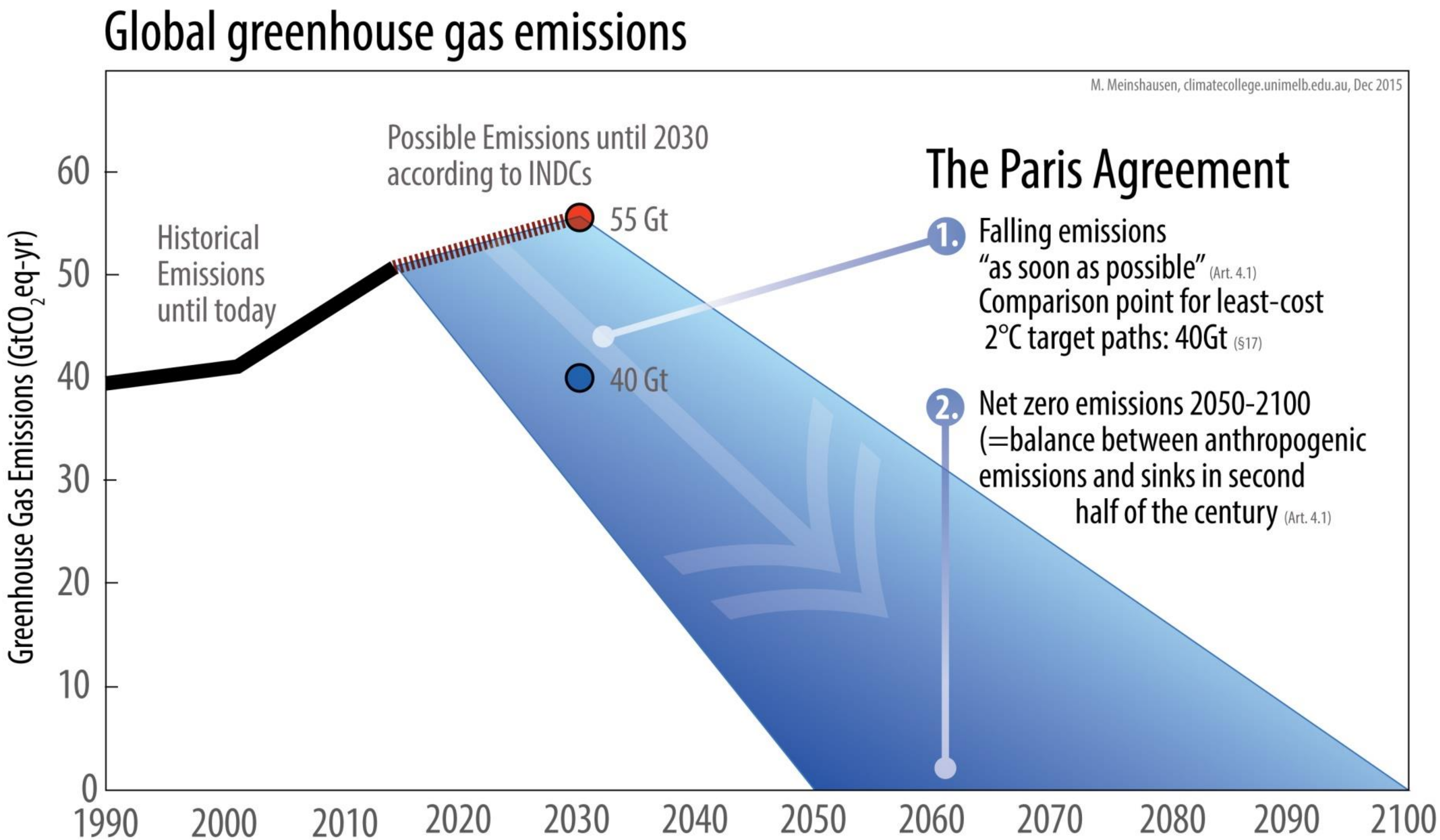
- Limit GHG emissions, and
- meet the increasing energy demand!

Meeting the increasing demand is already a challenge in itself!



IEA 2015, WEO special report, Energy & Climate Change

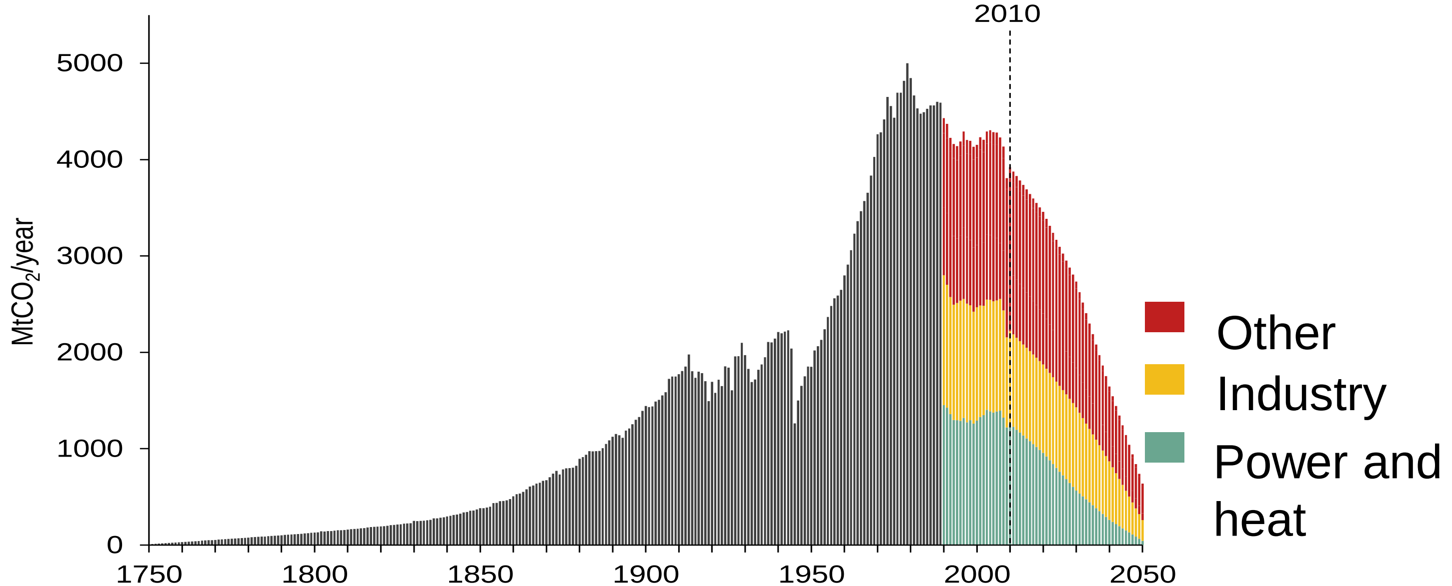
The COP […] notes that much greater emission reduction efforts will be required …



At european level…

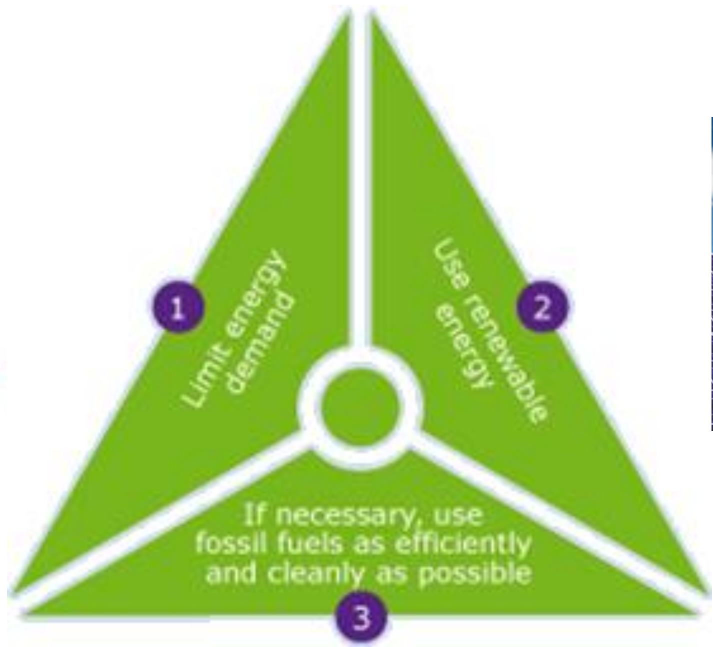
European targets

- \- 93 to 99% CO_2 in power and heat
- \- 83 to 87% CO_2 in the industry



Data sources: [Boden et al., 2010; EC-JRC/PBL, 2009; European Commission 2011; EEA, 2015]

