ECRA Academic Chair at the University of Mons: Nine years of achievements to support the implementation of Carbon Capture & Utilization in the cement industry

Global overview of the ECRA Academic Chair studies and activities since its creation in 2013

Nine years ago, in April 2013, the University of Mons (UMONS) and the European Cement Research Academy (ECRA), signed an agreement to create an Academic Chair within the UMONS Research Institute for Energy. The main objective of this Chair, coordinated scientifically by Prof. D. Thomas and Prof. G. De Weireld, was to build a Centre of scientific expertise in the specific field of "carbon capture in cement production and its reuse" and promote research and innovation through the works of PhD students, post-doctoral researchers, but also undergraduate students, supervised by professors with different field of expertise and with a Senior Researcher, namely Dr L. Dubois, as Research Coordinator. The present paper summarizes the main achievements of the ECRA Chair since 2013, whose framework is illustrated on **Figure 1**. Indeed, Carbon Capture & Utilization (CCU) process chain applied in the cement industry consists in capturing the CO_2 emitted at the outlet of the cement kiln, to purify it (if needed) and then to valorize it by converting it into different products that could be fuels, chemicals, minerals or other products. In this context, different studies were achieved in the framework of the ECRA Chair including **process modeling** and **optimization works**, **experiments**, **techno-economic analyzes** and **life cycle assessments**. All these works have generated data allowing to evaluate both the economic and the environmental performances of the investigated **carbon capture and utilization processes, specifically for the application to cement plant flue gases**.

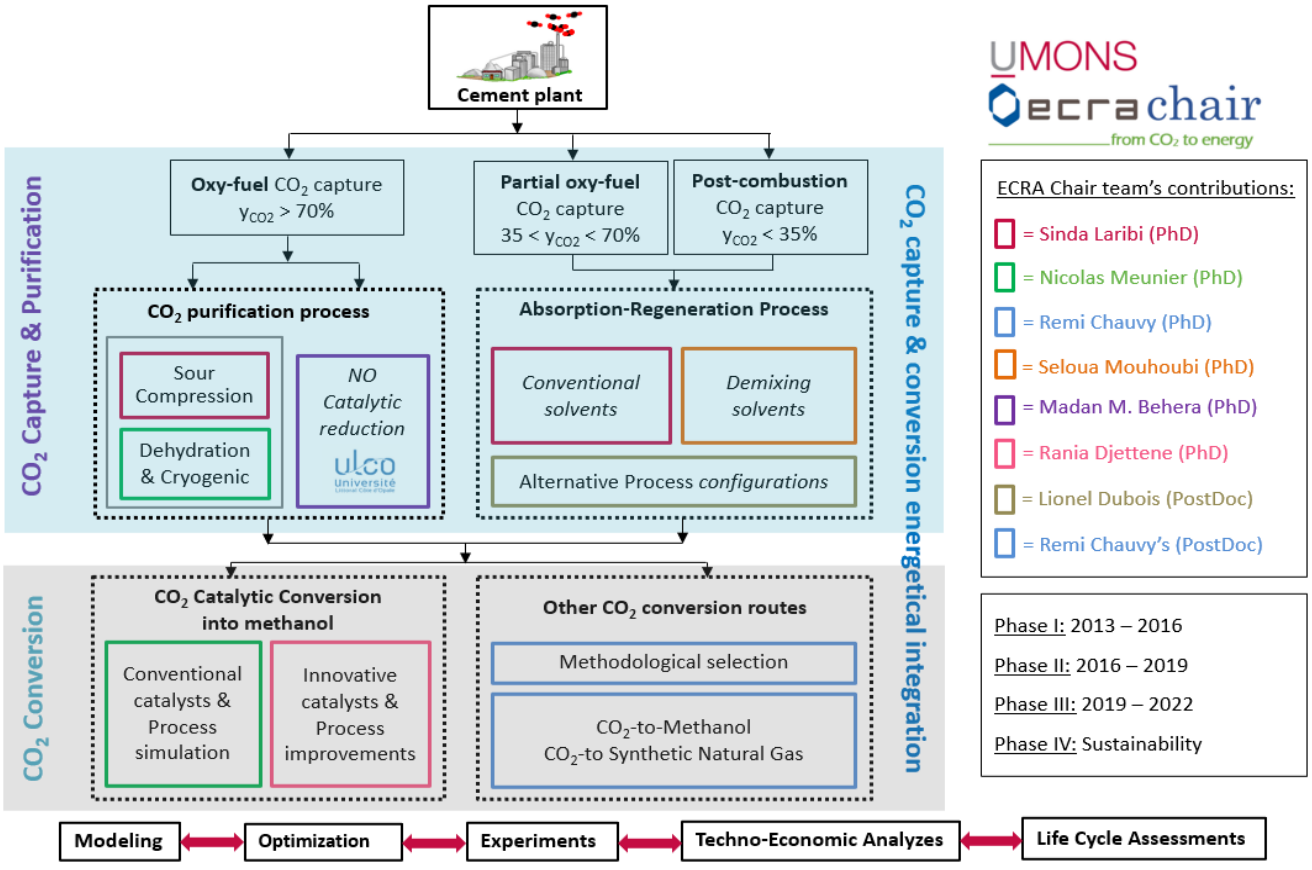

Figure 1: ECRA Academic Chair Framework

« (…) The main objective of the ECRA Academic Chair was to build a Centre of scientific expertise in carbon capture and reuse for the cement industry (…) »

How capturing the CO_2?

Globally three pathways exist for capturing industrial CO_2 emissions, namely: pre-combustion, post-combustion and (partial or total) oxy-fuel combustion. The first possibility (**pre-combustion**) is not an adequate solution to be implemented in the cement industry and was therefore not investigated in the ECRA Chair. Indeed, even if the carbon source of the fuel is eliminated before the combustion itself, that will not have an impact on the two-third of the CO_2 emissions which are coming from the limestone decarbonation ($CaCO_3$ → $CaO + CO_2$). The second process (**post-combustion**) is the most developed one as it does not imply any modification of the cement production process itself. The flue gas containing around 20 mol.% of CO_2 is sent to an "end-of-pipe" process which separates the CO_2 from the other gaseous components using absorption into a solvent (e.g. amine-based), adsorption onto porous materials, membrane process, cryogenic process or other technologies. The third possibility consists in performing the combustion using pure oxygen instead of air (**oxyfuel mode**). The CO_2 concentration of the flue gas is higher than with conventional mode (>70 mol.%) which then allows to use a CO_2 Purification Unit (CPU) in order to get a pure CO_2 flow (>99 mol.%). An hybrid process called "partial oxy-fuel" is also possible. In such case, oxygen is added to air in order to increase the CO_2 content of the flue gas (>30 mol.%) and to facilitate the CO_2 separation from the other gaseous components using a similar process as for the post-combustion pathway.

