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There Is Something in the Air - *Carbon Mining*: How Chemists at LIKAT Extract Carbon from the Air

For the first time ever, chemists have succeeded in enriching CO_2 from the air on a catalytic material under normal pressure conditions and moderate temperatures and inducing a reaction. The reaction partner of CO_2 is methanol, the simplest representative of the alcohols substance class. This produces dimethyl carbonate, an ester of carbonic acid, which could be used as a fuel and can replace toxic chemicals in industry. Researchers at the Leibniz Institute for Catalysis in Rostock succeeded in carrying out this reaction.

The work, led by Dr. Sebastian Wohlrab, paves the way for two major goals in chemistry: firstly, to "harvest" carbon dioxide directly from the air and thus reduce the proportion of climate gas in the atmosphere. On the other hand, according to Sebastian Wohlrab, the aim is to provide carbon for basic chemical processes. This is done by "carbon mining", as he says, "when we will no longer have sufficient fossil carbon carriers - crude oil, natural gas and coal - at our disposal.

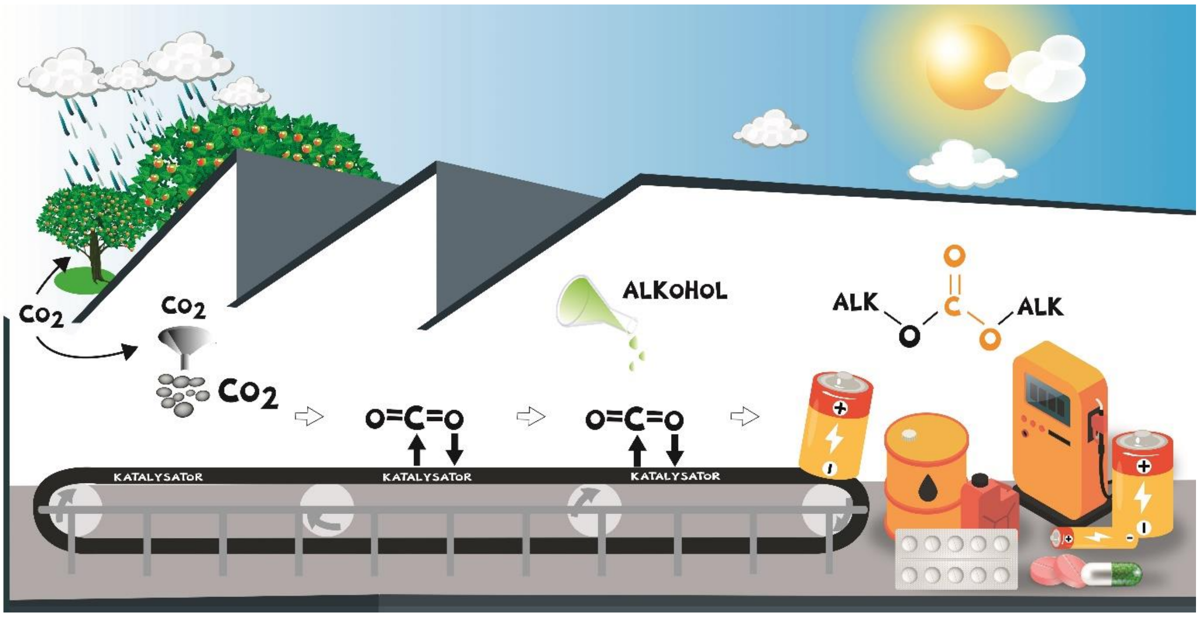

Fig. 1: „Harvesting" CO_2 from air: A suitable catalyst is used to enrich the carbon dioxide from the air and activate the inert gas. In this way, it can be directly converted with alcohols into new products. (picture: LIKAT)

Essential Element

The permanent supply of carbon is one of the most pressing issues worldwide. Like no other chemical element, carbon, C, is capable of forming rings and long chains with itself and thereby integrating other elements and molecular groups for an incredible number of functions. In this way, it forms millions of chemical compounds. This property makes carbon an essential element. Both for the biosphere - in the form of proteins, fats and carbohydrates - and for industrial production.

However, with a share of 0.027 percent in the earth's crust, carbon is one of the scarce resources. So far, the main suppliers to industry are oil, natural gas and coal. And the coal and petrochemical industries are becoming obsolete as awareness of ecological management grows. For this reason, chemists around the world are researching alternative processes based on renewable feedstocks such as wood or agricultural waste, which are capable of replacing large-scale petrochemical processes.

Vision and Illusion

"However, it is a big illusion to assume that the global economy will be able to cover its carbon needs from renewable resources alone," says Sebastian Wohlrab, citing representative statistics.[1] According to these statistics, global plant growth binds 56,400 million tons of elemental carbon per year. And only 14 percent of this, i.e. almost 7,900 million tons per year, is achieved by plant cultivation, which is the food basis for the world's population. This means that only this amount would be available for the sustainable extraction of raw materials - if we do not want to completely destroy the rainforest.

Almost the same amount of carbon, almost 7,000 million tonnes/year, is currently being processed into products by the petrochemical industry worldwide. "So if we want to replace oil and gas with green chemistry without depriving humanity of its food supply, the global economy must be capable of extreme measures," says Dr. Wohlrab: Either dramatically reduce carbon consumption, i.e. decreasing the production of goods. Or to double the amount of land available for plant cultivation, which would be ecologically devastating. "This highlights the urgent need to develop entirely different sources of carbon." One source is CO_2 in the atmosphere.

Tap into this carbon source and you're faced with a tricky task, as Sebastian Wohlrab further explains. "The CO_2 concentration in the air is very low, 400 ppm too little for a chemical reaction with effective results." Previous processes for converting carbon dioxide, such as urea synthesis, use highly concentrated CO_2 streams. And the esterification of CO_2 in the laboratory so far only works under high pressure.

With one exception: In 2017, a Chinese exchange student in Sebastian Wohlrab's research department succeeded in esterification at atmospheric pressure - with highly concentrated carbon dioxide. This experiment inspired the imagination of Dr. Wohlrab's team. "The idea was to see whether CO_2 could also be converted from normal room air at extremely low concentrations."

Saturation with Carbon Dioxide

The trick is to enrich the CO_2 on the catalyst material. This means passing air under normal atmospheric pressure over the material until it is saturated with CO_2. This works because the material, a mixed oxide in powder form, contains basic centres. Chemist Wohlrab: "CO_2 is an acidic gas. And as opposites attract, it accumulates at the basic centers." The CO_2-free exhaust

[1] a) C. B. Field et al., *Science* **281** (5374), 237-240. b) BP Statistical Review of World Energy, 2019, 68th edition. c) FAOSTAT data on land use, 2015.

air is discharged. If the catalyst material is saturated with CO_2, methanol is added, and everything reacts to form dimethyl carbonate. At 90 degrees Celsius, which is a moderate temperature for chemists.

The process of CO_2 enrichment and reaction with methanol still takes three and a half hours. "That is far too long for a technical process," says Dr. Wohlrab. "But the product yield is already pointing the way ahead." Three out of four of the adsorbed CO_2 molecules are successfully converted.

"The principle works. We have shown that we can extract carbon from the air and use a climate gas as a raw material." The researchers know the adjusting screws they now have to turn to optimize the reaction. And Dr. Wohlrab suspects that other reactions with atmospheric CO_2 will also be possible using this principle.