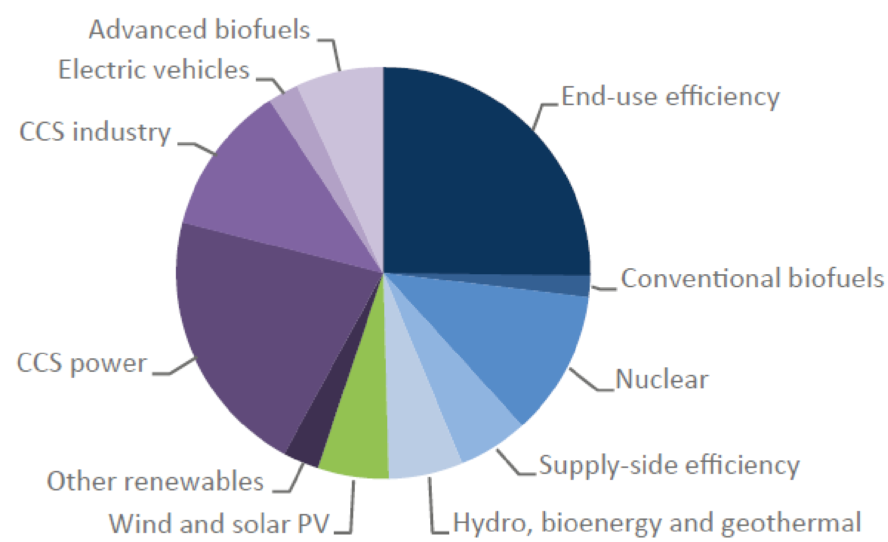
Possible answers: Trias Energetica



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

CCUS forecasts

- CCUS = Carbon Capture, Utilization and Storage
  - Carbon capture and storage is mature & flexible technology, but cost only!
  - Re-use is at different maturity levels, depending on final product



World CO_2 emissions abatement in the 450 Scenario (Bridge Scenario 2015-2040), IEA **2015**, WEO special report, Energy & Climate Change

2. CO_2 Capture technologies & configurations

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CO_2 capture is basically fluid separation

- Purity of sources varies between 0.04% and 100%
  - Usually mixture of CO_2, N_2, H_2O, H_2, CH_4, O_2 …
- Exists for more than 50 years

India, 2006, Urea production,
2x450 tpd CO_2

Algeria, Natural gas sweetening:
1400 -2800 tpd CO_2

Pictures: Mitchell R. (2008), MHI; Berchiche M. (2017). Global CCS Institute (2017).

Pros and cons

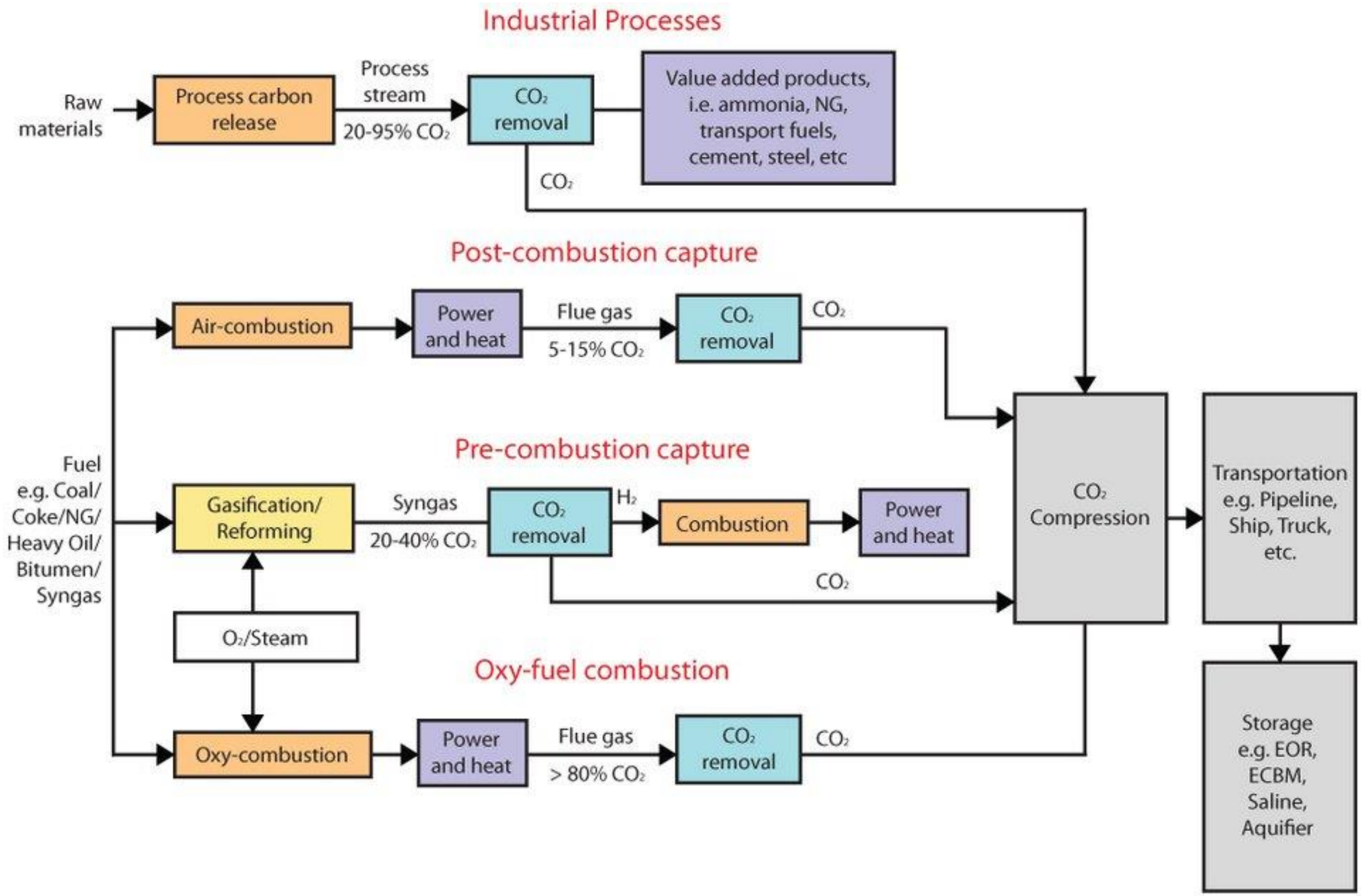
Pros:

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

Cons:

- Large initial investissement
- Significant operating costs (efficiency drops by ~10-40%)
- Secondary emissions

CO_2 capture configurations

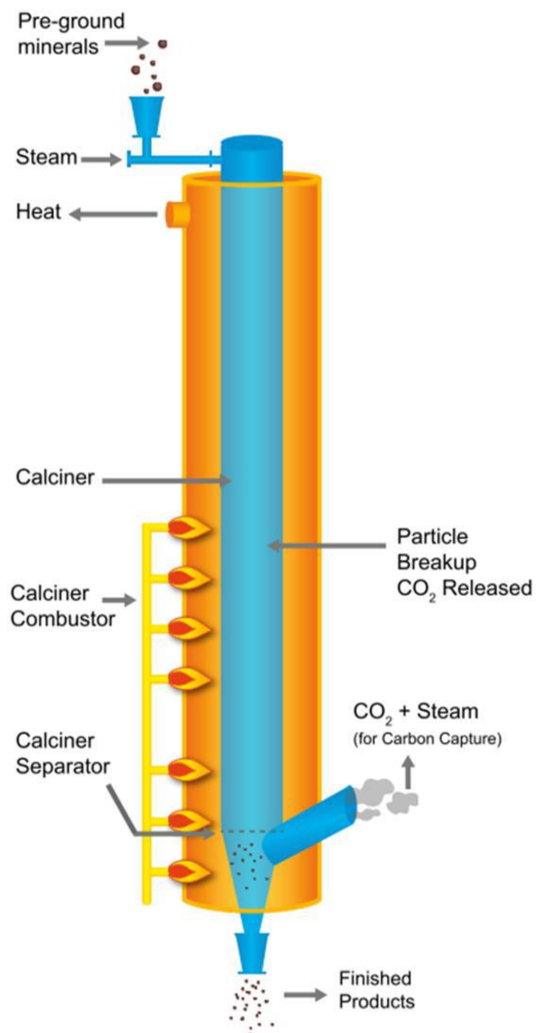


Industrial processes

1. CO_2 not resulting from combustion

- Cement plants
  - $CaCO_3 \rightarrow CaO + CO_2$
  - Potential gain: -60% CO_2
  - High temperature → 1000°C

