Les réseaux de gaz de demain: enjeux d’une conversion énergétique

Grégoire LEONARD

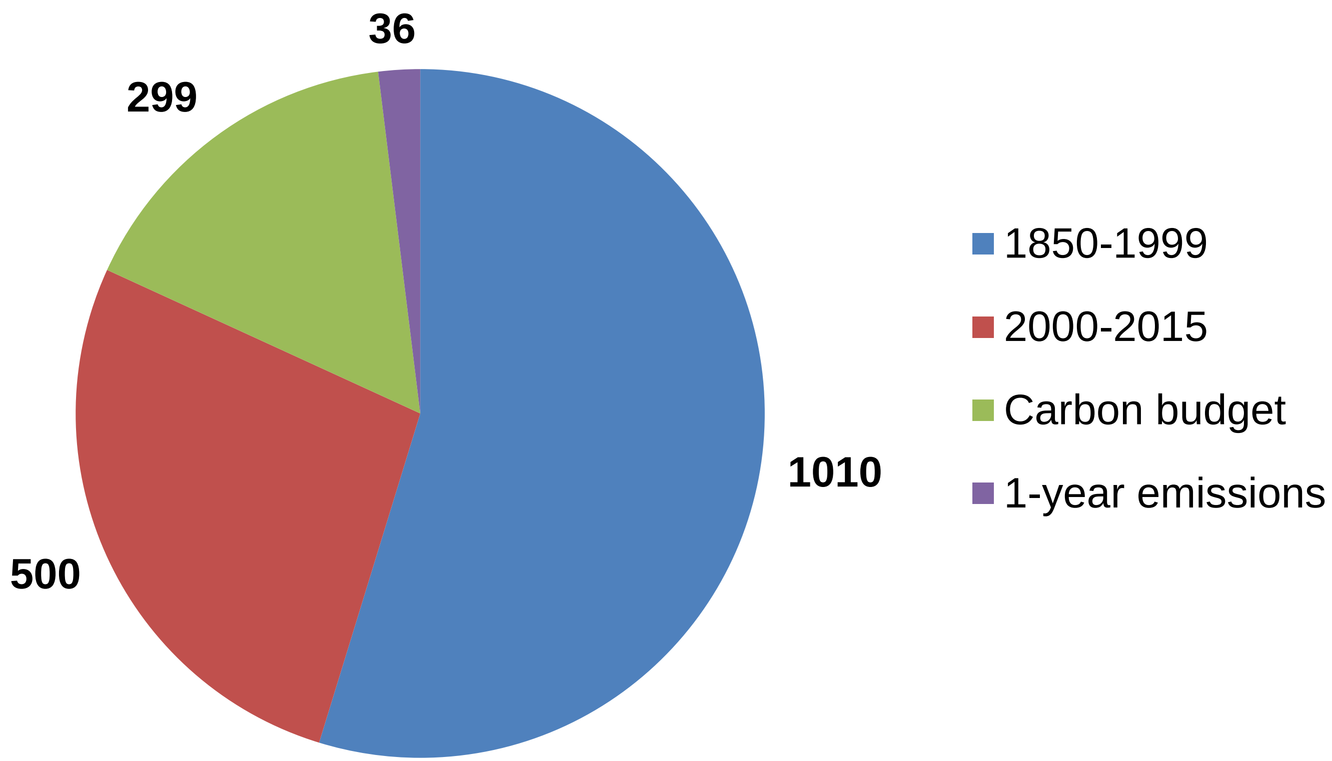
2020-2021

CHEMICAL ENGINEERING

LIÈGE université

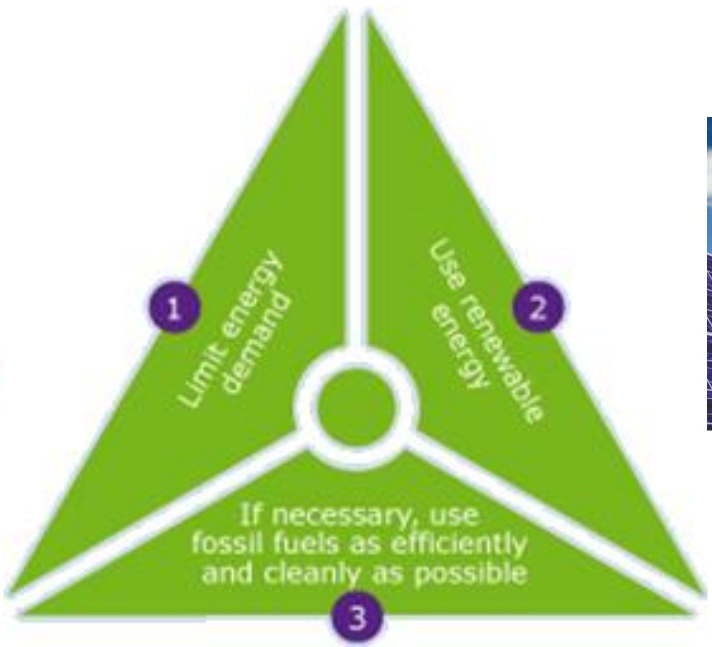
CO_2 Budget

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



Note: Values in Gt CO_2 eq

Possible answers: Trias Energetica



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

Deployment of renewables

- Many policies have supported the deployment of renewables

- Increasing but still low!
  - ~ 20% of primary energy is electricity
  - ~ 20% of electricity is coming from renewables
  - ~ 70% of renewables are PV & Wind
    - 0.2*0.2*0.7 ~ 2.8%

- But renewables are variable and not dispatchable!
  - Electricity consumption must equal production at any time!
  - High variation of electricity prices
  - 2019: 12 TWh energy curtailed in Germany

Chefneux L., 2021. La révolution énergétique en Belgique

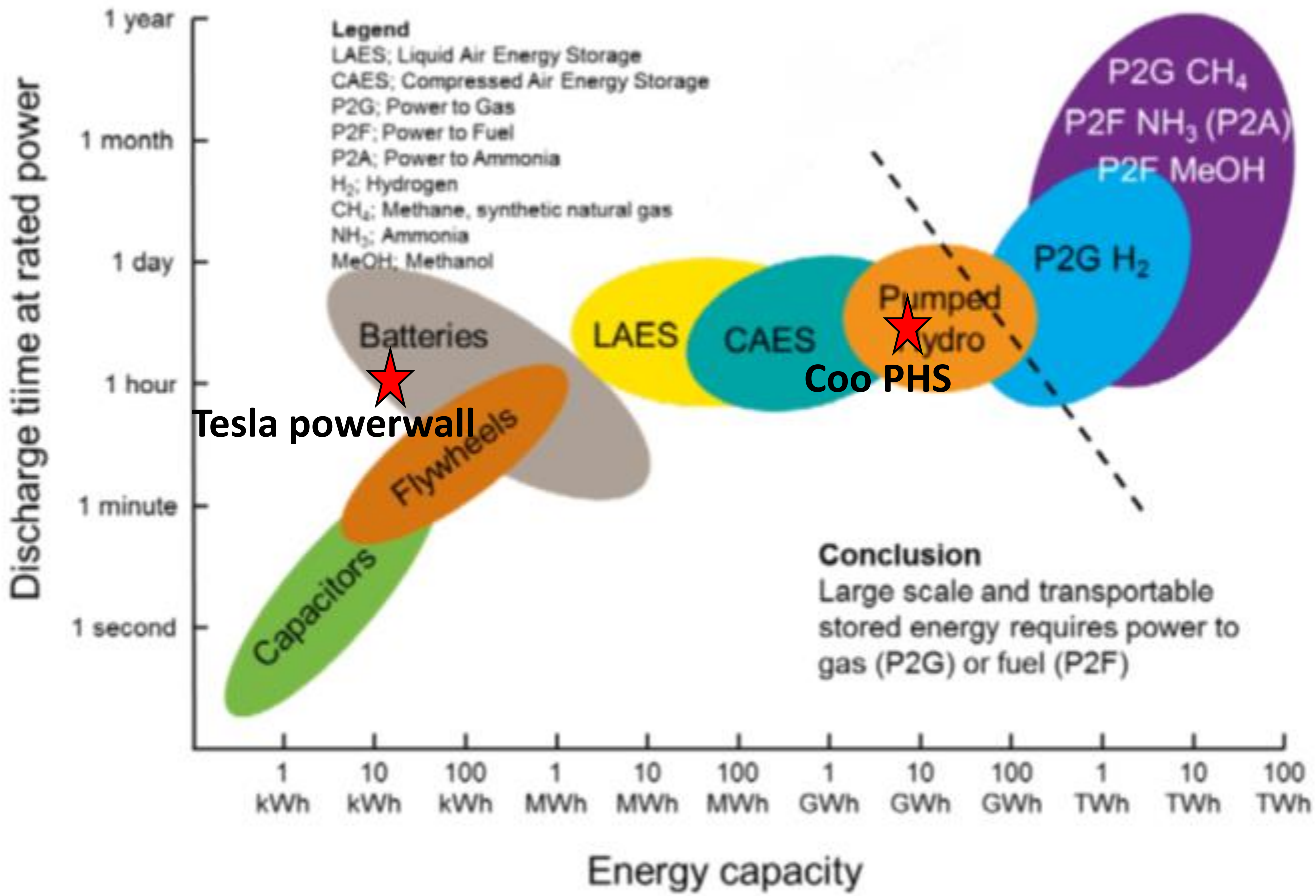
Deployment of renewables

- Energy networks need to be green and flexible

- Possible solutions to variability
  - More flexible demand
    - Demand response
  - More flexible supply
    - Grid interconnections
    - Dispatchable units
  - Energy storage

