Rationals behind CCUS & DAC

Grégoire LEONARD

February 2, 2021

CHEMICAL ENGINEERING

LIÈGE université

Outline

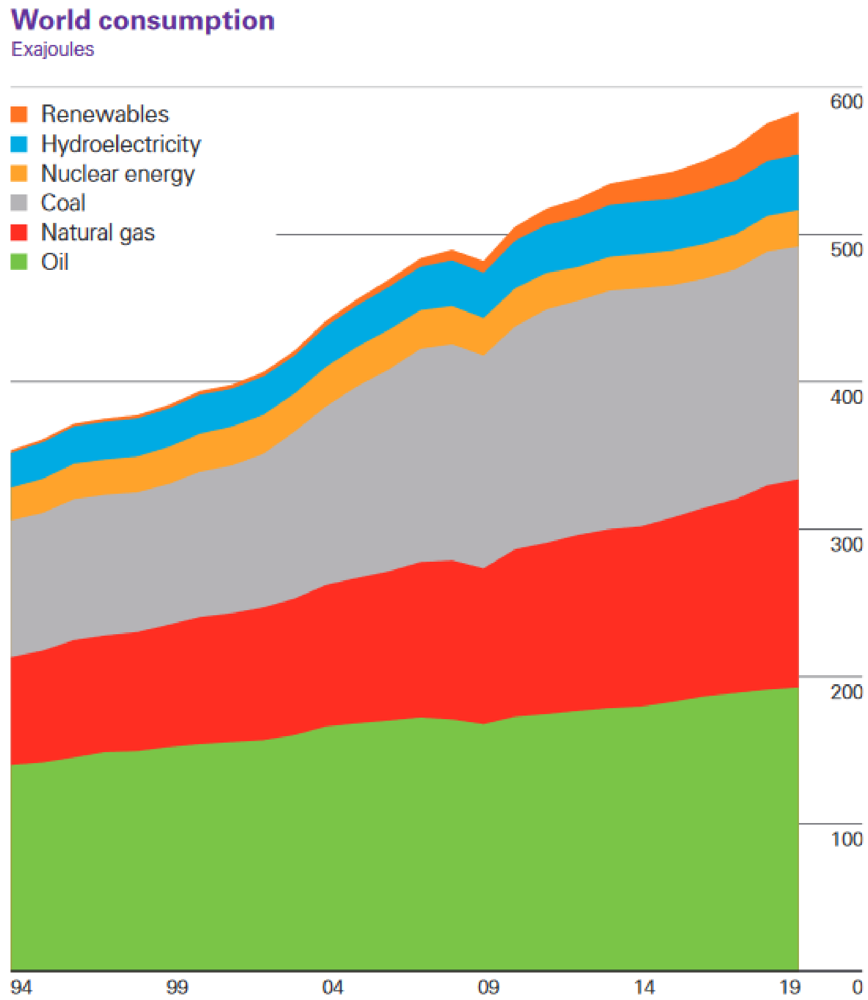
1. How big is the CO_2 challenge?
2. Carbon Capture
3. Storage and/or re-use?
4. Perspectives

The energy transition is on-going…

It has to address 2 objectives in contradiction:

- Limit GHG emissions
- Meet the worldwide increasing energy demand!

Meeting the increasing demand is already a challenge in itself!

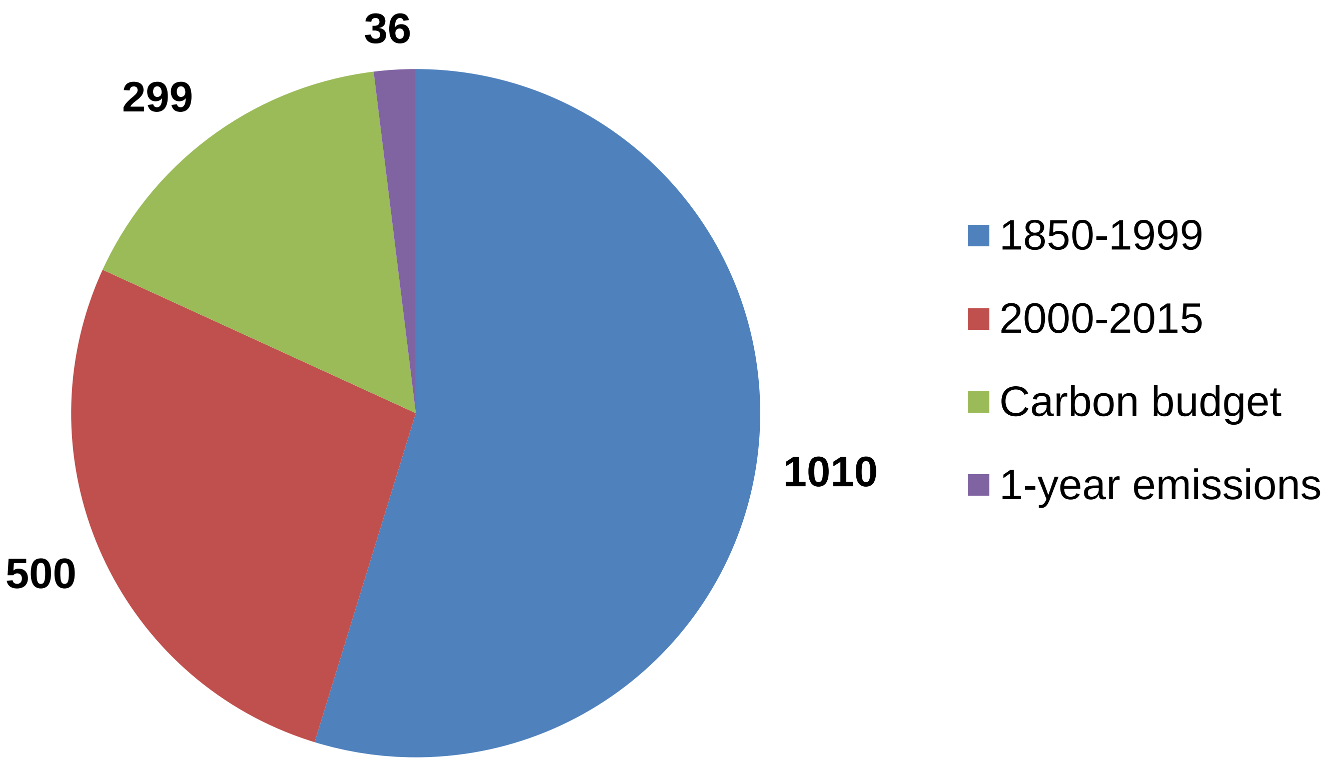


5%
6.5%
4.3%
27%
24.2%
33%

BP Statistical Review of World Energy 2020.

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).

