ACT LAUNCH Project No 299662

The LAUNCH project is funded through the ACT programme (Accelerating CCS Technologies, Horizon2020 Project No 294766). Financial contributions are made from: Netherlands Ministry of Economic Affairs and Climate Policy, the Netherlands; Federal Ministry of Economic Affairs and Climate Action on the basis of a decision by the German Bundestag, Germany; Gassnova SF (GN), Norway; Department for Business, Energy & Industrial Strategy (BEIS) together with extra funding from NERC and EPSRC research councils, United Kingdom; US-Department of Energy (US-DOE), USA.
All funders are gratefully acknowledged.

Lowering **A**bsorption process **UN**certainty, risks and **C**osts by predicting and controlling amine degradation

LAUNCH Deliverable D6.1.1b

Feasibility of non-metallic materials of construction for CO2 capture plants

Dissemination level	Confidential	
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Issue date	07.04.2023	

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1 Introduction

In the LAUNCH project, several pathways towards enhancing understanding of solvent degradation in post-combustion carbon capture systems are researched. This also includes the evaluation of several mitigation strategies aiming to reduce solvent costs. One of the pathways is the deployment of non-metallic materials of construction for the processes. There can be two main reasons for employing non-metallic materials of construction:

1. Reducing solvent degradation: metals are seen as a main contributor of accelerated degradation, acting as a catalyst. Preventing metals from accumulating in the solvent (by corrosion) could extend the solvent lifetime significantly, especially for relatively fast degrading solvents like MEA.
2. Reducing CAPEX: Using (cheaper) non-metallic materials for the columns, CAPEX could be reduced, as the columns normally cover a large part of the CAPEX for post-combustion carbon capture systems

Using the non-metallic LAUNCH rig constructed in the LAUNCH project, an experimental campaign was conducted focusing on the behaviour of the solvent under controlled metal concentrations. The results are summarized in D6.1.1a of the LAUNCH project, and show that the tests were inconclusive to further comment on a potential reduction in degradation rate by using non-metallic equipment.

In this report, the focus will be towards the CAPEX implications of non-metallic equipment for the main equipment in a full-scale CO_2 capture plant, further assessing the feasibility of non-metallic materials of construction for CO_2 capture systems. Additionally, an analysis is performed regarding the effect of different solvent degradation rates on solvent replacement costs.

It has to be noted that this report focuses solely on the economic perspectives of implementing non-metallic materials and decreasing solvent degradation by using these materials. Detailed LCA's are needed to assess the full-chain influence of using non-metallic materials of construction (MOC's).

Introduction to Beform

This report uses the expertise of Beform/Becapture as input for the techno-economic analysis of the non-metallic MOC's case study. Becapture is a business area within Beform AS. The latter is a company that develops and manufactures products in plastic and polymeric materials. The company has extensive experience with products for flue gas purification for SO_2 and now most recently CO_2.

Beform has invested considerable of its own funds and internal hours in several projects that aim to make CO_2 capture cheaper, with high efficiency and low energy consumption. Some projects have been completed, while others are still ongoing (2023) with both national and international partners. Two of these are clusters that are supported by EUIF.
Through this, Beform has built up considerable expertise. This competence encompasses a large area which includes:

- Product development: how to design and develop sustainable products and equipment with high performance and long life. The products should contribute to increase efficiency and lower the operating costs (OPEX) in capture facilities.
- Material knowledge: Research and develop polymeric materials with high performance and chemical resistance for use within the CCUS area. This entails modification of existing materials as well as the development of new types of additive materials (additives) to improve function.
- Testing: Experience from testing both chemical and mechanical properties in materials, products and equipment. This has been built up through collaboration with external companies and institutions for complementary work.
- Carbon capture process expertise: Carbon capture takes place today using several different types of technology. These include amines, hot potassium, chilled ammonia, and several others. This is process chemistry at a high level and the products for this industry must be well adapted in order to function as best as possible. Beform has built up the necessary expertise in this area.
- Manufacturing: The use of new material combinations affects the manufacturing process. This is because new conditions for flow characteristics, temperatures and others come into force. In order

to achieve long-term high quality of the products, optimized process conditions are important. Beform has built up extensive expertise in this area.