Energy storage

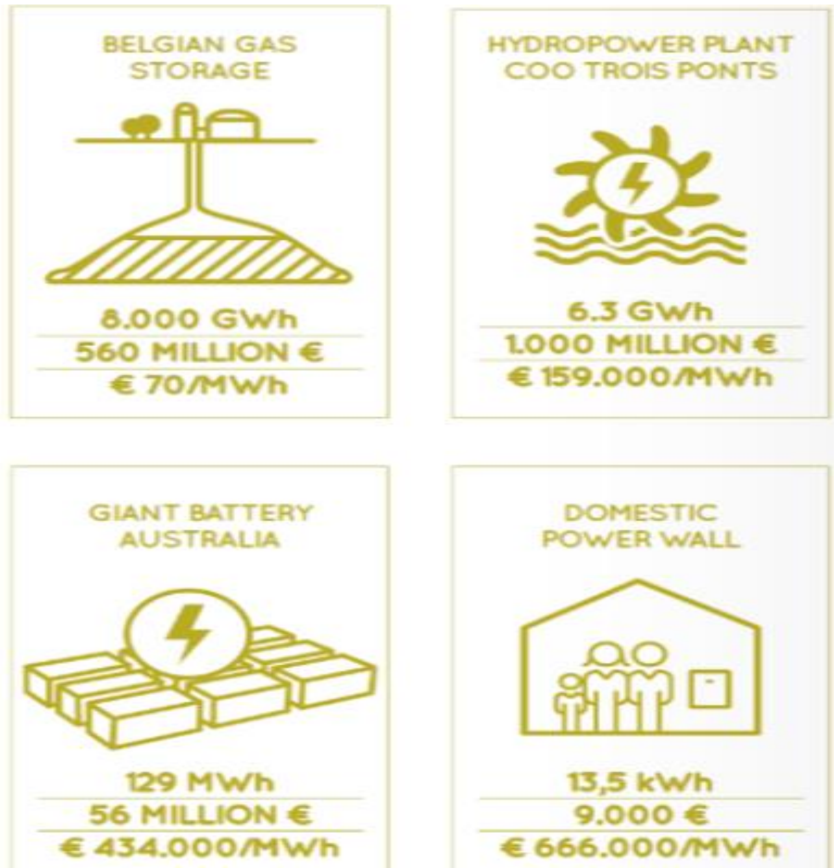
- Some technologies for energy storage



Source: Power-to-ammonia, Institute for Sustainable Process Technology, 2017

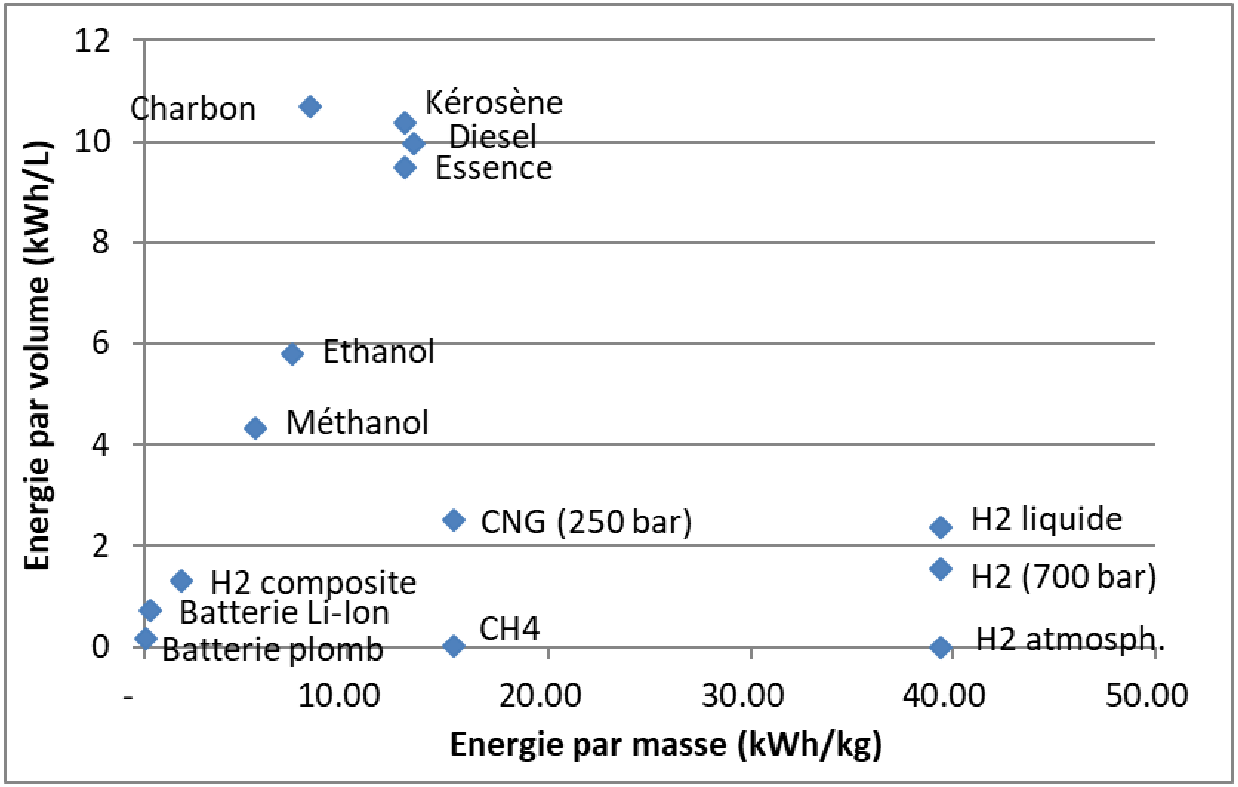
Energy storage

- Some technologies for energy storage



Energy storage

- Decisive advantage of chemical storage: a fantastic energy density!
  - => Interseasonal energy storage becomes possible



CHEMICAL ENGINEERING

LIÈGE université

Energy storage

- Quick calculations
  - How many cars tanking at the same time are needed to develop a power of 1 GW?
  - What would be the hourly gage for one worker based on fossil fuel cost?

Energy storage

- Quick calculations
  - How many cars tanking at the same time are needed to develop a power of 1 GW?
    - 1 L/s gas transfer
    - Gas ~ 35 MJ/L
    - => 1 car = 35 MW
    - 1 GW = 29 cars

Energy storage

- Quick calculations
  - What would be the hourly gage for one worker based on fossil fuel cost?
    - Physical activity ~300 W
    - 1 h = 300 Wh = 0.3 kWh = 1.08 MJ

    - Cost of one barrel (159 L oil) ~50 USD
    - 159 L oil @ 40 MJ/L = 6360 MJ

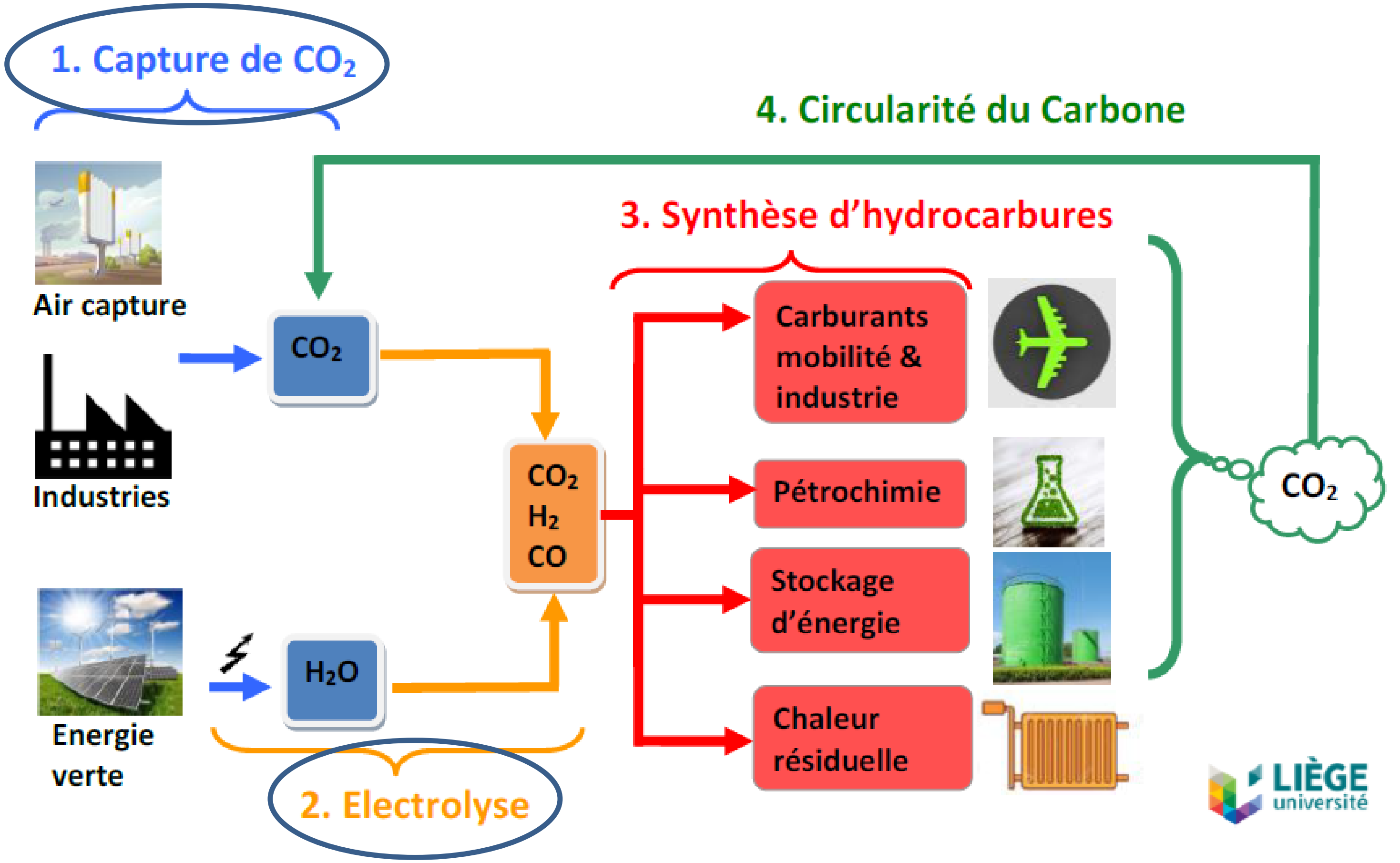
    - => 1 hour of human work at standard fossil energy prices

    = 1.08 MJ * 50 USD/6360 MJ = 0.0085 USD

jancovici.com/transition-energetique/l-energie-et-nous/combien-suis-je-un-esclavagiste/

