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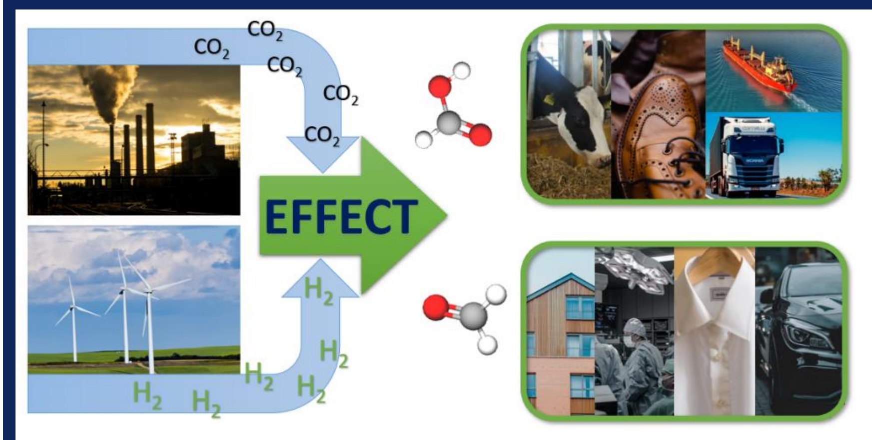

Partners

TNO FLUOR

ChemCom industries ECOVER

Institute for
Sustainable
Process Technology

1 Final report (Public summary)

1.1 Motivation

The EFFECT project is aimed at developing the CHARLIE technology where carbon capture and utilization are integrated in a single process to produce formic acid and formaldehyde. Using a process intensification methodology, the CO_2 is converted directly in the carbon capture liquid to value added products. Consequently, this integration reduces the necessary equipment & operations and improves the overall efficiency. The primary goal of EFFECT is to advance and optimize the CHARLIE technology. CHARLIE consists of 4 main operations: 1) Absorption of CO_2, 2) Hydrogenation in the capture liquid, 3) Separation of Formic Acid product and 4) Potential conversion to formaldehyde. The products formic acid and formaldehyde are purified in downstream separation units.

EFFECT offers the unique opportunity to develop and optimize this next-generation CCU technology. A strong consortium of technology developers (TNO), end-consumers (Ecover & ChemCom) and future technology implementers (Fluor) enables the technology development.

A conceptual design for a commercial-scale process has been done in this project, accompanied by a techno-economic evaluation to offer a perspective on the project's potential and future development requirements.

1.2 Approach

Initially, CO_2 is captured from the flue gas of a biomass power station using potassium hydroxide. The bicarbonate-rich solution is sent to Hydrogenation Reactor 1, where it reacts with H_2 gas to produce formate ions and water, see Figure 1. The effluent stream is then processed in an electrodialysis unit to separate potassium hydroxide and formic acid. Potassium hydroxide is recycled back to the absorber. The formic acid-rich stream is directed to Hydrogenation Reactor 2, where formic acid reacts to produce formaldehyde. In this step CO and CO_2, with varying conversion rates are produced as by-products. The effluent from this reactor is purified in two stages to achieve the desired formaldehyde purity. Finally, a small stream of formic acid is upgraded to higher purity using a distillation column. This integrated process highlights the potential for significant CO_2 reduction and production of formic acid and formaldehyde. Environmentally, the CHARLIE process significantly reduces CO_2 emissions by removing 2.3 kg CO_2 per kg formaldehyde, compared to the conventional process that emits 1.5 kg CO_2 per kg formaldehyde.

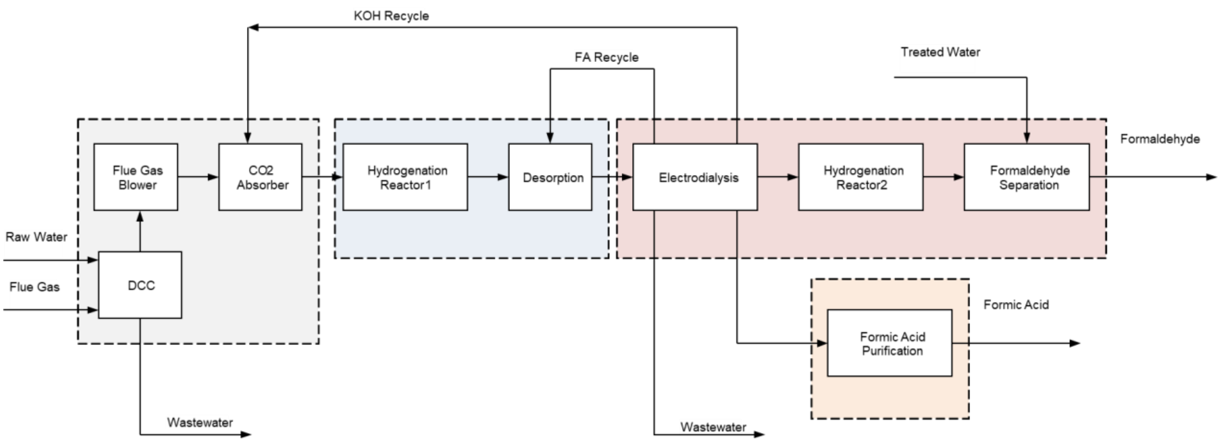

Figure 1: Process flow diagram of the CHARLIE concept.