At european level…

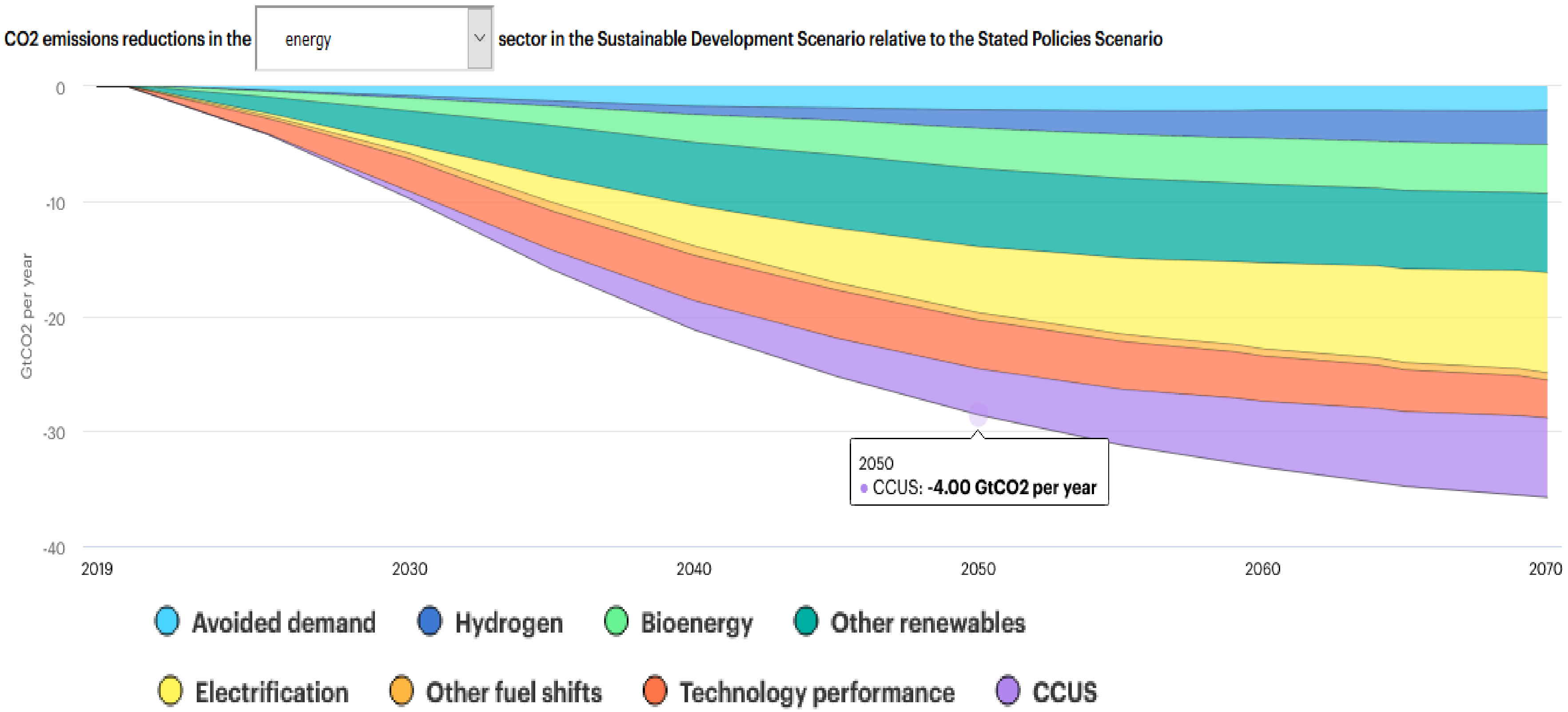
The EU Green Deal

- Carbon neutrality by 2050
- - 55% CO_2 by 2030

The Economist

CCUS forecasts

- CCUS = Carbon Capture, Utilization and Storage



IEA, 2020. https://www.iea.org/reports/energy-technology-perspectives-2020

2. CO_2 Capture

CHEMICAL ENGINEERING

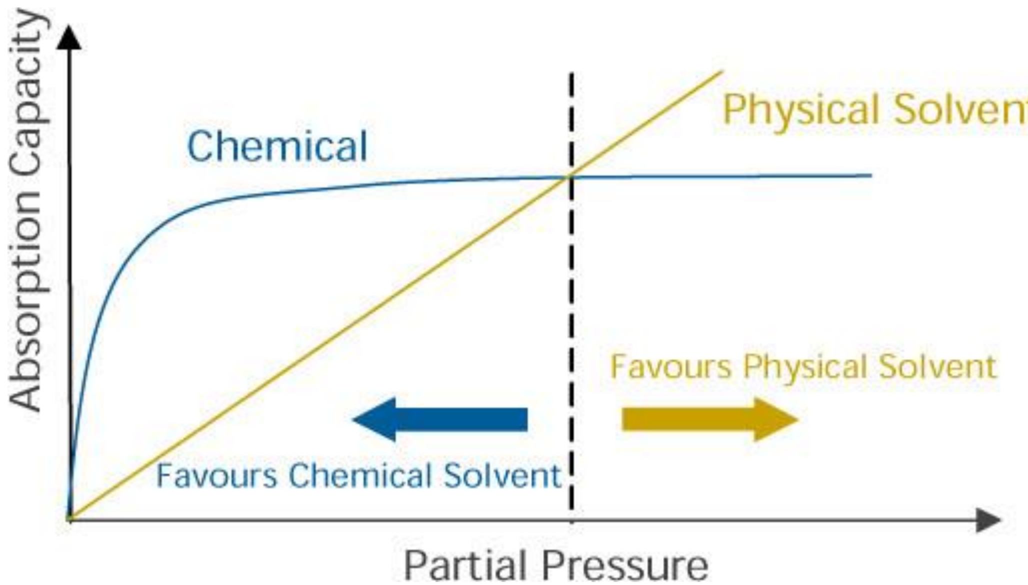
LIÈGE université

CO_2 capture

- It's a question of fluid separation!
  - 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%
  - Mature (exist for >50 years) & flexible, but cost only!

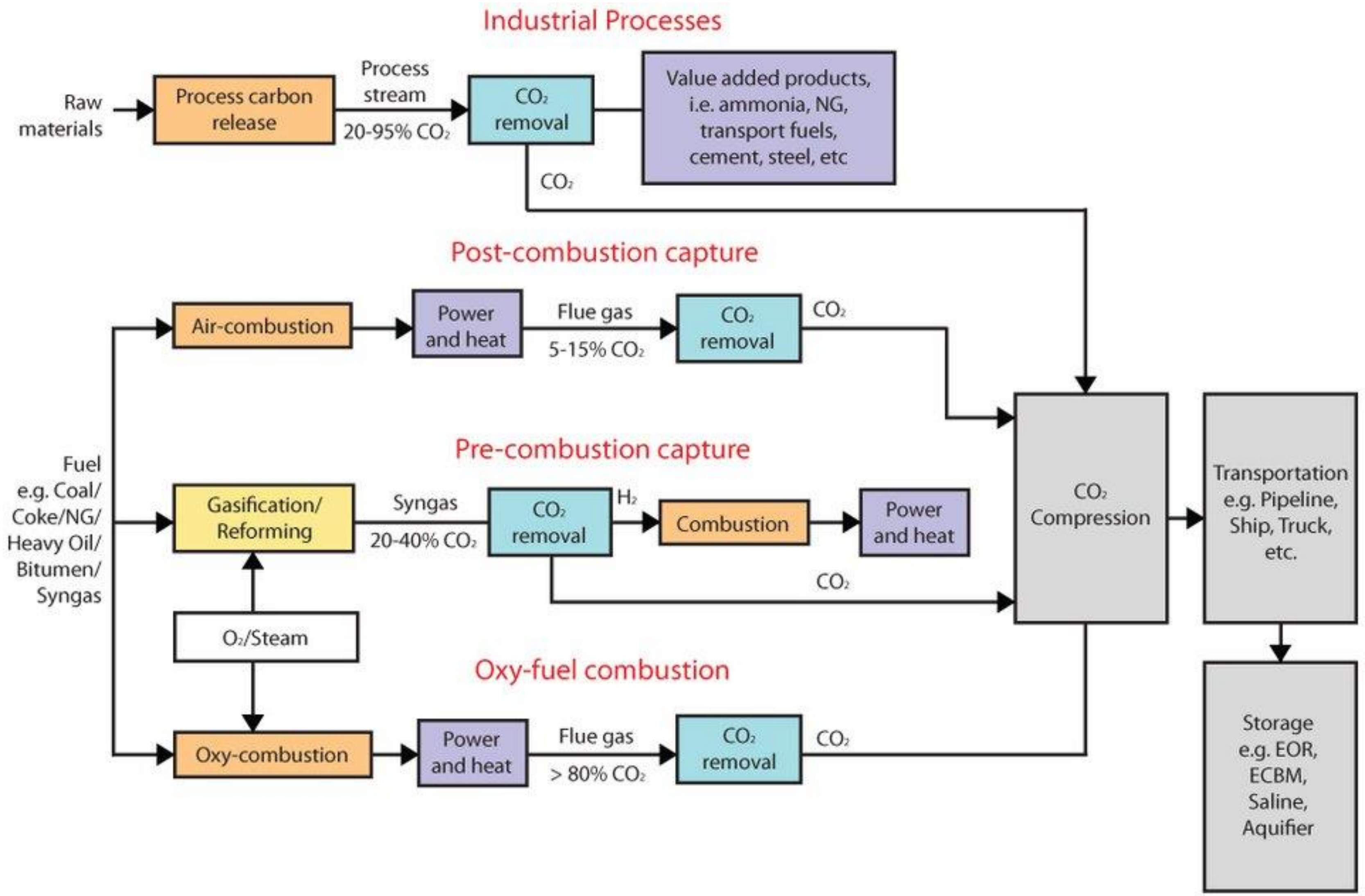
CO_2 separation technologies

- Avoid fluid mixtures
- Absorption
  - Physical
  - Chemical
- Adsorption
- Membranes
- Cryogenic separation
- Others…