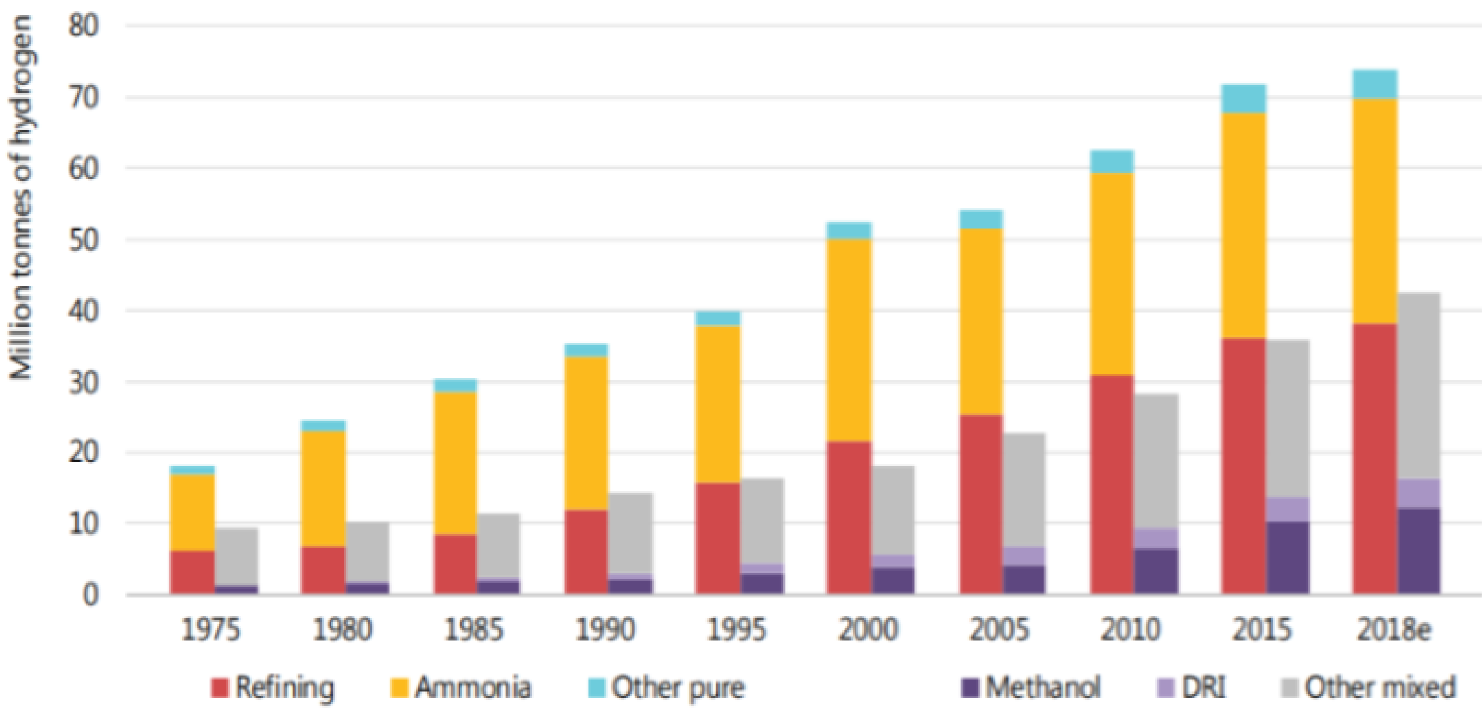
Power-to-fuels

- Power-to-H_2, and hydrogen sub-products



Hydrogen is not new!

Figure 1. Global annual demand for hydrogen since 1975



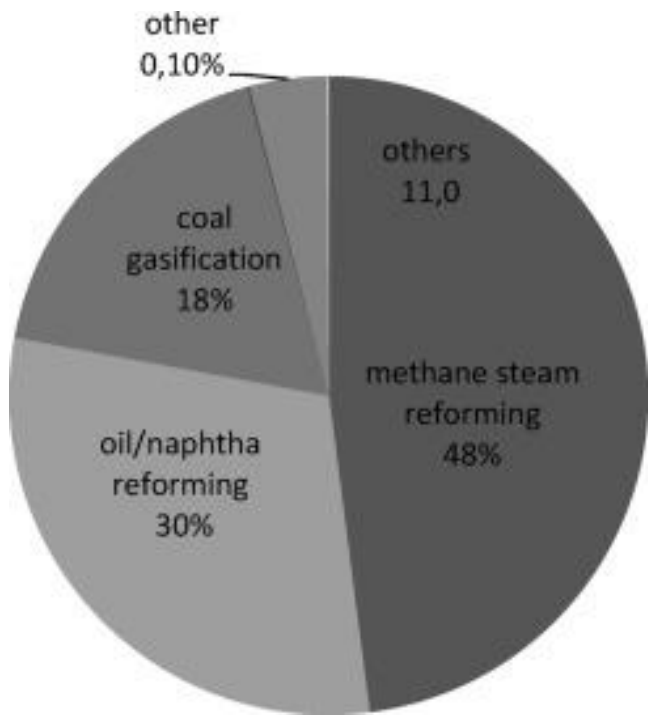
Notes: DRI = direct reduced iron steel production. Refining, ammonia and "other pure" represent demand for specific applications that require hydrogen with only small levels of additives or contaminants tolerated. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.

Source: IEA 2019.

Source: IEA, *Global demand for pure hydrogen, 1975-2018*, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-demand-for-pure-hydrogen-1975-2018

Hydrogen generation

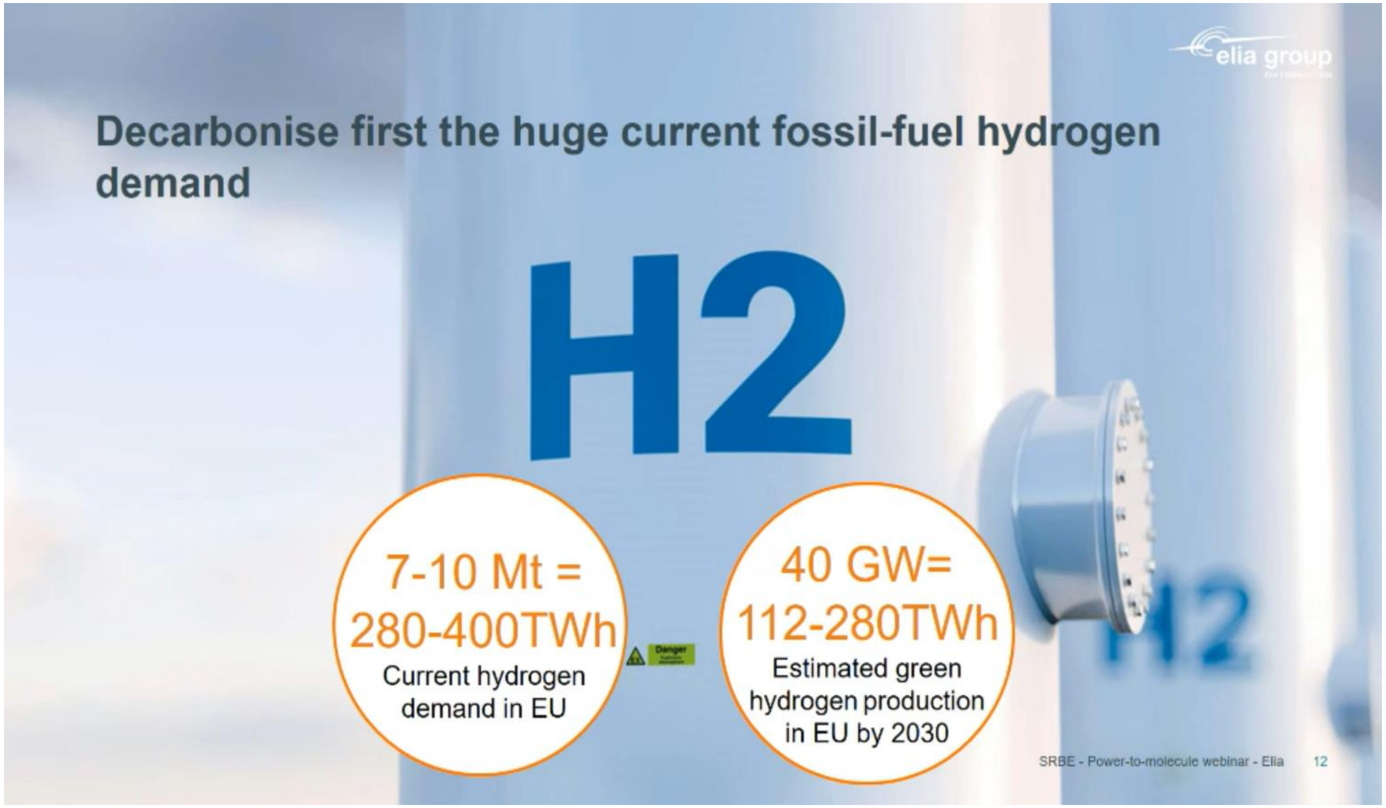
- Current processes for H_2 strongly rely on fossil fuels



Source: https://doi.org/10.1016/j.ijhydene.2016.08.219

Producing green H_2 for today's needs is already a big challenge!

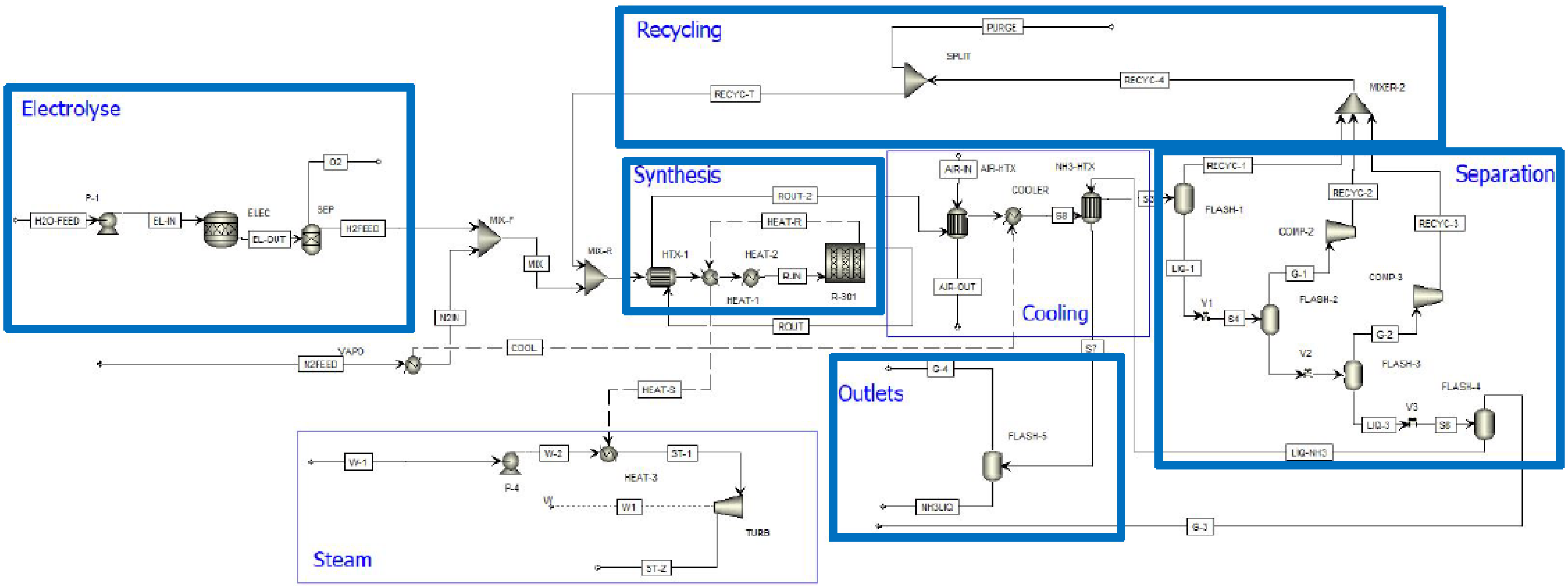
- H_2 = 40 kWh/kg



Source: Nicolas Gielis, Elia, Power-to-molecules SRBE Webinar, Nov-Dec 2020

Producing green H_2 is already a big challenge!

