CO_2 as a raw material — good for the climate?

WWF's position on Carbon Capture and Utilization (CCU)

Footnotes

1 https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive (Revision 2018)
2 https://www.theicct.org/publications/final-recast-renewable-energy-directive-2021-2030-european-union
3 https://www.iass-potsdam.de/sites/default/files/files/iass_study_nov2016_en_co2-as_value_stufff.pdf
4 https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/impulspapier-strom-2030.pdf?blob=publicationFile&v=23
5 https://dechema.de/dechema_media/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf
6 From the Kopernikus project Power-to-X (https://www.kopernikus-projekte.de/projekte/power-to-x) based on data from AGEB, BMWi, BAB
7 https://shop.dena.de/fileadmin/denashop/media/Downloads_Dateien/esd/9261_dena-Leitstudie_Integrierte_Energiewende_kurz.pdf
8 https://bdi.eu/publikation/news/klimapfade-fuer-deutschland/
9 https://www.leopoldina.org/uploads/tx_leopublication/2017_11_14_ESYS_Sektorkopplung.pdf
10 https://www.agora-energiewende.de/fileadmin2/Projekte/2017/Big_Picture/Agora_Big-Picture_WEB.pdf
11 Mac Dowell et al. "The Role of CO2 Capturing and Utilization in Mitigating Climate Change" Nature Climate Change Perspective DOI:10.1038/NCLIMATE3231
12 Quotes have not been included in this section. as including quotes would mean that specific projects would be mentioned at specific companies, potentially creating misunderstandings as to whether WWF recommends the company or the product as a whole.

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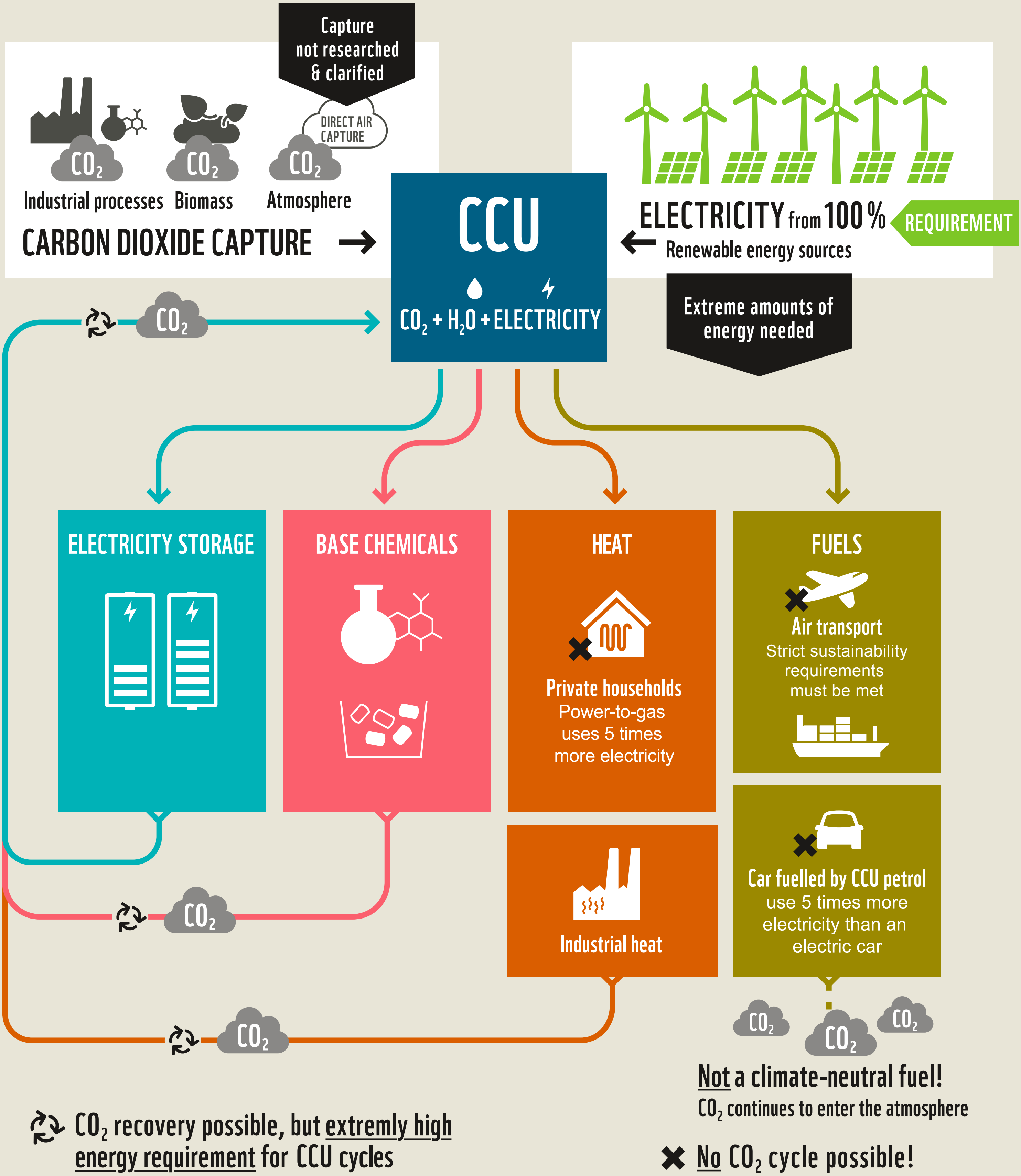

It is wishful thinking to believe that CCU is a climate-neutral fuel.