Threshold value ~15 vol-% in flue gas, or 4 bar of P_CO2

CO_2 capture configurations



CO_2 capture thermodynamics

- Thermodynamic study on energy costs and penalties

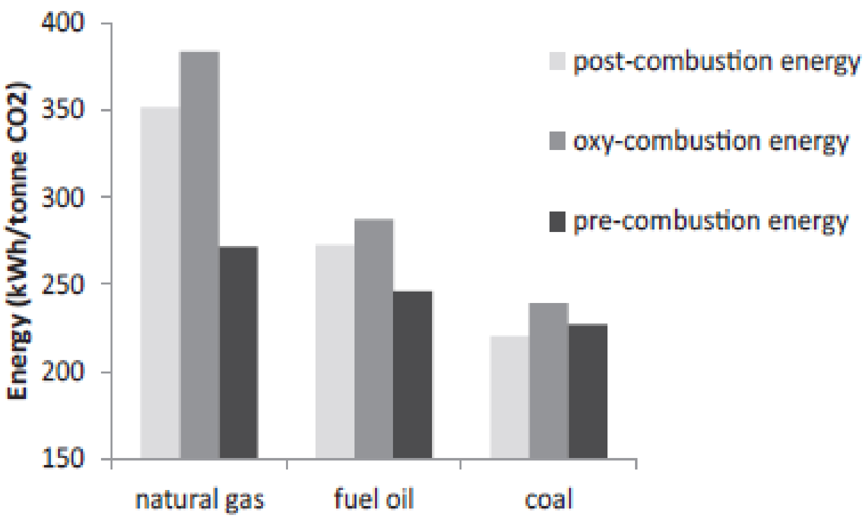


Fig. 2. Energy cost for different methods for CO_2 capture.

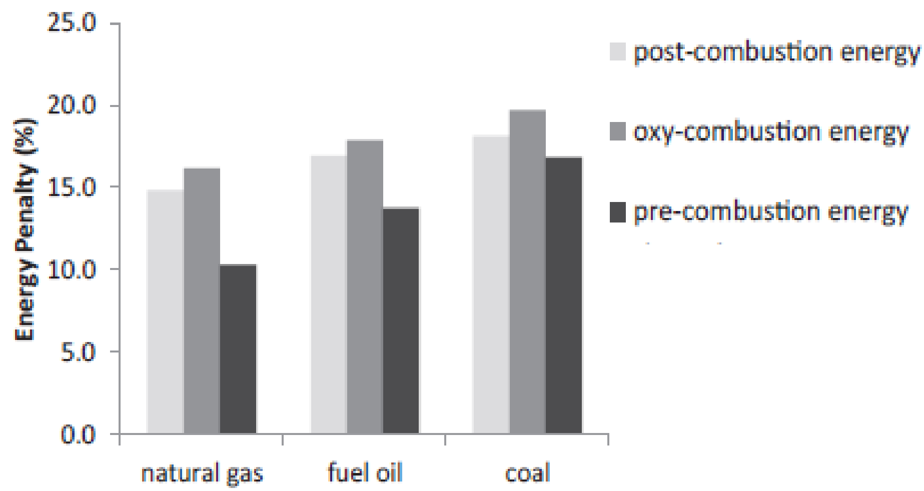


Fig. 3. Target energy penalties for different methods of CO_2 capture.

Energy 103 (2016), 709. http://dx.doi.org/10.1016/j.energy.2016.02.154

CO_2 capture benchmark – Power sector

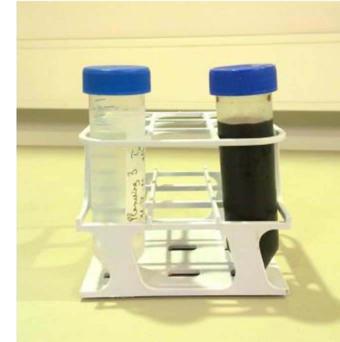
	Ultra-supercritical coal-fired power plant			Natural-gas combined-cycle power plant		
	W/O PCC	MEA	PZ/AMP	W/O PCC	MEA	PZ/AMP
Technical performance						
Gross power output (MW)	900	900	900	890	890	890
Auxiliary power (MW)	83	266.1	215.6	12	161.8	128.2
Net power output (MW)	817	633.9	684.4	878	728.2	761.9
Net plant higher heating value efficiency (%)	42.5	32.97	35.59	52.66	43.91	45.94
Net plant lower heating value efficiency (%)	44.4	34.48	37.23	58.25	48.57	50.82
CO_2 generation (t/h)	604	604	603.3	310	310	310
CO_2 emission (t/h)	604	61	59.1	310	31	31
CO_2 emission (t/MWh)	0.739	0.095	0.084	0.353	0.042	0.040
CO_2 capture (t/h)	0	543	544	0	279	279
Equivalent energy consumption (MWh/tCO_2)	–	0.337	0.244	–	0.506	0.423
Economic performance						
Total capital requirement (million €)	1342.8	1681.1	1659.5	835.7	1172.8	1166.3
Specific capital requirement (€/kW)	1647	2654	2424	939	1611	1531
Fixed operations & maintenance (O&M) (million €)	37.7	46.3	45.9	29.2	39.7	39.5
Variable O&M (million €)	7.54	20.1	17.8	3.41	11.9	9.1
LCOE (€/MWh)	51.6	87.0	79.5	52.9	77.6	73.8
CO_2 avoided cost (€/tCO_2)	–	55.0	42.8	–	79.3	67.1

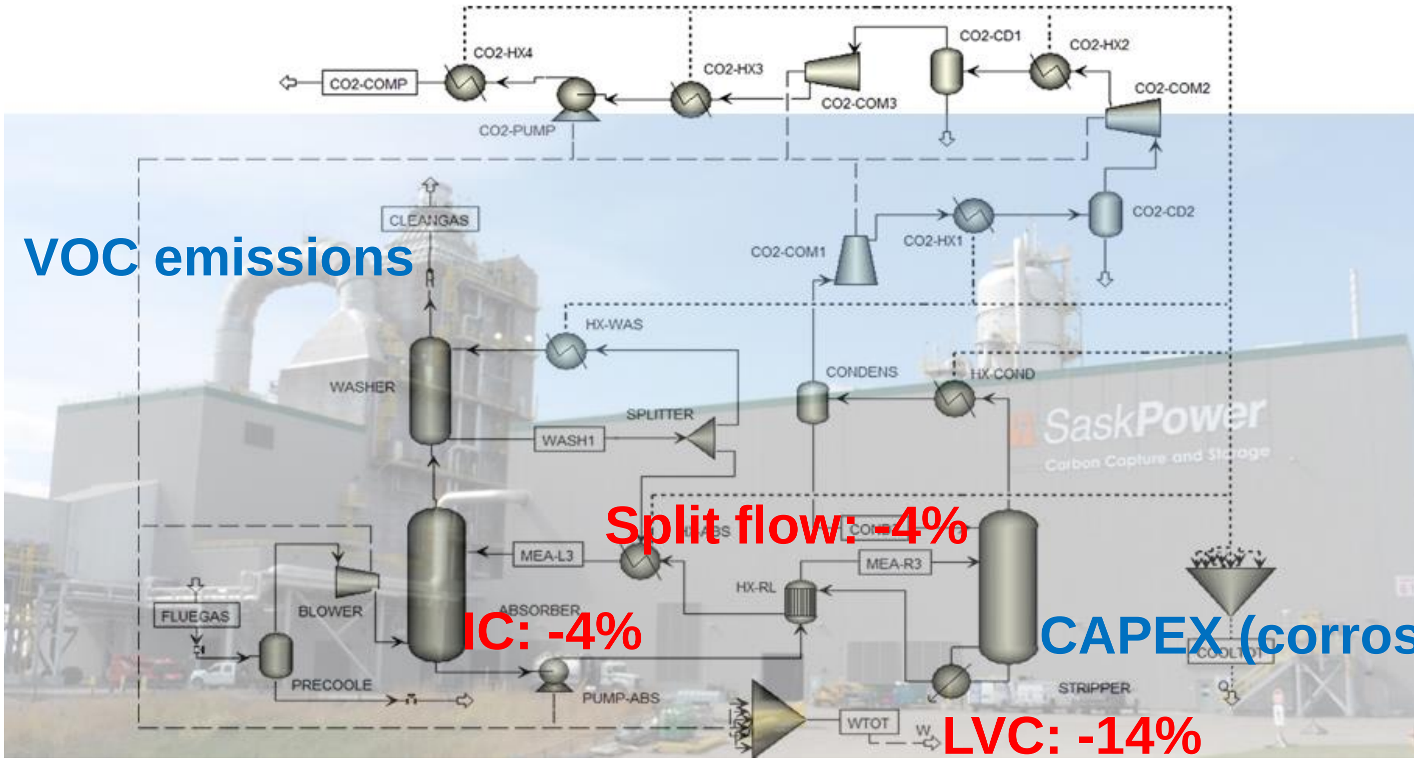
W/O PCC = without post-combustion capture