1.3 Principle

Conventional formaldehyde and formic acid are produced from fossil fuel-derived methanol and CO, produced in a high temperature reaction powered by natural gas consumption. Most of the CO_2 emissions occur in the production of grey methanol, but the CHARLIE process has a more significant impact than just replacing the methanol (see Figure 2). Starting from one mole of CO_2, one mole of hydrogen is used to produce formic acid and two moles are used to produce formaldehyde. Synthetic methanol production requires three moles, hence producing methanol and oxidizing that back to the desired products would be a waste of valuable hydrogen and energy. CHARLIE technology delivers the desired products with a minimal consumption of green hydrogen.

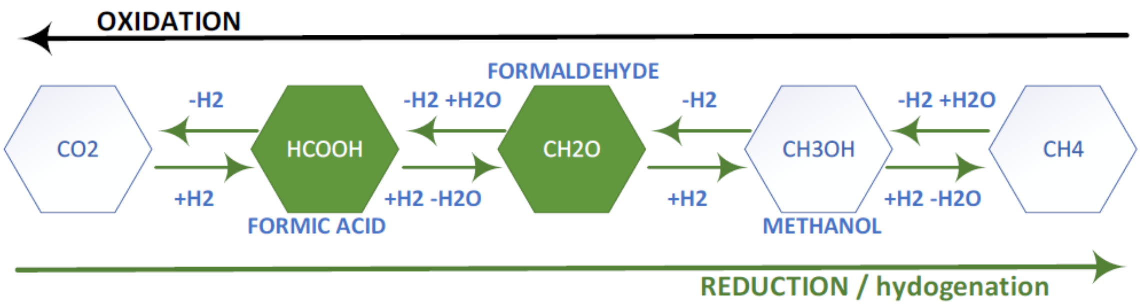

Figure 2: Reduction products of CO_2.

By replacing the conventional processes with an alternative process using captured CO_2 and sustainable hydrogen, significant CO_2 emissions reduction can be achieved. The Dutch formaldehyde production is roughly 300 ktpa. If replaced by the process developed in this project, up to 720 ktpa CO_2 emissions can be reduced in the Netherlands alone, of which roughly 280 ktpa are emitted during methanol and formaldehyde synthesis, and 440 ktpa is prevented by the necessity to capture (green) CO_2 as a feedstock for the process. This carbon is potentially sequestered for a long time (e.g. when used in construction materials), though in other products it might be eventually emitted again.

1.4 Objectives and achievements

The most innovative aspect of the CHARLIE concept is the integration of CO_2 capture with direct utilization in the capture liquid, saving a significant amount of energy in the CO_2 separation steps. Also, the liquid phase synthesis of formaldehyde from formic acid solution is very novel. Moreover, the CHARLIE technology presents a new production pathway for formic acid and formaldehyde.

Hydrogenation of aqueous $KHCO_3$, from CO_2 capture facility, to $KHCO_2$ is experimentally carried out in this project with high conversion rates > 97%. These results give the confidence about the technical feasibility of the thermocatalytic hydrogenation of bicarbonate to formate.

Moreover, we have broadened the knowledge for new carbon-neutral pathways towards formic acid and formaldehyde that will consolidating a strong knowledge position in the upcoming circular fuels and chemicals economy. The scientific results will be published in peer-reviewed journals.

1.5 Future directions

Process improvements are needed in the following areas to reduce CAPEX and OPEX to make the process more feasible:

- Reactor efficiency must be increased, which will impact capital expenditures (CAPEX).
- The efficiency of the electrodialysis unit must be improved, specifically by reducing the kWh/kg-product, which will affect both CAPEX and operational expenditure (OPEX).
- Energy integration should be implemented to reduce overall power consumption.

1.6 Conclusions

All the experimental steps of the CHARLIE concept have been successfully carried out and the results are encouraging to continue with this line of research when the conditions in the energy market are more stable and renewable energy well established and economically beneficial.

The production costs of formic acid and formaldehyde via the CHARLIE concept are higher than via the conventional fossil-based routes. The TRL of the alternative routes, catalytic hydrogenation of CO_2 to formate, are still far too low (TRL 1–2) and the economic feasibility of these technologies have not been demonstrated.

Presently formic acid (in the form of formates) is synthesized in industry from methanol and carbon monoxide using strong bases.

The introduction CO_2 emissions cost could increase the cost of natural gas-based methanol, thus significantly improving the cost competitiveness of the CHARLIE concept.

2 Acknowledgement

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