What can be done with the captured CO_2?

Once the CO_2 captured, different possibilities exist for its valorization. Historically, the first way envisaged for using large amounts of captured CO_2 is its geological storage (Carbon Capture & Storage – CCS) in coal seams, saline aquifers, depleted oil and gas reservoirs, or for performing Enhanced Oil Recovery (EOR) or Enhanced Coal Bed Methane (ECBM). Since several years now, with a circular economy vision, the possibility of really reusing the CO_2 for producing usable products has emerged. Indeed, a lot of different products can be obtained using CO_2 as building blocks. Some of these products use commercialized processes (e.g. urea production) or at demonstration scale (TRL – Technology Readiness Level – of 7 to 9, e.g. methane, methanol, etc.), and others still need some developments (TRL 4 to 6, e.g. formic acid, ethylene glycol) or are still at the R&D level (TRL 1 to 3, e.g. dimethylether, acetic acid, isocyanates, etc.).

What has been performed within the ECRA Academic Chair regarding CO_2 capture?

Regarding the **oxy-fuel CO_2 capture process**, the focus was put on the **CO_2 purification process**. Indeed, the concentrated flow of CO_2 at the outlet of an oxy-fuel cement kiln needs to be purified and especially, residual NOx and SO_2 species must be removed in a CO_2 Purification Unit, see **Figure 2**. For such purpose, in the framework of the PhD Thesis of S. Laribi, a process called "Sour Compression Unit" (SCU) using pressurized water has been investigated and optimized through modeling works using Aspen Plus™ software. In addition to thermodynamic properties, a complete set of chemical reactions (Laribi et al., 2019a) had to be implemented to reach the objectives. One of the main achievements of this research was the adaptation of the SCU from a 2-column process to a singe-column one (see **Figure 3**) and the optimization of the process (in terms

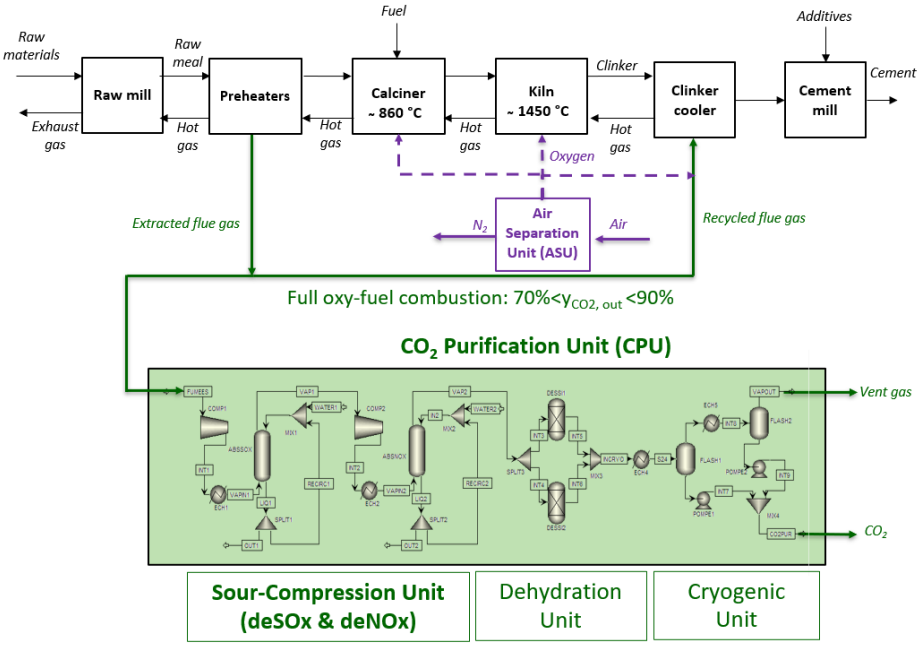

Figure 2: Illustration of the total oxy-fuel process chain in a cement plant

« (…) a lot of different products can be obtained using CO_2 as building blocks. Some of these products use commercialized processes (e.g. urea production) or at demonstration scale (e.g. methane, methanol, etc.), and others still need some developments (TRL 4 to 6, e.g. formic acid, ethylene glycol) or are still at the R&D level (dimethylether, acetic acid, etc.). (…) »

of pressure level, water flow rate, recycle flow rate, etc.) which allowed to decrease both the CAPEX (CAPital Expenditures) and the OPEX (OPerational Expenditures) by 10% and 6% respectively while keeping excellent NOx and SO_2 removal performances (abatement rates higher than 90%).

The works on the CPU (illustrated on **Figure 2)** were also completed in collaboration with N. Meunier (Meunier et al., 2014) for the implementation of a dehydration unit using a Temperature Swing Adsorption (TSA) unit and a final cryogenic unit to reach a final CO_2 purity higher than 98 mol.%.

In October 2019, as joint-supervised PhD Thesis with ULCO (Université du Littoral Côte d'Opale, Dunkerque, France), M. Behera began his PhD Thesis on the optimization of a catalytic process for the CO_2 purification from oxy-fuel combustion. More precisely, an innovative deNOx process is investigated where NO species are reduced by oxidizing carbon monoxide (CO). CO is therefore used as a reducing agent of NOx (essentially NO) by a catalytic way. Nitrogen and water are produced while CO is converted to CO_2, enriching advantageously the flue gas in CO_2. The research works include the development and the characterization of new catalysts, such as the optimization of the catalytic material by catalytic tests in a micro-reactor (at ULCO). The shaping of the material is also realized in order to perform micro-pilot tests (at UMONS) such as the development of a modelling of the catalytic process at industrial scale applied to the cement industry for performing techno-economic and environmental analyses.