- Calculation and cost calculation. The number of requests for new facilities for CCUS installations is increasing. Beform has calculation models for strength, structure and price.

2 Case study definition

As a basis for the case study, the ALIGN CCUS project is used [1]. In that study, a lignite fired power plant, a waste-to-energy (WtE) and a cement case study were worked out. For this report, the 200 kton waste-to-energy case study was chosen as the basis, as it represents a scale at which CO_2 capture systems are starting to be implemented in industry at the moment of writing this report (2023), in the range of 100 to 400 thousand tonnes of CO_2 captured per year (ktpa). The boundaries of that case study are only related to the capture plant itself, and is shown in *Figure 1*. In this case study, metallic MOC's are considered, with all equipment being constructed with some grade of stainless steel.

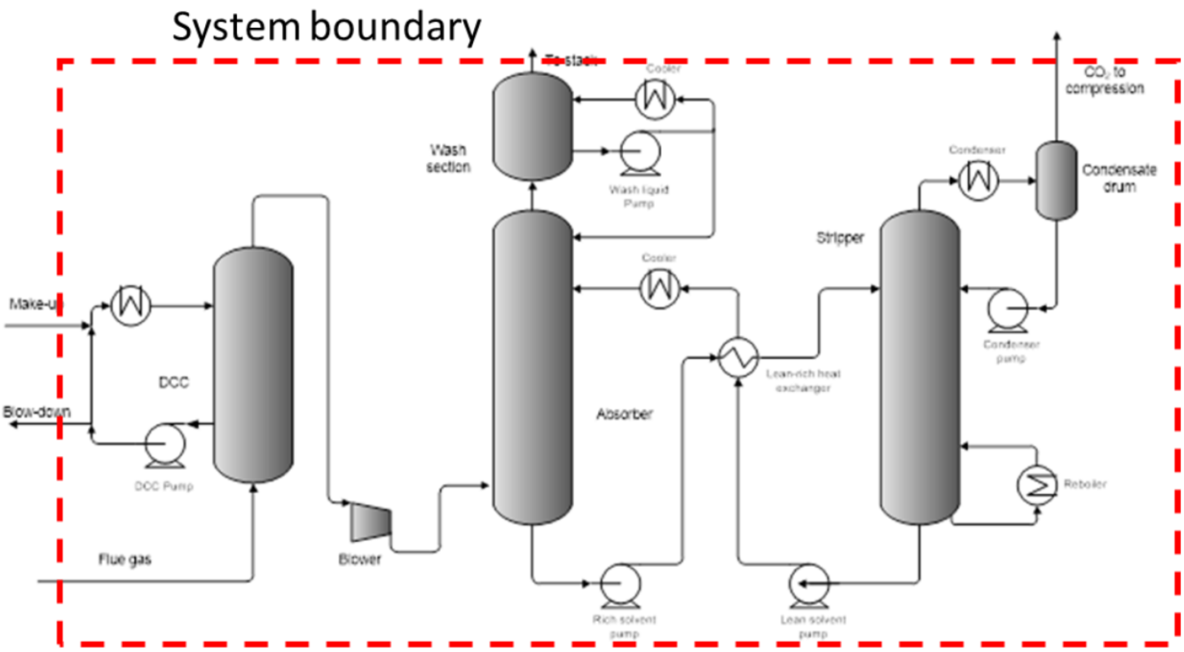

Figure 1, boundary conditions for the ALIGN-CCUS case study [1], also used for this study.

A breakdown of the CAPEX and variable OPEX for the ALIGN CCUS study using MEA as the solvent is shown in *Figure 2*. For the variable OPEX, a heat cost of 6 €/GJ is chosen, while for the rest of the costs, the framework used in the ALIGN case study is followed. regarding CAPEX, the columns make up 60% of the total plant cost, which indicates that reducing column costs can significantly reduce the total CAPEX of the system. The total cost of CO_2 capture with variable heat costs and a cost of electricity of 0.10 €/kWh is shown in *Figure 3*. The result of the ALIGN report using 2016 cost basis (100.23 index value) have been updated to a 2022 cost index (135.60 index value). It can be seen that variable OPEX is the major contributor to the total cost at 4 and 6 €/GJ case, while variable OPEX and CAPEX are comparable for the 2 €/GJ case. This further shows the importance of the energetic efficiency of the capture plant, and any non-metallic construction materials should not decrease the performance of the process (for a system of the same size), as heat costs easily become prohibitive for carbon capture systems.

