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CO_2 as an Asset?

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Carbon dioxide (CO_2) is typically perceived as a harmful greenhouse gas. Yet CO_2 contains carbon (C), the substance from which all organic life derives and the basic ingredient of countless chemical products. In recent years research on the practical use of CO_2 has yielded a number of important initial breakthroughs. The capture and use of carbon dioxide, known as Carbon Capture and Utilisation (CCU), opens up new perspectives on how we might deal with CO_2 emissions in a circular economy.

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What is Carbon Capture and Utilisation?

The term Carbon Capture and Utilisation[1] refers to technologies and processes that use carbon dioxide either directly or, after chemical conversion, as part of a carbon compound in materials or energy carriers. Although both technologies seek to extract CO_2 from industrial emissions, CCU is fundamentally different from controversial Carbon Capture and Storage (CCS) methods. While CCS aims to store CO_2 permanently underground, CCU attempts to use CO_2 emissions as an alternative source of carbon with a view to closing the industrial carbon cycle.

CO_2 is already used directly in its solid or liquid/gaseous state in dry ice, fire extinguishers and drinks (so-called physical or direct use). In the near future, air-conditioning systems in cars could also use CO_2 as a coolant. Furthermore, CO_2 after chemical conversion can serve as a raw material in the production of energetically superior carbon compounds. Today, this utilisation in materials is common in pharmaceutical products, solvents and fertilizers.

CO_2 could play a role in the production of plastics, foams, paints, coatings and cement. In principle, carbon dioxide can also be used as a raw material in the production of energy carriers: in different processes synthetic gaseous and liquid fuels can be produced with CO_2 for possible use in energy storage.

Given that CO_2 is very inert, aids are usually required to allow it to play a role in chemical reactions to develop materials with a higher energetic value. Additional energy can make this possible. Alternatively, chemical catalysts can be employed to develop a more energy-efficient process. Thus catalysis research is crucial to the development of successful CCU technologies.

Where does the CO_2 used in CCU come from?

The CO_2 required for CCU technologies can be extracted from various sources.

CO_2 is a by-product of a number of chemical processes, for example, alcoholic fermentation or the production of ammonia. With the help of commercially established recovery technologies, this CO_2 can be isolated and made available for use in a highly pure form.

CO_2 can be filtered from flue gases using carbon capture technologies such as amine scrubbing. There are numerous potential industrial sources of CO_2, from small smoke stacks to large coal-fired power plants. With the help of existing methods, they could provide large quantites of CO_2. However, due to the high cost of capturing CO_2 and low demand until now, these technologies are not widespread. Moreover, the possible side effects of carbon capture technologies have not yet been sufficiently clarified and may prove detrimental to the environment.[2]

The atmosphere is another source of CO_2. One method that is not yet commercially feasible attempts to filter previously emitted CO_2 from the atmosphere by way of chemical engineering procedures (Direct Air Capture).

It should be noted that after its capture, CO_2 would have to be transported to the place where it is to be used and, if necessary, stored temporarily. This might pose dangers to people and the environment.

What are the effects of CCU on the environment?

CCU technologies can help to mitigate the harmful effects of industry on the environment by enabling us to

- substitute fossil raw materials;
- reduce the amount of energy used;
- and store CO_2 emissions at least temporarily.

By using CO_2 that would otherwise be emitted, we can slow down the rate of emissions over the life cycle of a particular product. Indeed, it may also be possible to prevent emissions in the long term by binding CO_2 permanently, for example, in cement. However, this is unlikely to contribute significantly to climate protection due to the limited amounts of CO_2 that can be used in materials: it is estimated that only about 180 million tons of CO_2 can be incorporated annually into polymers and other basic chemical products worldwide.[3]

The production of synthetic sustainable fuels – for example, methanol and dimethyl ether (DME) – seems to be more promising. Here, an estimated 1 800 million tons of CO_2 could potentially be used across the globe each year.[4] By way of comparison: worldwide human-made CO_2 emissions were of the order of about 36 000 million tons in 2013.[5] However, to ensure that CO_2 from CCU technologies can be used together with hydrogen (H_2) to produce fuels in an ecologically sound way, the availability of renewable energies at every stage of the production process is essential.[6]

