Brightsite

Transforming industry

Research on CCU capabilities at Chemelot

Carbon Capture and Utilisation (CCU)—the use of captured carbon dioxide (CO_2) as a raw material for new production processes—is one possible way of making chemistry more sustainable. To meet the climate objectives for 2030 and 2050, Brightsite's program line 3 'Process innovation' aims to reduce greenhouse gas emissions by capturing and storing or using CO_2. TNO researcher Juliana Monteiro has led a study on the potential of CCU for Chemelot within Brightsite.

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Exploring all options

"Program line 3 'Process innovation', is focusing on options to reduce CO_2 emissions at Chemelot. We are looking at options to reduce emissions from the current processes and which new technologies can help with this", explains Lianne van Oord, Program Manager at Brightsite. One of the options under investigation is whether CCU is a way of reducing scope 1 CO_2 emissions in addition to, for example, storing CO_2 (CCS – Carbon Capture and Storage). "Whereas CCS is about storing CO_2, CCU focuses on reusing captured CO_2 for new products. Because why store CO_2 when you can use it? We know that recycling plastic to replace fossil fuels, will not be enough to replace natural gas and naphtha. Therefore we need to look for more options, so we asked Chemical Engineer Juliana Monteiro to find out what the possibilities and challenges for CCU are at Chemelot", says Van Oord. The first exploratory steps quickly demonstrated that CCU is not a solution for scope 1 reduction, because only applications that store CO_2 for at least 100 years count. In addition, a route is only considered green if the CO_2 that is stored does not come from fossil fuel sources.

Closing the carbon cycle

"In light of the efforts to achieve a climate-neutral chemical sector, a transition away from fossil feedstock is required. We need to find the feedstock that we currently extract from fossil fuels elsewhere. CO_2 is an interesting source alongside other options we have, such as (plastic) waste and biomass. In the best, most circular scenario, recycling is expected to meet 65% of the carbon requirements of the chemical industry in Europe. CO_2 can be used to close the carbon cycle. In this research "CO_2 utilisation opportunities at Chemelot", we focused purely and only on CO_2 as an alternative carbon source. We need carbon so it has to come from somewhere. Biogenic sources will be limited and extracting CO_2 from the air is expensive. CCU may not be the obvious answer to climate change, but it can be a reliable carbon source in a highly "defossilised" future. However, converting CO_2 into usable components is not that easy. Reusing CO_2 requires a lot of chemistry and energy", says Monteiro.

Lianne van Oord, *Program Manager Brightsite:*

"At Brightsite, we weigh up what, where and when appropriate action can be taken to tackle the challenge of climate change."