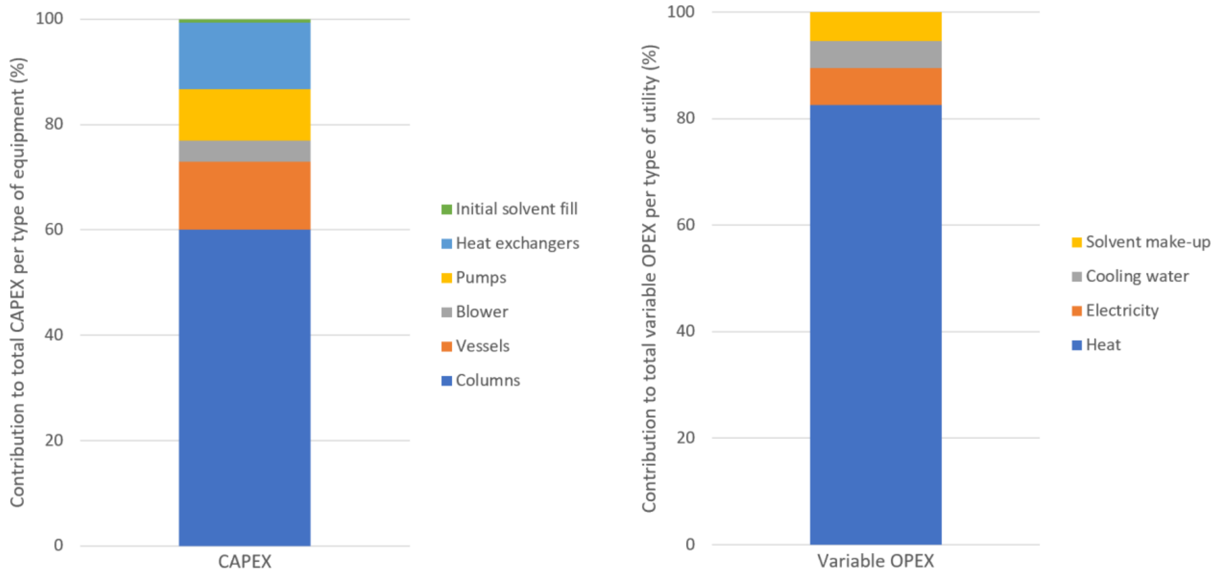

Figure 2, CAPEX and variable OPEX breakdown for the MEA base case study from the ALIGN CCUS project per type of unit and type of utility respectively

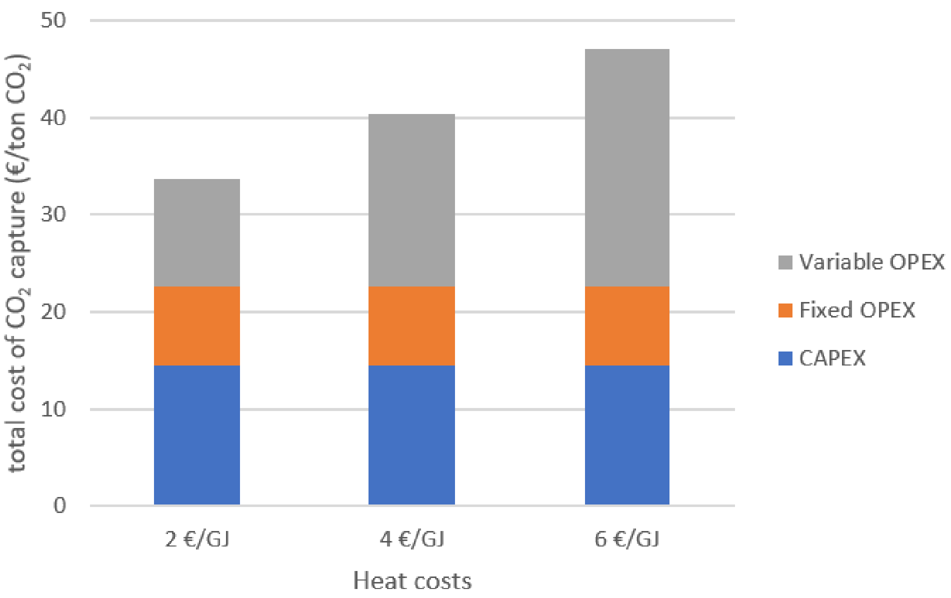

Figure 3, total cost of CO_2 capture, with variable heat costs for the base ALIGN CCUS case

