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ALIGN-CCUS: Production of dimethyl ether from CO_2 and its use as an energy carrier - Results from the CCU demonstration plant

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Abstract

After two years of development and engineering as part of the European ALIGN-CCUS project the CCU demonstration plant was commissioned at the Innovation Center at Niederaussem. It comprises the realization of a complete Power-to-Fuel CCU process chain towards dimethyl ether (DME) and the reconversion of the synthetic diesel substitute DME into electricity. Liquefied DME (at ambient temperature, 5 bar(a)) has a high energy density (lower calorific value of liquid DME approx. 18.4 MJ / l at 20 ° C) and can be fueled like Liquefied Petroleum Gas (LPG), which makes it attractive for long-term storage of renewable electricity and as fuel for long distance transportation (trucks, ships and locomotives) that cannot be electrified. Due to its chemical constitution, i.e. it has no C-C bonding, it combusts without soot formation and enables the reduction of NO_x emissions from diesel engines. Additionally, DME can be used as feedstock for the synthesis of gasoline and kerosene or valuable chemical compounds.

The starting point for the DME synthesis is CO_2 that is captured from the flue gas of the adjacent 1000 MW lignite-fired block K of the power plant at Niederaussem. Since 2009, the amine-based post-combustion capture pilot plant is in operation and has achieved meanwhile more than 80,000 operating hours. The captured CO_2 is compressed, liquefied and stored in a pressure tank (pressure 16.5 bar(a) - 17.5 bar(a), temperature: -26.5 °C, tank capacity 18 t). The depressurized, heated and gaseous CO_2 is sent to the DME synthesis unit at a pressure of approx. 11 bar (a). Up to 180 kilograms CO_2 per day are converted in combination with hydrogen, which is obtained by alkaline electrolysis from water (up to 22 kilograms H_2 per day, 140 kW_{el} power demand) into DME. The necessary electricity is ideally supplied from renewable energy sources, but for now for practical reasons still from the lignite power plant. The synthesis plant produces up to 50 kilograms DME daily and is based on a one-step monolithic reactor coated with a bifunctional catalyst. This allows simultaneous efficient synthesis of methanol as well as the

dehydration of methanol to DME. DME is used at Niederaussem for the reconversion into peak-electricity in an adapted diesel power generator with an output of 240 kW_{el}. The engine is fueled by three 500 liters tanks and consumes between 60 - 80 liters DME per hour. In this manner the efficient energy storage and usage of DME is shown by a fully developed supply chain.
The technical and economical analysis of the CCU process results in an energetic Power-to-DME efficiency of 60%. Main consumer of energy in the process is the electrolyser for the supply of hydrogen. A sensitivity analysis of the DME production cost takes the costs of electricity, hydrogen, CO_2 and cooling water into consideration. Using average costs factors results in DME product cost of 1.85 € per liter diesel equivalent. When comparing this with the cost of electric cars, which are heavily subsidised it becomes clear that the synthetic CCU fuel DME can be competitive. Taking into account the infrastructure for the fuel supply (DME: LPG filling stations, e-car: charging stations) and the effort at the end customer side (DME: adaption of existing car, e-car: construction of a new car) the advantages of the CCU fuel are manifested. To level the playing field for the evaluation of the CCU technology chain, a cradle–to-grave approach for Life Cycle Assessment (LCA) is applied. The LCA shows that the global warming potential of the CCU route can be viable in comparison with e-cars when using renewable electricity.
For large-scale application a variety of optimisation options of the demonstrated Power-to-DME-to-Power process exist, e.g. waste heat utilisation and improved process integration. In particular the efficiency increase by the use of waste heat from the peak-power engine as well as reaction heat from the DME synthesis reactor in the power plant process or for the regeneration of the CO_2 capture solvent could increase the overall efficiency and reduce the CO_2 footprint of the CCU fuel. Especially for retrofits of peak-power generators, the admixture of the engine exhaust gas to the flue gas upstream of the CO_2 capture plant and the use of the heat content of the exhaust gas in the water-steam cycle of a power plant or for combustion air preheating is a promising route. At CO_2 capture rates of 90% every carbon atom can theoretically be used ten times which reduces the CO_2 footprint of peak-power generation significantly. Due to the recycling of the CO_2 the CO_2 footprint of peak-power generation from CCU fuels can be significantly reduced

The paper presents the results of the test programme of the unique CCU demonstration plant.

The ALIGN-CCUS testing facility realises the full CCU-chain from CO_2 capture to synthesis of the synthetic fuel DME and the reconversion into electric power. In the front: peak-power generator module of RWE Power; right behind: two containers with the electrolyser from Asahi Kasei Europe; right in the back: three containers with the DME synthesis unit from MHPS Europe; left in the back: open housing for the storage of the crude DME.

Keywords: CCU, diemethyl ether, carbon recycling, Power-to-X, LCA