When it comes to climate policy, the transport sector is one of the biggest headaches. Which is why efforts to identify alternative, carbon-neutral drives are being intensified. The current debate increasingly revolves around what are known as “climate-neutral fuels” or “renewable fuels”, which are usually made from carbon dioxide in a process called Carbon Capture and Utilization (CCU). In this process, CO_2 is separated from exhaust gases released by an industrial plant or from the air and chemically converted to other substances. In other words, carbon dioxide is captured and used as a raw material, often called a feedstock, in CCU processes.

Since carbon dioxide is consumed during production, fuels stemming from CCU processes are often described as “climate-neutral”. But this is misleading!

Greenhouse gas neutrality can only be achieved with CCU if the energy used for all CCU processes is 100 % renewable. In addition, the carbon dioxide must originate from the atmosphere or from sustainably produced biomass. If these two conditions are not met, the harmful emissions from CCU could even be significantly higher than those emitted by conventional petroleum-based fuels.

Climate criteria need to be defined for CCU to make sense. Otherwise, CCU could even increase emissions harmful to the climate.

The WWF is closely following the debate about the reputedly high potential of CCU to mitigate climate change with great concern and has called for the EU’s Renewable Energy Directive (RED) to establish clear sustainability criteria for “renewable fuels”. However, if fuels from CCU processes are imported, the following criteria have to apply:

» The energy used is 100 % renewable

» No fossil-based CO_2 sources may be used

» A life cycle analysis must be performed to determine the minimum savings compared to the existing reference fuel – for example, at least 70 % of the total greenhouse gas saving

Without these criteria, the EU runs the risk of approving fuels as “renewable” that, in the end, release more greenhouse gas emissions than conventional fuels and lead to increased consumption of fossil fuels.

What is the potential of CCU?

The use of CCU makes good sense. As long-term storage in the electricity system, as a raw material for the chemical industry and, to a limited extent, also as fuel, for example, in aviation, it plays a role in establishing a climate-friendly economy independent of coal, petroleum and natural gas. However, it is important not to create the impression that a “climate-friendly diesel” alternative exists.

This position paper compiles key facts about Carbon Capture and Utilization (CCU) and explains the limited potential of the technology in climate change mitigation. It also outlines why WWF

» is pressing for sufficient sustainability criteria to be defined for CCU fuels used in aviation and rejects these fuels for use in other modes of transport,

» largely advocates the use of CCU for long-term storage in the electricity system and chemical feedstocks if certain sustainability criteria are met.

What do the different terms in the CCU discussion stand for?

CCU (Carbon Capture and Utilization) is defined as a group of new processes used to produce the same substances that are currently mined as fossil fuels or are made from or replaced by fossil fuels in emission-intensive chemical processes. These include in particular methane (natural gas), fuels (petrol, diesel, kerosene), synthesis gas and other base chemicals as feedstock for the production of e. g. plastics, paints, personal hygiene products and other products found in the chemical and pharmaceutical industries. CCU, however, uses carbon dioxide (CO_2) and water in an electricity-based process (electrolysis) to obtain these substances.

The term power-to-gas also refers to a product that contains no carbon: hydrogen. That´s not CCU.

Power-to-gas is a group of processes that converts electrical power to a gaseous fuel by means of electrolysis. This is usually either hydrogen (H_2, from water) or methane, the natural gas equivalent (CH_4, from water and carbon dioxide). The terms power-to-gas and CCU are both used to refer to methane production, depending on what's more important: gas as the final product (power-to-gas) or the carbon content (CCU). Hydrogen production falls under power-to-gas, but not under CCU because carbon dioxide is not an input material nor does the output contain carbon.

Power-to-liquid is similar. It is a group of processes that produces liquid fuels by means of electrolysis. Power-to-liquid processes are CCU processes that produce products equivalent to petrol, diesel and kerosene (fuel for aircraft). The term power-to-liquid is usually linked to the use of the product as a fuel in the transport sector (also known as high energy density liquid fuels).

Power-to-X x is an umbrella term that highlights the broad range of products and applications that can be provided by electricity. It includes all power-to-gas, power-to-liquid and CCU processes and could be expanded in the future to other electrolysis processes, for example, to the production of nitrogen compounds. The same principle (water, carbon dioxide, electrolysis) is applied to produce a number of different substances which are used as feedstock in the chemical industry, as fuels in transport and to generate heat or electricity (reconverted back to electricity, long-term storage). This term also includes power-to-heat, i. e. when electricity is used to generate heat. Examples of this are heat pumps in buildings or electrode boilers in industry.

„Renewable liquid and gaseous transport fuels of non-biological origin“[1] is the technical term from the EU's Renewable Energy Directive (RED) for power-to-X products in the transport sector. According to the EU, these fuels can increase the share of renewable energy sources in road transport. The name chosen by the EU is unfortunately misleading, as these products would only be "renewable" if their production were subject to a number of criteria. However, these requirements are not currently set out in the Directive. By expanding the relevant paragraphs to include the use of fossil CO_2 sources and various electricity sources, including fossil fuels, the RED runs the risk of approving fuels as "renewable", which would result in higher greenhouse gas emissions than conventional fuels. Criteria need to be developed and added by the end of 2021.[2]

Sufficient sustainability criteria for CCU products must absolutely be added to the EU Renewable Energy Directive.