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

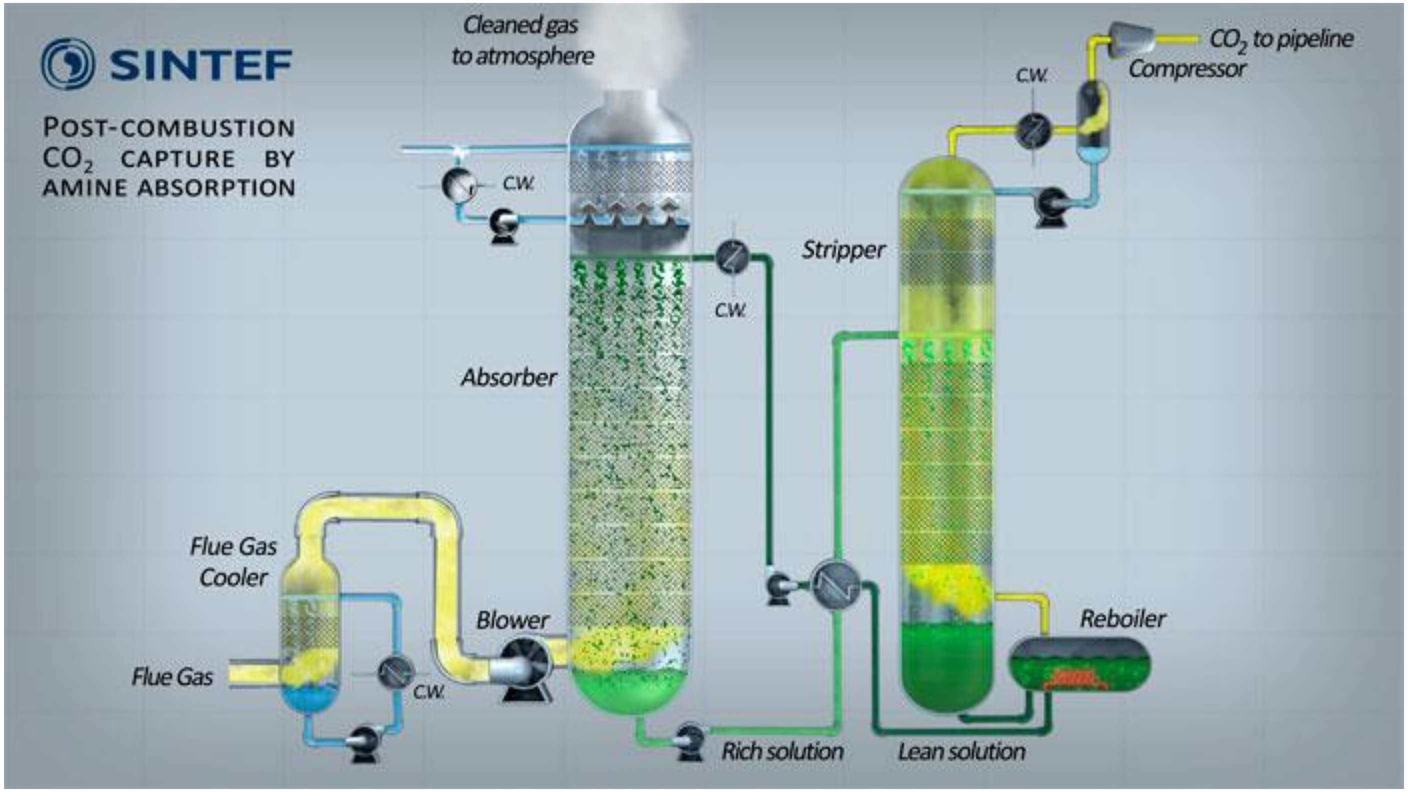


LEILAC public preFEED report, 2016

Post-combustion capture

2. Capture CO_2 from combustion gases

- Usually absorption-regeneration loop with chemical solvents



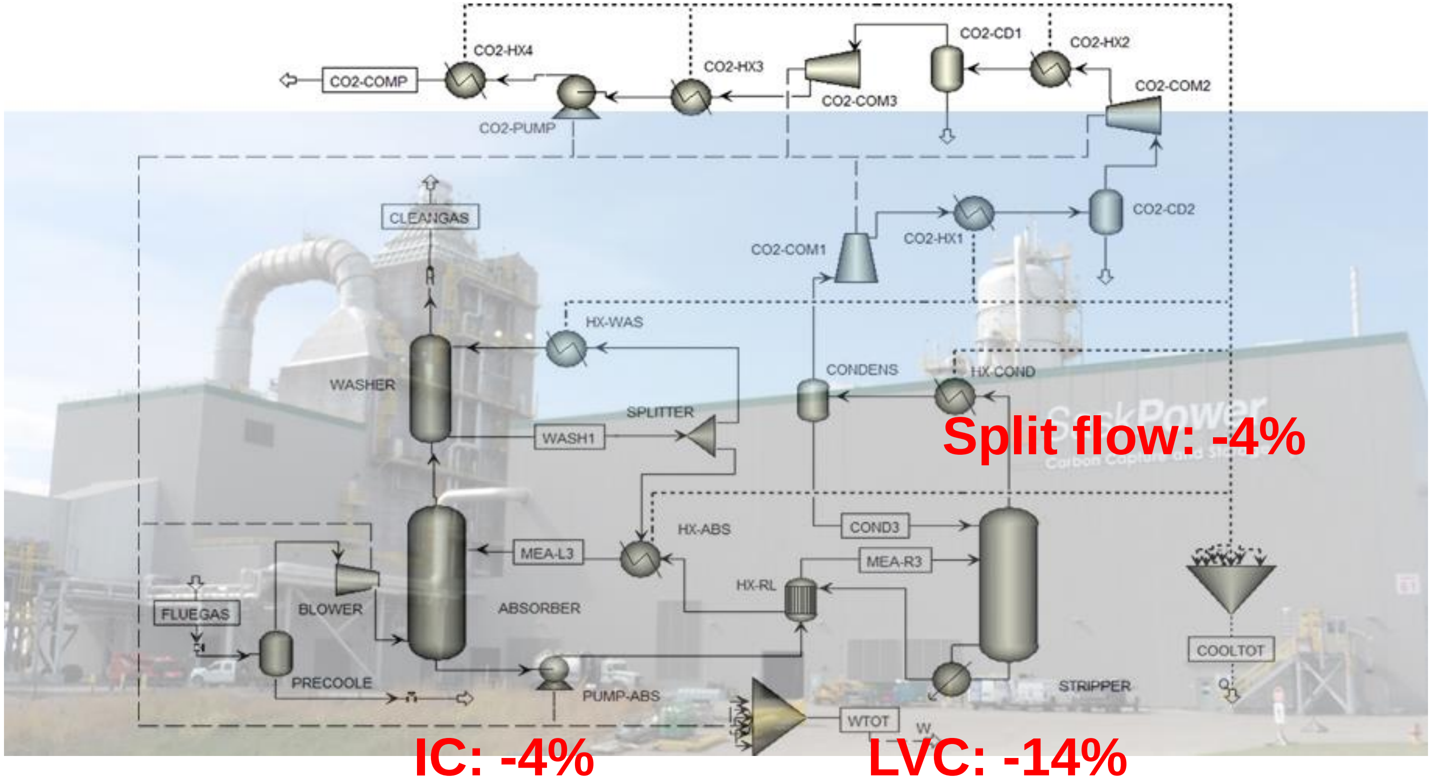
Post-combustion capture

- 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$

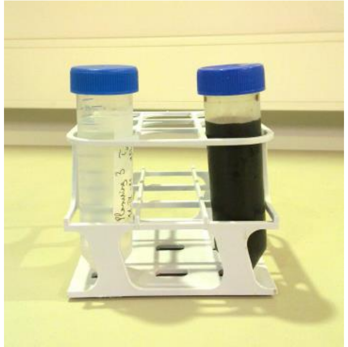
Post-combustion capture

- Focus: research at ULiège
  - Modeling and energy optimization of systems

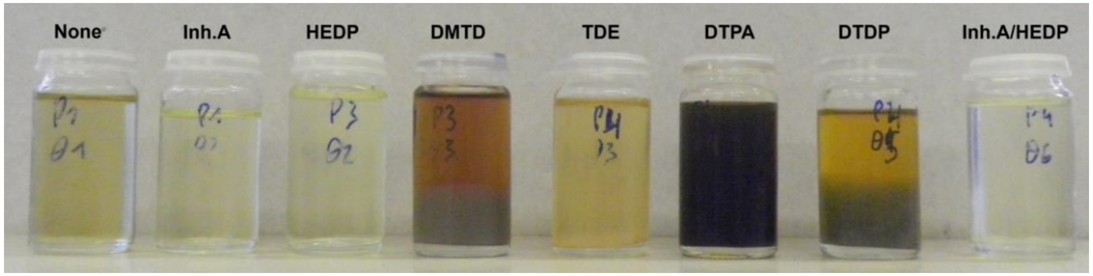


Léonard et al., 2014&2015. DOI:10.1021/ie5036572, DOI: 10.1016/j.compchemeng.2015.05.003