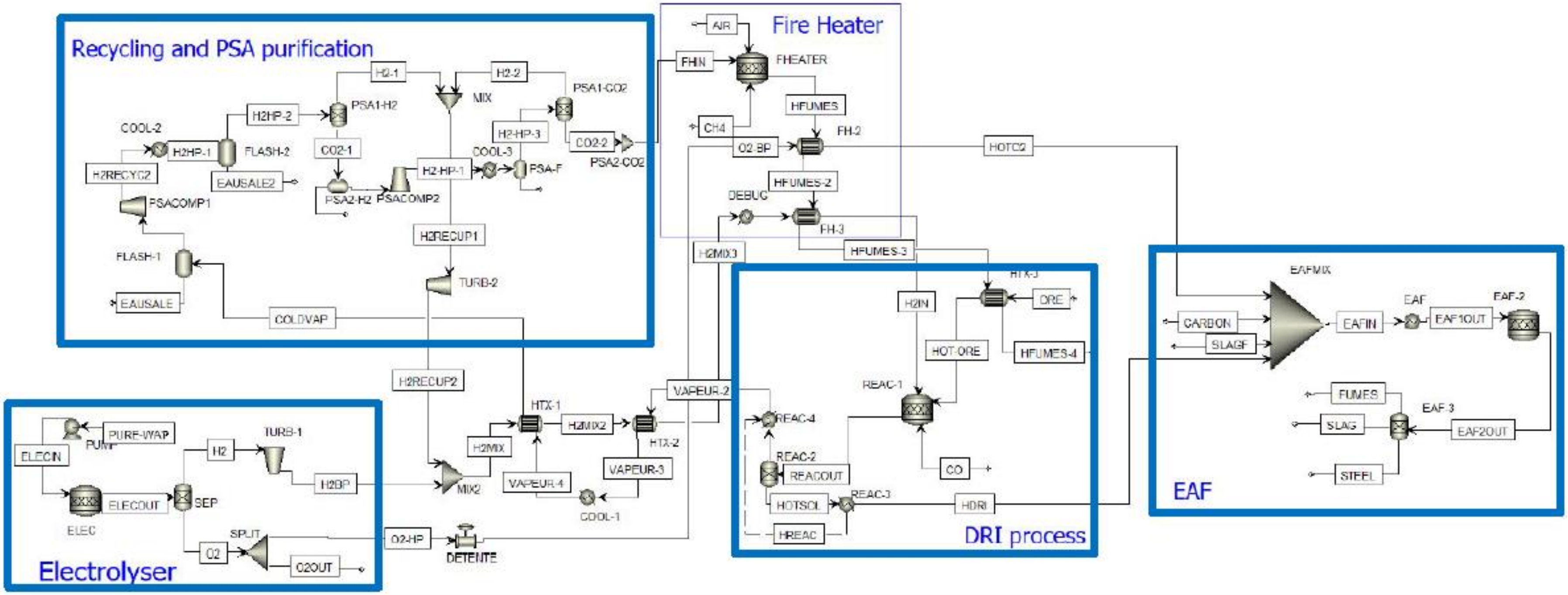
- Case study at ULiège: Ammonia production from H_2



Source: Hoxha J.-L., Caspar M., Donceel A., Fraselle J., Philippart de Foy M., Poncelet R., Léonard G., 2020. Feasibility study of low-carbon ammonia and steel production in Europe. Eceee Industrial Summer Study Proceedings.

Producing green H_2 is already a big challenge!

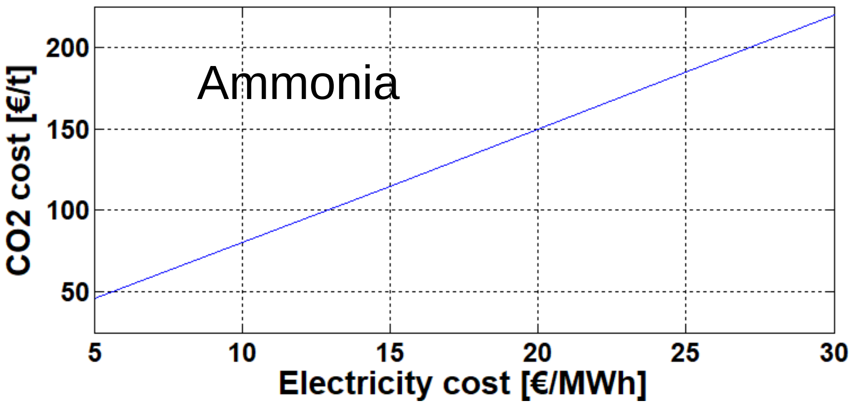
- Case study at ULiège: Steelmaking with H_2

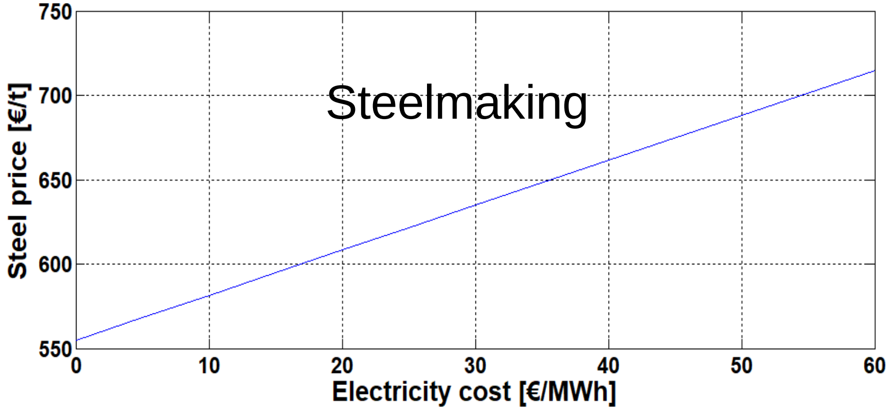


Source: Hoxha J.-L., Caspar M., Donceel A., Fraselle J., Philippart de Foy M., Poncelet R., Léonard G., 2020. Feasibility study of low-carbon ammonia and steel production in Europe. Eceee Industrial Summer Study Proceedings.

Producing green H_2 is already a big challenge!

- Assuming 85% efficiency, the H_2 needs in green industry would be:
  - For a typical ammonia plant (540 kt NH_3/year) => 700 MW power
  - For a typical steel making plant (1 Mt steel/year) => 400 MW power
  - Break-even costs (left: ammonia; right: steelmaking)





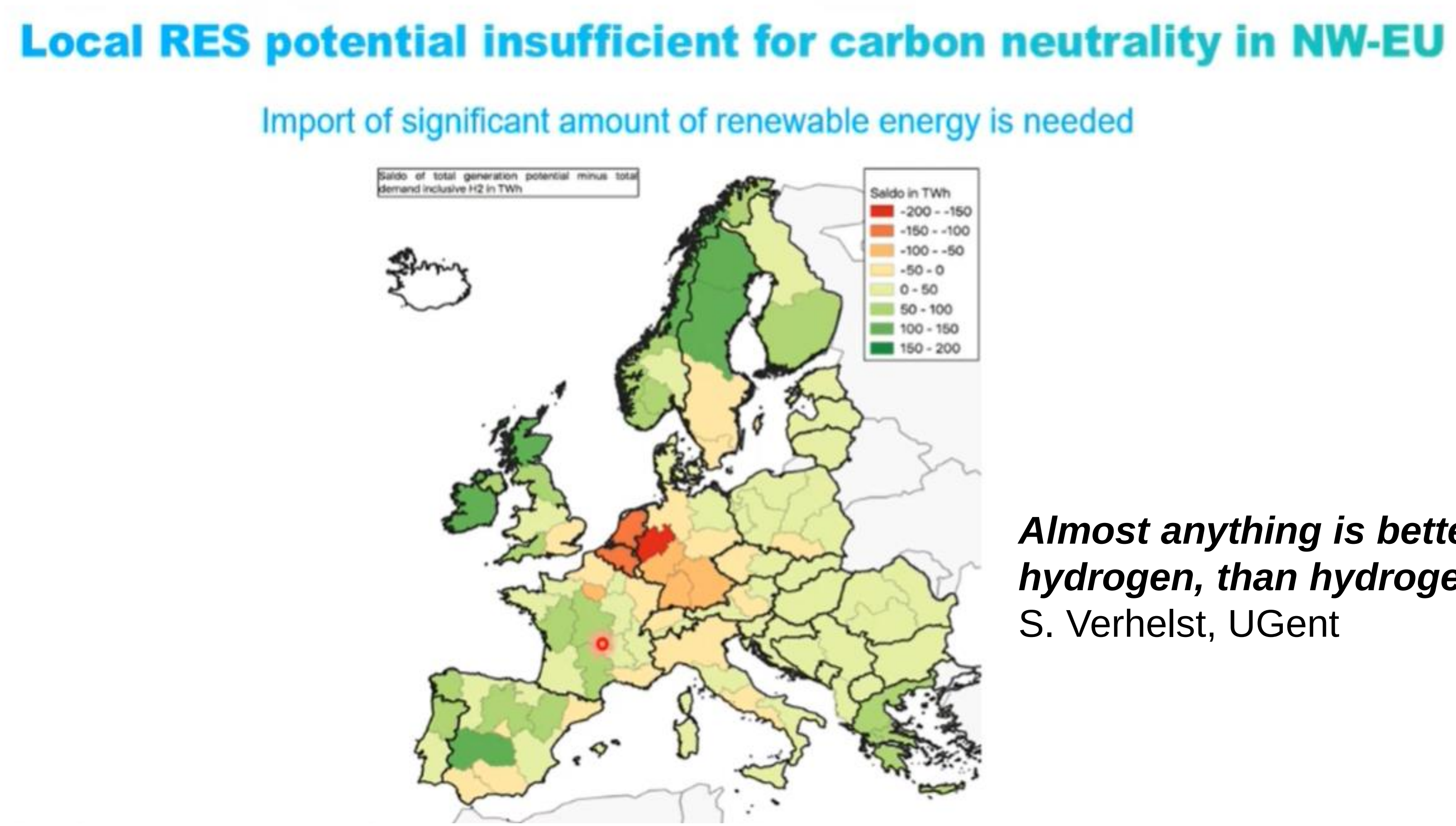
CHEMICAL ENGINEERING

Source: Hoxha J.-L., Caspar M., Donceel A., Fraselle J., Philippart de Foy M., Poncelet R., Léonard G., 2020. Feasibility study of low-carbon ammonia and steel production in Europe. Eceee Industrial Summer Study Proceedings.