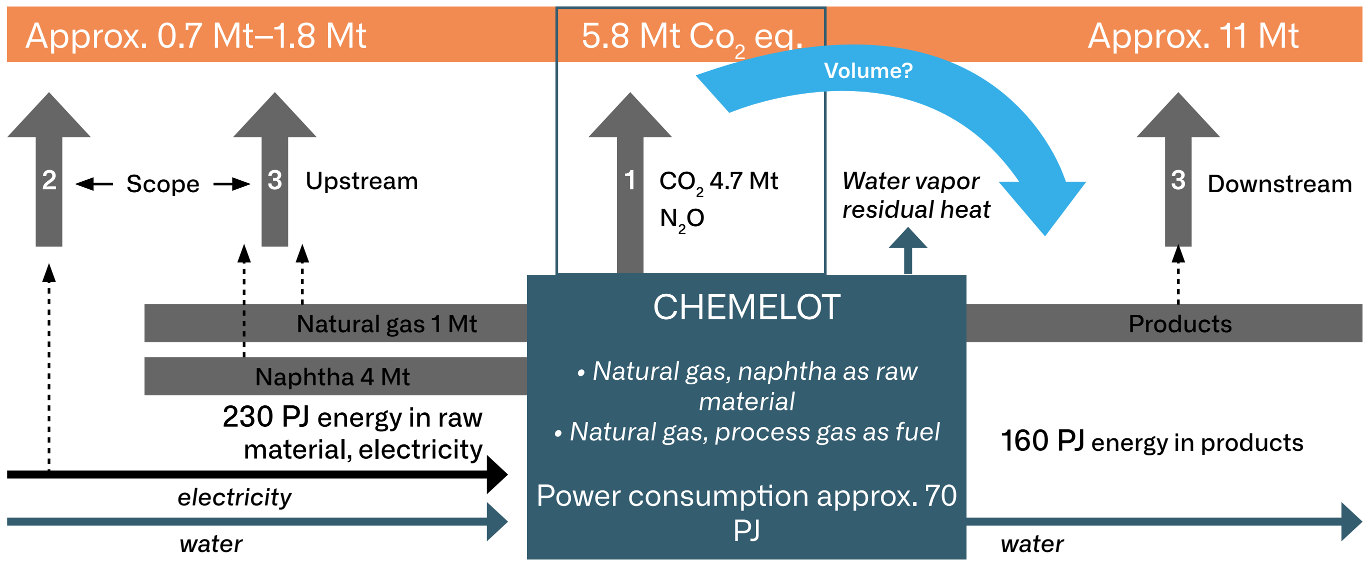

Figure 1: Raw materials and energy streams and Scope 1, 2, 3 emissions at Chemelot in 2019.

CO_2 conversion is energy intensive

"Chemelot is currently producing 4.3 Mt of CO_2, which is expected to be reduced to 2.9 Mt in 2030. Not every process will be suitable for CCU. If the steam methane reformers (SMRs) continue to operate, 300 kt of pure CO_2 will be available in 2030. Furthermore, a lot of CO_2 is found in flue gases (6–12 volume%), expected to equate to 2.65 Mt in 2030. With current state-of-the-art technology, 95% (2.5 Mt) of this CO_2 can be captured. However, this involves a considerable cost, unlike the pure CO_2 obtained from the SMRs. In total, this would mean 0.76 Mt of carbon could be recovered from this captured CO_2 in 2030. This would enable CCU to supply approx. 20% of the carbon Chemelot requires, so it could be an important source", says Monteiro.

However, a lot of energy is needed to reuse CO_2. "CO_2 is a low-energy molecule, so the CCU route by which CO_2 is converted to high-energy molecules requires a lot of energy. To go from CO_2 to the components required for the chemical industry—such as CH_4, CO, CH_3OH and HCOOH—always requires energy (Figure 2). To convert the 0.76 Mt of carbon in CO_2 available in 2030 would require up to 60 PJ/year of CO_2-free, renewable energy. For comparison, across the whole of the Netherlands, the wind and solar energy consumed in 2020 was 80 PJ. In addition, the electrification of processes at Chemelot is expected to require between 20 and 60 PJ by that time", explains Monteiro.

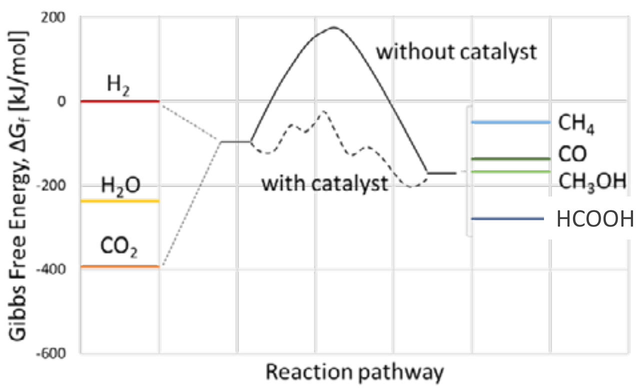

Figure 2: Gibbs free energies of formation for CO_2, H_2, water and potential CCU products as produced through C1 hydrogenation chemistry.

