From climate offender to raw material

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Global CO_2 emissions are rising rather than falling. Steps taken to date to curb emissions clearly have been inadequate. A contribution could be made by the chemical industry, however, by using carbon dioxide as a new building block for key plastics. Doing so would both conserve fossil resources and help the climate.

The latest figures are alarming. Despite all efforts, energy-related CO_2 emissions increased worldwide in 2012 by 1.4 per cent to the record mark of 31.6 billion metric tons. And in May 2013, the carbon dioxide concentration in the atmosphere reached a new level for the first time in hundreds of thousands of years. It is now at over 400 parts per million.

According to the International Energy Agency, if we continue in this way, we will not succeed in limiting global warming to two per cent in the long term. In other words, additional efforts are urgently needed to stem CO_2 emissions. But that is easier said than done, as the current dispute in the European Union surrounding the surplus of pollution rights shows.

On the other hand, the EU, in particular, has set very ambitious targets. By mid-century, emissions there are to be reduced by at least 80 per cent, and the ecological restructuring of our industrial society into a low carbon society is to be far advanced.

Chemical industry offers solutions

Besides certificate trading, the main instrument the Europeans are using to get there is greater efficiency. Managing energy and fossil fuels more efficiently is the second most important means for protecting the climate. The chemical industry can do a number of things to contribute in this context. For instance, the industry in Germany today uses only half as much energy for the same product as it did two decades ago.

And new opportunities for improvement are being discovered all the time. Chlorine, for example, can now be produced with one-third less electricity using a new technology developed by Bayer and Thyssen. If this technology were used throughout Germany, it would reduce the country's total electricity consumption by one per cent. These examples illustrate just how much potential still exists for improving energy efficiency. Potential we must exploit, because the best solution undoubtedly is to conserve resources and avoid releasing greenhouse gas in the first place.

Another idea is to separate CO_2 at its source, such as a power plant, and to store it geologically long-term – Carbon Capture and Storage (CCS) is the technical term for this process. However, separation causes efficiency losses during power generation. What is more, there is still some uncertainty as to the capacities and safety of CO_2 sequestration, and in many locations such projects have met with resistance from local residents.

CO_2 as a supplier of carbon

But we can do more with carbon dioxide than just bury it underground, because the gas contains something quite valuable: the element carbon, the foundation of all life. The chemist and writer Primo Levi recognised this fact years ago: "Man has never tried to extract from carbon dioxide the carbon he needs to feed, clothe and warm himself," the Italian noted in his 1975 book The Periodic Table. "He has not done so because he has not needed to. But for how many more decades?"

Today this question can be answered. Some 40 years later, we have reached the point where the CO_2 produced

New process: At this pilot plant in Leverkusen, Bayer produces a key chemical intermediate with the help of CO_2

by man can no longer be viewed merely as something useless and harmful. On the contrary, this climate gas can be put to good use, for instance as a new raw material for the manufacture of high-grade plastics.

Carbon Capture and Usage (CCU) is the name of this third method, which several chemical companies worldwide already are pursuing, including Bayer. The public sector likewise is pinning its hopes on this option and funding related projects. The German government, for example, has set aside a total of 100 million euros for this purpose, and its investment apparently is a good one. German Minister of Research Johanna Wanka stressed in spring 2013 that "impressive progress" has been made in the field.

Of course, we basically have been using carbon dioxide for a long time. As an industrial gas, CO_2 provides the carbonic acid in sparkling water, can be found in fire extinguishers and also serves as a coolant. In addition, it is traditionally used as a synthesis building block in chemical reactions to make products such as fertilisers and drugs.

Substitute for petroleum

But now there is a new and promising possibility: to also manufacture plastics using carbon dioxide. Plastics in the past were based primarily on petrochemical raw materials, meaning ultimately petroleum. However, unlike CO_2, this important carbon source has only limited availability, and its price is constantly rising. Furthermore, processing petroleum into chemical precursors consumes a tremendous amount of energy, meaning it releases CO_2.

