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Editorial: Pathways Towards Negative Emissions in Industry

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Editorial on the Research Topic

Pathways Towards Negative Emissions in Industry

As the carbon budget is rapidly diminishing, realistic roadmaps to meet global mitigation targets necessarily rely more and more on negative emissions (IPCC, 2018). Industry presents significant challenges to reduce emissions down to zero and beyond, while remaining competitive (Leeson et al., 2017). Energy efficiency and electrification can only deliver partial decarbonization of industrial production but fail to address issues such as the supply of high temperature heat and the presence of inherent process emissions. Additional options like fuel and feedstock switching and CO_2 capture might be considered to reach negative emissions. The specificity of the various industrial processes necessitates the development of a portfolio of technological solutions. Finally, a whole value chain perspective for capture, transport, and storage is necessary to estimate negative emissions in industry.

Krishnamurthy et al. (2021) evaluate the performance of 3D printed sorbent containing polyethyleneimine (PEI) and multiwalled carbon nanotubes to capture CO_2 from flue gas in a power plant that uses biomass as fuel. Breakthrough experiments reveal that 3.6 mol of CO_2 per m^3 of sorbent can be captured at 70°C, whereas the adsorption capacity was observed higher at 80 and 90°C. Experimental results are used to model and optimize a six-step vacuum swing adsorption (VSA) process with minimum energy requirement to capture 90% CO_2 with 95% purity. In the feed, 15% CO_2 is more suited in the six-step VSA process, resulting in 0.6 MJ of electricity demand per kg CO_2 captured and 2.2 mol/m^3-adsorbent.

Carbon dioxide capture with further storage can be applied to several existing industrial processes and thereby contribute to negative emissions. The study by Svensson et al. (2021) analyses a novel calcination process, applied to the pulp and paper industry, that uses electric gas-plasma technology combined with steam slaking in two kraft mills. The aim of this study is to evaluate its potential combination with CCS from the calcination plant. The potential reduction of greenhouse gas emissions depends strongly on the emissions intensity and fuel type used. As the results show, avoided CO_2 emissions can be significant, reaching 50 kt/a for a mill of 400 kt pulp per year and almost 100 kt/a for the mill of 700 kt pulp, respectively. By electrifying the calcination process further emission reductions are possible through CCS. Capture potential is than equal to 95 kt/a (for a 400 kt mill) and 164 kt/a (for a 700 kt mill), and CCS costs reach 36–60 EUR/tCO_2.

Enhanced weathering is a carbon dioxide removal (CDR) measure that consists of accelerating the natural chemical weathering processes of rocks, which sequesters atmospheric CO_2 through alkalinity production. A feasible feedstock for enhanced weathering consists of the large quantities of mine tailings produced by the global mining industry. The study by Bullock et al. (2021) assesses the global CDR potential of this concept. A global database of mined metal and diamond commodity tailings was established. From the database a theoretical CDR capacity in the range between 1.1 and 4.5 Gt CO_2 per year was estimated. However, dissolution

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rate considerations suggest that only a fraction (up to a maximum of 21%) of such potential may be realised on a relevant timescale. Yet, those figures demonstrate that enhanced weathering might substantially contribute to delivering negative emissions in an industry that annually emits about 3.6 Gt of CO_2.

Tiefenthaler et al. (2021) present a proof of technology for the industrial scale negative emissions value chain in the concrete sector specific to Switzerland, with focus on sequestration of CO_2 in the form of calcium carbonate in the recycled concrete aggregate (RCA). The CO_2 for carbonation is assumed to be derived from upgrading of biogas produced from anaerobic digestion of bio waste. Lab-scale experiments revealed that 7.2 g CO_2 can be stored per kg RCA. The authors also performed life cycle assessment (LCA) and prove that the proposed negative emissions value chain is capable of storing 93.6% of the CO_2 used for carbonation and that the RCA produced has the lowest global warming potential compared to virgin and recycled cement. The authors extrapolate the results to show that it is possible to achieve 0.56 Mt of CO_2-eq. per year of negative emissions in Switzerland in 2050, when compared to the global potential of 500 Mt of CO_2-eq. per year.

Installing CCS on waste-to-energy can result in negative emissions due to the relatively large biogenic content of municipal solid waste. Integrating CCS in a waste-to-energy plant results in high investment and operation costs for the CO_2 capture process, and currently there is a lack of incentives for negative carbon dioxide emissions. Torvanger (2021) explores possible business models for incentivizing the implementation of CCS from waste-to-energy. The business models are based on two main options: waste renovation customers being able and willing to pay for the additional cost of producing negative emissions of carbon dioxide directly, and through certificates or investments in CCS being supported by government through tax rebates for negative emissions of CO_2 or a guaranteed price.

Overall, CCS demonstrated to be an effective technological solution to provide negative emissions, especially in industries with feedstocks and fuels with a significant biogenic content. Leveraging on waste streams from industrial activities to provide CDR could allow for additional pathways. Implementing technological solutions for negative emissions comes at a high cost and might interfere with industry main products competing in global markets. Currently, financial incentives for CDR are lacking and there is a need to develop sustainable business models and new value chains to enable early movers. A clear and shared framework for carbon accounting and for guaranteeing the sustainability of bioresources is also fundamental. Material development with innovative manufacturing techniques, innovative process integration, and synergies with electrification all represent potential drivers toward cost-efficient negative emissions from industry. R&D should be accompanied with industrial demonstrations to accelerate the deployment of the proposed technological solutions.

AUTHOR CONTRIBUTIONS

All authors wrote paragraphs for each article in the Research Topic that they edited. RM and LR wrote the introduction and conclusion section. All authors worked together to edit and improve the final text of the whole article.

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