IEAGHG, 2019. Further assessment of emerging CO_2 capture technologies for the power sector and their potential to reduce costs

Focus: research at ULiège

- Modeling and optimization of processes
- Stability of chemical solvents





VOC emissions

Split flow: -4%

IC: -4%

CAPEX (corrosion)

LVC: -14%

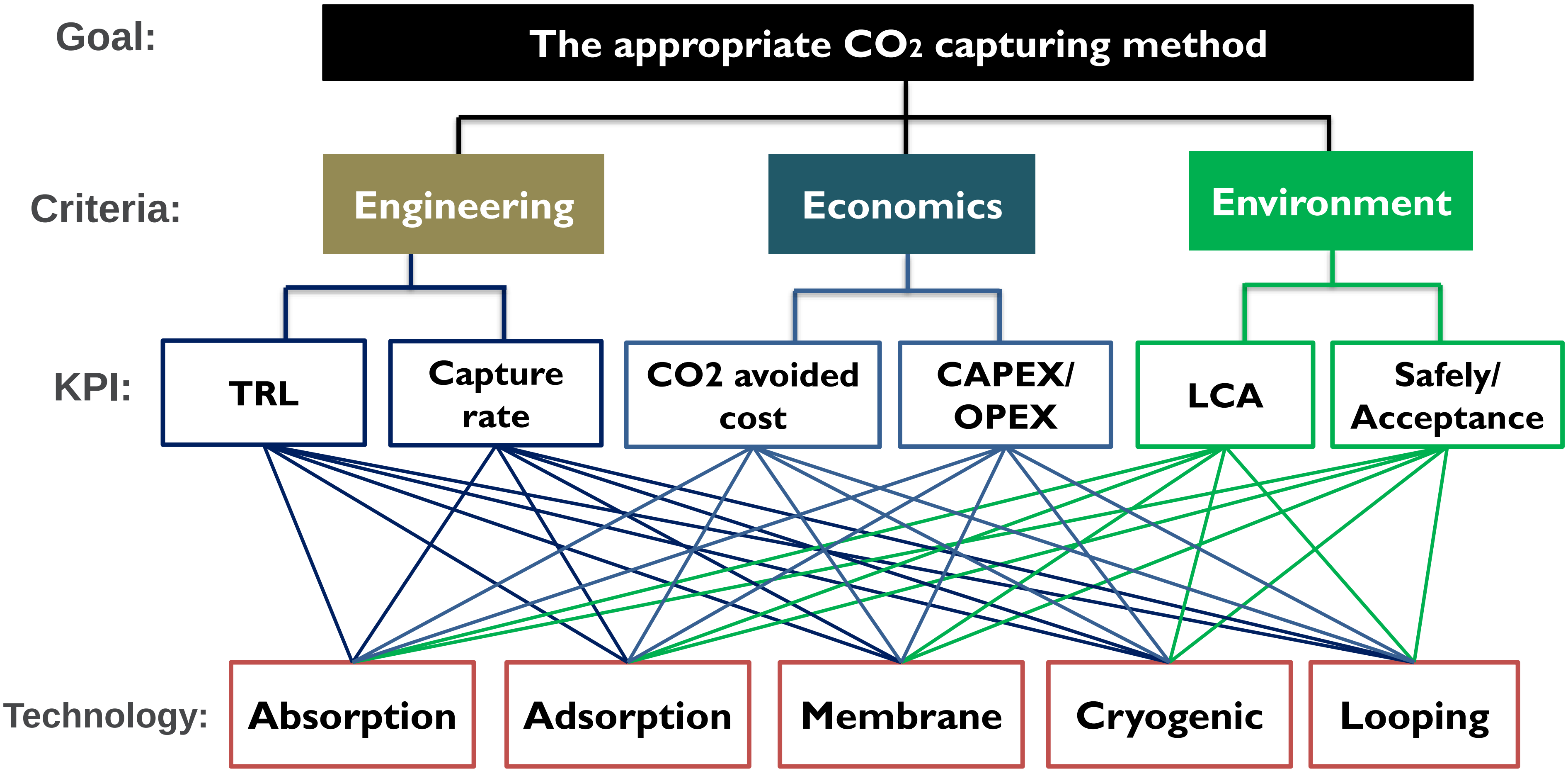
OPEX: viscosity, altered properties…

CHEMICAL ENGINEERING

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

LIÈGE université

PROCURA ETF: Decision support tool



Direct Air Capture (DAC)

- Negative CO_2 emissions
  - BECCS or DAC

Elon Musk promet 100 millions de dollars à celui qui pourra l'aider à résoudre ce problème

K.S. Lackner, CNCE ASU, 2017.

Direct Air Capture

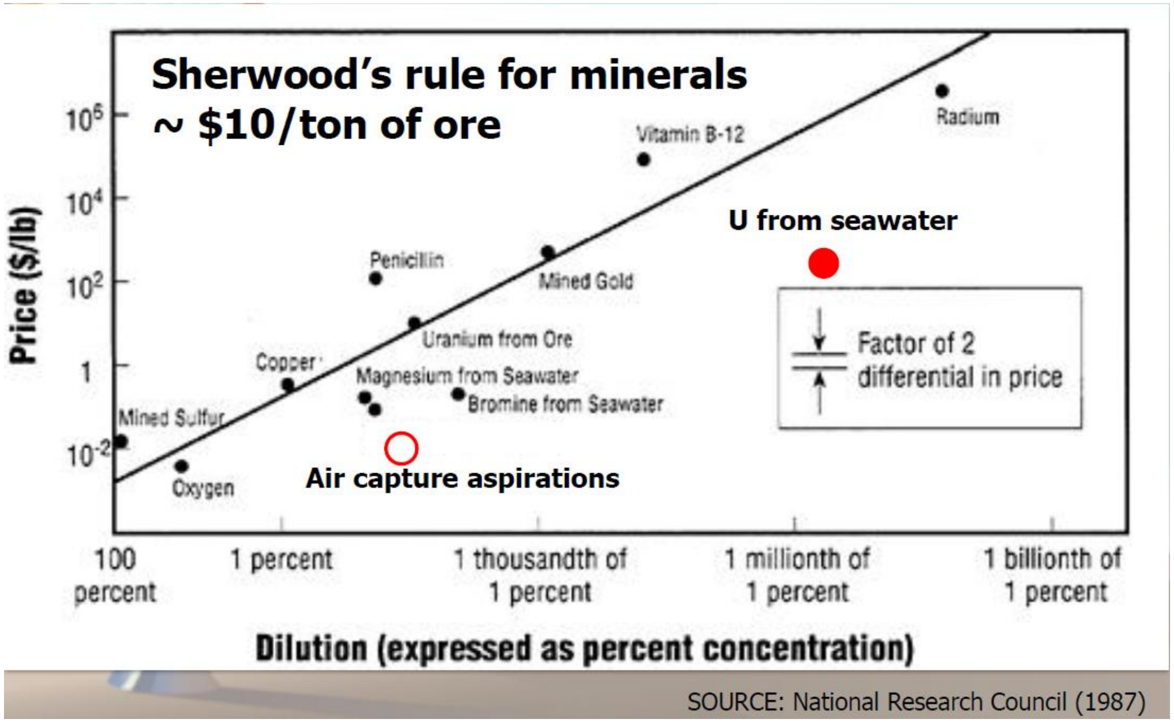
- Motivations
  - Address non-concentrated CO_2 emissions
  - Close the carbon cycle of synthetic fuels
  - Reduce the need for transporting CO_2
    - No Nimby effect, you can go wherever you want, incl. close to use or storage sites
  - Long-term considerations: remove C from the atmosphere