Which routes and products are of interest

In this CCU study, Monteiro also looked at which routes and products CCU would be more promising for at Chemelot. Adipic acid (short-term, 2030), synthesis gas (medium-term, 2040) and ethylene (long-term, after 2050) are the most interesting. "Adipic acid is a product that could be used immediately in Chemelot's infrastructure — 12.5 kt is currently used annually to produce nylon, among other things. This could be a first step. We are not talking about huge quantities; it would consume 7.5 kt of CO_2 per year (2.5% of the SMR CO_2)", says Monteiro. "Of course, we would have to ensure that the process is also green. Currently the CO_2 from the SMR is still from fossil fuels", adds Van Oord. "Besides CO_2, butadiene is also needed to produce adipic acid, and that also has to be green, of course. With an electrochemical yield above 60–70% there would be a business case for making adipic acid out of green CO_2 and butadiene. This electrochemical process is in its early stage of development, more research is needed", says Monteiro. Synthesis gas—a mixture of H_2 and CO—also known as syngas, has the advantage that we already know how to make and process it. The disadvantage is that it requires more energy: converting the 300 kt of SMR CO_2 to syngas would require (green) hydrogen, meaning at least 6 PJ of green electricity. "Making syngas may be relevant in the future, but for this the price of hydrogen (H_2) would have to come down. Ethylene, as I have said, may play a role in the long term. It is difficult to make a business case for it, although it is an option for the future and an important raw material for Chemelot. Again, the problem here is the energy cost and some knowledge gaps. We will have to solve those first", Monteiro explains.

CCU not a feasible solution right now

It is clear that Chemelot will need multiple carbon sources to eliminate fossil fuels. "CCU may eventually play a role at Chemelot, but it is unlikely to be the most important route for recarbonisation because it is so energy-intensive. This study has shown that applying CCU to Chemelot's CO_2 emissions could provide a maximum of ca. 20% of the carbon required in 2030. It is important to recognise that CCU does not directly lead to lower emissions. The availability of sufficient, relatively cheap renewable energy will be essential. Making an impact on the climate requires green CO_2 and technological progress", says Monteiro.

"At Brightsite we try to assess the challenges that Chemelot and the chemical industry face and weigh up what, where and when appropriate action can be taken. We are therefore investigating all routes to reduce CO_2 emissions. CCU is one of these, as has been said. This study has shown that CCU of Chemelot's current CO_2 is not a preferred method of reducing scope 1 CO_2 emissions and in general is not an easy source to use to replace carbon from fossil fuels. It is not at the top of our list, given the amount of renewable energy required.

We will not incorporate CCU of CO_2 directly into projects or pilots, but we will continue to monitor how the technology develops. Should a catalyst be developed to make the process more efficient, this situation could change", says Van Oord. Monteiro is very much in agreement with Van Oord's conclusion. "I agree with this conclusion. Electrify first and CCU may be an option after that. It also helps that Chemelot is an integrated site. Assets, products and energy supplies can be shared, which reduces costs and increases the options."

