Climate Action Programme for the Chemical Industry

International PtX Hub

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CARBON CAPTURE & UTILISATION

Factsheet

Introduction

According to estimations by the Intergovernmental Panel on Climate Change (IPCC), global warming is expected to exceed 1.5°C between 2030 and 2050 if global greenhouse gas emissions are not significantly reduced. As carbon dioxide (CO_2) is the primary greenhouse gas, efforts not only for reducing its emissions but also for removing it from exhaust gases and the atmosphere are increasingly important. [1]

The chemical industry is one of the biggest emitters of greenhouse gases for two reasons. The first one is the high carbon demand of many chemicals and products. Carbon is the most important element in the production of chemicals. Today's carbon sources are almost entirely fossil raw materials such as oil, gas and coal, the conversion of which often produces CO_2 emissions. Carbon capture does not only help to reduce greenhouse gases, but can evolve into a sustainable carbon source when based on bio-residues or some other selected waste streams.

The second contributor to greenhouse gas emissions of the chemical sector is the high demand for energy, which is still almost entirely met by fossil fuels. Switching to electric processes whenever possible as well as migrating to Power-to-X based molecules lay the ground to become totally emission-free when based on clean energy alternatives such as solar or wind power.

The chemical industry therefore has two main levers to reduce greenhouse gas emissions. In addition to the mentioned switch to renewable electric power, carbon - as an indispensable feedstock - must also be obtained from non-fossil sources. There are three overarching sources of 'renewable carbon': (1) carbon capture from exhaust gas or direct air capturing, where CO_2 is taken out of the ambient air, (2) bio-residues e.g. from agricultural waste or biogas, and (3) plastic waste feedstock e.g through chemical recycling. In any case, this Carbon Capture and Utilisation (CCU) will be a necessary building block on the way to a defossilised economy and to provide the volume of carbon needed in chemical production. The worldwide recycling rate of plastic waste is still under 10 %, but the chemical industry envisages to drastically increase the rate in the next years through mechanical and chemical recycling. [2] In greenhouse gas reduction strategies of the chemical industry, all three options of alternative carbon sourcing play a crucial role. [3]

In many technological applications of CCU, the CO_2 is filtered out of an exhaust gas stream using membranes and then converted into carbon monoxide (CO). Combined with green hydrogen (H_2) from renewably powered electrolysis so-called synthesis gas ('syngas') is produced and then converted into other molecules for chemical processes or fuel. Powered by renewable energies and renewable carbon, this approach replaces fossil fuels and feedstocks, thereby helping to make the chemical industry carbon-neutral, a model called Power-to-Chemicals (PtC).

As PtC is not always a feasible option in places where CO_2 emissions are generated, Carbon Capture and Storage (CCS) in suitable rocks underground may be a valid approach, at least as a bridging technology, to avoid the over-exploitation of the atmosphere as a carbon sink. But it is an end-of-pipe approach and not in the focus of this paper. CCU is more in line with the paradigm of a circular economy, by (re-)using CO_2 as a carbon (re)source – at least, when its emissions cannot be avoided. CCU technologies can typically be used in various industries, e.g. in the energy sector (e.g. synthetic fuel production for the aviation sector) or in the production of chemicals that then are sometimes called 'green chemicals.' [4]

In general, both, CCU and CCS, are seen as potential building blocks on the path to reduce CO_2 emissions into the atmosphere. [5, 6] Nevertheless, with regards to the chemical industry, it should be emphasised that particularly CCU offers interesting potentials as an alternative carbon source whereas CCS is just used to sequester and store excessive CO_2 in underground geological formations, preventing that it enters the atmosphere but without making use of carbon as an alternative feedstock.

