NECOC – Negative Emissions Through Separation of Atmospheric CO_2 into Economically Usable Carbon Black and Oxygen

Numerous studies show that the formulated climate protection target cannot be achieved solely by reducing emissions from existing plants, processes, and means of transport or by complete electrification. Rather, it is absolutely necessary to remove CO_2 from the atmosphere in a targeted manner and store it permanently in a way that is not harmful to the climate, i.e. to generate negative emissions. This requires novel technologies.

One such innovative technology is the process network developed in NECOC and funded by the Federal Ministry for Economic Affairs and Climate Action in the 7th Energy Research Program with approx. 1.5 million euros. A demonstration plant for the generation of negative emissions by the decomposition of atmospheric carbon dioxide (CO_2) into elemental carbon (carbon black, C) and oxygen (O_2) is being built on a pilot scale.

The overall process consists of a combination of four process steps (see Fig. 1). CO_2 is separated from the ambient air by means of an adsorber and then converted into methane (CH_4) and water (H_2O) with the aid of hydrogen (H_2) in a microstructured reactor. CH_4 is finally separated into H_2 and C in a hot bubble column reactor filled with liquid tin. The H_2O is split into O_2 and H_2 by electrolysis. All the hydrogen produced in the pyrolysis is recycled as feedstock for methanation. The solid carbon, which accumulates in the process as very fine powder, is separated and subsequently commercially exploited as a potentially high-priced reactant, for example in the rubber, construction, or electrical industries. A key aspect in the development of the overall process is the efficient material and energy coupling of the subprocess steps, which have been developed on a laboratory scale and are now largely established. A plant of this kind is currently unique worldwide.

The project is implemented by a consortium of the Karlsruhe Liquid Metal Laboratory (KALLA) at the Institute for Thermal Energy Technology and Safety (ITES) and the Institute of Thermal Process Engineering (TVT) of the Karlsruhe Institute of Technology (KIT) as well as the company Climeworks Deutschland GmbH and the company INERATEC GmbH.

CO_2 Adsorption/Direct Air Capture: Climeworks

Climeworks designs, builds, and operates Direct Air Capture (DAC) systems that remove CO_2 directly from ambient air. The plants use only renewable energy or waste heat as an energy source. The removal of CO_2 is based on a cyclic adsorption/desorption process with a structured adsorber material (Fig. 2). CO_2 is subsequently made available as a pure gas.

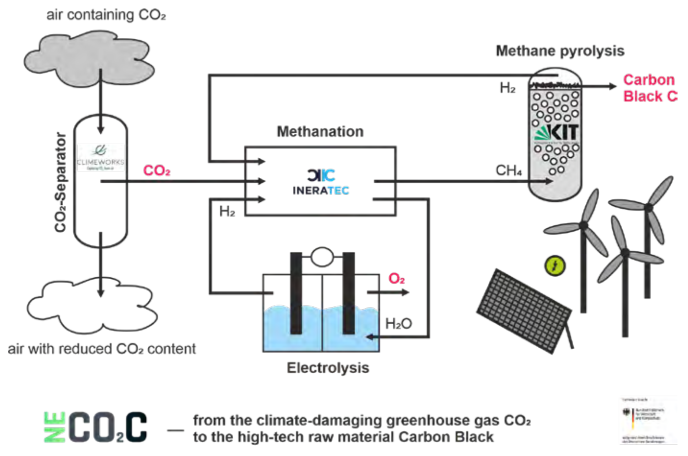

Fig. 1: Overview of NECOC.

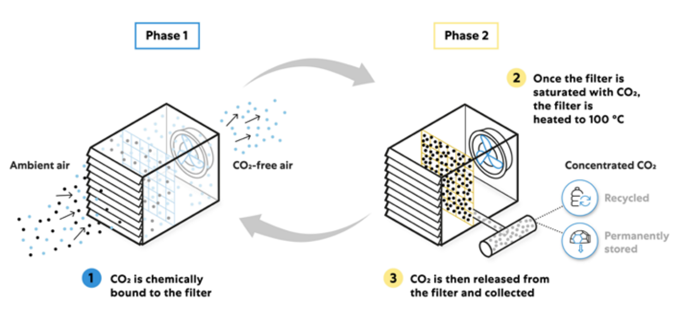

Fig. 2: Principle of the cyclic adsorption/desorption process of the Climeworks DAC technology (Graphics: Climeworks).