LIÈGE université

Recent work: H_2 Import Coalition

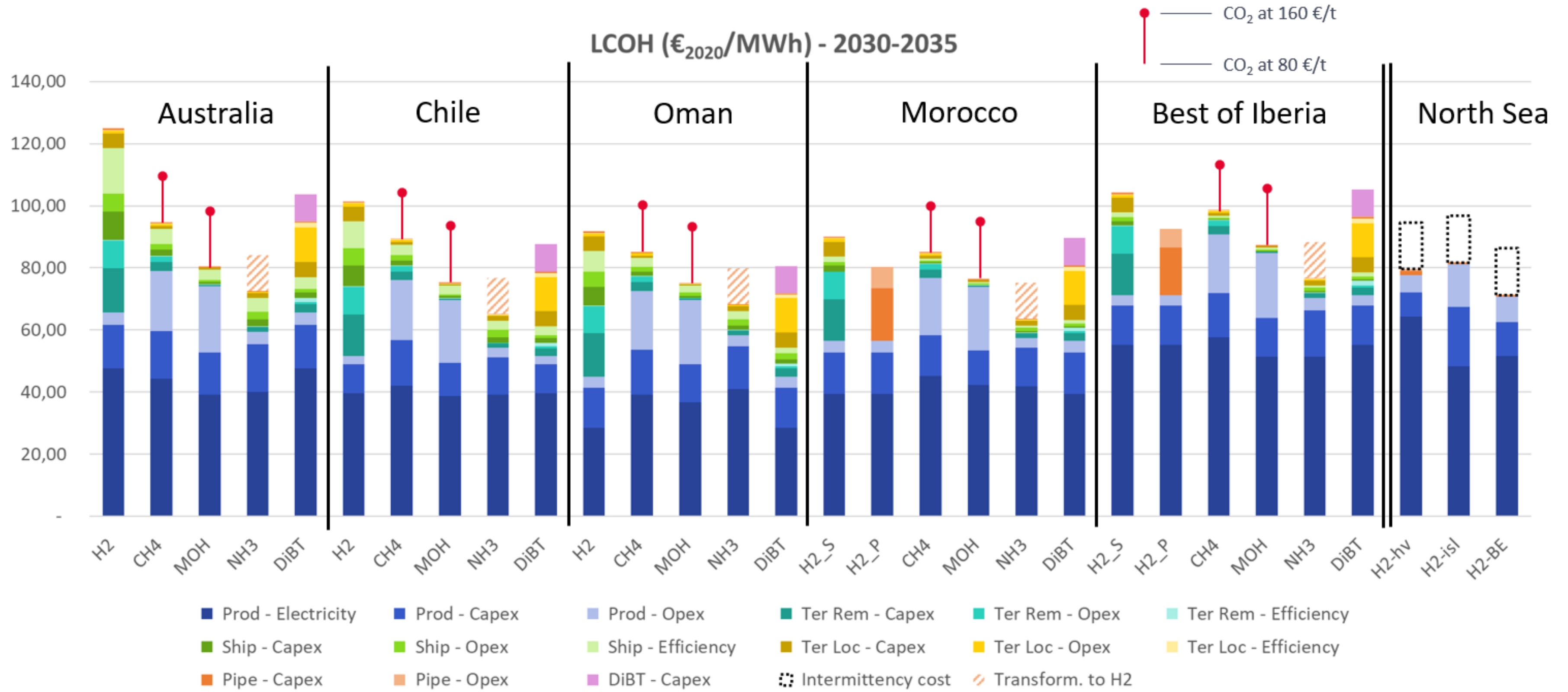
- If not producing H_2 in Europe, then import it!



Almost anything is better at storing hydrogen, than hydrogen itself
S. Verhelst, UGent

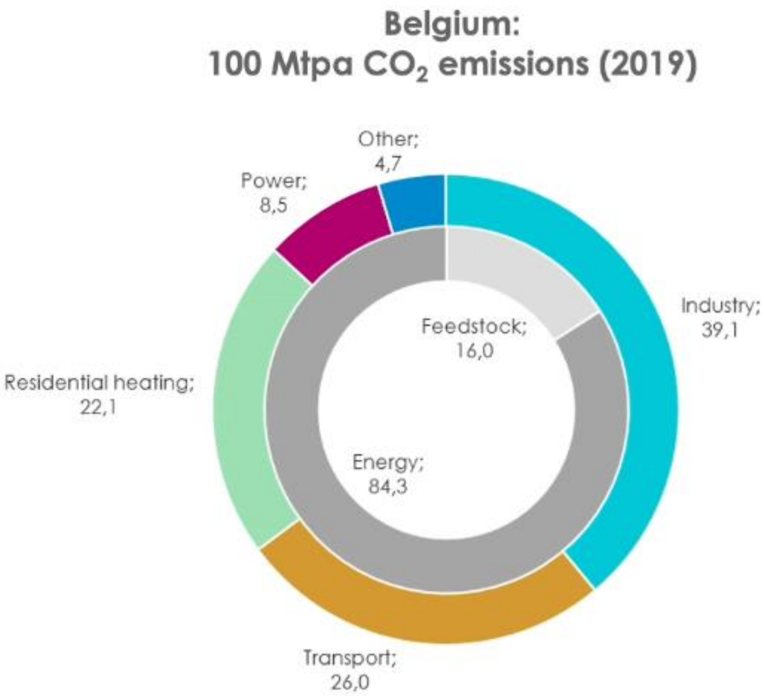
Recent work: H_2 Import Coalition

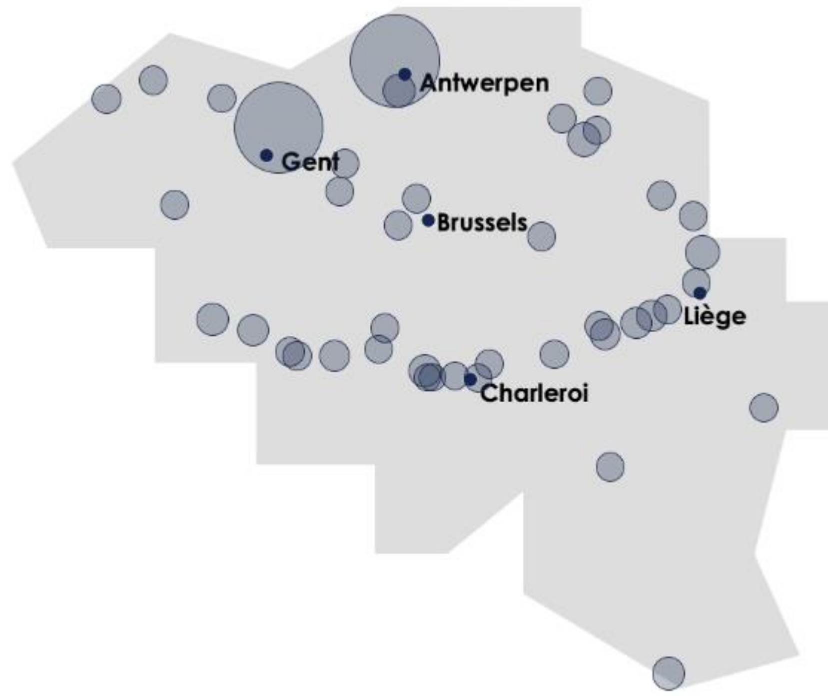
- Comparison of import areas and energy carriers



H2 Import Coalition, 2020

CO_2 inévitable dans notre société





Source: Fluxys

Technologies de capture du CO_2

- = Séparation de fluides
  - La source contient entre 0.04% et ~100% de CO_2 + N_2, H_2O, H_2, CH_4, O_2
  - Panel de technologies, certaines mature (>50 ans), d'autres en développement
  - En general: technologies flexibles, parfois applicables à des installations existantes, mais toujours coûteuses!

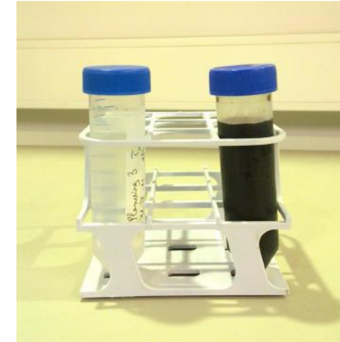
Capture du CO_2

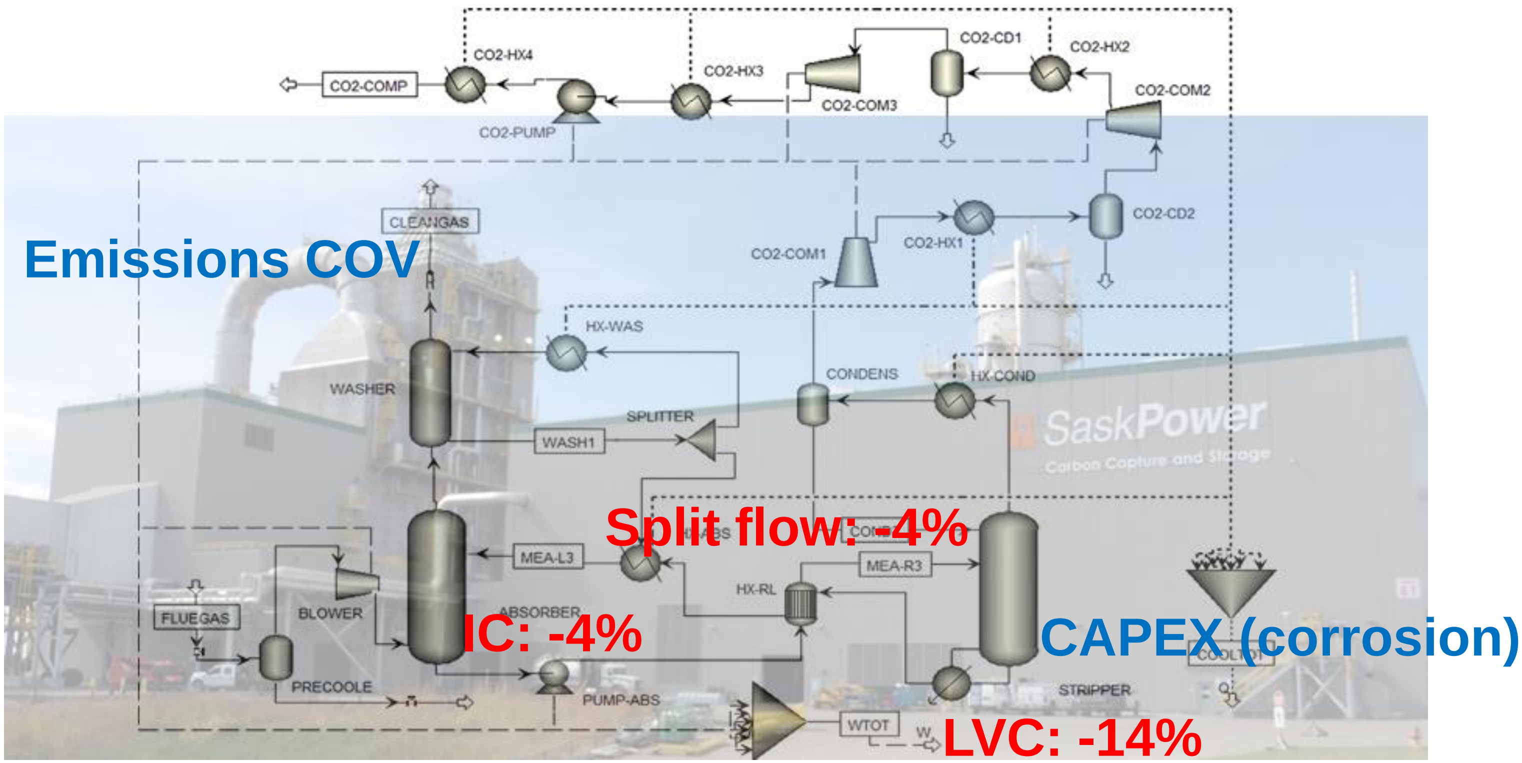
- Coût entre 10 et 120 €/t en fonction de la concentration
- DAC ~ 200-600 €/t
- Marché: European Emissions Trading System (ETS)