3 Full scale equipment using non-metallic materials of construction

Beform has evaluated the suitability of non-metallic materials in CO_2 capture systems, and availability of non-metallic equipment at the scale of interest (at least 100 ktpa).

Suitability of non-metallic materials
Beform has tested materials in different projects to assess the resistance of different materials on the carbon capture environment. The following results were drawn:

- Specially formulated epoxy grades (by Beform) are suitable at temperatures up to at least 125°C.
- Polytetrafluorethylene (PTFE) is suitable at temperatures up to at least 125°C.
- Polypropylene (PP) is suitable at temperatures up to 70°C.
- Ceramic coated metal surfaces is also believed to be fit for the purpose, but is not tested by Beform yet.

It is recommended to use the specially formulated epoxy grades or PTFE materials for high temperature equipment in the carbon capture process (stripper side). Polypropylene could be a viable low cost material for the low temperature parts of the system (absorber side).

The availability of large scale non-metallic equipment
In order to build a complete non-metal system, the following major components must be available:
Columns, column internals, pipes and fittings, pumps and heat exchangers. The availability of these components is briefly described below.

<u>Columns and vessels</u>
Columns and vessels can be build with proven technology in steel, polymer composites or concrete to be lined with suitable epoxy composites or thermoplastic materials like PP and PTFE.

<u>Internals</u>
"Packings" or packing bodies refer to a number of specially designed products for use in absorption and distillation columns and chemical reactors. Structured packings typically consist of thin corrugated plates with an open bead structure that forces liquid to take complicated paths through the column, thereby creating a large surface area for contact between different phases. The products offer very low resistance to gas flow. The surface enhancements have been chosen to maximize liquid dispersion. These properties tend to show significant performance advantages in low-pressure, low-speed applications. This is an area where Beform has extensive experience from products for the SO_2 market. These products are important, and separate versions have been developed for use within CC. In addition, there will be a number of supplementary products for other functions.
Beform has manufactured several systems for water distribution in flue gas SO2 absorption reactors. The materials used in those systems, fibre glass reinforced vinyl esters, are known to be unsuitable in CO_2 solvent systems. From tests performed by Beform, special grade epoxy and carbon fibre reinforcements is concluded to be the preferred material of choice by Beform. However in this cost study, in order to eliminate design uncertainty, we have chosen to base calculation on a distribution system with PTFE lined steel pipes. Which means a material cost at approximately two times the price of a conventional steel unit.

<u>Pipes and fittings</u>
Suitable pipes and fittings are readily available in steel with PTFE lining. Pure PTFE piping (without support) is not recommended, as it is a soft material and will need additional mechanical support. In this regard, polymer composites could be an alternative to using metal as the backing material.

<u>Pumps</u>
Pumps exceeding 350m^3/h capacity (the rich solvent flow rate in the case study) are available with PTFE and PP lining in addition to ceramic coated types. Example of a company manufacturing these is Leakless India Engineering. The reason for the higher cost is due to the fact that the coating process increases material and manufacturing costs.

Heat exchangers

Heat exchangers represent a special challenge due to the low heat transfer rates in polymers and inferior mechanical properties compared to metals. This means in practice that the component in polymers will need higher wall thicknesses and larger surfaces than their metal counterparts. This results in dimensionally larger units and higher pressure losses, i.e. less efficient units. Heat exchangers with different types of coating, thin polymers layers or ceramic types are present at the market and are believed to be more efficient alternatives. These are not tested by Beform in practice. Examples of companies manufacturing these are Curran International and SEC Heat Exchangers.