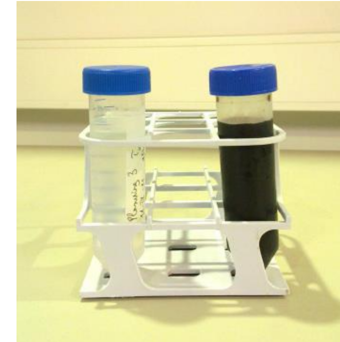
Post-combustion capture



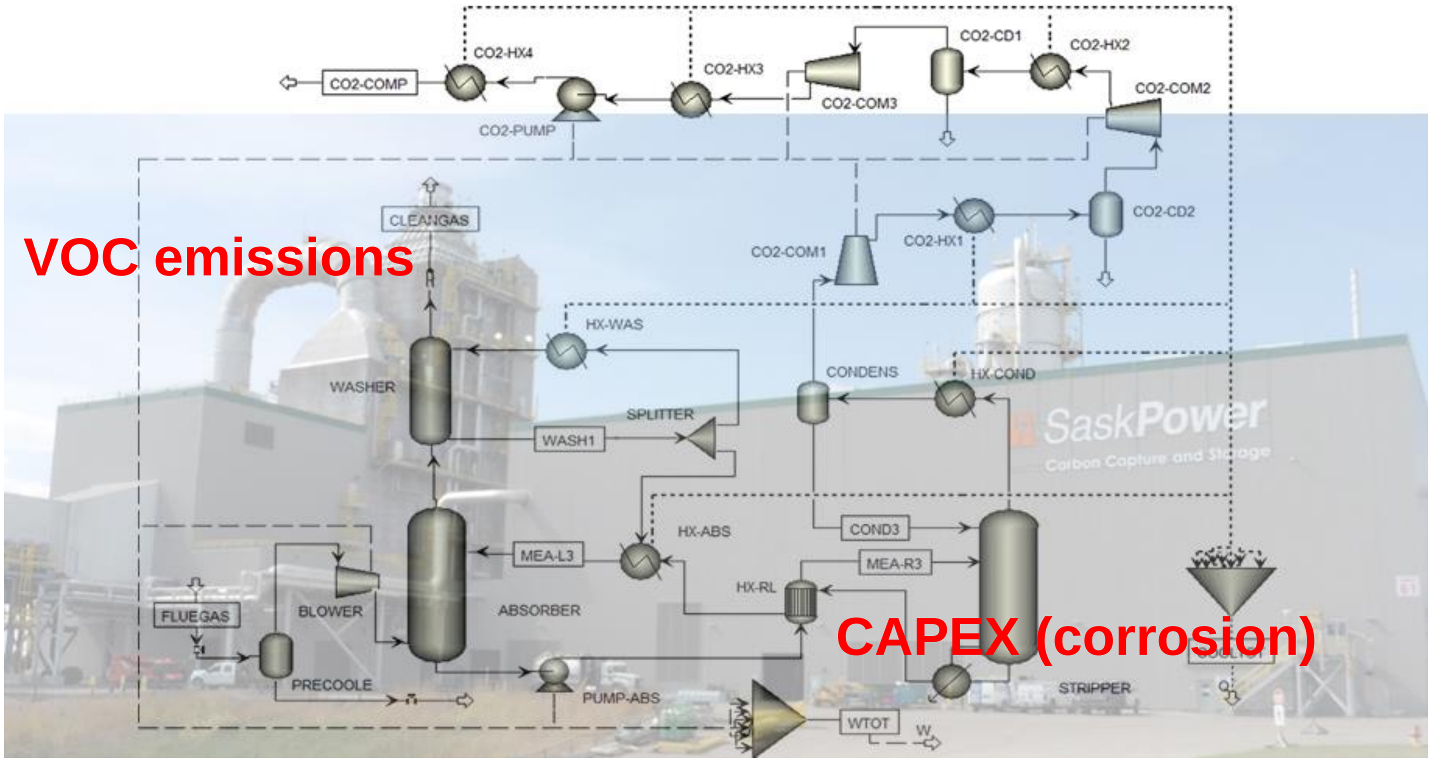
- Focus: research at ULiège
  - Stability of chemical solvents
  - Operational issues
    - Viscosity change, decrease of solvent properties…
    - Corrosivity of amine systems
    - Emissions of VOC
  - Different types of degradation
    - Oxidative
    - Thermal
    - SO_X, NO_X …



Post-combustion capture



- Focus: research at ULiège
  - Stability of chemical solvents



VOC emissions

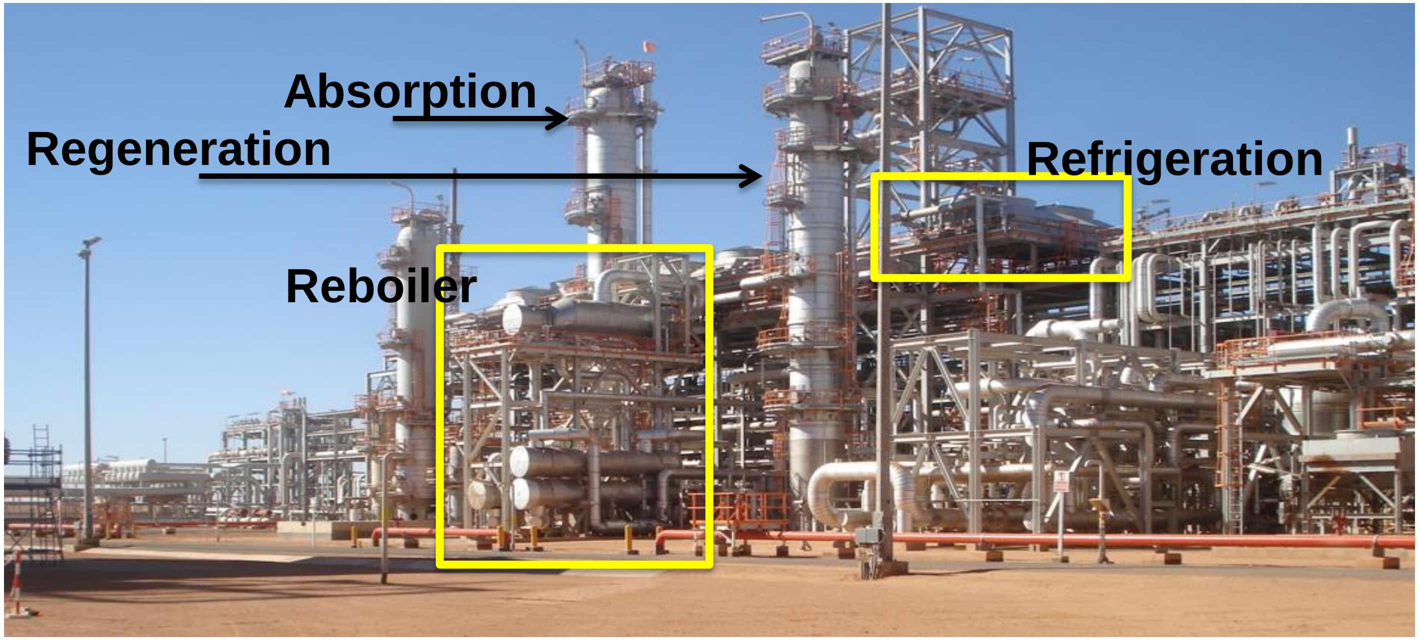
CAPEX (corrosion)

OPEX: viscosity, altered properties…

Léonard et al., 2014&2015. DOI:10.1021/ie5036572, DOI: 10.1016/j.compchemeng.2015.05.003

Pre-combustion capture

3. **Remove C from the fuel => Natural gas sweetening**
   - Conventional process: absorption with solvents
   - From 80 to 2 vol%; down to 50 ppm if liquefaction



- => Multi-objective optimization of sour natural gas sweetening processes

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Picture: Berchiche M. (2017).

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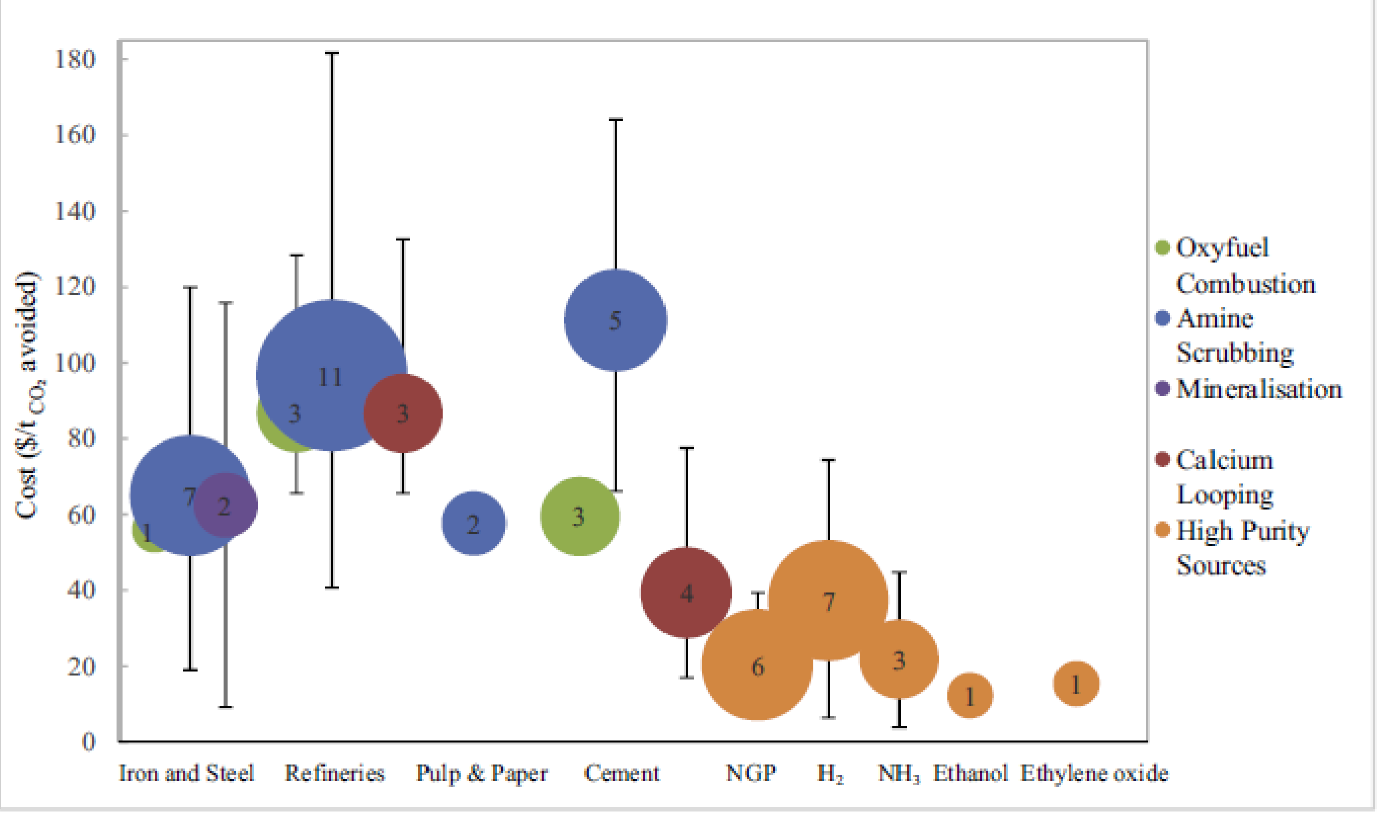
Future challenges