CCU is not climate neutral

A carbon cycle is defined as the chemical conversion of carbon-containing compounds without releasing additional CO_2 into the atmosphere in the process. This is also the ultimate goal of CCU.

When CCU is used in the transport sector, additional CO_2 is still released into the atmosphere.

However, if CCU is used to produce transport fuels, no closed-loop carbon cycle is created. CO_2 continues to be released into the atmosphere. If CCU gas is used to heat residential buildings, there is also no closed carbon cycle. However, the production of base chemicals and their use for long-term storage in the energy system can lead to clearly traceable carbon cycles that can be controlled by the plant operators. However, a lot of electricity is need for CCU. Whether or not the carbon cycle is then also climate-neutral depends on how the electricity is generated.

Production of base chemicals

CO_2 can become the new feedstock for the chemical industry. A sustainable carbon cycle requires durable, recyclable products and renewable energy sources.

CCU can create a closed carbon cycle. Most convincing is the use of CCU to produce base chemicals that are processed to become durable and recyclable products. First carbon is sequestered in the recycling process, it is then used at the end of its service life to produce energy from residues that can no longer be recycled and recycled again into the base chemical via CCU. Figure 1 provides a diagram of this process.

It is important to note that this process creates a closed carbon cycle but not a closed energy cycle. A lot of energy is lost in every cycle due to efficiency losses and the additional energy needed to capture CO_2 from the combustion gases. The fewer CCU cycles there are, the less energy is lost, making product durability and material recycling essential factors in the sustainability of this cycle.

However, there is a danger that practical implementation will diverge from the ideal case. This cycle can become very energy-intensive if, for example, packaging is made that is not durable or recycled, and if CO_2 from a fossil-based source is also introduced into the process cycle. In practice, it is possible that the result would be more emissions harmful to the climate than the status quo. Whether or not a concrete CCU application makes sense should always be assessed on the basis of a comprehensive life cycle analysis. Despite these limitations, CCU could still form parts of a new feedstock base for the chemical industry independent of coal, petroleum and natural gas if the process chain is sustainably structured.