Adding the lessons learned from building the non-metallic rig in the LAUNCH project, it is believed that CAPEX could be higher for a full non-metallic system, compared to a metallic system, since all non metal components had a significantly higher cost than metal equivalents. The section below will discuss Beform's efforts to assess the costs of non-metallic full-scale equipment, with a focus on the columns.

4 Results of the non-metallic materials of construction case study

CAPEX calculations and total cost of CO_2 capture comparison

The CAPEX from the base case using metallic MOC's is taken as a basis, and changed accordingly to get to the costs of non-metallic MOC's. The following assumptions are made:

- Quench pumps and heat exchangers do not have to be build in non-metallic MOC's, as there is no contact between the solvent and these units, meaning no metals from this part of the process can be transferred to the solvent. In principle the same holds for the quench column, but this column is evaluated in non-metallic MOC's either way
- Columns are analyzed in detail by Beform (see explanation below)
- For the installation costs of the non-metallic columns, 40% of the material costs are taken. Beform has indicated that the installation factor is expected to be between 40 and 70%. For the metal counterparts, these values are 40%, 60% and 110% for the Absorber, Desorber and quench respectively, which was calculated by Aspen. The 40% to 70% for non-metallic equipment is based on experience of Beform.
- Vessels are the same price in non-metallic MOC's as compared to metallic MOC's, based on Beform's experience.
- Cost of pumps and heat exchangers is assumed to be 100% more expensive in non-metallic MOC's compared to metallic MOC's, based on Beform's experience, and to keep the techno-economic relatively simple, as cost correlations for non-metallic pumps and heat exchangers are not readily available.
- Fixed OPEX to CAPEX relations are the same in non-metallic MOC's compared to metallic MOC's. This assumption is taken to simplify the case study, and should be further verified. A consequence of using non-metallic MOC's could for instance be increased change of leakage, due to the restriction of not being able to use all materials of choice for this. This could increase the maintenance costs (part of Fixed OPEX) significantly. Also for instance replacing or fixing equipment might be harder, as welding is not possible.
- The performance of the non-metallic MOC CO_2 capture process is identical to the metal equivalent process. This is an important assumption that should be extensively verified by comparing metal and non-metallic MOC's under real operating conditions. For instance mass transfer limitations in the absorber (due to less efficient packing wetting) can occur, and also heat exchanger efficiencies will normally be much lower in non-metallic MOC's compared to their metal counterparts.

For the quench, absorber and desorber, Beform has performed more in depth calculations on the material costs for the shell in a special epoxy formulation, and non-metallic packing material for the columns. The results of this analysis, and the comparison to metallic MOC can be found in *Table 1*. Based on the calculations, it is expected that non-metallic MOC can results in cheaper columns. However, the calculations performed in this study are still relatively high level, compared to the calculations in the Aspen Capital Cost Estimator for metallic equipment.

Table 1, comparing calculated column costs and total CAPEX in non-metallic MOC versus metallic MOC.

Parameter	Unit	Metallic MOC	Non-metallic MOC
Quench + Packing	M€	1.91	1.47
Absorber + Packing	M€	4.70	2.84
Desorber	M€	1.92	0.70
Vessels	M€	1.85	1.85
Fan	M€	0.56	0.56
Pumps	M€	1.40	1.97
Heat exchangers	M€	1.79	3.37
Initial solvent fill	M€	0.07	0.07
EPC costs	M€	3.00	3.00

Contingencies	M€	6.89	6.33
Total CAPEX	M€	24.10	22.17

The division in CAPEX per type of equipment for both the metallic and non-metallic MOC are shown in *Figure 4*. For non-metallic MOC, the percentage of costs of the columns is decreased from 60% to 39%, while the percentage of cost from the pumps and heat exchangers have increased from 9.9% to 15.4% and 12.6 to 26.3% respectively. However, as shown in *Table 1*, the total CAPEX is calculated 1.9 M€ lower for the non-metallic MOC compared to the metallic MOC. The total cost of CO_2 capture is shown in *Figure 5*, which translates the CAPEX advantage of non-metallic materials into the total cost of CO_2 capture, as the fixed OPEX is mostly a function of CAPEX, and the variable OPEX is assumed constant.