  - Cost mostly due to sorbent regeneration, not from air contacting
  - Sorbent regeneration has similar cost whatever the CO_2 concentration in the gas stream

www.pnas.org/cgi/doi/10.1073/pnas.1108765109
DOI: 10.1140/epjst/e2009-01150-3

Direct air capture

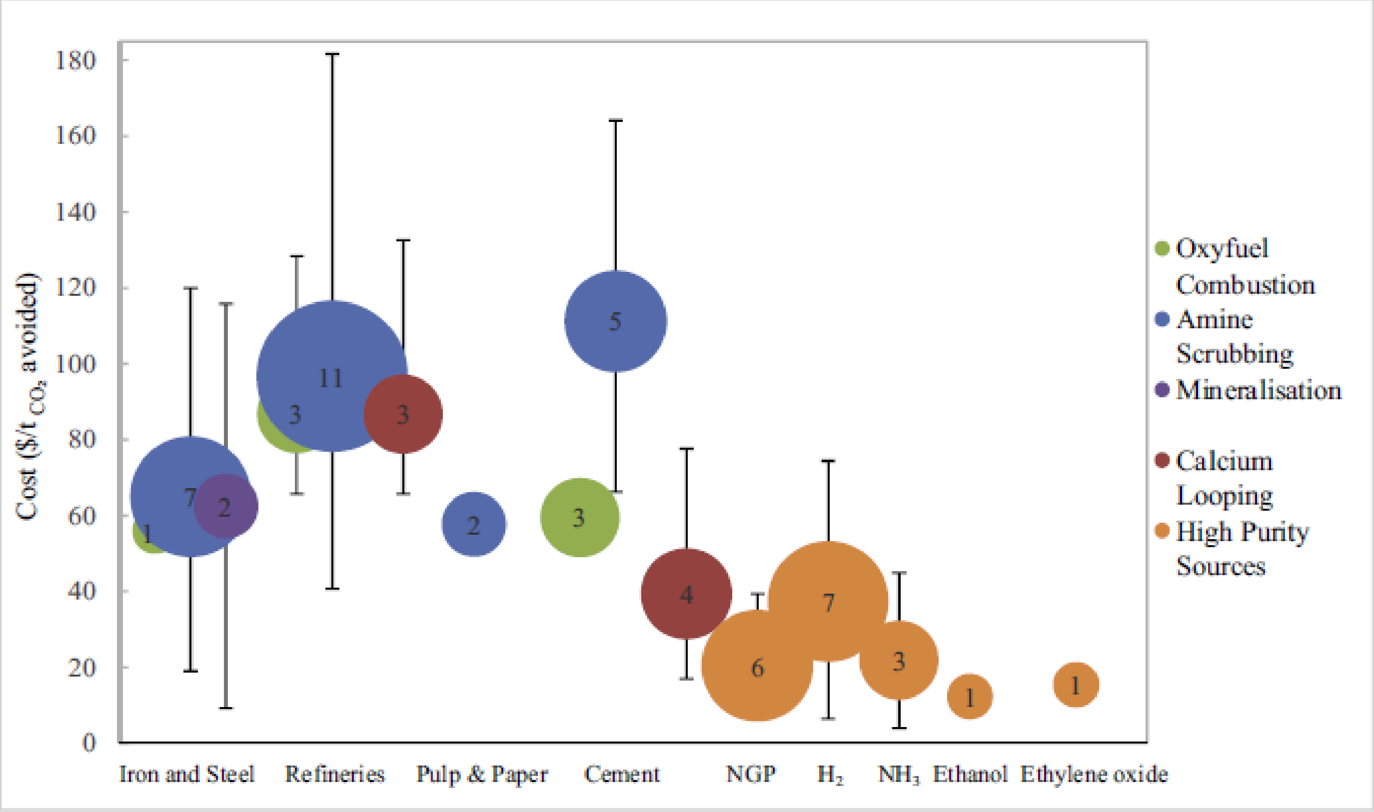
- ~ 410 ppm in the air
  - Adsorption / Absorption
  - Temperature-swing, moisture-swing
  - Expected costs vary between 100 and 800 $/ton



Wang et al, Environ. Sci. Technol., 45, 6670–6675, 2011
engineering.asu.edu/cnce

Cost of CO_2 capture

- Estimated cost for different industries
  - Opex ~75% of the cost



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

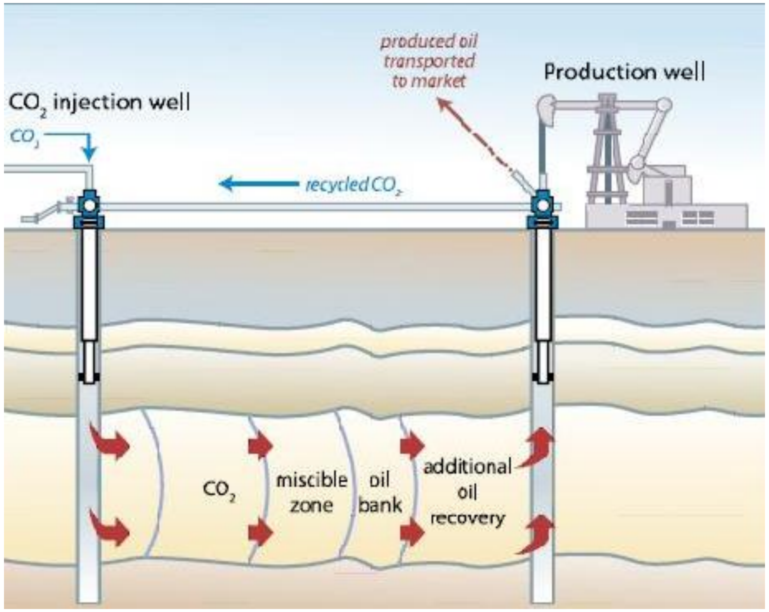
- European Emissions Trading System (ETS)
- CO_2 price now reaches > 30 €/t!

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

3. Storage and/or re-use of CO_2 ?

Storage is state-of-the-art

- Potential for storage exceeds by far the needs
  - 5000 – 25 000 GtCO_2 vs. ~ 2000 GtCO_2
  - Pure storage: ~ 5 Mtpa
  - Capture and EOR: ~ 30 Mtpa in 2016
- Storage costs ~7-30 USD/t, large infrastructure costs needed!