Possible carbon cycle

with CCU for the production of base chemicals

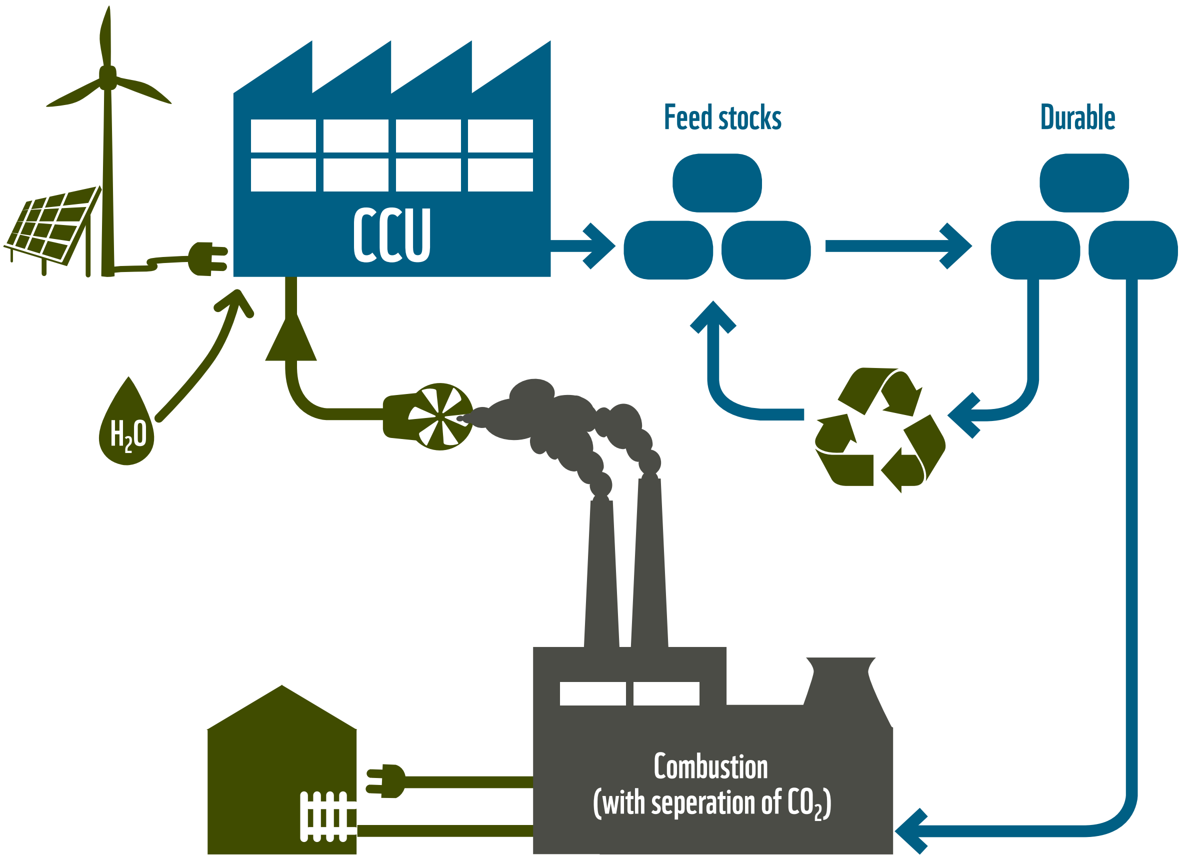

Figure 1: Possible carbon cycle with CCU for the production of base chemicals

Long-term storage in the electricity system

Carbon is also recycled when CCU is used as a long-term storage in the electricity system (Figure 2). Here, too, this process creates a closed carbon cycle but not a closed energy cycle. Most of the energy to be stored is lost due to efficiency losses and the additional energy consumption. As a result, the use of CCU for long-term storage must always be weighed in terms of cost-effectiveness, resource and land consumption compared to other options, such as the carbon-free power-to-gas process (hydrogen electrolysis). Grid expansion, more flexible demand and other storage technologies are also alternatives. Despite the disadvantages, CCU could become a useful component of a climate-neutral electricity system in the future to produce the natural gas equivalent methane as a long-term storage technology. One possible advantage would be, for example, the well-developed technology for the reliable long-term storage and long-distance transport of natural gas/methane in existing natural gas storage facilities and pipelines.

Carbon cycle

with CCU as long-term storage in the electricity system

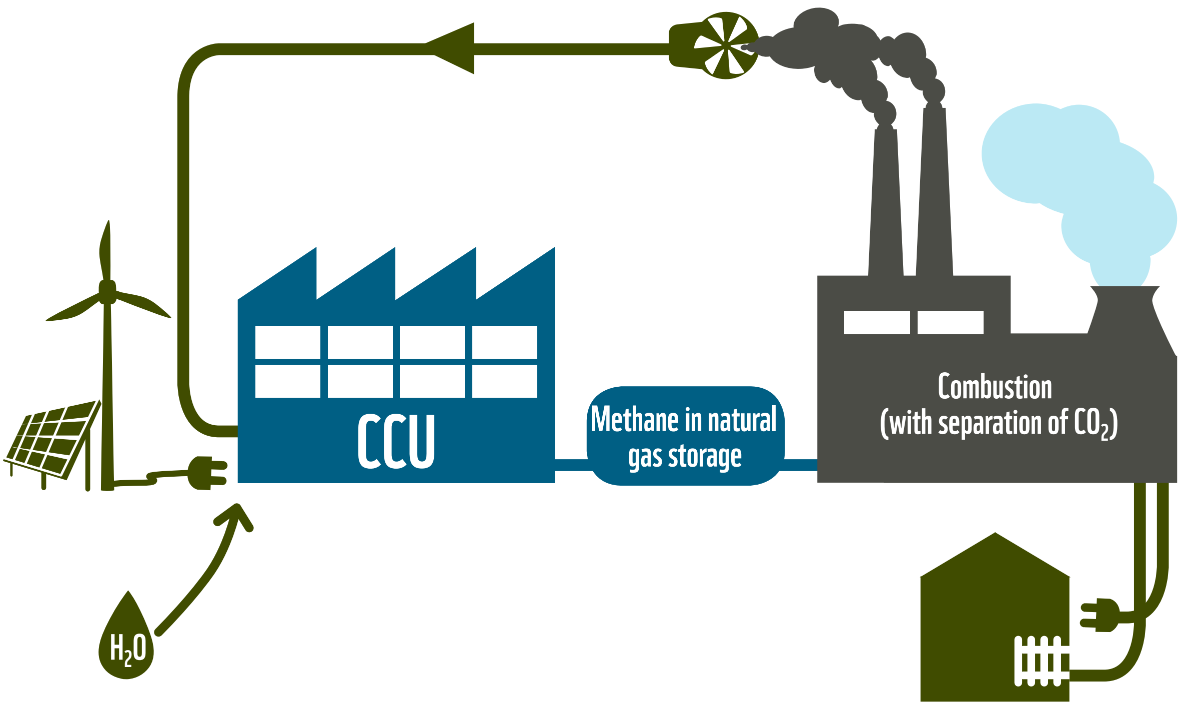

Figure 2: Carbon cycle with CCU as long-term storage in the electricity system

Fuel for the transport sector

The focus of the current debate is the use of CCU in transport. “Climate neutral fuels” or “renewable fuels” are seen as a solution. However, CO_2 produced during combustion in cars cannot be captured and stored for reuse. It is still theoretically possible to describe a cycle here as well, either through direct air capture or biomass (Figure 3).