Technology

Remove CO_2 from exhaust gas

In the CCU concept, CO_2 is removed directly from the exhaust gases of coal, oil, gas or biomass-fired power, steel or cement plants, in order to use it for industrial purposes or to sell it. [6] One technical solution is membrane-based gas separation, in which the gas flow is usually passed through a membrane via a pressure gradient. Separation takes place when the flue gas flows through the pores of the membrane. This method has several advantages over other CO_2 capture techniques, including energy efficiency, cost effectiveness, ease of operation, scalability and environmental friendliness. However, membranes are generally expensive and, a significant amount of energy is required to pressurise the gas. [7]

Direct Air Capturing

Direct Air Capturing (DAC) is a technology that adsorbs CO_2 from ambient air. The adsorbant can be either liquid or solid and has the ability to catch CO_2 molecules which are regenerated through the use of heat. The CO_2 captured in this way can then be used as a raw material (CCU) or stored (CCS). However, this technology is controversial due to the high costs associated with capturing one tonne of CO_2, as the ambient air only contains 0.04% CO_2. It is crucial that the energy used to operate the system comes from renewable sources to avoid any emissions. Currently, there are numerous research projects exploring adsorbents and integration variants that are both environmentally friendly and available in sufficient quantities to enable upscaling of the systems.

Carbon Capture and Storage

Carbon Capture and Storage (CCS) is a collection of technologies that involve trapping CO_2 emitted from industrial facilities before it is expulsed into the atmosphere. In CCS, CO_2 is compressed and transported to a suitable storage site via pipeline or ship, or a combination of both, where it is injected into underground geological formations. In this case, CCS is an end-of-pipe-technology with highly non-productive costs and still under development, promoted on a voluntary basis. In theory, it has the potential to become more widespread if CO_2 prices are high enough or if it is mandatory. Current technologies are evolving and are claimed to be an option to prevent direct CO_2 emissions in production processes where fossil fuels are still used. Other options for carbon sequestration from the atmosphere include storage in biomass, e.g. in forests. In principle, CCS through plant growth could cause negative emissions, but sustainability aspects need to be studied carefully.

Power to Chemicals

The term Power-to-X is used for a wide range of applications based on renewable electricity. The X refers to the field of application, one of which could be chemicals, hence the term Power-to-Chemicals (PtC). PtC refers to the use of electrical energy from renewable sources for producing green hydrogen via electrolysis, and then another element like carbon or nitrogren to syntethize other downstream chemicals. In this sense, PtC is a way to defossilize large parts of the chemical industry's value chains that so far still rely on fossil feedstocks. For example, electricity can be used to produce basic and platform chemicals, gas or fuels. In this context, electricity is used in electrochemistry to produce synthesis gas from CO_2 and water, and then processed to solvents or other chemicals. The use of power-to-chemicals is therefore an important step for creating a low-emission circular economy. Existing methods can effectively reduce GHG emissions by using renewable energy. Currently, the costs of transitioning to a low-emission economy are higher than those of an economy based on fossil fuels. However, this may change in the future as renewable energies are further expanded becoming less and less expensive, while CO_2 pricing might provide additional incentives.

Challenges

So far, a broad-scale application of CCU technologies faces a series of challenges. In addition to technological aspects such as the prevention of CO_2 leakage, the economic equation does not yet fit in most cases, due to additional costs and energy inputs. Capturing carbon, always requires a certain amount of energy. It is important to note that the climate balance is only positive, if the required energy is generated by renewable sources. The use of carbon from fossil sources is – under the prevailing framework conditions - much cheaper than the use of carbon from CCU because most of the relevant chemical production processes consume much energy and innovative technologies require significant initial investments for their implementation. However, this monetary arguing is flawed since we know that no additional fossil carbon should enter the atmosphere if we want to limit climate damage. Even if we ban coal, oil, or natural gas as feedstocks of any kind, there will still be other unavoidable sources of CO_2 emissions. So, CCU is crucial and even CCS will be necessary according to many experts. [7]

Outlook

There are many ways to reduce CO_2 emissions. In terms of technological development in the CCU/CCS sector, promising new alternatives are emerging. CCU is an option of high relevance for the chemical industry that seeks to replace fossil carbon by alternative sources. Associated PtC technologies offer attractive possibilities for producing a wide range of platform chemicals as a basis for a sustainable and climate- friendly chemistry in future. The question today is, how (not if) we make this possible.

Literature

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Registered offices:
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Climate Action Programme for the Chemical Industry (CAPCI)
Friedrich-Ebert-Allee 32+36
53113 Bonn
I www.isc3.org/page/capci

International PtX Hub
Potsdamer Platz 10
10785 Berlin, Germany
E info@ptx-hub.org
I www.ptx-hub.org

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Authors:
Sarah Andreas, Dr. Detlef Schreiber, Philip Miltrup