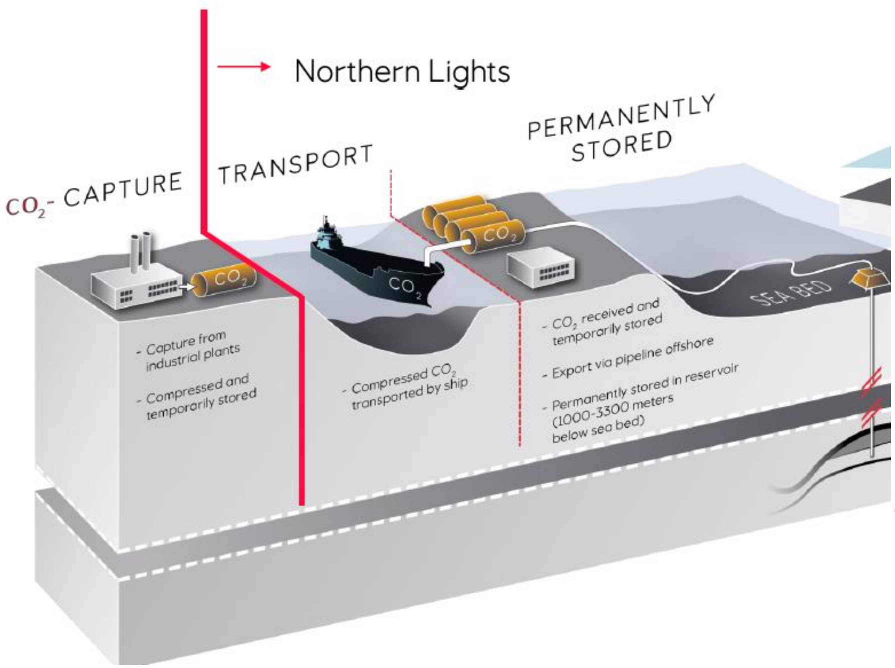


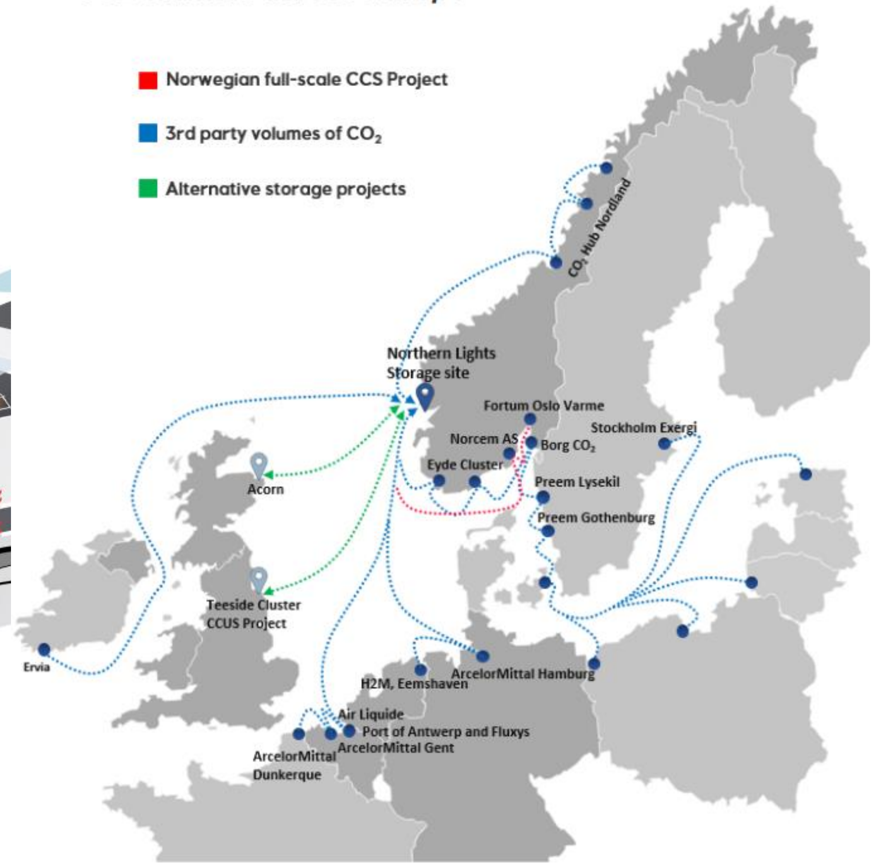
Global CCS Institute 2017
doi: 10.3389/fclim.2019.00009

Northern lights

- Norway, off-shore field, saline aquifer
- Up to 5 Mt CO_2/y

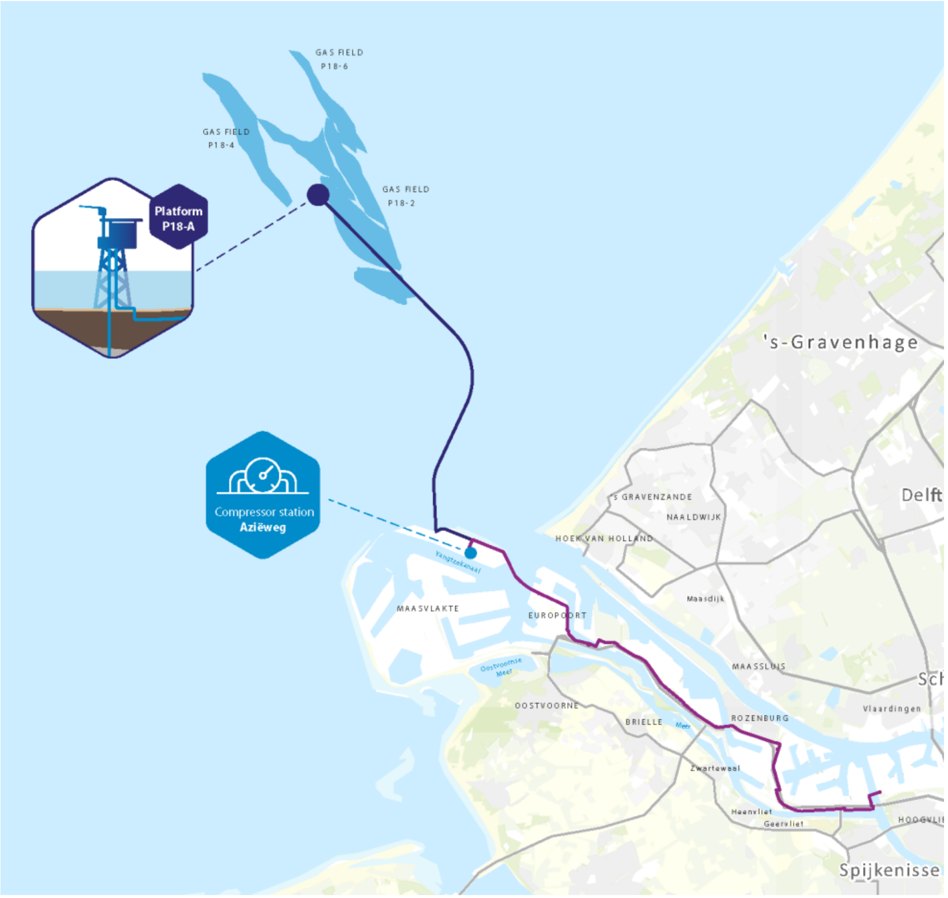
- A ship based solution means access for CO2 emitters across Europe