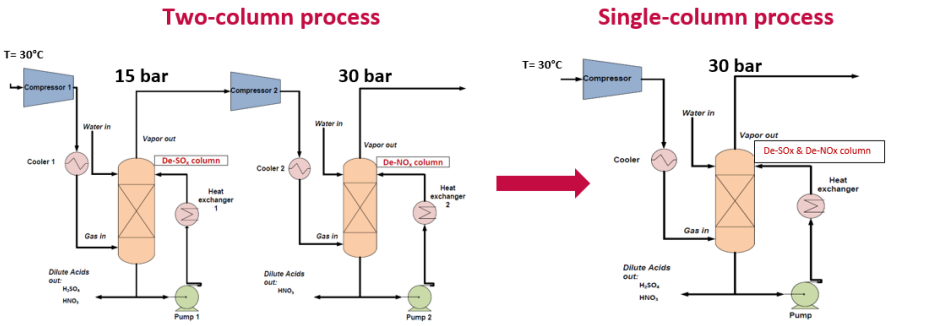

Figure 3: Illustration of the deSOx-deNOx Sour Compression Unit (SCU) improvement

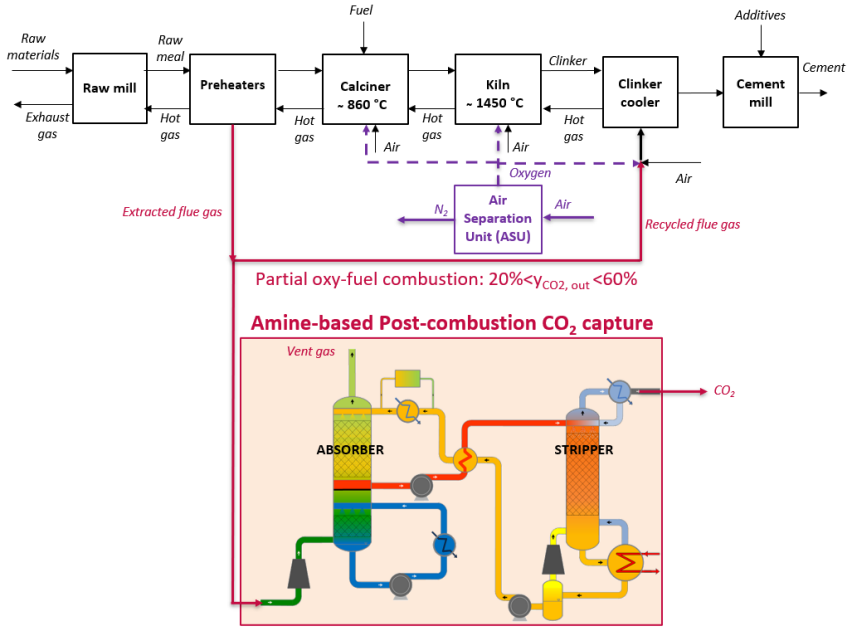

Figure 4: Illustration of the partial oxy-fuel process chain in a cement plant

Figure 5: Absorption-regeneration micro-pilot unit at UMONS

The implementation of a **partial oxy-fuel combustion process** in a cement plant was also investigated in the ECRA Chair by S. Laribi (see **Figure 4**). In such configuration, the CO_2 content of the flue gas (between 20% and 60%) is higher than in conventional combustion mode which allows to apply a **conventional CO_2 capture technology** (especially amine-based process) with reduced operational costs (Laribi et al., 2019b). Both experiments (using an absorption-regeneration micro-pilot unit available at UMONS, see **Figure 5**) and Aspen Hysys™ simulations were performed on this topic.

« (…) switching from a 2-column to a 1-column SCU CO_2 purification process allows to decrease both the CAPEX and the OPEX by 10% and 6% respectively while keeping excellent NOx and SO_2 removal performances. (…) »

It is important to remind the principle of the CO_2 capture absorption-regeneration process using amine-based solvent (see **Figure 6**). The flue gas to be treated is sent into a first column where the CO_2 is absorbed into a chemical solvent (e.g. monoethanolamine (MEA) 30 wt.%), which is then sent into a second column where it is regenerated thanks to heat. This regeneration step, releasing a quite pure CO_2 flow (98 mol.%), consumes a lot of energy (e.g. 3.4 GJ/t_{CO2} for MEA 30 wt.%) provided as steam. By increasing the CO_2 content of the flue gas from 20 mol.% to 40 mol.% using partial oxy-fuel combustion, it has been shown with different solvents (MEA, but also piperazine (PZ) and diethanolamine (DEA) and PZ blend, see **Figure 7**) that the solvent regeneration energy (and therefore the OPEX) can be reduced by around 25%. The increase of the CO_2 content of the flue gas to 60 mol.% did not lead to significant supplementary savings.

Focusing on the post-combustion CO_2 capture absorption-regeneration process, two other options were also investigated in the framework of the ECRA Chair for reducing its energy consumption and therefore its cost. The **first solution** was investigated by S. Mouhoubi in her PhD Thesis, namely the use of **demixing solvents** (see **Figure 8**). Indeed, thanks to the use of adequate proportions of specific amines (e.g. diethylethanolamine (DEEA) and methylamino-propylamine (MAPA) blends were investigated by the ECRA Chair), at a certain level of temperature and CO_2 loading of the solvent, two phases are formed and can be separated in a decanter unit: one lean-phase in CO_2 which can be directly recycled