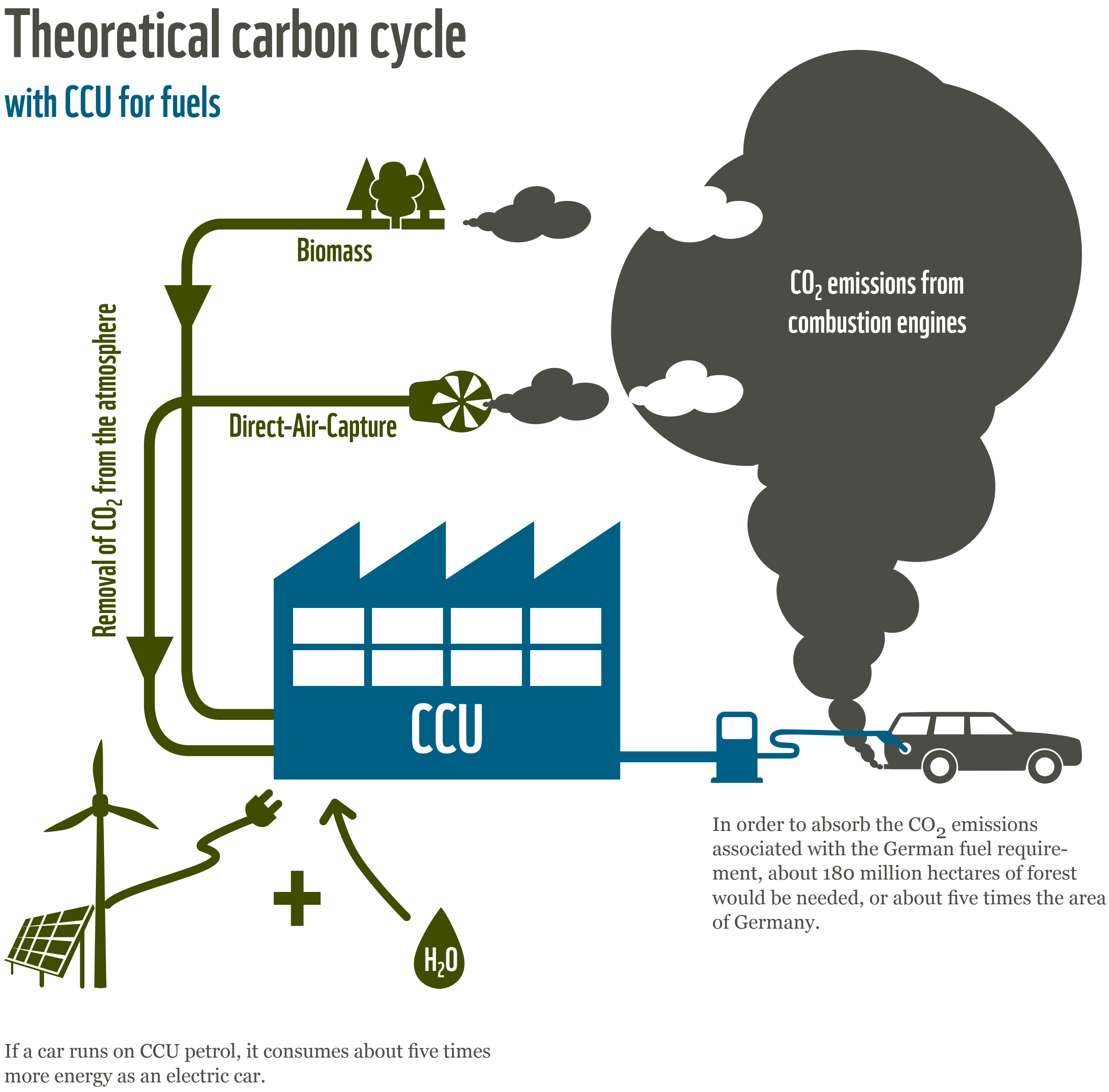

Figure 3: Theoretical carbon cycle with CCU for fuels – climate neutrality only when CO_2 is removed from the atmosphere

Direct air capture uses chemical binders to filter out CO_2 from normal ambient air. The problem here is the low concentration of CO_2 in the air which makes it necessary to move enormous amounts of air to the direct air capture facilities, which requires enormous amounts of electricity.

CO_2 from combustion engines can also be removed from the atmosphere by biomass. However, the problem in this case is the enormous amount of land needed to farm biomass, for example, forests. In order to absorb the CO_2 emissions associated with the German fuel requirement, approx. 180 million hectares of forest would be needed, i. e. about five times the area of Germany.[3] In addition, the question arises as to whether these forests are managed sustainably or whether intensive forestry use completely or partially invalidates CO_2 capture. It is sometimes argued that emissions from transport in Germany could be sequestered by sustainably managed forest areas abroad. However, it must be assumed that these countries need these forests to offset their own emissions and would therefore probably not contribute to the greenhouse gas neutrality of the fuels used in Germany – at least not without financial compensation.

In practice, if the carbon dioxide originates from an industrial process, more emissions harmful to the climate are produced. CCU can adversely affect the climate more than diesel and petrol.

Both in Germany and at EU level, discussions are underway on the increased use of CO_2 for fuel production that comes from industrial processes or fossil power plants. However, this does not create a closed climate-neutral cycle, but merely combines two emission sources (Figure 4).

The risk is that CCU processes in the transport sector emit significantly more CO_2 than diesel and petrol. This is not the way to achieve the goal of greenhouse gas neutrality set out in the Paris Climate Agreement.