- Cost of CO_2 capture



Leeson et al, 2017, DOI: 10.1016/j.ijggc.2017.03.020

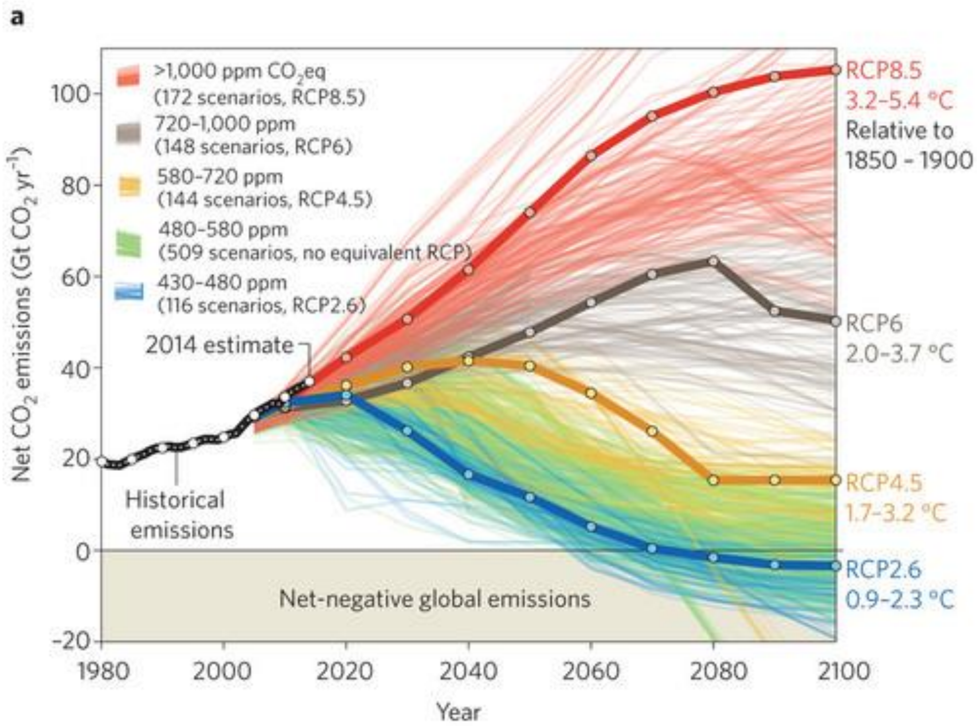
Future challenges

- European Emissions Trading System (ETS)
- CO_2 price now reaches 25 €/t!
- => Make processes cheaper!

https://markets.businessinsider.com/commodities/co2-emissionsrechte

Future challenges

- Negative CO_2 emissions

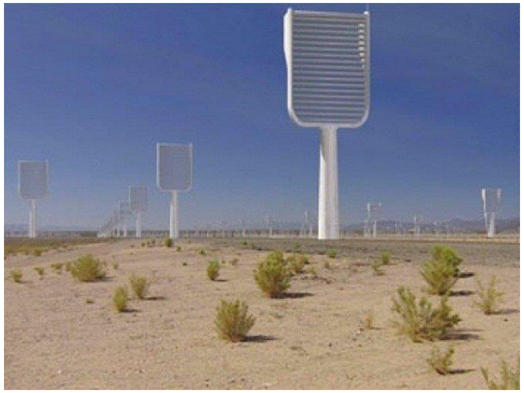


  - Use of biomass with CCS
  - Direct air capture
    - Expected costs vary between 100 and 800 $/ton

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

Future challenges

- CO_2 capture from air
  - Carbon Engineering, Climeworks, Antecy…
- At ULiège, new topic:
  - Study of sorbent stability



Exclusive: Carbon Engineering CEO discusses recent funding for DAC technology

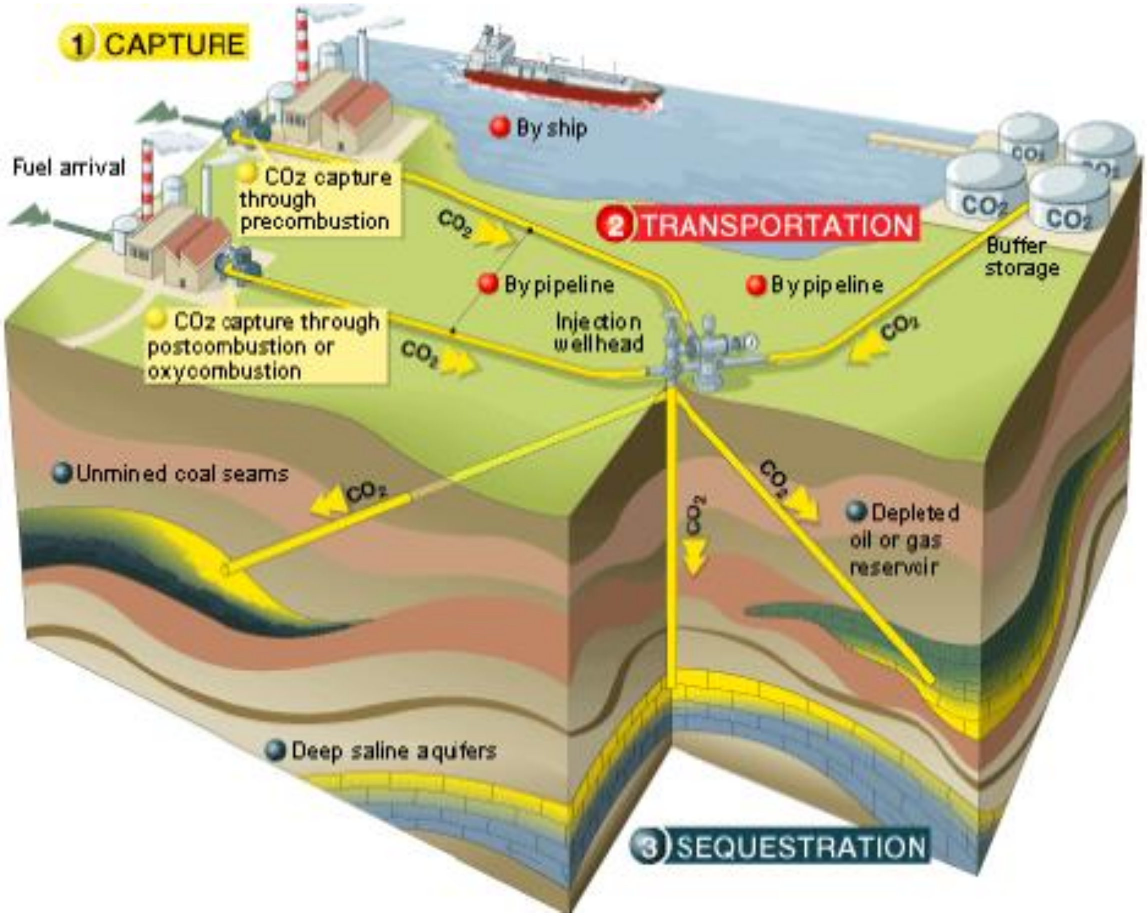
By Molly Burgess | 24 April 2019

Last month, Carbon Engineering, a Canadian clean energy company announced the completion of an equity financing round of $68m, marking the largest private investment made into a Direct Air Capture (DAC) company to date.

3. Storage and re-use of CO_2

Integrated chain

Capture – Transport – Storage



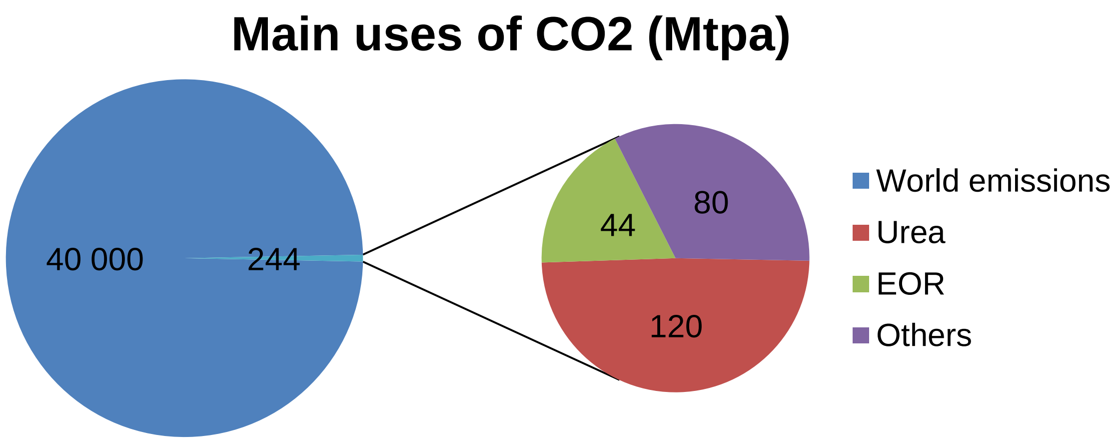
CO_2, waste or feedstock?

- CCS (excluding EOR) is a cost only technology!
  - Requires infrastructure off-site (pipelines, ships, storage sites determined by geology)
  - Basically permanent landfilling

- CO_2 capture is expensive
  - Captured CO_2 ~ 40 US$/t
  - ETS Market ~ 7-8 €/tCO_2 between 2011 and 2018
  - Now ~ 25 €/tCO_2

CO_2, waste or feedstock?