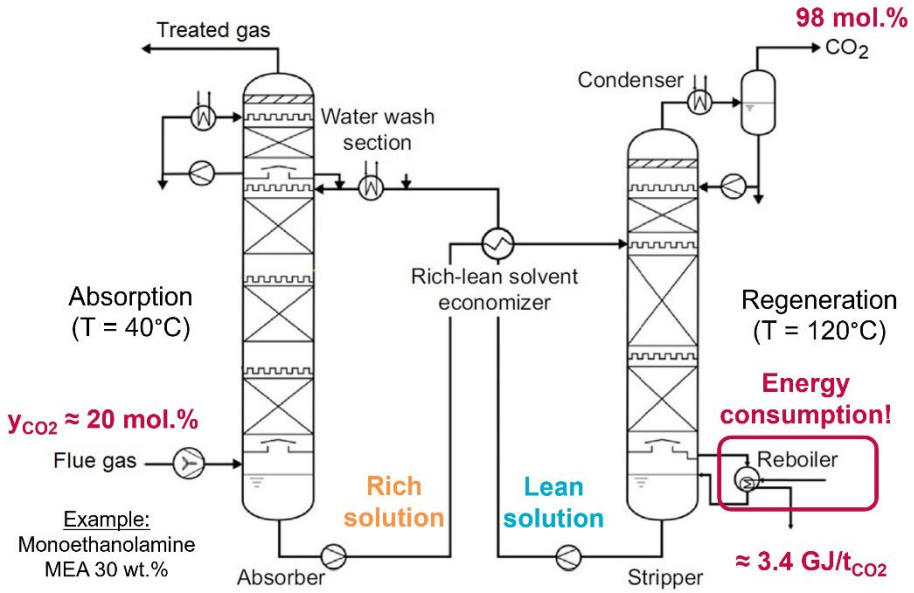

Figure 6: Conventional CO_2 capture absorption-regeneration using amine-based solvent (illustration for monoethanolamine (MEA) 30 wt.%)

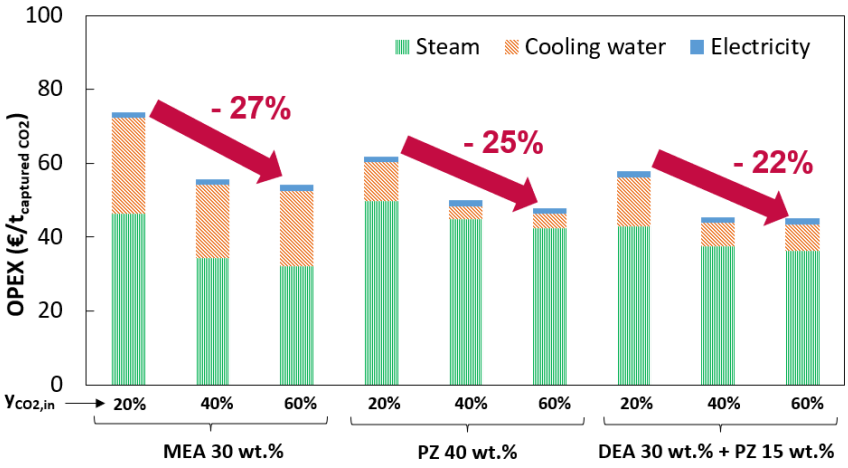

Figure 7: OPEX results for different partial oxy-fuel conditions and solvents

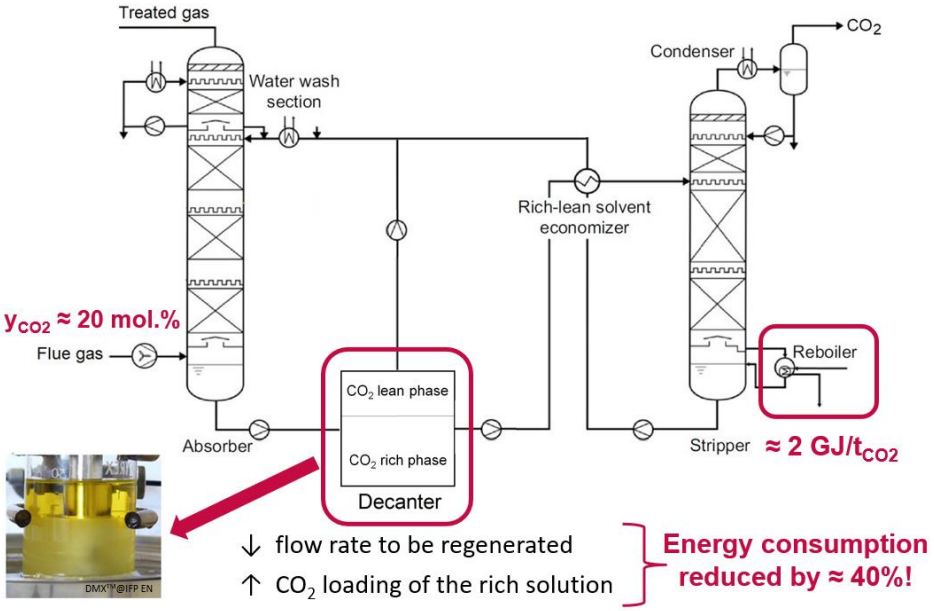

Figure 8: CO_2 capture absorption-regeneration process using a demixing solvent

« (…) increasing the CO_2 content of the flue gas to 40% thanks to partial oxy-fuel combustion decreases the CO_2 capture OPEX by 26%. (…) »

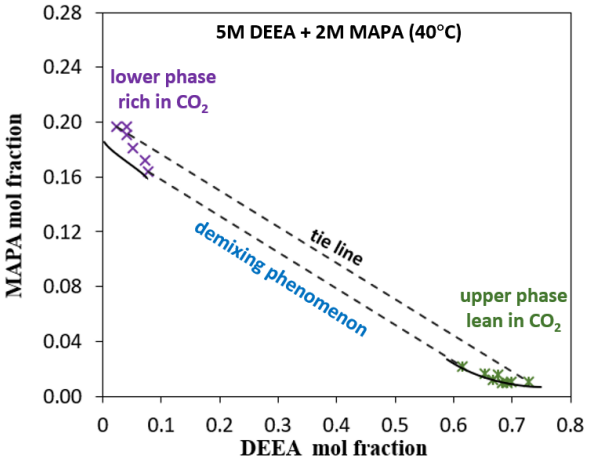

Figure 9: Thermodynamic modeling of liquid-liquid equilibrium for DEEA-MAPA demixing blend