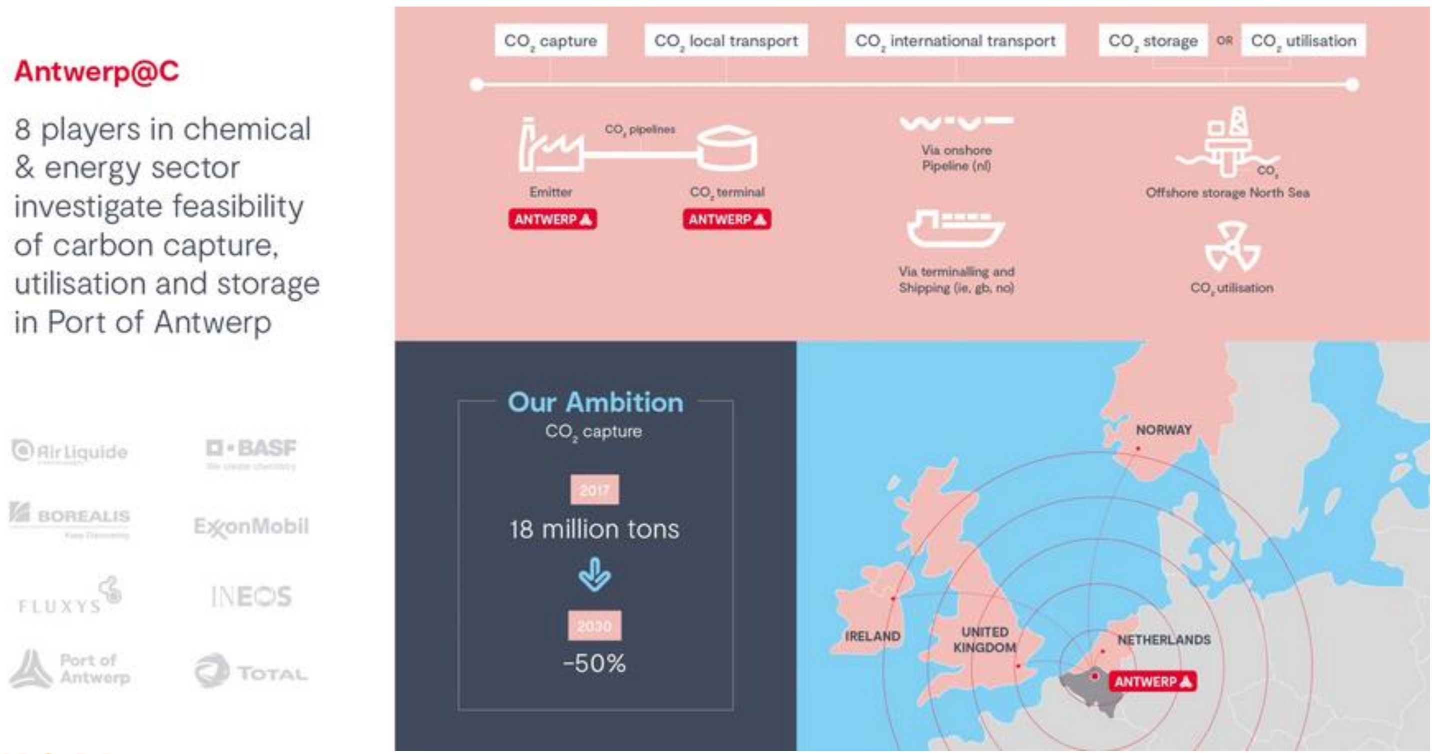
Porthos

- Rotterdam, off-shore depleted gas field
- 2.5 Mt CO_2/y



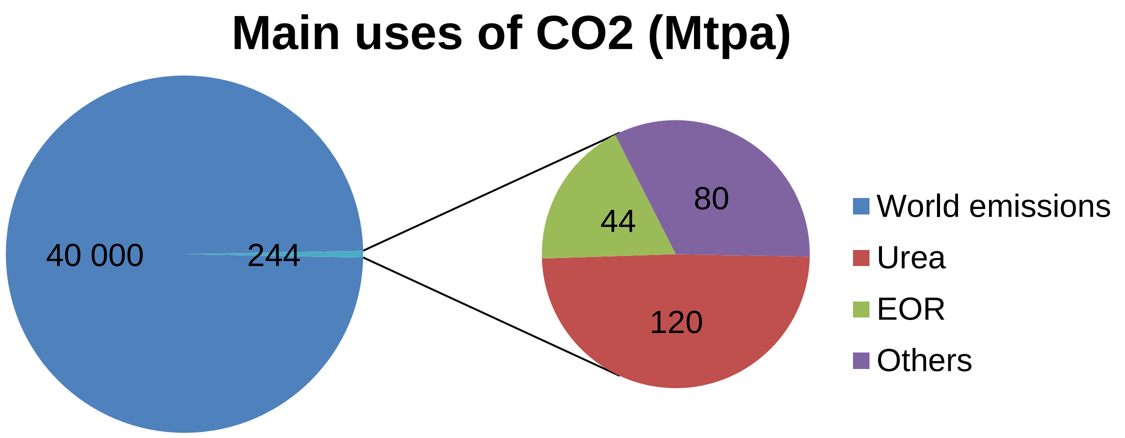
Antwerp@C

- No storage capacity offshore of Belgium
  - Antwerp@C studies the infrastructure for connection to Norway and The Netherlands
  - => Pipelines, intermediate storage, liquefaction unit…



CO_2, waste or feedstock?

- Sequestration or re-use?
  - Consider CO_2 as a resource, not as waste



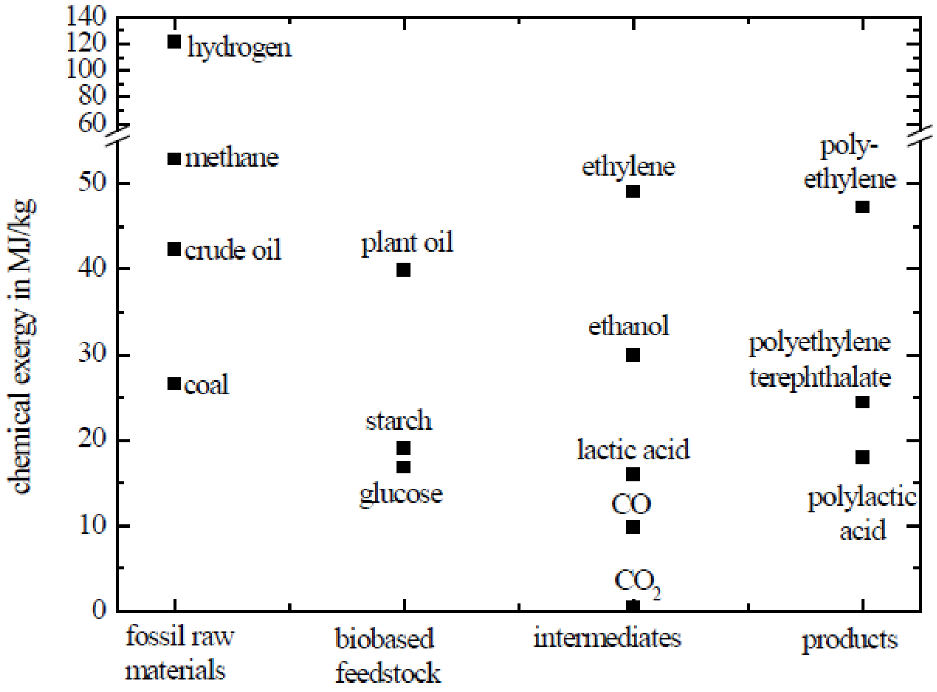
- CO_2 re-use potential up to ~ 4 – 16 Gtpa

- So far, sources for CO_2 are high-purity ones
  - Industrial (Ethanol, Ammonia, Ethylene, Natural gas…)
  - Natural (Dome)

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

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

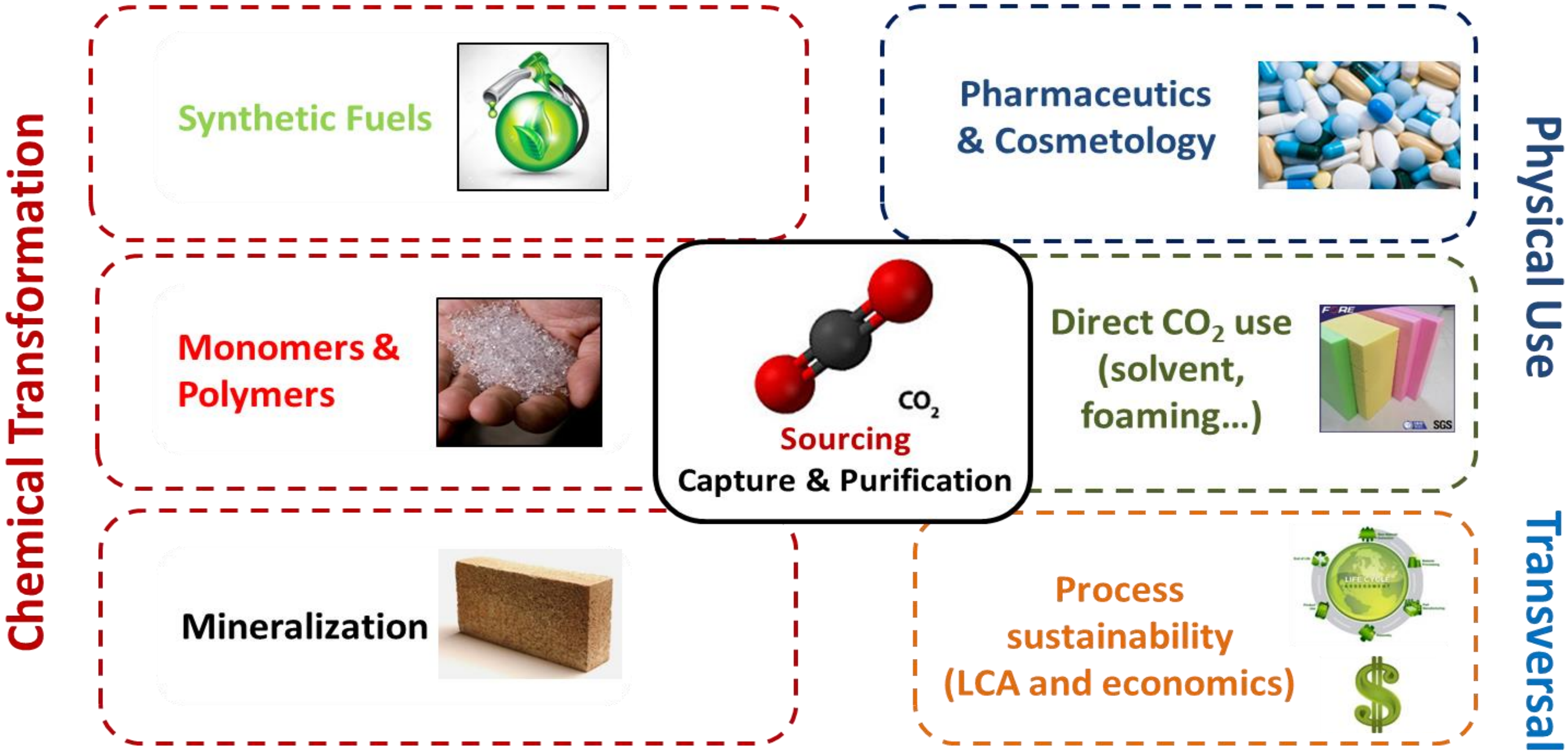


=> At large scale, need to make sure that energy comes from renewables!