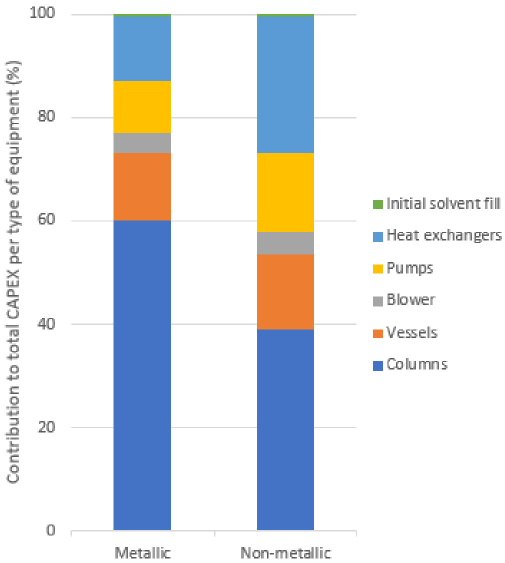

Figure 4, contribution to total CAPEX per type of equipment for metallic and non-metallic MOC.

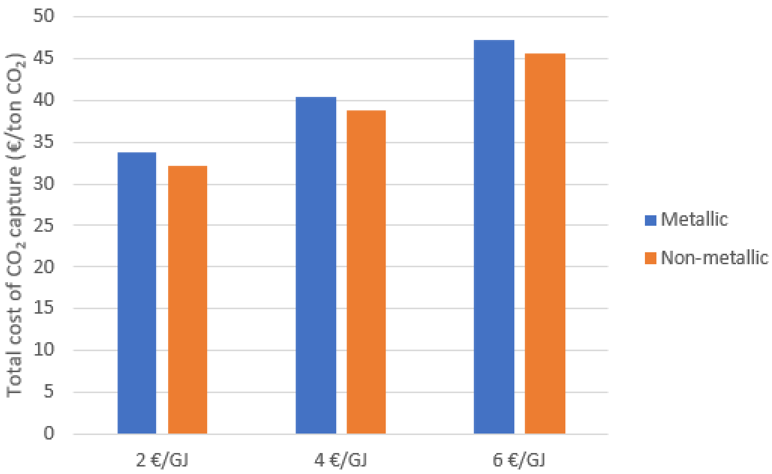

Figure 5, total cost of CO_2 capture, comparing metallic MOC with non-metallic MOC.

From this analysis, it seems possible be that non-metallic MOC can have a cost advantage over metallic MOC. However, a detailed economic study and long-term solvent tests in a relevant scale pilot are needed to check whether the assumptions used in this case study are valid, to assess whether non-metallic materials of construction can have an actual advantage over metallic MOC.

Another difference between metallic and non-metallic MOC could be the solvent lifetime. A sensitivity on the cost of solvent in CO_2 capture systems is performed below, to further assess the economic potential of non-metallic MOC.

Solvent consumption sensitivity analysis

A remaining open question that could not be solved with the experimental campaign in the non-metallic rig is the decrease in degradation that a non-metallic plant could bring compared to the metallic variant. Therefore, a sensitivity study is performed on the solvent consumption in a metallic plant versus a non-metallic plant. As a base case, the solvent consumption in the RWE pilot campaign using MEA is taken, in the linear degradation regime [2]. The total solvent loss rates are divided between continuous losses at 350 g/ton CO_2 based on the long-term testing at the RWE campaign and solvent replacement. For solvent replacement, 200 days is assumed for the base case, which is based on the long-term testing results at RWE in the linear degradation regime. This means that for the full-scale case study considered in this work, the amount of solvent that is lost (creating degradation products) before accelerated degradation takes place can be calculated, using these values. This is 41.3 ton MEA using a total solvent inventory of 114 ton (with 34 tons of MEA), resulting in a full replacement of the solvent after using 1.21 times the total MEA inventory in the plant. This example is shown in the first column of Table 2. For the sensitivity analysis, this ratio is kept constant when considering other solvent loss rates than 350 g/ton CO_2, arguing that the exponential behaviour would still occur after the same amount of solvent is lost. A hypothetical case for using metallic MOC's with a degradation rate of 700 g/ton CO_2 is shown in the second column of Table 2. It has to be noted that solvent management strategies like a thermal reclaimer should be considered over full solvent replacement, but as a worst case scenario, full solvent replacement is assumed for this study.