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

Focus: Recherche ULiège

- Modélisation et optimisation de procédés
- Stabilité des solvants





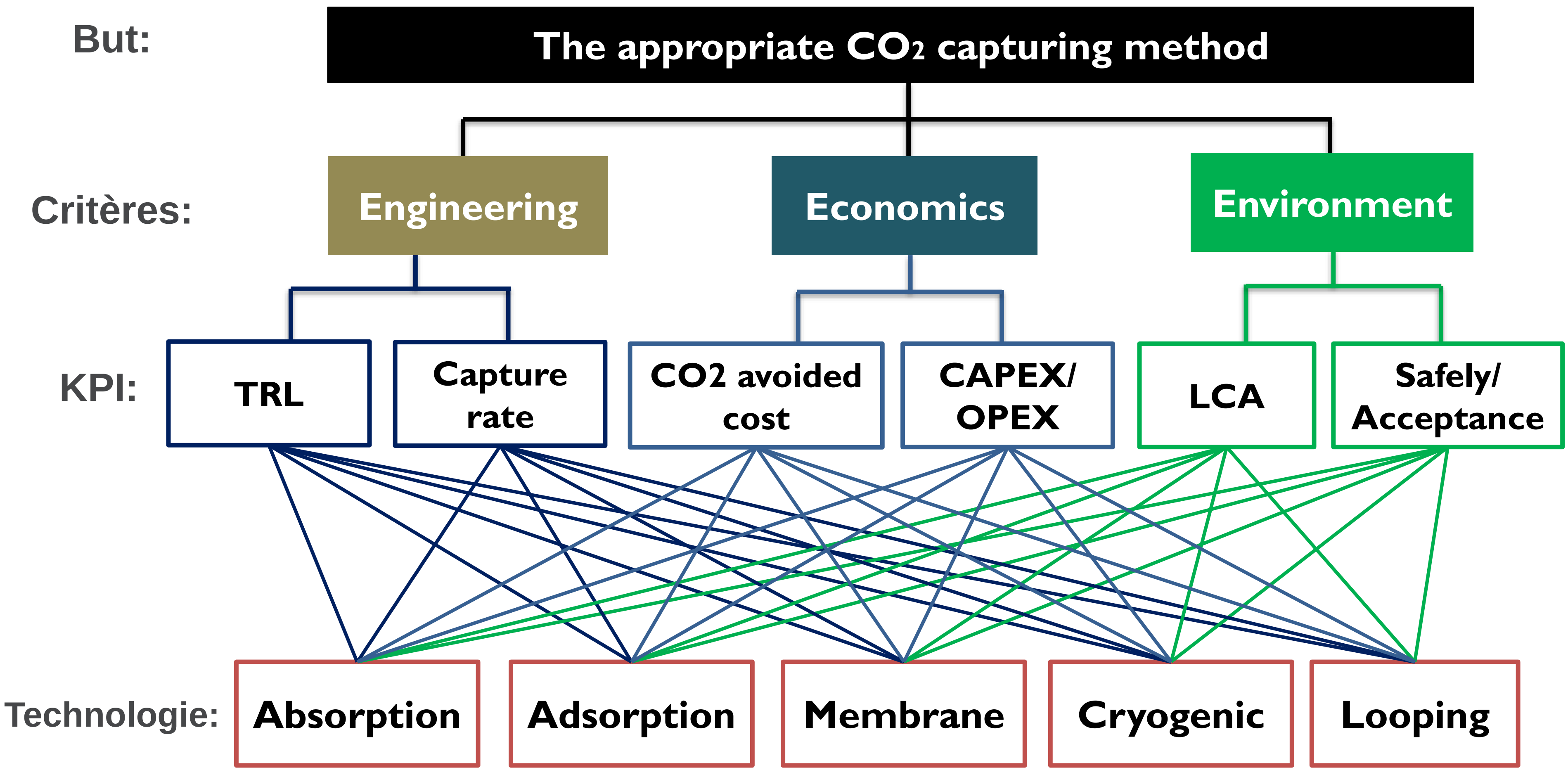
OPEX: viscosité, propriétés diminuées…

CHEMICAL ENGINEERING

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

LIÈGE université

PROCURA FTE: Outil d'aide à la décision



Decision-support tool

LIÈGE université

Contact details:

Grégoire Léonard <g.leonard@uliege.be>
So-Mang Kim <SM.Kim@uliege.be>
Riccardo Bonanno <riccardobonanno7@gmail.com>

WELCOME!

The purpose of this Decision Support Tool (DST) is to provide a consistent and robust selection approach to CO_2 capture technologies. There are 4 main categories in CO_2 capture processes:

OXY-COMBUSTION PRE-COMBUSTION POST-COMBUSTION DIRECT AIR CAPTURE (DAC)

If you are not familiar with the capture process types, It is strongly encouraged to refer to the details of each category by clicking the **BLUE BOXES with the corresponding name below**.

If you are a returning user, please remember that prior to using the DST, please first save it onto your computer as a .xlsm file to avoid any malfunctioning of this model. It is also good practice to save each DST assessment as a new file to have a clean template to work with each time.

If you are already familiar with the DST, please click the **START button** at the bottom of this page. Otherwise, please access the **User Guide**

CO_2 CAPTURE TECHNOLOGY

Oxy-combustion	Pre-combustion	Pos-tcombustion	Direct Air Capture
1. Applied in the steel and glass industry **2. Suitable for fuels with low heating power** **3. Retrofit and repowering option** **4. Small scale application only at the moment, but applicable to large scale too.**	**1. Flue gas characteristics:** **1.1** Percentage of CO2 [Vol %]: 20-40%. **1.2** Typical operating pressure: 10-80 bar. **2. Work with a gasification system**	**1. Flue gas characteristics:** **1.1** Percentage of CO2 [Vol %] 4-15%. **1.2** Typical operating pressure: 1 bar. **2. suitable for retrofitting** **3. Applicable to the majority of existing coal-fired power plants**	**1. Manage emissions from distributed sources** **2. Treats percentage of CO2 in volume around 0.04%** **3. Can be installed almost everywhere but large volume are needed**

The decision support tool (DST) assesses and compares widely available CO2 capture technologies in terms of **three main criteria: ENGINEERING, ECONOMICS,** and **ENVIRONMENT**. There are various key performance indicators (KPIs) under each criterion which play important roles. Then, you can express your **preferences in terms of a score system (1 to 9)** in two points. **First**, inserting which criteria, economic, engineering, or environment is preferable with respect to others. your preferences will be used to calculate and provide the first set of weights to each criterion. Inside each criterion, there are KPI factors that must be **evaluated** by you following the same procedure to obtain the second set of weights of each KPI. In this way you will show your preferences in two phases of the process and based on that, the suitability of each technology will be analyzed. A database associated with each KPI is built and used to score each technology accordingly. Lastly, CO2 capture technology options are evaluated and **ranked** to screen and recommend suitable possibilities considering all important criteria

START

Decision-support tool

- Following the Analytical Hierarchy Process

4. Analytical Hierarchy Process - KPIs for Environment criteria

Table 4.1

Environment																		
Please rate importances of these KPIs																		
(j - k)																		
Criterion j	Extreme favors		Very Strong favors		Strongly favors		Slightly favors		Equal		Slightly favors		Strongly favors		Very Strong favors		Extreme favors	Criterion k
(LCA score	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	○ 1	○ 2	● 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Safety Issue)
(LCA score	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	○ 2	● 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Public acceptance)
(Safety Issue	○ 9	○ 8	○ 7	○ 6	○ 5	○ 4	○ 3	● 2	○ 1	○ 2	○ 3	○ 4	○ 5	○ 6	○ 7	○ 8	○ 9	- Public acceptance)

Table 4.2

KPIs	KPIs Weight
LCA score	0.210
Safety Issue	0.550
Public acceptance	0.240

Inconsistency	0.016

Total Inconsistency	0.074

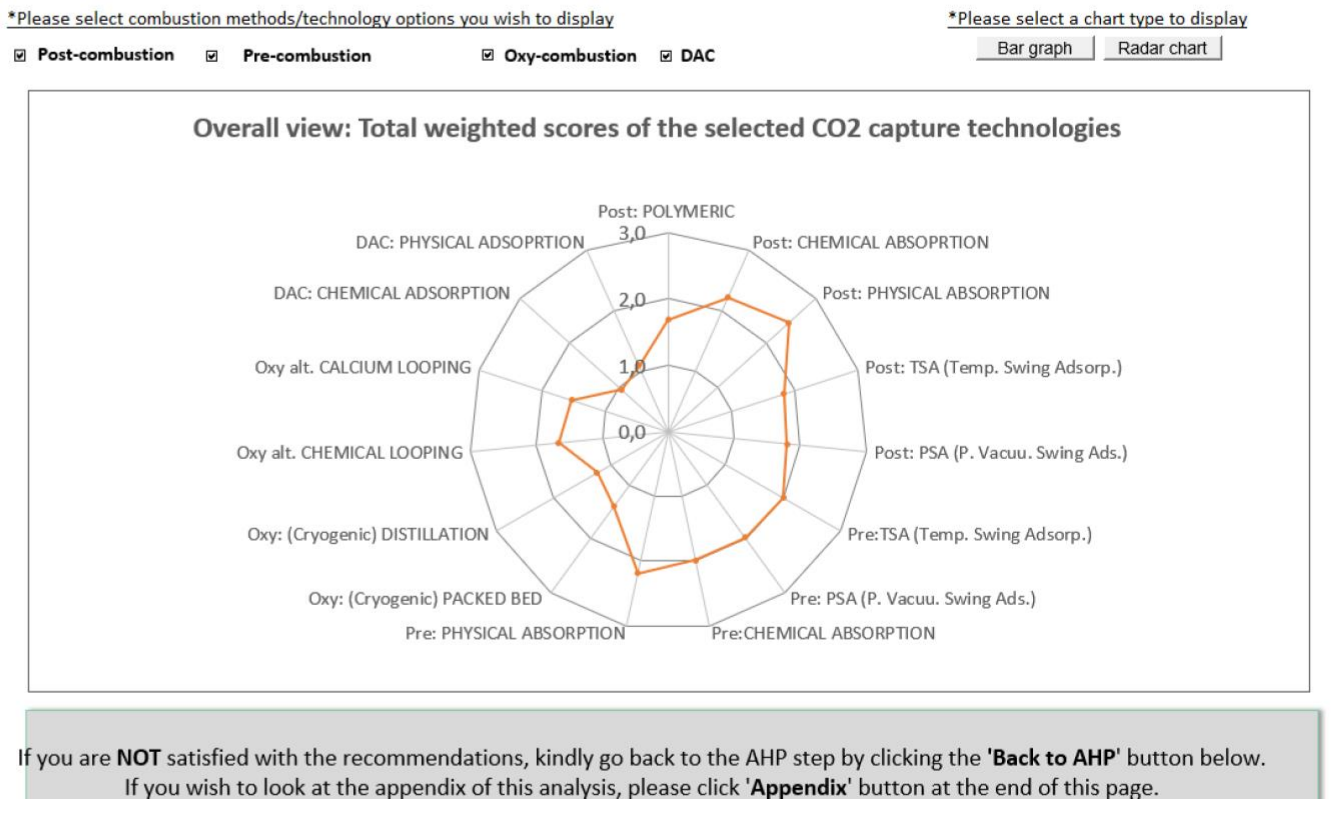
If you are satisfied with the criteria weights and KPI weights of each criterion, please click the **'Go to Results' button** to display analyzed results. If you wish to re-evaluate your preferences, please click the **'Back to Top' button** to scroll up and you may repeat the rating process.