- How to improve the economics of CO_2 capture?
  - Consider CO_2 as a resource, not as waste

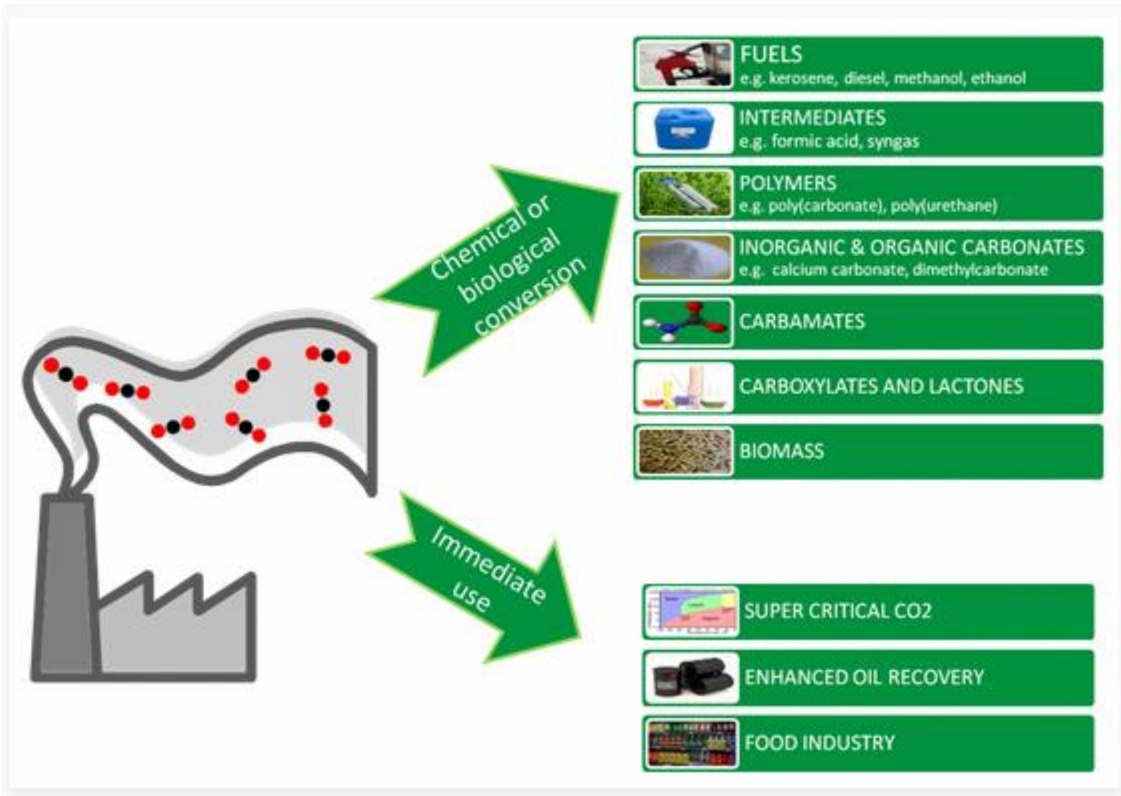


- So far, sources for CO_2 are high-purity ones
  - Industrial (Ethanol, Ammonia, Ethylene, Natural gas…)
  - Natural (Dome)
  - CO_2 from power plants (~2.4 Mtpa)

Global CCS Institute. Global Status of CCS 2016: Summary Report.
Koytsumpa et al, 2016. https://doi.org/10.1016/j.supflu.2017.07.029

Main CO_2 re-use pathways

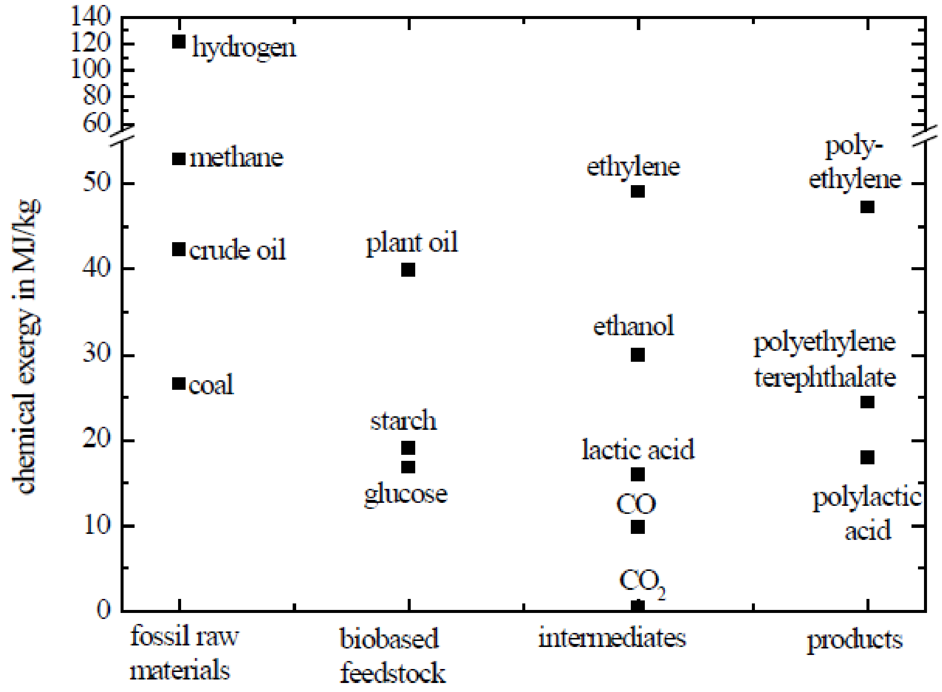
Many different products, as CO_2 can be seen as a carbon source => leads to almost all petrochemical products!



Source: CO2Chem

Main CO_2 re-use pathways

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

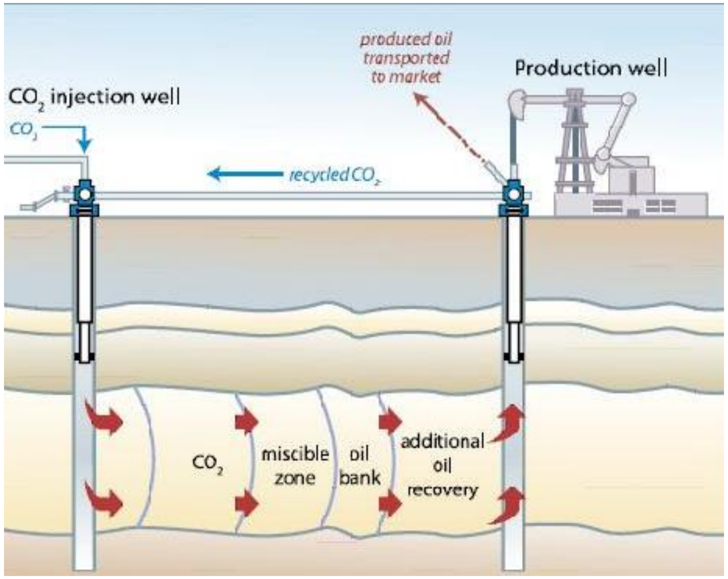


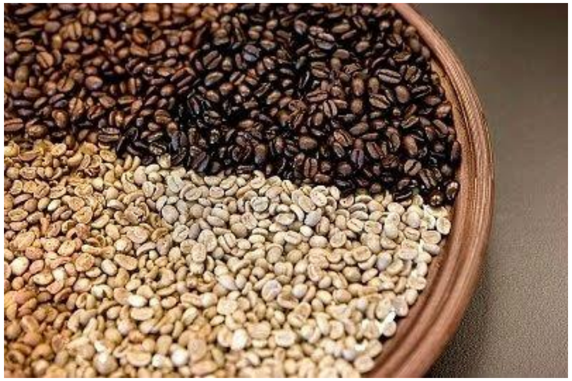
=> At large scale, need to make sure that energy comes from renewables!

Frenzel et al, 2014. Doi:10.3390/polym6020327

Direct use of CO_2

- Enhanced oil recovery
  - 66 $MtCO_2$/a, increasing
- Others: ~ 20 $MtCO_2$/an
- Long or short-term CO_2 storage





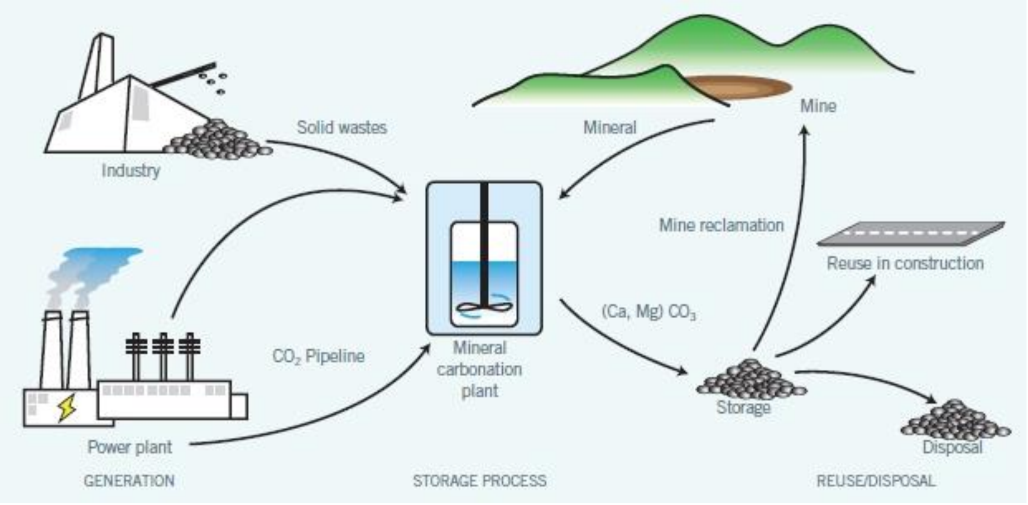
Biological transformation of CO_2

- Photosynthesis
  - Greenhouses
  - Microalgae

- Drawbacks:
  - Area for cultivation (+- 120 t CO_2/ha)
  - Energy for post-processing