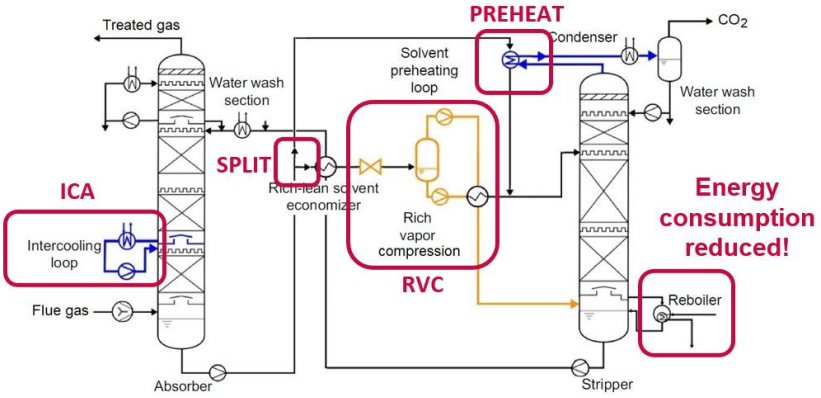

Figure 10: Advanced configuration of the CO_2 capture absorption-regeneration process

back to the absorber and one rich-phase in CO_2 which is sent to the stripper for its regeneration. By performing such operation, as the CO_2 loading of the rich solution is higher than with the conventional process and as the solvent flow rate to be regenerated is reduced, the process energy consumption is decreased. The purpose of the PhD Thesis of S. Mouhoubi was to develop a modeling in order to simulate such demixing process. This modeling was implemented in Aspen Plus™ software and its development needed to take into account the different aspects: thermodynamics (see illustrations on **Figure 9**), kinetics, physical properties, etc. (Mouhoubi et al., 2020). Some of the modeling results in non-demixing conditions were also validated using the UMONS micro-pilot unit (**Figure 5**). Based on the simulations developed considering a BAT (Best Available Technology) cement plant, it was estimated that the solvent regeneration energy could be reduced by 40% (2 GJ/t_{CO2}) with such demixing process in a comparison with a conventional MEA 30 wt.% technology. A techno-economic analysis also highlighted that the CO_2 capture costs could be reduced by 35%.

The addition of a decanter leads only to 1% increase of the CAPEX.

The **second solution** to reduce the energy consumption of such CO_2 capture process, that was investigated in the ECRA Chair by L. Dubois as Senior Researcher, is the **implementation of advanced process configurations with amines blends** (Dubois and Thomas, 2018; Dubois and Thomas, 2021). Actually, as illustrated on **Figure 10**, by implementing supplementary units (e.g. intercooling absorber (ICA), rich vapor compression (RVC), split and preheat, etc.) to the absorption-regeneration process it is possible to significantly reduce its energy consumption, especially if a more efficient solvent than MEA 30 wt.% (e.g. methyldiethanolamine (MDEA) and piperazine (PZ) blend) is implemented.

The investigation of different process configurations considering different solvents was performed through Aspen Hysys™ simulations. Considering the process represented on **Figure 10** and the implementation of MDEA+PZ blend, it was shown (see **Figure 11**) that 41% energy saving is possible in comparison with the conventional MEA process. In terms of economics, despite an increase of 10 to 15% of the CAPEX, a decrease of 31% of the global CO_2 capture costs was estimated.

Globally, the research works performed within the ECRA Chair have clearly highlighted different **technical solutions that could help to reduce the CO_2 capture energy consumption** and its cost for the application in the cement industry.

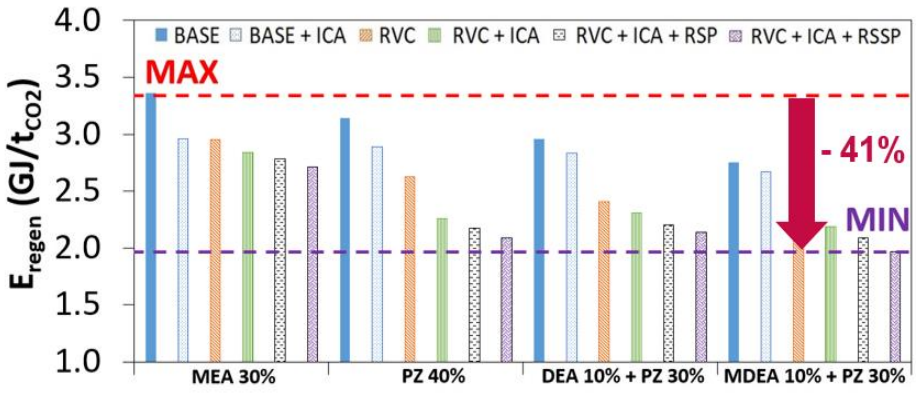

Figure 11: Regeneration energy for different solvents and process configurations

« (…) Both demixing solvents and advanced process configurations allows to decrease the solvent regeneration energy by 40% (…) »

What about CO_2 conversion?

As illustrated on **Figure 1**, the ECRA Academic Chair research activities also focused on different CO_2 utilization options. In the framework of the PhD thesis of R. Chauvy, an **original multistep method** was developed (Chauvy et al., 2019) to **classify different CO_2 conversion alternatives** and to **identify the best emerging options** to be implemented in short- to mid-term via a multi-criteria assessment including technical, economic, energetic, environmental and market considerations. The impact of different factors on the assessment results was also investigated (Chauvy et al., 2020a). Different alternatives were reviewed (Chauvy and De Weireld, 2020), involving the production of compounds that have a low unit price, but significant market volume, such as methanol, methane, calcium or sodium carbonates, microalgae, urea, syngas and ethanol, and compounds that have a high unit price but low market volume, such as dimethyl carbonates, polycarbonates, formic acid and salicylic acid (see **Figure 12**). Globally, methanol and methane (as Synthetic Natural Gas – SNG) were identified as two of the most promising CO_2-based products among examined cases through the sensitivity analysis and were therefore more deeply investigated in the ECRA Chair.

The **CO_2 catalytic conversion to methanol** was specifically studied within the ECRA Chair by N. Meunier. During his PhD Thesis, N. Meunier worked both on the development of a modeling of such process, but also on the establishment of a micro-pilot unit (see **Figure 13**).