As explained in the AHP theory page, **Pairwise matrices** can be displayed when you click the 'Show Pairwise Matrix' button provided below.

Home | Back to 'Top' | Show Pairwise Matrix | Go to 'Results'

Decision-support tool

- Results display



Decision-support tool

- Information support

In this section you can visualize **GLOBAL RESULTS**.

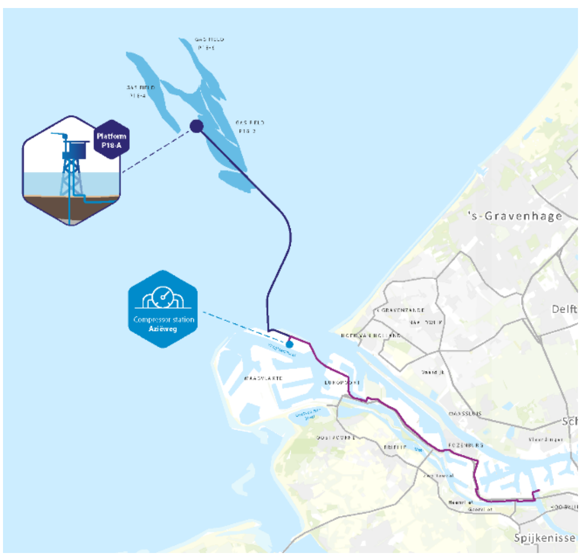
Table 1 represents the different technologies and their scores, which are function of the respective techniques **only**. The results shown are the outcomes of **literature searches** and objective **modelling analyses**, therefore each is examined from an experimental-scientific point of view.

1. Table with scores (Original)

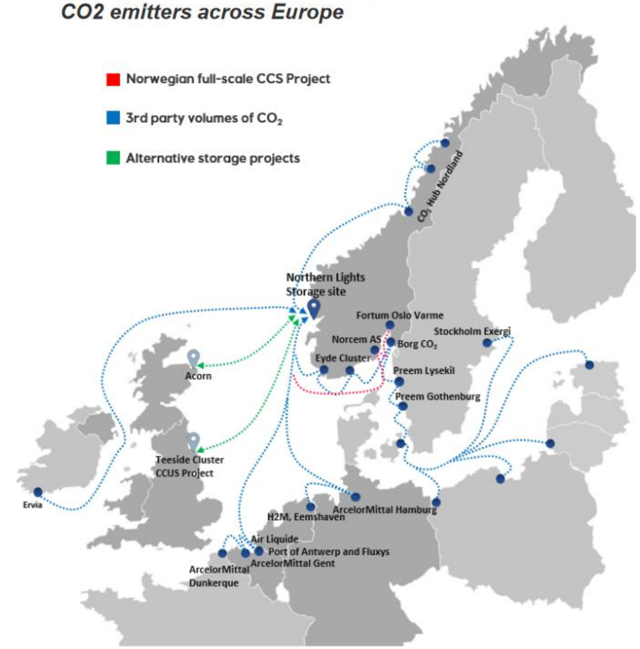
TECHNOLOGIES OVERVIEW TABLE		0-VERY BAD / 1-BAD / 2-OK / 3-GOOD	Engineering			Economics			Environment		
			TRL	CO2 capture rate	SOx NOx	Cost per CO2 avoided [euro/tonCO2]	CAPEX per kg of CO2 captured	OPEX per kg of CO2 captured	LCA score	Safety issues	Public acceptance
POSTCOMBUSTION	MEMBRANE	POLYMERIC	2	2	1	2	1	1	3	3	2
		CERAMIC	1	2	3	1	0	2	3	3	2
		INORGANIC	1	2	3	1	0	2	3	3	2
		HYBRID	1	2	2	1	0	2	2	3	2
	ABSORPTION	CHEMICAL	3	3	1	3	2	1	2	2	3
		PHYSICAL	3	3	3	2	2	2	2	2	2
	ADSORPTION	TSA (Temp. Swing Adsorp.)	2	3	1	2	2	1	2	2	1
		PSA (Press. Vacuu. Swing Ads.)	2	3	1	2	2	1	2	1	1
PRECOMBUSTION	ADSORPTION	TSA (Temp. Swing Adsorp.)	2	3	1	2	1	2	2	2	1
		PSA (Press. Vacuu. Swing Ads.)	2	3	1	2	1	2	2	1	1
	ABSORPTION	CHEMICAL	2	3	1	2	1	2	2	1	2
		PHYSICAL	3	3	3	2	2	1	2	1	2
	MEMBRANE	ORGANIC FRAMEWORK	1	3	3	2	2	1	2	2	2
OXYCOMBUSTION	CRYOGENIC	PACKED BED	2	3	0	1	1	1	1	0	3
		DISTILLATION	2	3	0	0	2	1	1	0	3
	MEMBRANE	OXYGEN TRANSPORT MEMBRANE (OTM)	1	2	1	2	2	2	2	1	1
		ION TRANSPORT MEMBRANE (ITM)	1	2	0	2	2	2	2	1	1
	CHEMICAL LOOPING		2	2	2	1	1	2	1	1	1
	CALCIUM LOOPING		2	3	1	0	1	2	1	1	1
DIRECT AIR CAPTURE	ADSORPTION	CHEMICAL	2	2	1	0	0	0	2	2	2
		PHYSICAL	2	2	2	0	0	0	2	3	2

Stockage ou utilisation?

- Potentiel de stockage >> besoins
  - 5000 – 25 000 GtCO_2 vs. ~ 2000 GtCO_2
  - Stockage pur : ~ 5 Mtpa ; EOR ~ 30 Mtpa en 2016
  - Mais projets en cours (Porthos, Northern lights, Antwerp@C...)
- Coûts de stockage ~2-15 USD/t, mais infrastructure coûteuse!
- ~ Mise en décharge? => Carbonates



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



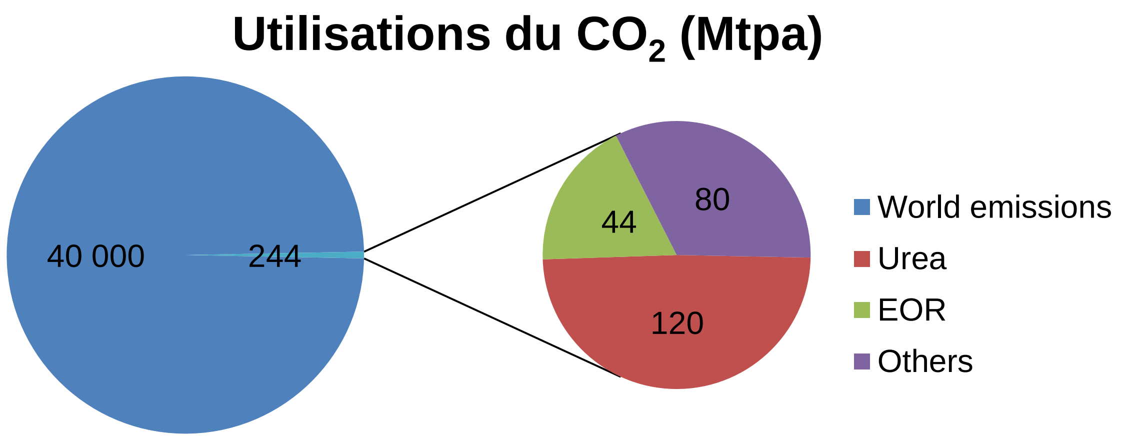
CHEMICAL ENGINEERING

Global CCS Institute 2017
doi: 10.3389/fclim.2019.00009

LIÈGE université

Utilisation du CO_2

- Notre société basée sur les ressources fossiles a besoin de carbone!
  - CO_2 = ressource, pas un déchet

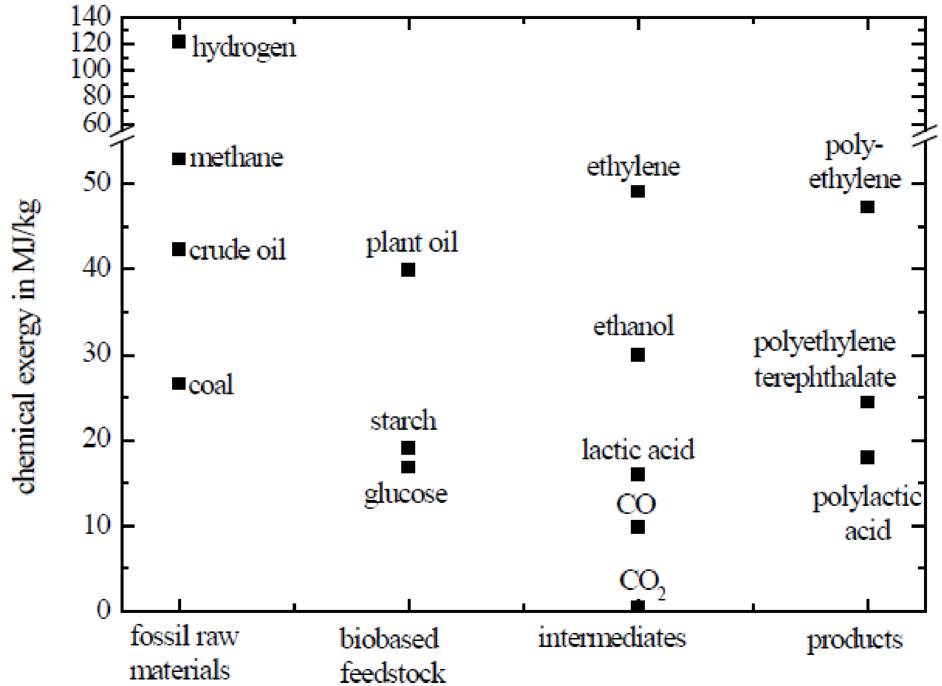


- Potentiel d'utilisation ~ 4 – 16 Gtpa
- Jusqu'ici, CO_2 vient de sources concentrées (industrie, sous-terraine)