Methanation: INERATEC

INERATEC manufactures modular chemical plants that produce sustainable fuels and chemicals, such as methane, from CO_2 and renewable electricity. INERATEC's chemical methanation reactors are microstructured inside and equipped with an innovative evaporative cooling system (Fig. 3). This allows high CO_2 conversion rates to be achieved in compact reactors with good temperature control at the same time, resulting in longer catalyst service lives.

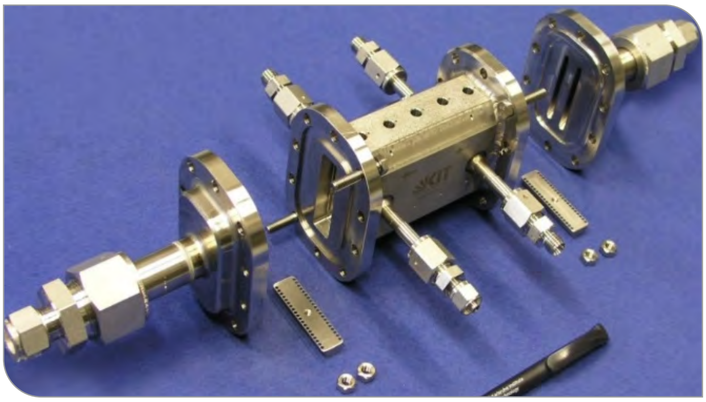

Fig. 3: INERATEC methanation reactor, manufactured in cooperation with KIT.

Liquid Metal-based Methane Pyrolysis: KALLA/TVT at KIT

At the Karlsruhe Liquid Metal Laboratory (KALLA) at KIT's Institute for Thermal Energy Technology and Safety (ITES), an innovative process for the production of H_2 and solid carbon by a liquid metal-based methane pyrolysis process is being researched. Using renewable energy, CH_4 is fed from below into an externally heated reactor filled with liquid tin. Bubbles form and rise in the liquid metal, where CH_4 is broken down into its components (Fig. 4).

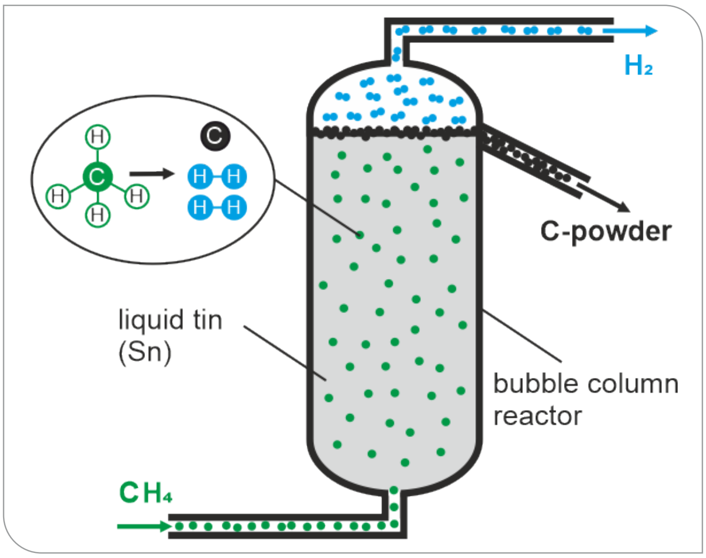

Fig. 4: Innovative KIT technology for the production of a high-tech raw material by means of thermal cracking of methane in a hot, liquid tin column.

The use of molten metal offers advantages for heat transfer in the process. In addition, the powdered carbon floats on the surface of the liquid metal due to its lower density and can be separated from the reactor using conventional separation techniques. This avoids the problems observed with other processes, such as reactor clogging or catalyst deactivation due to carbon deposits. In previous test, a maximum hydrogen yield of 78 percent was achieved.

Outlook: Solar Hydrogen (KALLA/KIT)

The energy for the pyrolysis process can be provided from renewable sources. Since heat is ultimately required, the process can be flexibly supplied directly with solar heat or via heating with electrical energy from photovoltaics or wind power. As part of the Innovation Pool project „Solar Hydrogen - Highly Pure and Compressed," the use of solar energy for the production of hydrogen by direct thermal pyrolysis of methane in the bubble column reactor filled with tin is being developed at KALLA.

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