Combining two emission sources

Consumption of fossil fuels will be reduced, but not stopped

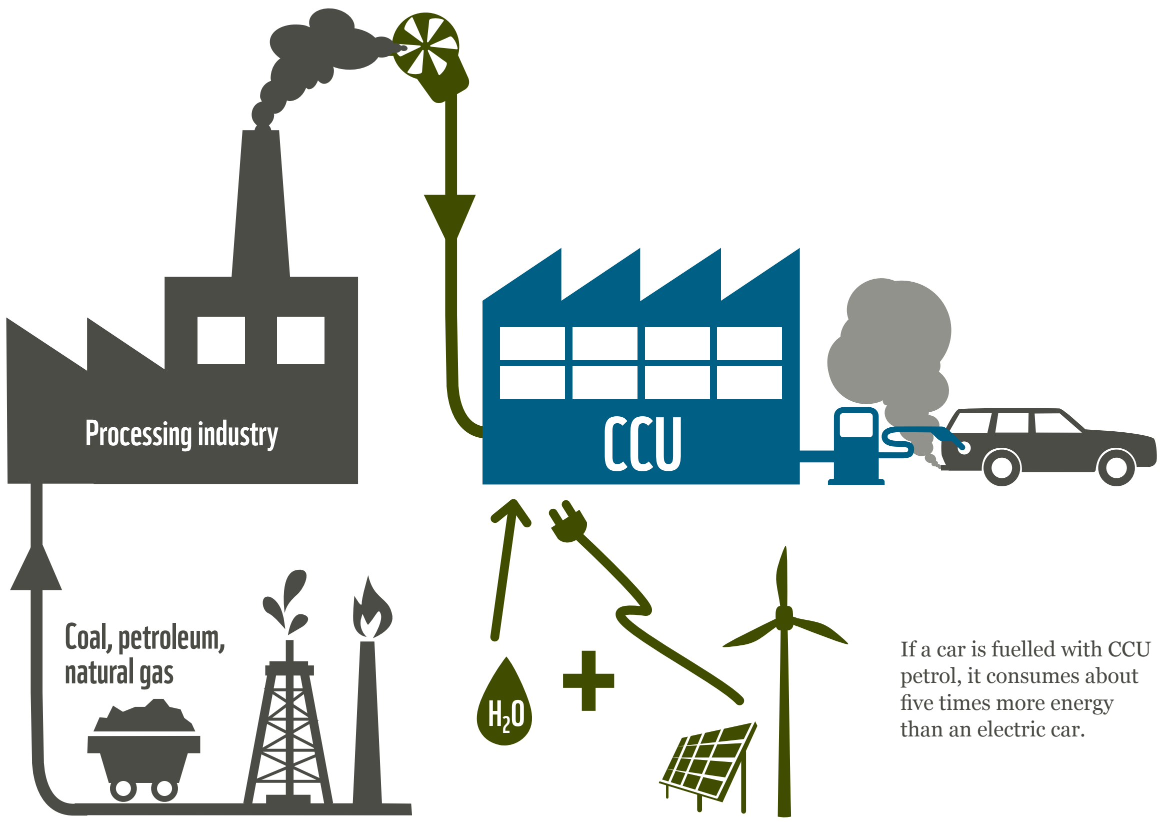

Figure 4: Combining two emission sources. Consumption of fossil fuels will be reduced, but not stopped.

Heating material

There are two extreme cases when using CCU for heating: very low temperatures (below 100 °C), very small quantities of energy generated in a large number of widely distributed very small heating systems – heating and hot water in residential buildings. Very high temperatures of several hundred or more than 1,000 °C, very large amounts of energy concentrated in one place in one large plant – industrial facilities and heating plants.

The first case is similar to fuels. It seems impossible to capture the CO_2, so no closed carbon cycle is created. In the second case, the CO_2 could be captured and used for repeated heat and power generation, similar to reconversion back to electricity after a CCU step. It would have the same disadvantage: each CCU loop would be associated with high energy losses.

Fernwärme Wien operates the largest Austrian fossil-fired district heating plant with a thermal output of 358,000 kW.

CCU is an energy guzzler

CU requires about five times the amount of electricity as comparable processes. If a car is fueled with CCU petrol, it consumes about five times more energy than an electric car. If a residential heating system uses CCU heating gas, it consumes about five times as much electricity as a heat pump. The additional electricity required to produce base chemicals could reach current levels of electricity consumption.

Petroleum and natural gas contain a lot of energy. The molecules CO_2 and water, on the other hand, are among the chemical compounds with the lowest energy content. The combustion of petroleum and natural gas into CO_2 and water releases so much energy that the entire energy supply today is based on this chemical conversion. Conversely, this means that if we want to turn CO_2 and water into petroleum and natural gas equivalents, huge amounts of energy have to be channeled into the conversion process. Even with the best possible, optimized CCU process, the energy requirement would remain extremely high and would have to be met with electricity from renewable sources.

An analysis by the German Federal Minister for Economic Affairs and Energy shows the relative electricity requirements of CCU solutions compared to other options (Figures 5 and 6). Direct electrification would therefore always be the preferred option as it is more resource efficient, and CCU solutions would be limited to cases where direct electrification is not possible. In the transport sector, for example, this would apply to air transport.