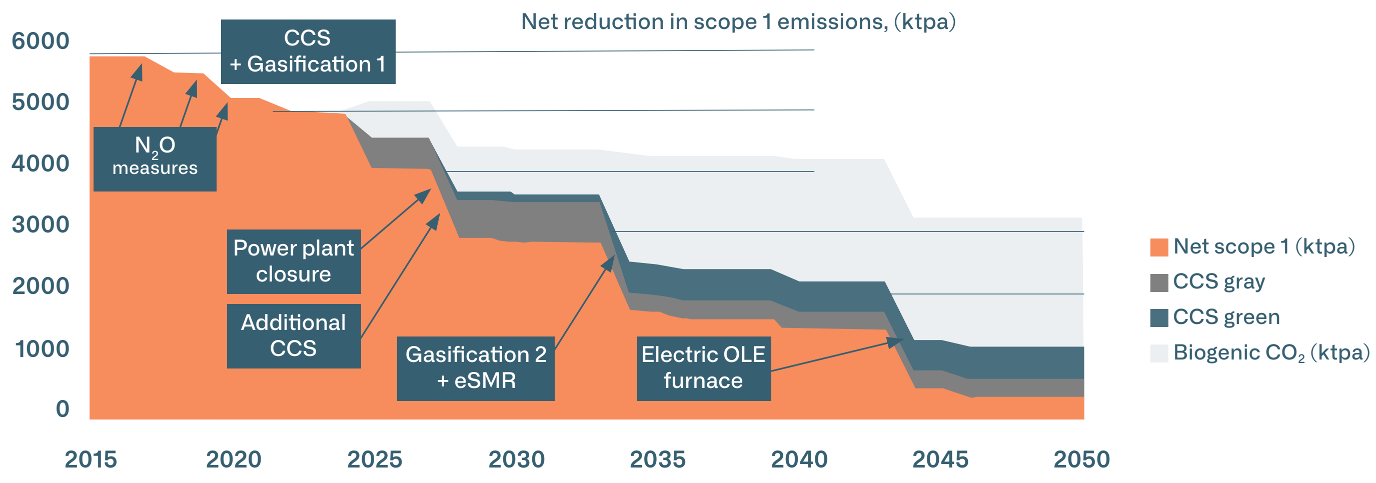

Figure 3: The Brightsite Chemelot Integrated Model System (CIMS) model shows a combination of possible interventions and the resulting cost-optimal transition path.

Juliana Monteiro, *Chemical Engineer TNO:*

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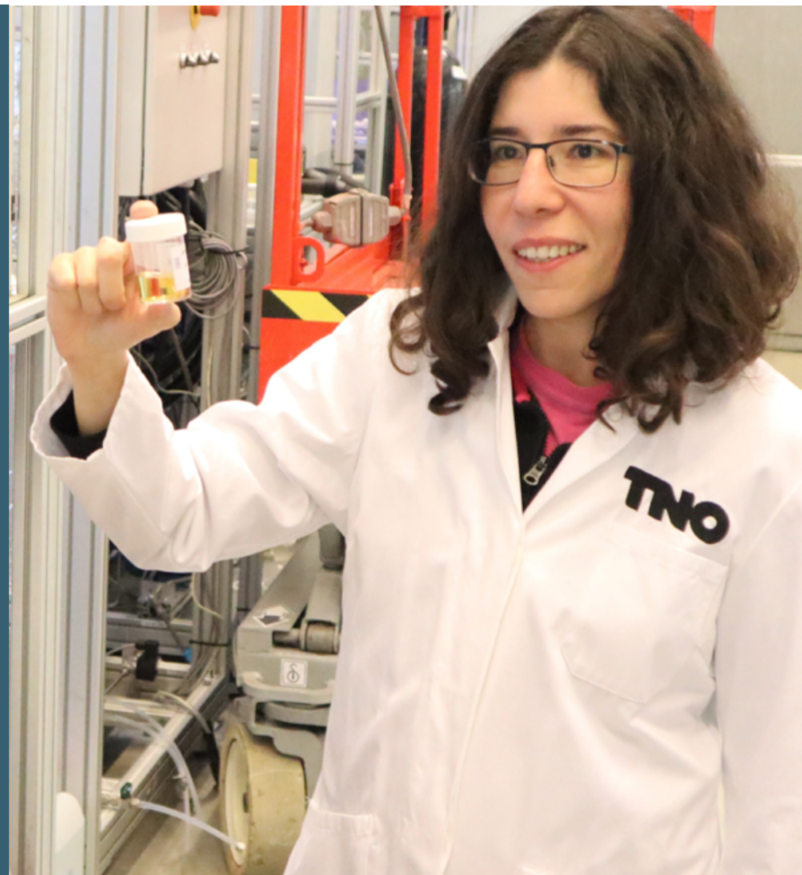

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