Table 2, explanation of solvent sensitivity analysis.

Parameter	Unit	RWE results	Hypothetical case – metallic MOC's	Hypothetical case – non-metallic MOC's
Continuous MEA consumption rate	kg/ton CO_2	0.35	0.7	0.7
MEA consumption rate before exchanging solvent	kg MEA consumed / kg MEA in original inventory	1.21	1.21	2.41
Solvent replacement time	Days	200	100	200

Figure 6 shows the corresponding time to full solvent replacement as a function of the MEA consumption rate. *Figure 7* shows the associated costs towards continuous replacement and full inventory replacement as a function of the MEA consumption rate. Both the continuous make-up rate, and the solvent replacement costs are in the same ballpark for all solvent consumption rates considered. Where the total solvent replacement costs in the 100 g/ton CO_2 case are around 0.4 €/ton CO_2, for the 1500 g/ton CO_2 case this increases to 5.8 €/ton CO_2, a significant cost in a full CO_2 capture system.

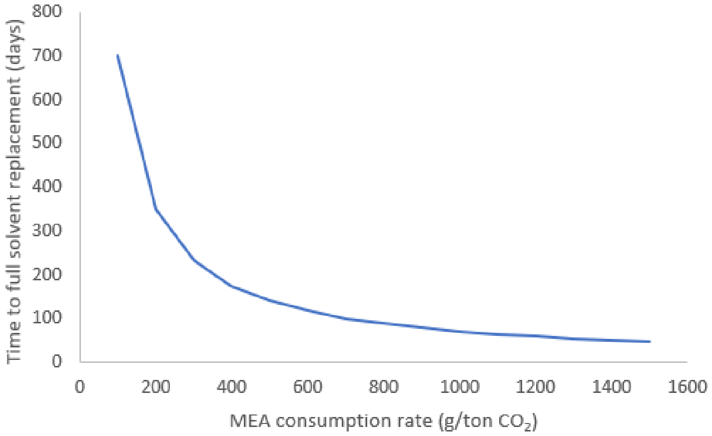

Figure 6, time to full solvent replacement as a function of the MEA consumption rate.

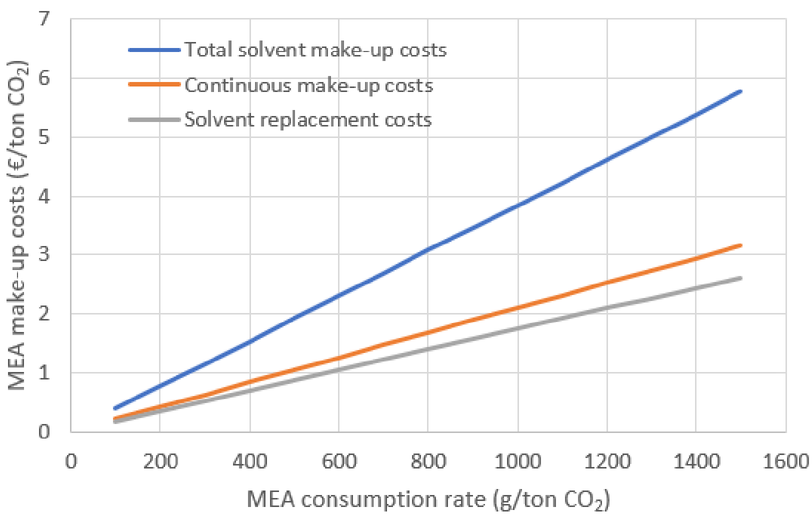

Figure 7, MEA make-up costs as a function of the MEA consumption rate in the process.

To compare the results in metal to non-metallic MOC, an assumption has been made that non-metallic MOC's could extend the solvent lifetime by a factor two. This would mean that the solvent has to be replaced after 82582 kg of MEA has reacted away, or 2.41 times the original MEA inventory. The argumentation around this can be that since no metals can be taken up by the solvent from the plant, the solvent can endure more degradation before causing large (exponential) degradation problems. The continuous degradation rate remains the same as for the metallic MOC's case study. This hypothetical case is further shown in the third column of Table 2, using a continuous degradation rate of 700 g/ton CO_2. *Figure 8* shows the comparison between the metallic and non-metallic MOC using the data described above. From this, it becomes clear that the solvent make-up costs can be decreased by 0.1-1.3 €/ton CO_2 , based on the 100-1500 g/ton CO_2 solvent consumption rates that are assumed in this study, assuming that non-metallic equipment can extend the lifetime of the solvent by a factor 2.