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

Principales voies d'utilisation

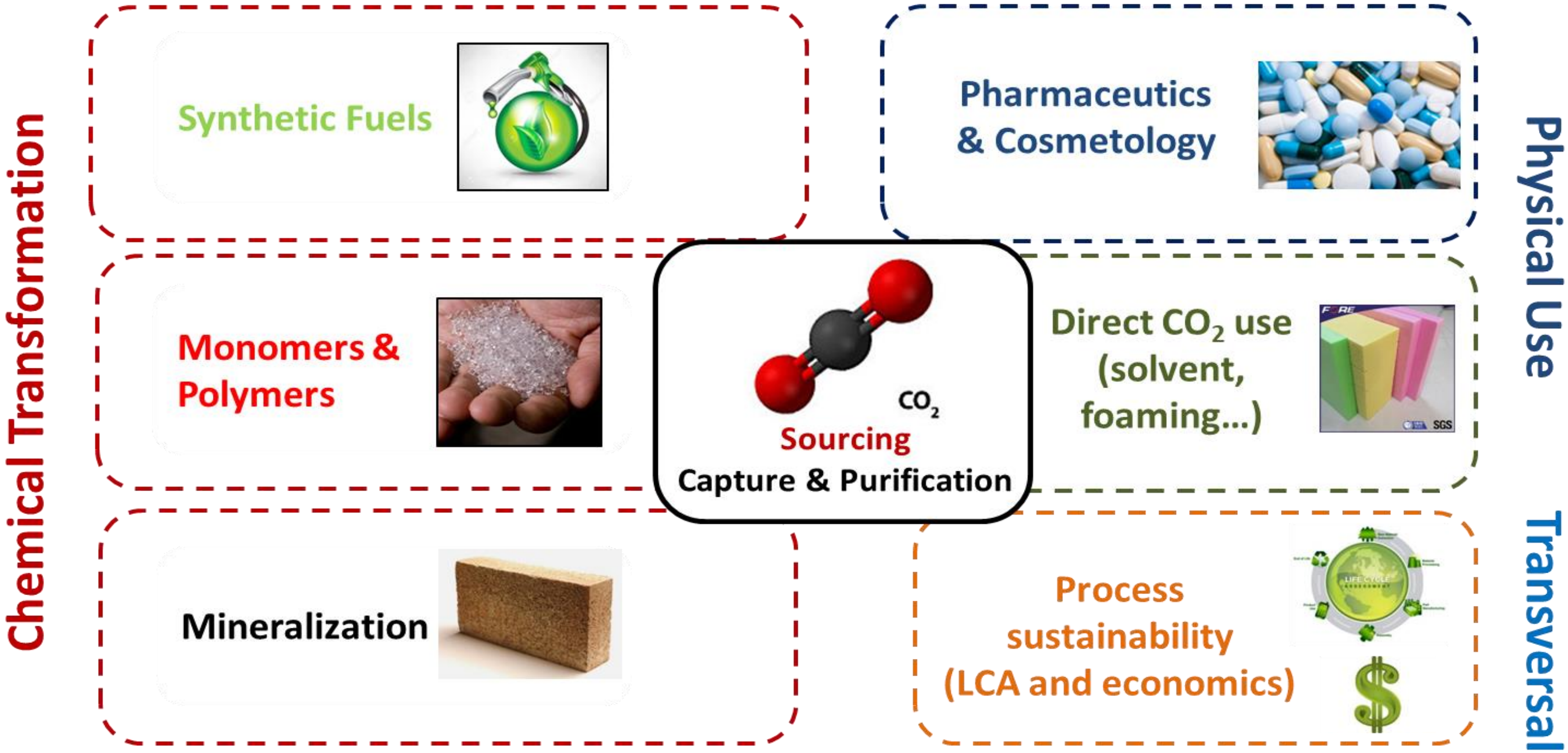
- Utilisation directe sans transformation
- Transformation biologique
- Transformation chimique
  - Sans apport d'énergie
    - Carbonatation
  - Avec apport d'énergie
    - e-Fuels
    - Industrie chimique
    - …



=> Mais cet apport d'énergie doit être bas-carbone!

Perspective ULiège: Plateforme FRITCO_2T

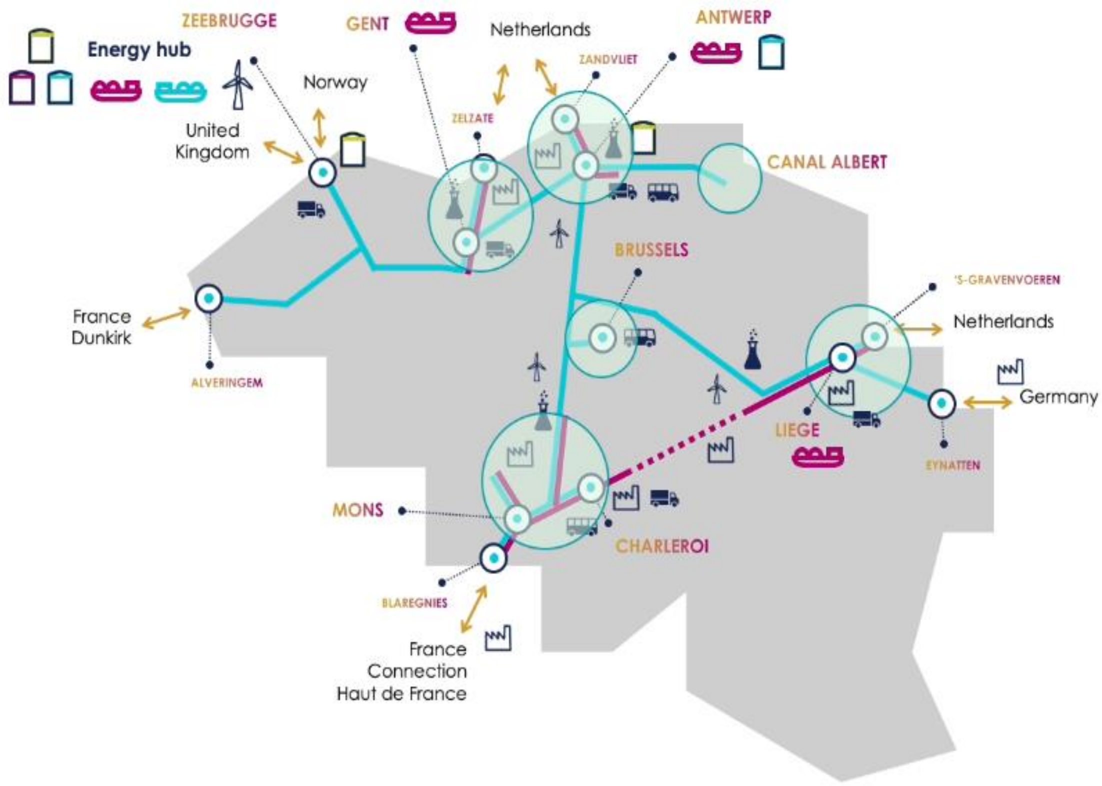
***F**ederation of **R**esearchers in **I**nnovative **T**echnologies for **CO$_2$** **T**ransformation*



Conclusions and perspectives

Nécessité d'infrastructures H_2 et CO_2

- Rôle de hub énergétique pour la Belgique



Quid des réseaux de gaz de demain?

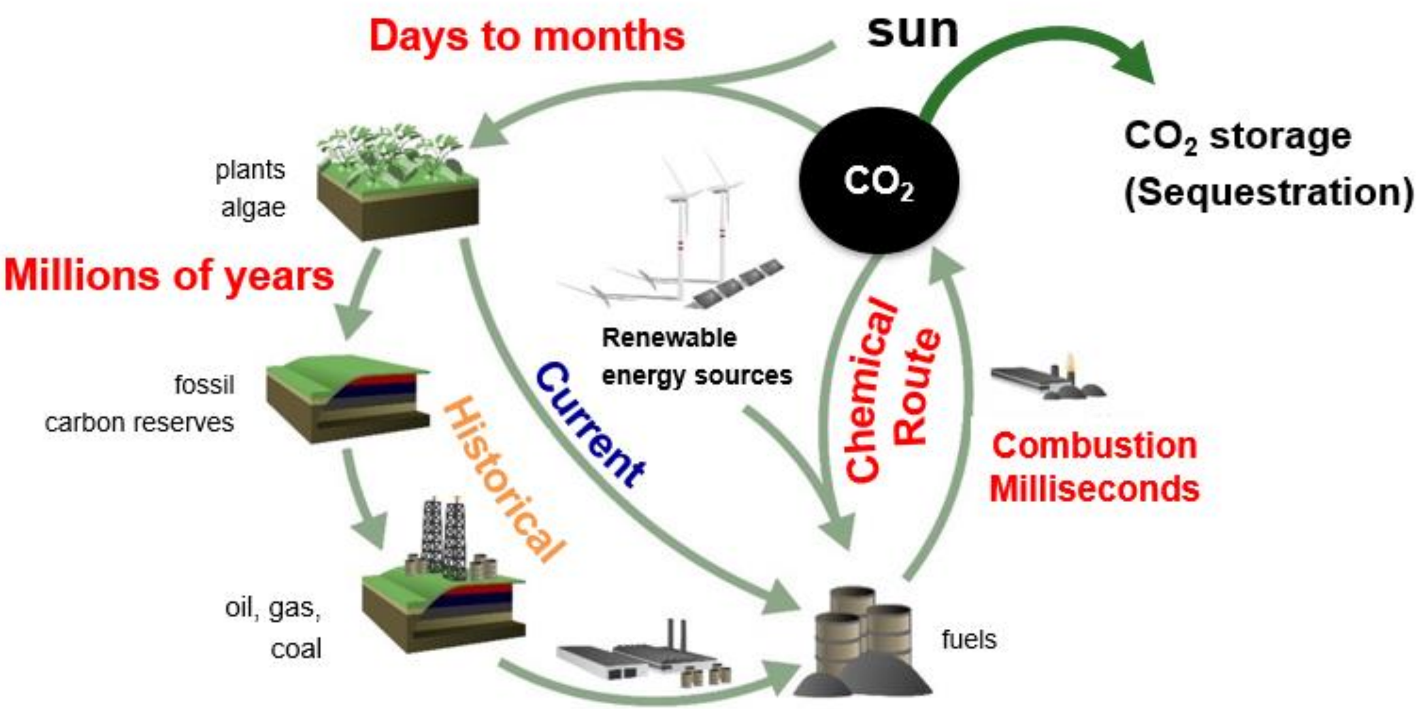
- Passage d'un vecteur à un autre est source de pertes
  - Efficacité de conversion power-to-fuel ~ 50-70%

- Mais ce sont des technologies nécessaires dans une société défossilisée!
  - Réponse à la variabilité des Energies Renouvelables

- Perspective de recherche: projet N-Kéro
  - DAC
  - Réactions Fischer-Tropsch
  - Production de kérosène défossilisé

Perspective

- Société basée sur le carbone pour de bonnes raisons!
- Un futur neutre en CO_2 est possible et en vue, mais pas sans CO_2!
- Accélération récente en lien avec le marché ETS et le Green Deal
- Challenges passionnants pour scientifiques et pour la société



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

Merci pour votre attention!

g.leonard@uliege.be

www.chemeng.uliege.be/fritco2t

CHEMICAL ENGINEERING

LIÈGE université