Frenzel et al, 2014. Doi:10.3390/polym6020327

Perspective ULiège: FRITCO$_2$T platform

Federation of Researchers in Innovative Technologies for CO_2 Transformation



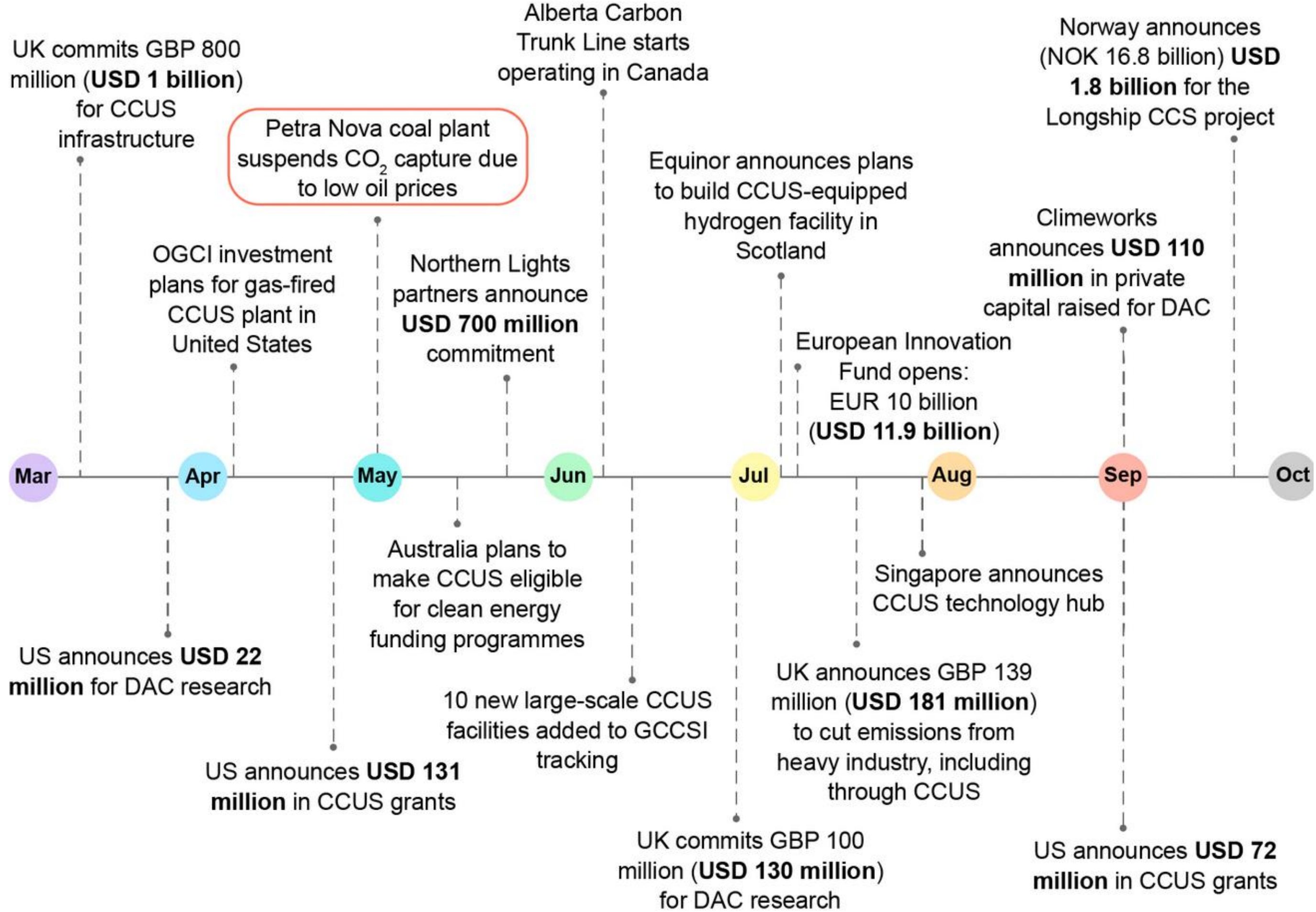
4. Conclusions and perspectives

State of technology CCUS

- Capture of CO_2
  - Mature but limited application yet
- Storage
  - Commercially applied (mostly EOR)
- Re-use
  - Maturity depends on technology, from TRL 1 to 9

- Big acceleration due to Paris COP21 agreement and environmental urgency
  - European Green Deal

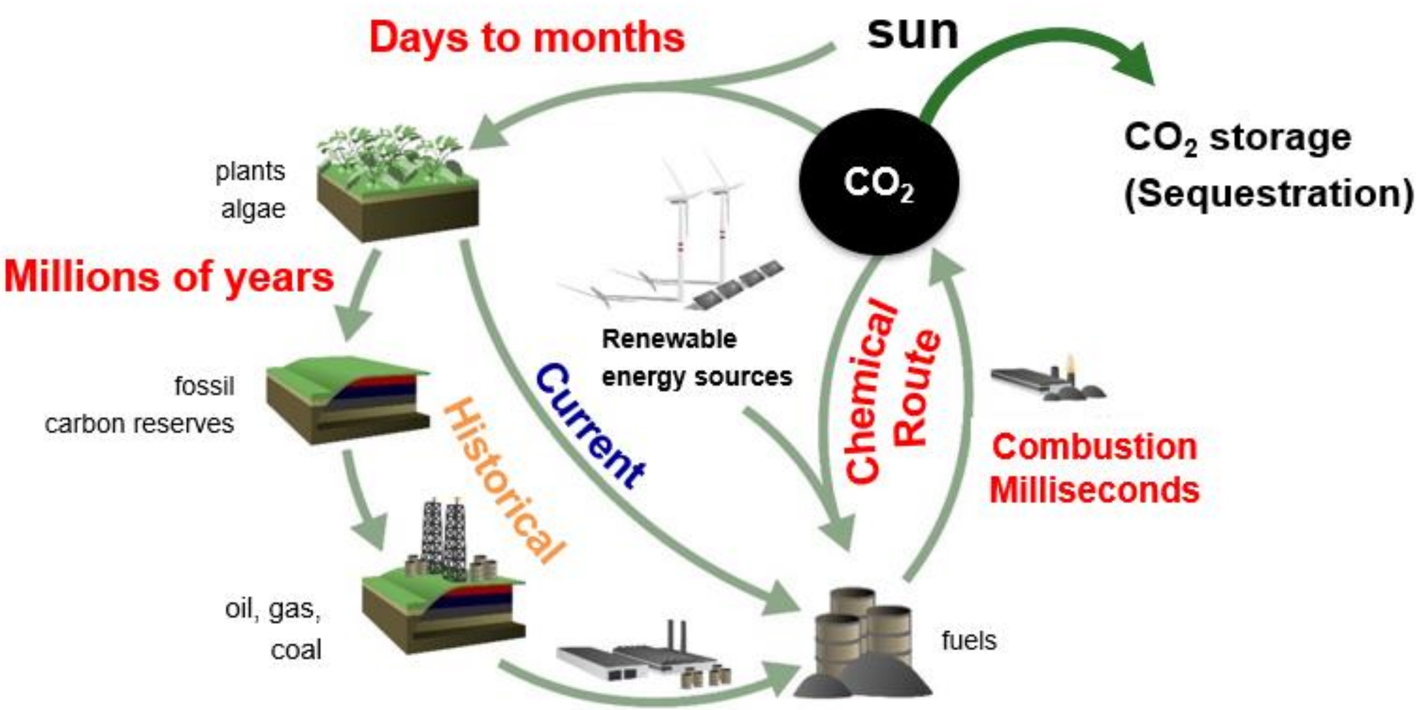
Perspective



IEA, 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions

Perspective

- We live in a carbon-based society, with very good reasons for that !
- A CO_2 neutral future is in sight with passionating (and huge) challenges for engineers!



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

Thank you for your attention!

g.leonard@uliege.be
chemeng.uliege.be

CHEMICAL ENGINEERING

LIÈGE université