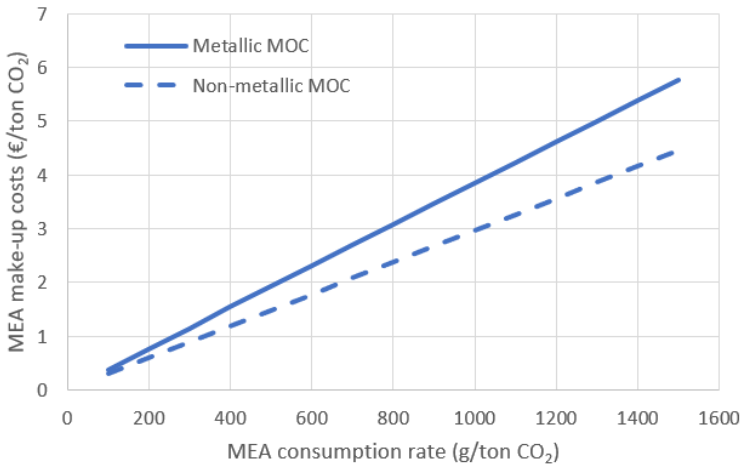

Figure 8, comparison between solvent make-up costs between metallic and non-metallic MOC, as a function of the MEA consumption rate.

5 Conclusion

Non-metallic materials of construction have been evaluated for a full-scale WtE system (200 kton waste/year) and compared towards metallic MOC, using MEA as a solvent. Many assumptions had to be made to perform a TEA for the non-metallic MOC case study, as there is relatively little information available for non-metallic MOC's (regarding both applicability and costs). With all these assumptions in place, non-metallic materials of construction could give slightly lower CAPEX (-8%) and consequent total cost of CO_2 capture compared to metallic counterparts. On the contrary, for the non-metallic rig built in the LAUNCH project, non-metallic MOC gave significantly higher CAPEX (+50 to +100%) than their metal counterparts. However, it needs to be noted that the non-metallic rig is a small lab set-up, and cost correlations cannot be directly extrapolated to large scale systems, as production methods are completely different. Even with this study in place, knowledge gaps remain on the exact CAPEX comparison between metallic and non-metallic MOC's. Additionally, long term testing of a non-metallic pilot system under relevant conditions, and detailed techno-economic analyses of full scale systems are needed to verify these assumptions, to further assess the feasibility of non-metallic materials of construction.

Additionally, the potential reduction in solvent make-up costs for non-metallic MOC has been evaluated, assuming that the solvent lifetime is increased by 100% compared to metallic MOC's, but the continuous make-up rate remains similar to metallic MOC's, as linear degradation of the solvent is expected to remain the same between metallic and non-metallic MOC's. It is concluded that cost reductions can be obtained, ranging from 0.1-1.3 €/ton CO_2, based on a solvent consumption rate of 100-1500 g/ton CO_2 respectively. While this might help for MEA based systems, it is unclear how non-metallic MOC's could help decreasing the solvent make-up costs for systems that don't exhibit exponential degradation like CESAR1, as tested in RWE.

While the economic benefits of changing to non-metallic MOC's seem minor, further research is needed in the form of LCA's to assess the full chain influence of changing towards non-metallic MOC's to further assess the potential of these materials.

6 References

[1] S. Garcia *et al.*, “ALIGN D1.4.3: Guidelines and Cost-drivers of capture plants operating with advanced solvents,” 2021.

[2] P. Moser *et al.*, “Results of the 18-month test with MEA at the post-combustion capture pilot plant at Niederaussem – new impetus to solvent management, emissions and dynamic behaviour,” *Int. J. Greenh. Gas Control*, vol. 95, p. 102945, Apr. 2020, doi: 10.1016/j.ijggc.2019.102945.