Understanding how a catalyst converts methane into ethene could prevent the flaring of natural gas

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Landfill burn off flare. Credit: Eddie Hagler/Public Domain

It would be a triple win—for the climate, raw material resources, and the chemical industry. With their work, scientists at the Fritz Haber Institute of the Max Planck Society in Berlin hope to create the basis for extracting useful chemical products such as plastics from the methane that is usually flared off during oil production. They are looking into how to design a catalyst that converts methane into ethene more efficiently than is currently possible. They have now found a ground-breaking clue.

Around 140 billion cubic meters of methane, which escapes during global oil production, are flared every year. This is considerably more than the estimated 90 billion cubic meters of natural gas that Germany consumed in 2019. This not only fuels climate change but also wastes a non-renewable fossil fuel. However, it would not be profitable to build pipelines or liquefaction plants for the relatively small quantities of methane extracted incidentally at individual oil production sites. It would, however, be worthwhile to transport the methane if it could be economically converted into substances that are of interest to the chemical industry. One such substance is ethene, the starting material for polyethylene and many other products. These are produced almost exclusively from crude oil. Unfortunately, the chemical reaction that converts methane directly into ethene proceeds at high temperatures. "This not only costs a lot of energy, but also results in a large proportion of the methane combusting to form the undesirable by-product CO_2," says Annette Trunschke, research group leader at the Fritz Haber Institute of the Max Planck Society. "So it doesn't quite make sense yet."

Sodium is the essential component

The chemist and her team want to change this. That's why they have set their sights on the decisive component of the process: the catalyst made of sodium, manganese, tungsten, and silicon. This facilitates the chemical conversion of methane into ethene—although so far only at 700°C. In order to develop catalysts that work at lower temperatures (i.e. with less energy input) and promote only the formation of the desired products, chemists first need to know what is important in a catalyst for this reaction. According to the research of Trunschke's group, this essential component is sodium.

"Until now, there have been several theories about which element in the catalyst is crucial for converting methane into ethene," says Trunschke. "It came as a bit of a surprise that sodium, of all things, was the important component because it should actually evaporate at the high temperatures of the reaction ". However, the research has revealed something else. At high temperatures, the alkali metal is converted into the catalytically active sodium oxide. The oxide is released only for a short time and in minute quantities because of close interaction with the other components of the catalyst, and is thus prevented from evaporating. "This makes it clear that the other components of the catalyst are needed only to release and stabilize the active form of the catalyst," says Trunschke.

Live connection to the working catalyst

The researchers came to this conclusion because they were the first to watch the catalyst in action. Using Raman spectroscopy in a specially developed apparatus, they analyzed which substances are produced on the catalyst while the starting materials of the reaction flowed over it. "So far, catalysts have been studied only before and after catalysis. Analyses using Raman spectroscopy at high temperatures have so far been carried out only on non-working catalysts," says Maximilian Werny, who did the experiments as part of his master's thesis. "Using Raman spectroscopy, we have observed for the first time how the products are created."

Both the possibility of getting a live image of the conversion of methane into ethene, and the knowledge of the catalyst made of sodium, manganese, tungsten, and silicon could help chemists to develop chemical mediators that work at lower temperatures and thus produce only the desired, useful products and no CO_2 in a more targeted manner. One approach could be to replace sodium with other alkali metals and test whether the corresponding catalysts produce ethene at lower temperatures. "You would probably need other components to hold the metal in place," say Trunschke. She and her team would then be able to follow the mode of action of candidates for alternative catalysts. Chemists should then be able to develop a catalyst that will help to prevent the waste of methane in oil production and make at least a small contribution to climate protection.

More information: Maximilian J. Werny et al. Fluctuating Storage of the Active Phase in a $Mn\text{-}Na_2WO_4/SiO_2$ Catalyst for the Oxidative Coupling of Methane, *Angewandte Chemie International Edition* (2020). DOI: 10.1002/anie.202004778

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