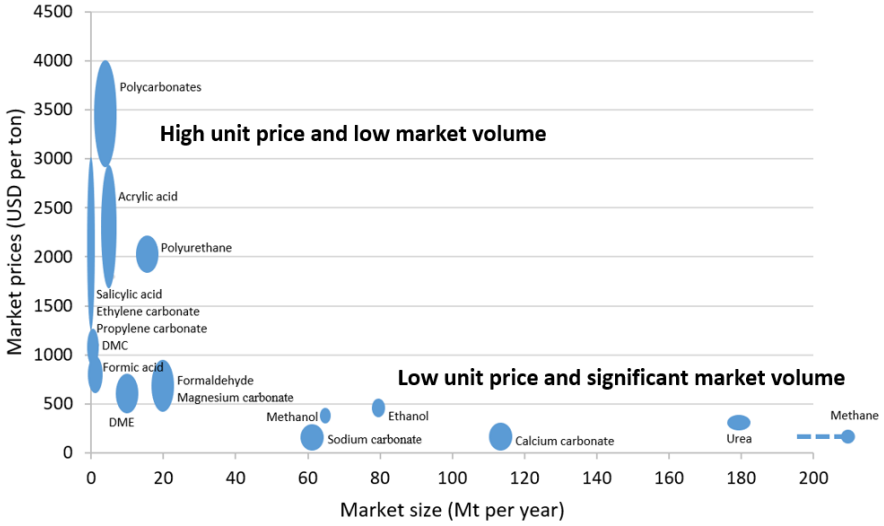

Figure 12: Market sizes and market prices for the main CO_2-based compounds (non-exhaustive) from (Chauvy et al., 2019)

Figure 13: CO_2 catalytic conversion to methanol micro-pilot unit at UMONS

The experimental investigation performed in the work of N. Meunier assessed the interest in developing innovative catalysts for the direct conversion of pure CO_2 into methanol by comparing two catalysts: a commercial $CuO/ZnO/Al_2O_3$ catalyst and an innovative homemade $CuO/ZnO/ZrO_2$ one, synthesized with the collaboration of the European School of Chemistry, Polymers and Materials (ECPM) from Strasbourg. This experimental investigation allowed the determination of kinetic constants related to both these catalysts. From the experiments, it was noticed that the temperature had a dramatic influence on the productivity and selectivity towards methanol. It has been pointed out that the commercial catalyst has a higher selectivity towards methanol at temperature higher than 250°C, where the zirconia supported catalyst has a higher selectivity towards methanol at temperature below 230°C.

The great interest in zirconia-supported catalyst was thus proven for the production of methanol as this kind of catalysts demonstrated higher methanol productivities than the commercial one.

« (…) Globally, methanol and methane (as Synthetic Natural Gas – SNG) were identified as two of the most promising CO_2-based products among examined cases (…) »

Together with other ECRA Chair researchers (Meunier et al., 2019), the determined kinetic parameters were then used for the development in Aspen Plus™ of a simulation of the CO_2 conversion to methanol process thermally integrated with a CO_2 capture unit (using amine-based technology), including techno-economic and environmental assessments. Indeed, the CO_2 conversion to methanol being an exothermal process, the possibility to recover the released heat to reduce the global energy consumption of both the CO_2 capture and the water-methanol distillation steps was investigated. From these developments, one of the main conclusions is the fact that significant energy savings are possible thanks to the implementation of thermally optimized CO_2 capture (quite similar advanced process as the one investigated by L. Dubois) and CO_2-to-methanol processes. Moreover, the renewable hydrogen production cost remains one of the key elements for such CCU process chain. The works on the CO_2 conversion into methanol are still in progress in the ECRA Chair through the PhD Thesis of R. Djettene, started in October 2019. The objective is to continue the optimization of the process thanks to the exploitation of the CO_2-to-methanol micro-pilot catalytic reactor (see **Figure 13**), including experiments with different catalysts, but also modeling development and process simulations (see **Figure 14**) in order to perform economic and environmental analyses.

As mentioned, the environmental evaluation (**Life Cycle Assessment (LCA)**) of the CCU processes (including CO_2-to-methanol one) was also performed in the framework of the ECRA Chair thanks to the works of R. Chauvy during his PhD Thesis and his Post-Doc. Such analysis allows to evaluate the environmental impact in terms of Climate Change (CC) ($kg_{CO2equ}/t_{CO2\text{-}based\text{-}product}$), but also in terms of fossil depletion, water depletion, metal/mineral depletion, etc. In the case of CO_2 conversion to methanol, as represented on **Figure 15** for the CC indicator, in comparison with a reference production system (methanol production from fossil-based syngas), a reduction of 54% of the equivalent CO_2 emissions was estimated, which confirms the interest of such integrated CCU process in comparison with a fossil-based one.

In addition to the analysis of the CO_2-to-methanol process, and in close collaboration with L. Dubois, R. Chauvy also investigated during his Post-Doc the entire CCUS chain, from industrial CO_2 capture from BAT cement plant flue gas, to its **conversion to SNG together with renewable hydrogen**, through simulation and process-to-process integration. It allowed to get relevant technical and economic parameters, and to perform LCA, identifying hotspots contribution and quantifying most significant environmental impacts. As for methanol, naturally the economic breakthrough was identified to be strongly related to high capital investments and electricity costs

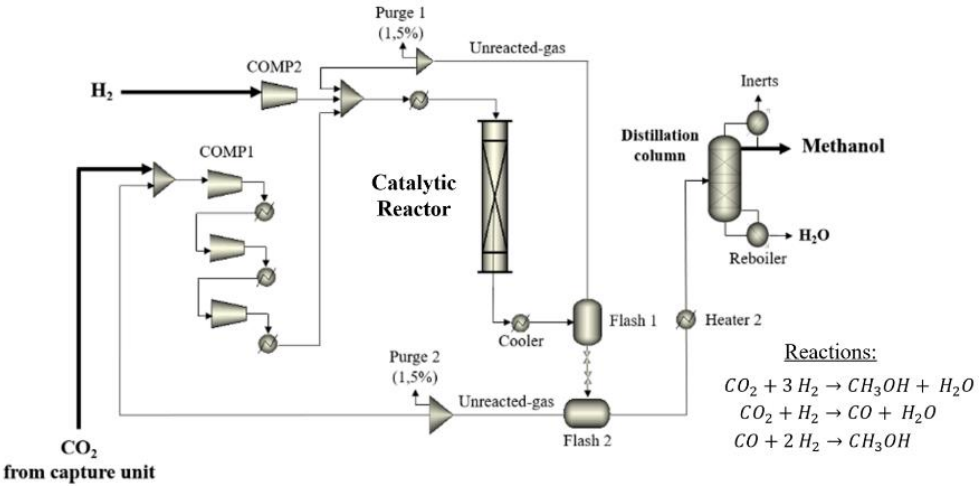

Figure 14: Aspen Plus™ modeling of CO_2 catalytic conversion to methanol process (without heat integration)