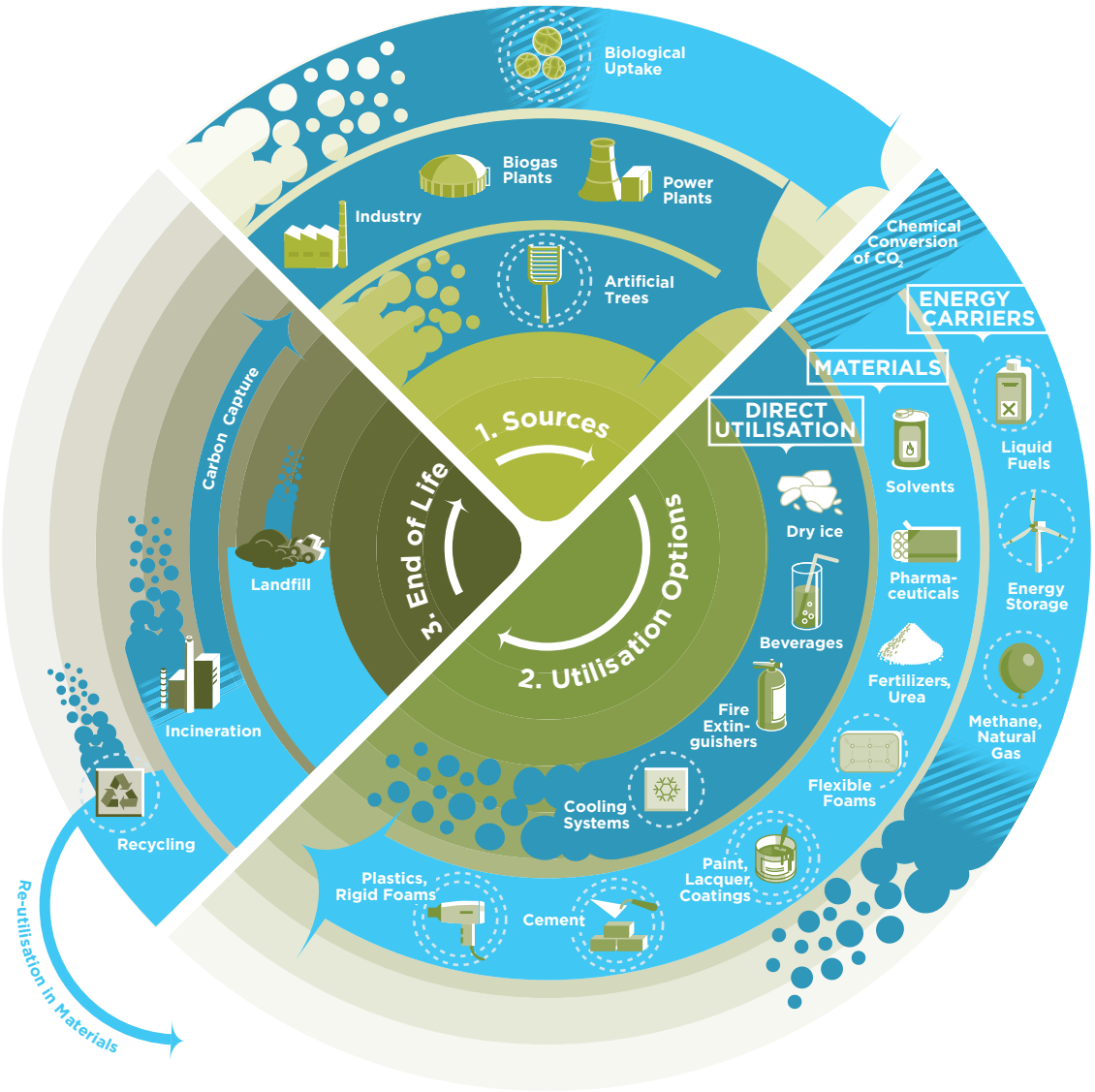

Figure 1: CO_2 as feedstock

Legend:

- Carbon dioxide
- Carbon compound
- Conversion
- Release into the atmosphere
- Near future
- Distant future

WORLDWIDE CO_2 USE TODAY

Direct use:

Around 20 million tons of CO_2 per annum, including around

- 50 % packaging for the food industry
- 35 % industrial gas
- 15 % carbonated drinks

Conversion into materials:

Around 130 million tons of CO_2 per annum

- mainly used in the production of urea
- small amounts used in the production of special chemicals such as cyclic carbonates and salicylic acid
- polymers and other materials still in the R&D stage

Use in Energy Carriers:

Around 10 000 tons of CO_2 per annum

- demonstration facilities for the production of liquid and gaseous fuels

1 Beverages
2 Packaging
3 Industrial gas
4 Fertilizers, urea
5 Pharmaceuticals
6 Plastics, rigid foams
7 Flexible foams
8 Liquid fuels
9 Methane, natural gas

Estimates are based on the most recent available data. See, for example, IHS Chemical (2013), International Fertilizer Association (2013), Audi (2014), Carbon Recycling International (2014).