Chemical transformation to lower energy

- Mineralization - Carbonatation
  - $CaO + CO_2 \rightarrow CaCO_3$
  - $MgO + CO_2 \rightarrow MgCO_3$
  - $Mg_2SiO_4 + 2\ CO_2 \rightarrow 2\ MgCO_3 + SiO_2$



Carbstone, ORBIX, 2019

- Use of Mg or Ca oxides as feedstock, coming from minerals or industrial wastes
- Spontaneous but slow reaction

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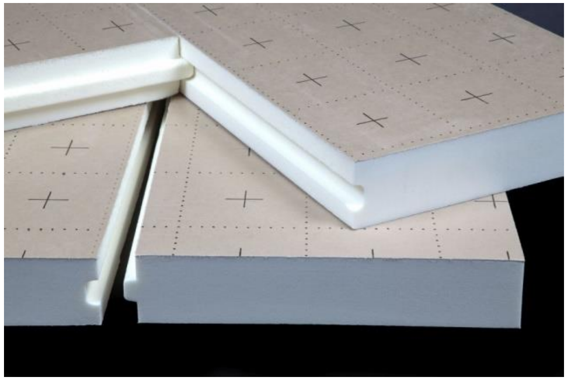
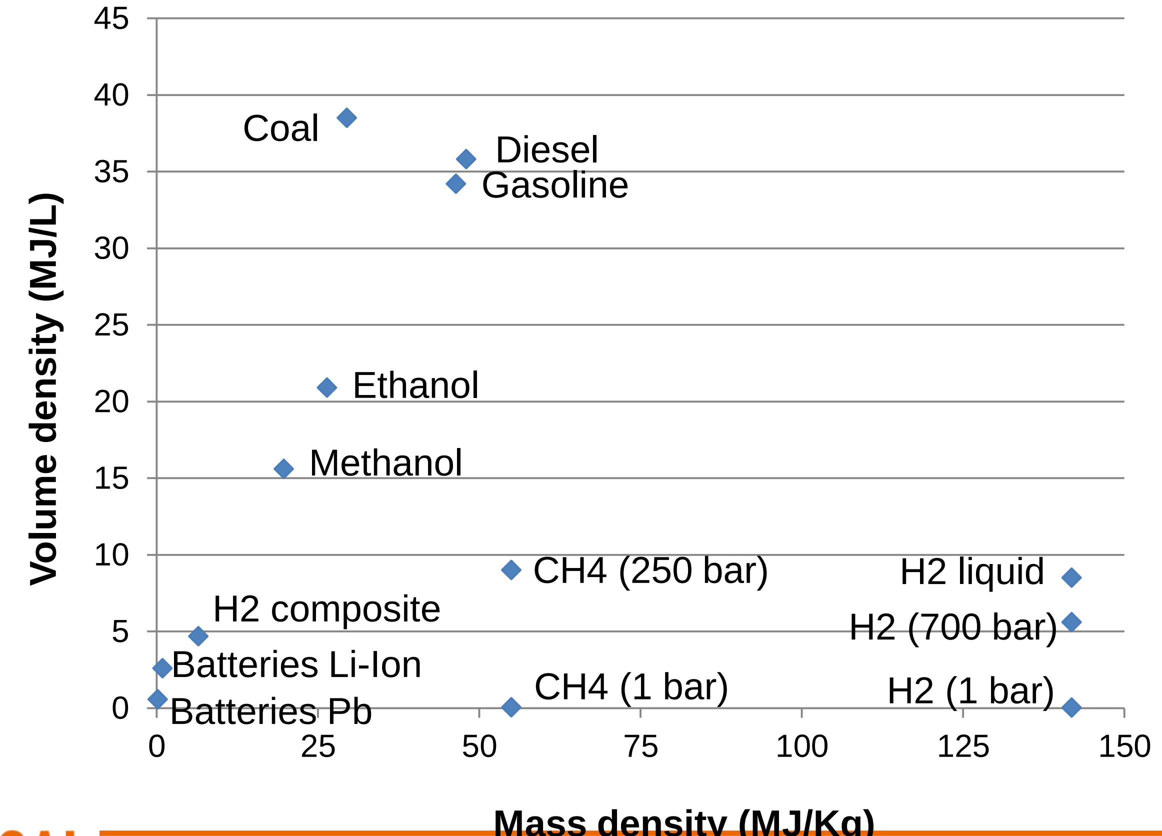
Chemical transformation to higher energy

- Some products made from CO_2
  - CO_2 can be a useful source of carbon for organic chemistry, it's just that you need energy!



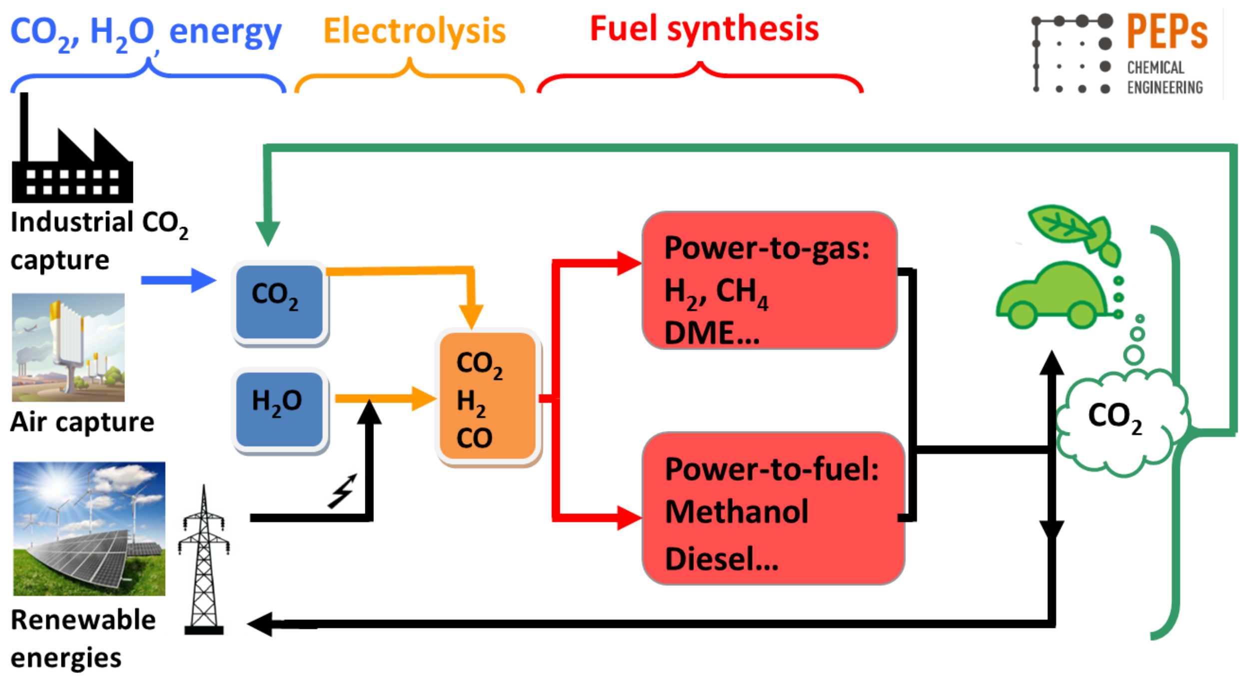
CO_2 to fuels

- Decisive advantage: a fantastic energy density!
  - => Inteseasonal energy storage becomes possible



CO_2 to fuels

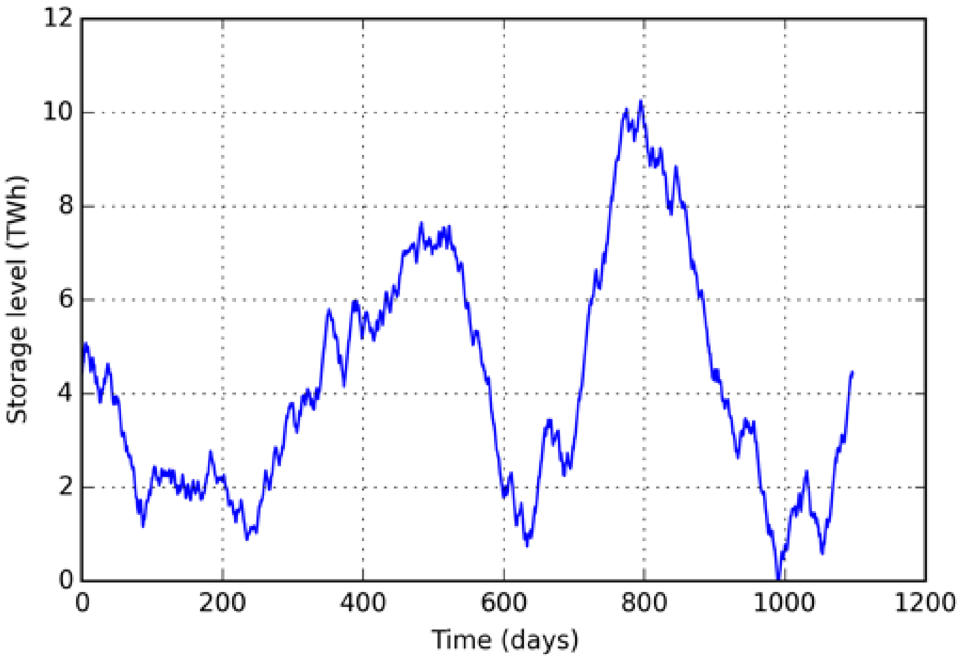
- Power-to-liquid, power-to-gas
  - $CO_2 + 3\ H_2 \rightarrow CH_3OH + H_2O$