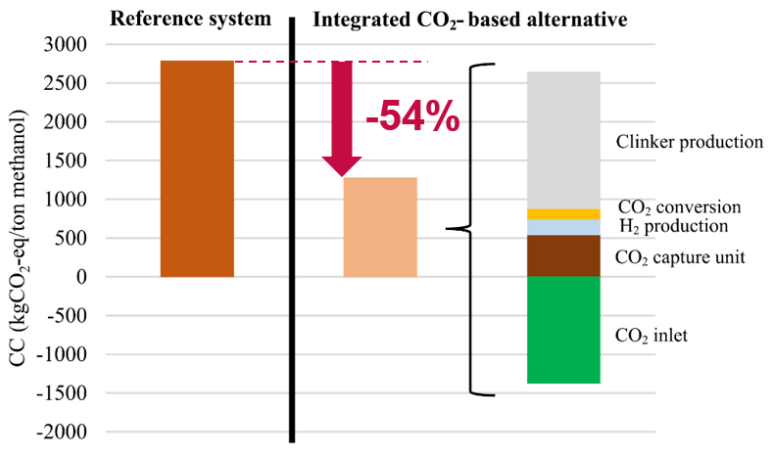

Figure 15: Comparison between the Climate Change impact (CC) of the integrated CO_2 conversion process with the conventional production of methanol (from syngas)

« (…) In comparison with a conventional methanol production system from fossil syngas, a reduction of 54% of the equivalent CO_2 emissions was estimated (…) »

required for the production of hydrogen, which is nevertheless expected to decrease in the upcoming years. As illustrated on **Figure 16**, the **thermal integration** between an advanced CO_2 capture unit and a CO_2 methanation unit was performed at a representative scale for current electrolyzers used for hydrogen production, namely 10 MW. Moreover, as the CO_2 methanation process is highly exothermic, in addition to be self-sufficient in terms of thermal energy, different options were investigated through Aspen Plus™ simulations for the valorization of the excess heat available, namely capturing more CO_2 (Case 1, see **Figure 17**) leading to some extra-CO_2 compressed in view of transport for other CCUS applications (Chauvy et al., 2021a), generating electricity (Case 2) (Chauvy et al., 2020b) or providing heat as steam available for other industrial processes (Case 3) in an industrial symbiosis vision (Chauvy et al., 2021b), all the details regarding these investigated cases being available in the mentioned papers. For example in Case 1, it was pointed out that the use of the entire excess heat for capturing the CO_2 allows to recover a supplementary flow corresponding to 70% of the quantity needed for the methanation unit. In Case 2, it was shown that the electricity generated using the excess heat covers the entire electrical demand of the methanation unit, covering also 5% of the electricity demand of the CO_2 capture unit. On the other hand, in Case 3, it was highlighted that only 60% of the excess heat is used for the CO_2 capture, meaning that 40% is still available as steam for other purposes. In terms of economics, one of the main observations is the fact that the supplementary CAPEX related to the heat integration (e.g. heat exchangers, pumps, etc.) represents only around 2% of the total CCU investment costs, while for example in Case 3 (total OPEX estimated to 117 €/t_{CO2} without H_2 production) the OPEX would be 30% higher if external steam must be provided to the capture unit (without heat integration).

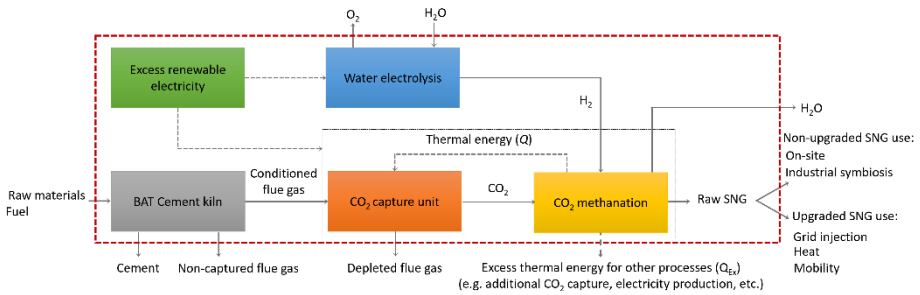

Figure 16: Integrated CO_2 capture and conversion process to Synthetic Natural Gas

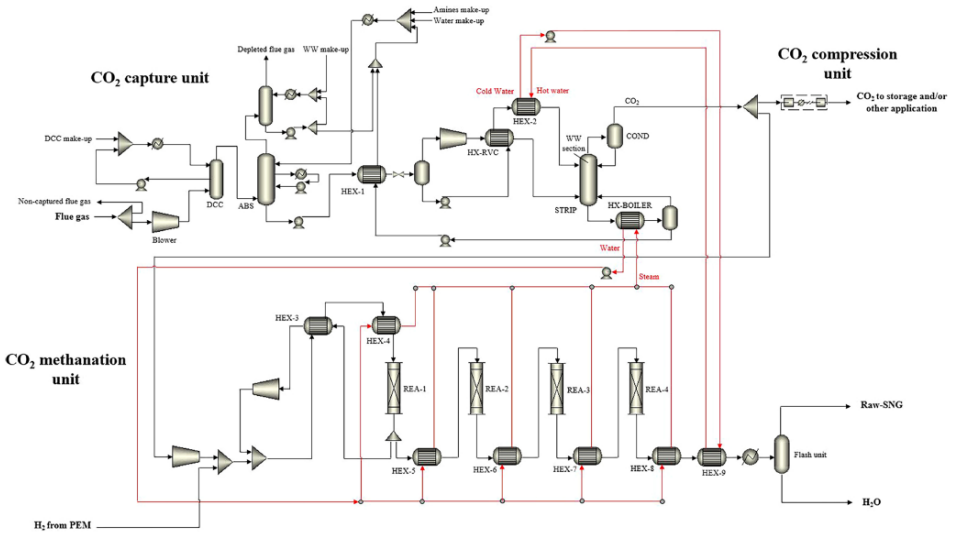

Figure 17: Aspen Plus™ flow sheet of the integrated CO_2 capture and methanation units with extra-CO_2 captured for CCUS purposes, from (Chauvy et al., 2021a)