Currently, most fuels and materials such as plastics are produced using fossil resources, in particular petroleum and coal. Thus the main benefit to the environment of using CO_2 lies in the substitution of these fossil carbon sources. This makes a more sustainable use of natural resources possible.

However, a product that has been produced using CCU technologies is not necessarily better for the environment. To evaluate the entire life cycle of a product, many different criteria have to be taken into account, including CO_2 sources, transportation, the production process, operating life, and recycling and disposal options. This Life Cycle Assessment (LCA) of CCU products aims to evaluate their effects on the environment in a transparent way. For ease of comparison, however, standard criteria are required, and until now these have only existed in the form of scientific recommendations.[7]

Do CCU technologies make economic sense?

In recent years, many companies in the chemical industry and the energy sector have been investing in research and development on the industrial use of CO_2. Volatile commodity prices and finite fossil resources are driving these efforts. The 'supply' of CO_2 for CCU technologies at local level would be guaranteed in the long term, technically feasible, and, in contrast to fossil resources, possible without incurring high raw material costs. Companies can become less dependent on suppliers of raw materials by availing of the opportunity to recycle emissions either from their own industrial plants or from cooperation partners. CCU processes can lead to a better ecological footprint. CCU technologies thus offer both ecological and economic advantages on a path to sustainable development.

From an economic point of view, CCU technologies have great potential. The option of using a new, local source of raw materials could give the regional chemical industry a competitive advantage at international level. It could also boost innovation and further the transfer of know-how across borders. The development of a 'CCU industry' could lead to economic growth and new jobs.

However, given that the production costs of some CCU products are currently higher than those of conventional products, industry has not put all technically feasible technologies into practice. For example, due to the very low price of CO_2 in current European emissions trading, there are few incentives for investing in CCU. Given the uncertainties regarding the costs involved and access to renewable energies, investment – in particular in CCU-based fuels – currently carries risks that only a few market participants are willing to take.

Using CO_2 – an option for the circular economy?

The possibility of using CO_2 means far more than a change of procedure for the chemical industry. It also entails a change of perspective: on the way to a more sustainable society we need to reassess our approach to alleged waste and finite resources.

CCU technologies touch on both aspects: they utilise a gas that is a central driver of climate change and they can simultaneously reduce the consumption of fossil resources. Particularly when combined with renewable energies, CCU offers many possibilities of improving or even closing industrial CO_2 cycles. To ensure that the potential of these technologies to contribute to a circular economy is fully realised, as yet unanswered questions (e.g. about Life Cycle Assessment and the political and economic parameters of using CO_2) must be answered and possible effects evaluated in a debate involving representatives of science, industry and politics.

SUMMARY

- CCU technologies have the potential to reduce our need for fossil resources by utilising CO_2. Already today, CO_2 is used as a raw material in a number of technical processes.
- Currently, large power stations and industrial plants represent possible sources for the capture of CO_2.
- The development of CO_2 as a new source of raw materials can bring ecological and economic advantages and reduce our dependence on volatile commodity markets.
- In the future, CCU technologies could help to close industrial carbon cycles, thus contributing to a more sustainable economy and way of life.
- CO_2 capturing technologies are at very different development stages and may prove to be damaging to the environment.
- According to current estimates, the potential uses of these technologies are small compared to the total anthropogenic emissions of CO_2.

[1] *Also known as Carbon Recycling or Carbon Dioxide Utilisation.*

[2] *See Dautzenberg & Bruhn (2013), 'Environmental Impacts of Carbon Capture Technologies', IASS Working Paper.*

[3] *See Federal Ministry of Education and Research (no year given) 'Wirtschaftlich- und klimarelevante Ansätze zur CO_2-Nutzung (CCU-Strategie)', available at: http://www.dechema.de/dechema_media/CCUstrategie.pdf (last accessed on 2 June 2014).*

[4] *Ibid.*

[5] *See Le Quéré et al. (2013), 'Global carbon budget 2013', Earth System Science Data Discussion, 6, 689–760.*

[6] *Sustainable fuels include synthetic hydrocarbons such as methane (CH_4) and methanol (CH_3OH), whose production is based on renewable energies. See Ferrari et al., 'Sustainable Synthetic Fuels', IASS Fact Sheet 1/2014.*

[7] *See von der Assen, Jung & Bardow (2013), 'Life-cycle assessment of carbon dioxide capture and utilization: avoiding the pitfalls', in: Energy & Environmental Science, 6 (9), 2721–2734.*

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