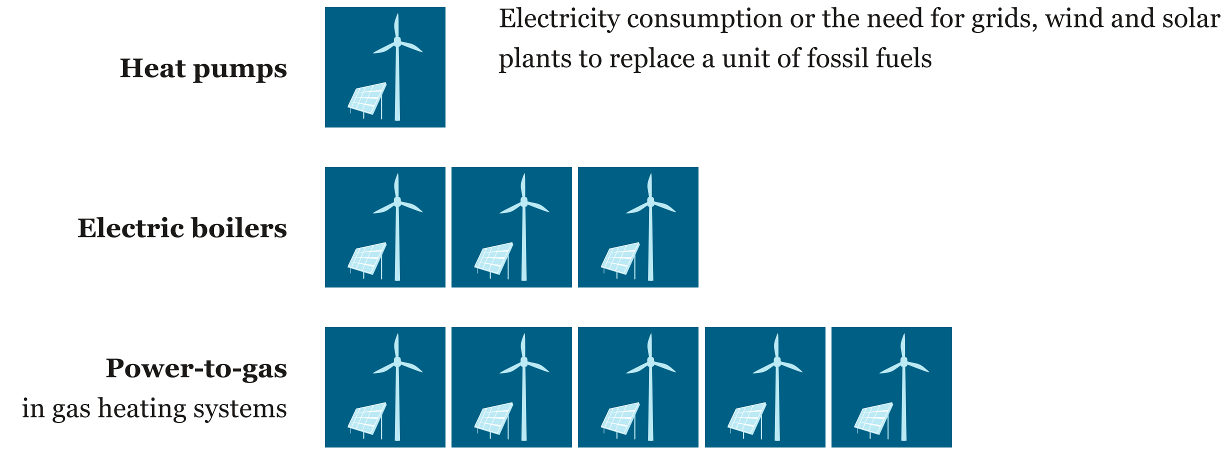

Figure 5: Electricity consumption of CCU solutions relative to other options – heating[4]

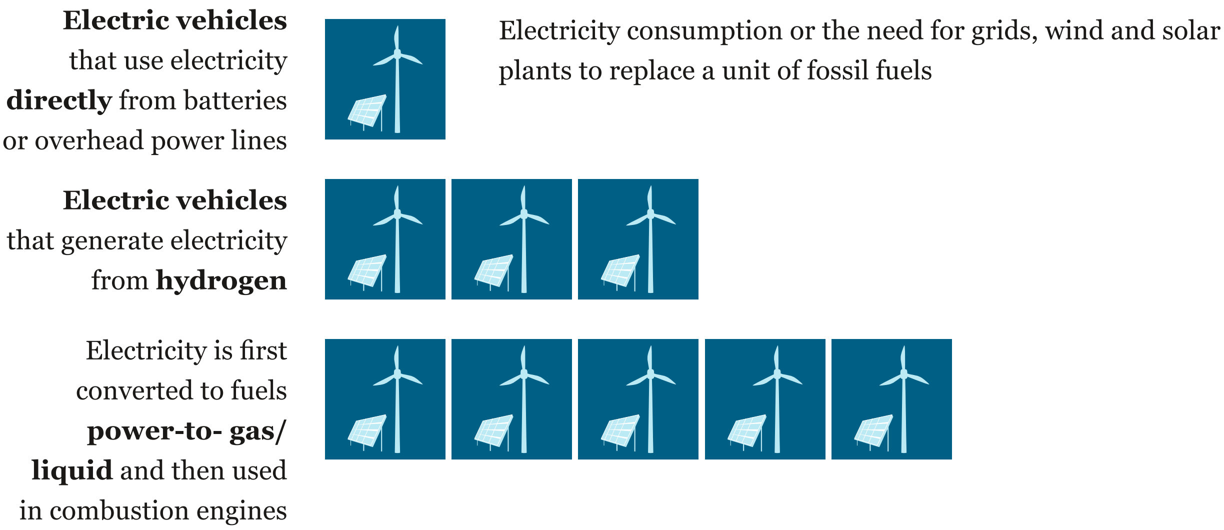

Figure 6: Electricity consumption of CCU solutions relative to other options – transport[4]

Electric cars and heat pumps are sometimes viewed critically as additional electricity consumers because they lead to an increase in wind and solar energy and additional grid expansion. However, CCU fuels are not a solution to this challenge, but in fact the exact opposite. The electricity needed for chemical feedstocks is also enormous. Only with durable products, alternative materials and optimal recycling will it be possible to limit the electricity requirement to a reasonable level.

The electricity needed for chemical feedstocks is also enormous. Only with durable products, alternative materials and optimal recycling will it be possible to limit the electricity requirement to a reasonable level.

The amount of electricity needed for chemical processes would be enormous. A study conducted by the DECHEMA Gesellschaft für chemische Technik und Biotechnologie e. V. on behalf of the European Chemical Industry Council cefic, determined that up to 4,900 TWh of electricity would be needed to reorganize processes in the chemical industry.[5] This would mean that electricity consumption of the European chemical industry would be a quarter higher in 2050 than the total electricity consumption of the EU at present.

It would certainly be possible to question the underlying assumptions and demand that this electricity requirement be reduced and limited by exploiting the full potential of closed-loop recycling, energy and material efficiency and material substitution. But these are dimensions that make it clear that:

» Accelerated expansion of renewable electricity production is urgently needed in Germany and the EU if we want to facilitate modern, climate-neutral industry at German and EU locations. It is essential that every opportunity to further develop renewable energy sources and to expand and optimize grids be pursued as quickly as possible so that industrial processes can be converted to climate-neutral, electricity-based production between 2030 and 2050 at the very latest.

» It would be illusory to think that Germany and Europe could be supplied with CCU fuels from domestic production at the level of today's fuel requirement. They would have to be imported. The prospect of increasing import independence and maintaining added value in Germany and Europe can only be reconciled if efficiency is increased and mainly direct electric drives are used.