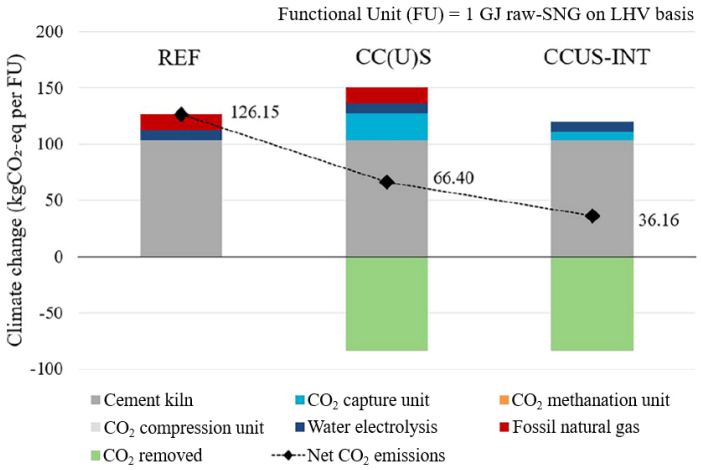

Figure 18: Climate Change impact (CC) of the CO_2 conversion process to SNG with thermal integration (CCUS-INT) in comparison with a reference cement plant (REF) and a CC(U)S process with fossil-based natural gas production, from (Chauvy et al., 2021a)

Globally, the three Cases have shown an environmental interest.

Different environmental impacts were investigated but focusing on CC) (see **Figure 18** for Case 1), in comparison with their respective reference scenario, the three approaches led to a relative decrease of the net CO_2 emissions higher than 70%.

« (…) Methanation excess heat could be used to produce electricity, to capture more CO_2 or valorized as steam for industrial symbiosis (…) »

ECRA Academic Chair Activities

As illustrated on **Figure 19**, in parallel of the scientific research works leading to PhD theses and international publications (see P11), the ECRA Chair members are taking part to different activities. Two times a year, ECRA and UMONS members meet for the ECRA Chair Scientific Committees.

The ECRA Chair Professors, Post-Docs and PhD Students also participate regularly to international scientific events in order to present the advancements of the ECRA Chair works. Moreover, in 2014 and 2016, the ECRA Chair organized his own Scientific Events with around 100 international attendees each time and including the visit of a cement plant. Undergraduate students are also associated to the ECRA Chair works for Master Theses, projects, internships, etc., and an ECRA Award is delivered annually to reward the best student work(s) achieved.

Final remarks & ECRA Academic Chair perspectives

The ECRA Academic Chair is contributing on different aspects (CO_2 capture, purification and conversion, both in (total/partial) oxy-fuel combustion and post-combustion) **to help for the implementation of CCU in the cement industry**. Different technologies and cases studies were studied. Nevertheless, it is important to highlight that each case investigated has specificities that need to be considered, such as: the production of electricity with excess heat needs either the establishment of, or to have access to, a high-pressure water network, as well as the implementation of a turbine, etc., which is not necessarily easy; the eventual extra-CO_2 captured needs to fulfill the CO_2 transport network specificities in terms of purity (and such network must be available), and a potential other utilization or geological storage capacity of this CO_2 must be ensured; and finally the valorization of excess thermal energy as steam is possible only if another industrial plant is situated not far from the cement plant itself in order to really perform an industrial symbiosis. For all the cases investigated considering methanol or methane as CO_2-based product, it has to be noted that the production of renewable H_2 remains an important factor for CCU, especially due to the high costs (both CAPEX and OPEX) of the electrolysis process, and also for the need of renewable electricity.

It is worth mentioning that **the methodologies developed in the framework of the ECRA Chair could be potentially applied considering other CO_2 capture and/or CO_2 conversion processes**. The works are still in progress with currently two PhD Theses, namely on CO_2 purification and on CO_2 conversion to methanol.

More globally, the ECRA Chair members at UMONS are working for the sustainability of the Centre of scientific expertise built since 2013, through the broadening of the collaborations, with cement industry actors but also with other industries and with the introduction of new research subjects (e.g. Direct Air Capture). Indeed, the ECRA Academic Chair at UMONS became a real Centre of scientific expertise for CCU application in the cement industry but also for other applications as UMONS is now regularly contacted for performing studies (e.g. technological guidance, process simulations, TEA, LCA, etc.) in order to help for implementing CCU options in different industrial sectors. Furthermore, in 2022, **ECRA and UMONS confirmed their common willingness to continue their cooperation until at least 2025 through the signing of a Memorandum of Understanding**.

The ECRA Chair really put on track a lot of activities and a real way of working that will be pursued because the fight to tackle climate change is not finished, still many battles have to be won!

Figure 19: Illustrations of some ECRA Academic Chair activities

« (…) The ECRA Academic Chair at UMONS became a real Centre of scientific expertise for CCU application in the cement industry but also for other applications. (…) »

ECRA Academic Chair Research Team at UMONS

Academic & Scientific Coordinator:

Prof. Diane Thomas
Chemical & Biochemical Process Engineering Unit

Academic & Scientific Supervisor:

Prof. Guy De Weireld
Thermodynamics Unit

Academic & Scientific Advisors:

Prof. Paul Lybaert
Thermal Engineering & Combustion Unit

Research Coordinator & Senior Researcher:

Dr Lionel Dubois
Chemical & Biochemical Process Engineering Unit

Prof. Anne-Lise Hantson
Chemical & Biochemical Process Engineering Unit

Prof. Ward De Paepe
Thermal Engineering & Combustion Unit

PhD Students & Post-Doc :

Dr Nicolas Meunier
(2018)

Dr Sinda Laribi
(2018)

Dr Remi Chauvy
*(2019)**

Dr Seloua Mouhoubi
(2020)

Ir Madan Behera
*(in progress)***

Ir Rania Djettene
(in progress)

**Post-Doctoral researcher from 2019 to 2020.*

***Joint-supervised PhD Thesis with ULCO (Université du Littoral-Côte-d'Opale, Dunkerque, France).*

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For more information on the ECRA Academic Chair: https://hosting.umons.ac.be/html/ecrachair

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In addition to these publications, numerous scientific communications were also presented in international conferences.

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