Using carbon dioxide to manufacture plastics thus benefits the environment in two ways. First, CO_2 emissions are avoided from the outset by partially eliminating the use of oil as a raw material. Second, CO_2 that would otherwise escape into the atmosphere is captured and bound in chemicals.

Naturally, this alone cannot save the climate. The demand for CO_2 for plastics and other chemical products is much too low. It is estimated at 180 million metric tons a year, which would be equivalent to 0.6 per cent of current global carbon dioxide emissions. However, a number of small steps together can add up to a great leap in progress.

The Dream Production project is an undertaking of this kind, in which the German power company RWE, the University of Aachen and its associated CAT Catalytic Center have joined forces under the leadership of Bayer. They have developed a process for manufacturing polyurethane foam using carbon dioxide from the energy industry. Polyurethane foam is a ubiquitous material in our everyday lives, used, for example, in mattresses, shoe soles and auto parts, or for insulating homes and refrigerators against heat and cold.

New raw material: The petroleum in these foam samples has been replaced in part by captured carbon dioxide from the energy industry

Products made from polyurethane promote sustainability in many ways. For instance, insulating panels made of the material can help to save 70 times more energy during their service life than is required for their manufacture.

Pilot plant in Leverkusen

With CO_2 as a raw material, polyurethane now also boasts a highly sustainable manufacturing process, which Bayer has been testing since early 2011 in a pilot plant at its company headquarters in Leverkusen, western Germany. The facility produces an important polyurethane precursor called polyol, initially for test purposes.

What is new is its chemical composition. The chemical no longer comprises only petroleum derivatives, rather it now contains

a double-digit percentage of carbon dioxide. The CO_2 originates from a lignite-fired power plant operated by RWE near Cologne, where it is scrubbed from the flue gas and liquefied.

From the novel polyol, Bayer then manufactures polyurethane samples. The quality of these foams is just as high as that of the conventional material; the carbon dioxide remains bound in the substance even at high temperatures.

But why has the industry waited so long to go this route, which Primo Levi and others already recognised decades ago? The reason was a seemingly insurmountable problem: the natural inertness of carbon dioxide. Forcing this gas to enter into a chemical bond normally requires a high energy input, which in turn generates CO_2 emissions. It was quite a dilemma — until now, that is.

Extensive tests: Bayer researcher Dr Christoph Gürtler with a foam sample made from CO_2

Catalysis makes the difference

The answer was a special catalyst, discovered by Bayer researchers and developed together with partners at the CAT Catalytic Center. Only with this "chemical matchmaker" does the CO_2 reaction run efficiently. The new process is ecologically effective, as verified by an analysis conducted by RWTH Aachen University, because in the end it releases not more, but less CO_2, also compared with traditional production processes.

CO_2-based foams are to be introduced to the market as from 2015. Developers have their eyes on mattresses as the first end product. This and other industries have already signaled great interest in such applications.

But more ideas exist as well, such as coupling CO_2 with renewable energies. This is the object of a research project called CO2RRECT, which includes 10 partners in industry and academia headed by Bayer and likewise receives public funding. In this case, excess wind power is used to produce hydrogen by means of electrolysis, enabling the otherwise short-lived electricity to be stored quasi chemically.

Doubly sustainable

The energy is "released" when the ecologically produced hydrogen is put to use. This is where the carbon dioxide comes in. If the two are combined, they produce important chemical intermediates – once again for polyurethanes or the high-performance plastic polycarbonate. This makes a twofold contribution to sustainability.

However, the process could be useful beyond the chemical industry. For example, it could help countries like Germany to succeed in restructuring their energy systems by offering new options for storing fluctuating renewable energies, excess quantities of which so far are sent to pumped storage plants or underground cavities.

But it will take many years to reach this point. Bayer's vision also must be seen in the long term: eco-friendly plastics containing virtually no petroleum. For which mostly alternative sources are used. Bio-based fuels, for instance – and of course carbon dioxide, which is well on its way to assuming a new role as something useful and no longer merely a burden on the climate. ❑