Power-to-methanol @ CRI => 4000 T/a, Efficiency ~50%
Power-to-diesel @ Sunfire => 58 m3/a, Efficiency ~70%

Research ULiège at system scale

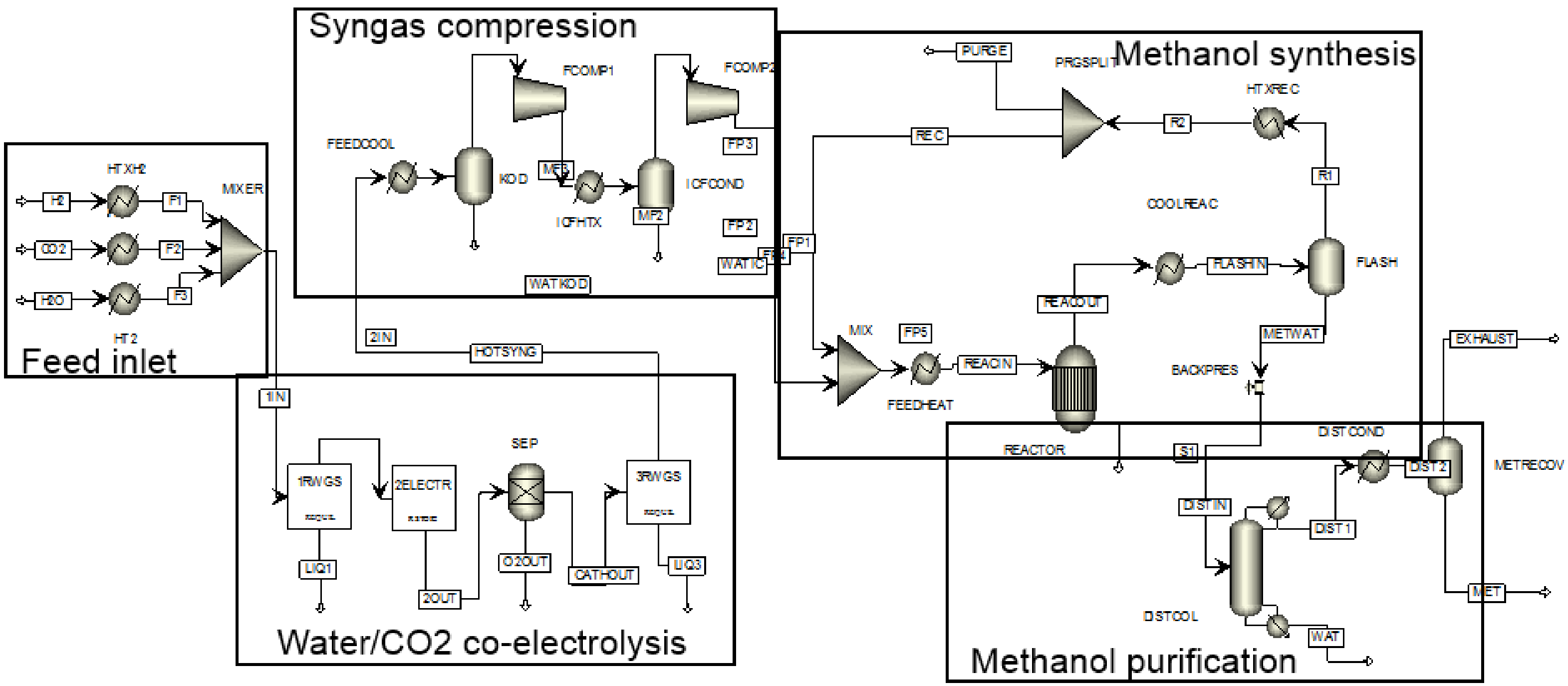
- Energy model with 100% variable renewables + storage for electricity grid:
  - Based on historical belgian data for load and capacity factors
  - Vary the installed capacity to minimize system costs and avoid black-outs



Léonard et al., 2015. Electricity storage with liquid fuels in a zone powered by 100% variable renewables, IEEE 978-1-4673-6692-2.

Research ULiège at process scale

- Process integration
  - Models for electrolysis, CO_2 capture and fuel synthesis



Léonard et al., 2016. Computer aided chemical engineering *38*, 1797.
DOI: 10.1016/B978-0-444-63428-3.50304-0

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5. Conclusions and perspectives

State of technology CCS

- Capture of CO_2
  - Commercially applied
  - 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
- Transport of CO_2
  - Commercially applied
  - Pipelines, ships
- Storage
  - Commercially applied
  - Risk assessment, monitoring, standards
- Use
  - Depends on the application

Conclusions et perspectives

Large potential but many challenges for CO_2!

- Society
  - Acceptation of new technologies

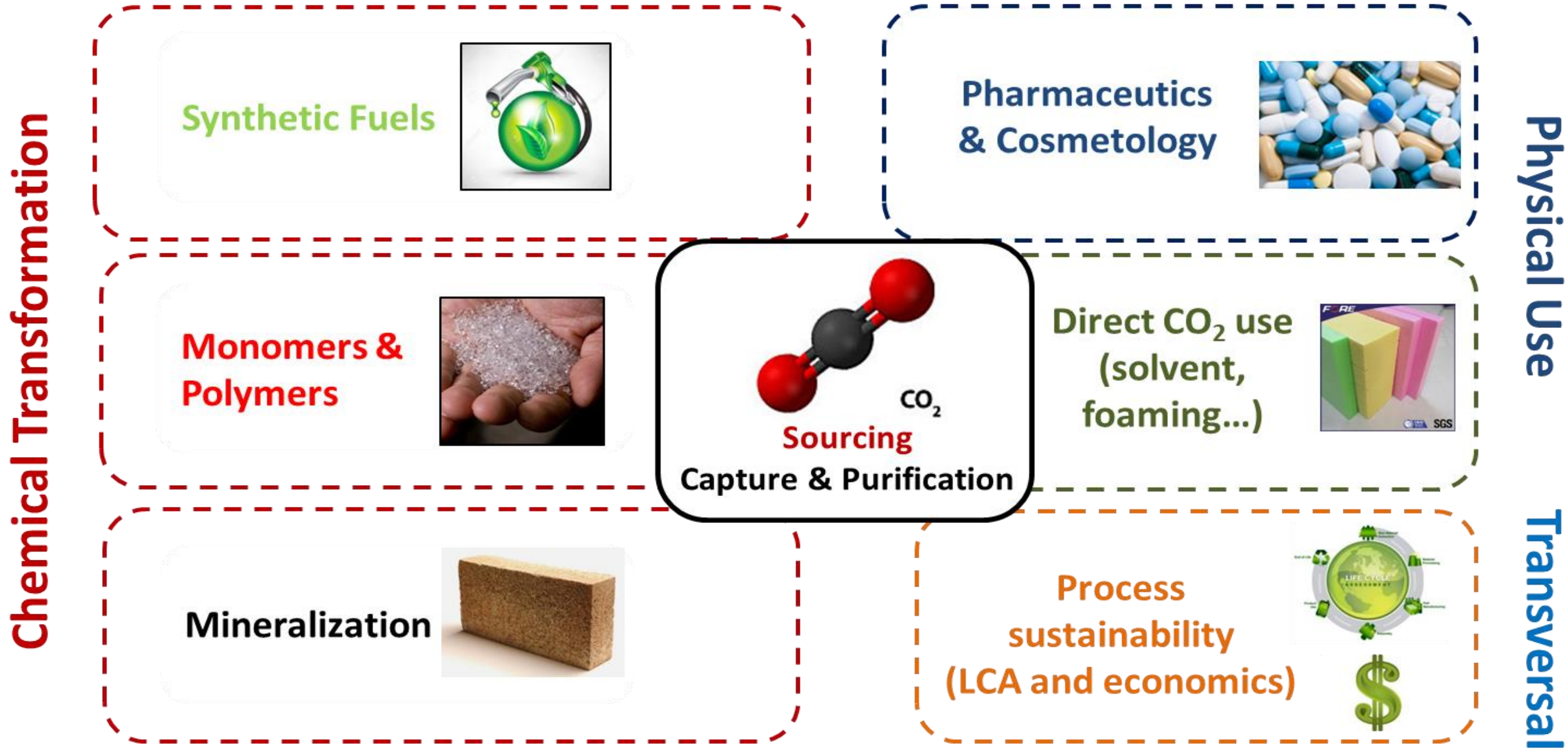
- R&D and industries
  - Develop these technologies, efficient & cheap
  - Integrate them to existing processes!
  - Be able to process huge flow rates

- Politics
  - Large-scale CCUS Demonstration projects are needed, but they are expensive!
  - Efficient legislative framework is needed to promote new technologies
  - Cost of CO_2 capture > 40 €/t vs. ETS market
  - Carbon tax? Label on CO_2-sourced goods? ...

NEUTRALIZED BY GREEN ENERGY 0% CO2 CERTIFIED

Perspective ULiège: FRITCO$_2$T platform

Federation of Researchers in Innovative Technologies for CO_2 Transformation



Thank you for your attention!

http://chemeng.uliege.be

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