» Heating systems are subject to similar considerations as transport: only if the energy requirement for heating systems is minimized through extensive energy-saving modernization of existing buildings and energy-efficient new buildings can the remaining demand be met primarily by heat pumps without adversely impacting the climate. CCU heating gas as a substitute for natural gas is only very limited as a solution in this case, unless massive imports are assumed.

CCU can only make a small contribution to cutting greenhouse gas emissions ...

The greenhouse gas potential of CCU processes and products varies greatly from case to case. But given Germany's electricity mix today, almost all CCU products release more emissions harmful to the climate than the status quo. Cars fueled by CCU petrol would only be on a par with normal petrol cars once the coal-fired power plants are shut down and approx. 80 % of Germany's electricity supply comes from renewable energy sources. Significant savings can only be achieved with virtually 100 % renewable electricity.[6]

As long as the electricity stems from coal, the debate about reputedly climate-neutral CCU fuels is dubious.

Current scenario studies, which analyses and quantify this problem in more detail in the context of energy transition and climate change mitigation are available.[7, 8, 9, 10] What they all have in common is that energy efficiency, direct electrification and hydrogen via power-to-gas are identified as the preferred and more advantageous technology options. The remaining potential will then be realized with CCU, with CCU fuels being imported predominantly or exclusively from regions with abundant sun or wind.

From the WWF's point of view, the emerging debate about supposedly "climate-neutral" fuels is therefore dubious - especially in view of the coal phase-out. Significant greenhouse gas savings would be feasible only after the end of coal-fired power generation with almost 100 % electricity supply from renewables. But renewable electricity is needed for other purposes. No greenhouse gas savings will be achieved with CCU fuels in car traffic, at least not with fuels produced at German locations.

Potential reductions as a result of CCU vary from product to product and must be determined in life cycle analyses.

Apart from the production of fuels for cars, there are generally better conditions for CCU to have a positive impact on the climate in places where a carbon cycle can form. The actual savings vary from product to product and from process to process and must be determined in a life cycle analysis.

There is no way around far-reaching CO_2 avoidance measures.

A current analysis concludes that, in total, only 1 % to a maximum of 8 % of CO_2 emissions could be reduced by CCU across all potential CCU technologies[11]. From the point of view of climate change mitigation, CCU can thus also be viewed critically as a "diversionary maneuver". In other words, CCU creates the impression that it is not really necessary to reduce fossil emissions because CO_2 from power stations and industrial plants would be a valuable feedstock. In fact, there is no way around far-reaching CO_2 avoidance measures because even if all CCU potential is exploited to the fullest extent, 99 to 92 % would simply have to be avoided.

… still plays an important role in a climate-neutral economy

On the other hand, every contribution is necessary to achieve the goal of climate neutrality and CCU is still needed even though it only makes a small contribution to reducing greenhouse gases.

The greater importance of CCU lies in a broader view of securing the feedstock base and resource efficiency. For the chemical industry, CCU processes form a new feedstock basis alongside sustainably produced biomass.

The greater importance of CCU lies in a broader view of securing the feedstock base and resource efficiency. In an energy supply system based almost 100 % on renewable energy, CCU processes are one option for the long-term storage of electricity. Their flexible use adapted to weather conditions contributes to the stability of the overall system and allows all available electricity quantities to be fully exploited. In a climate-neutral economy that no longer uses petroleum, natural gas and coal, CCU processes form the new feedstock basis for the chemical industry alongside sustainably produced biomass. CCU fuels are also an alternative to petroleum-based fuels for mobility for which no other drive systems are currently conceivable, in particular air transport.

How can CCU be further developed?[12]

Despite all criticism, CCU technologies are by no means doomed to failure. For further research and research funding the WWF sees the following priorities:

Long-term binding of CO_2: The determining factor is how CCU is used. Fuels for transport or heating gas for use in individual heating systems are fundamentally problematic and will produce CO_2 emissions even with highly optimized processes. CCU for chemical feedstocks, construction materials or energy storage, on the other hand, have a good chance of sequestering carbon in the long term and for clearly traceable carbon cycles that can be controlled by the plant operator.

Reduction of energy consumption in CO_2 capture: Retrofitting conventional plants with CO_2 scrubbers will inevitably require more energy for gas scrubbing. This can be very considerable and can amount to up to one third of the energy consumption of the plant. This leads to a sharp increase in the consumption of fossil fuels, which runs counter to the original goal of the CCU concept. To overcome this obstacle, various approaches are being pursued in plant engineering, for example, cement or steel plants. In this case, the process is completely different and CO_2 capturing is integrated. Overall, this results in a lower quantity of CO_2 that was also collected. These developments are very important and open-ended in the sense that the CO_2 could be used as feedstock or deposited in the soil (Carbon Capture and Storage, CCS). In any case, considerable progress is being made because energy consumption and the total amount of CO_2 produced are reduced.

Reduction of high amount of electricity required for the CCU process: CCU electrolysis processes currently use a lot of electricity. One promising way to bypass the electricity problem is to include biological processes. If, for example, the captured CO_2 is converted to biomass on a large scale in algae cultures, the energy obstacle is overcome by photosynthesis. Although the systems still need electricity to maintain constant lighting and temperature, for example, the amounts are negligible compared to the electricity required for electrolysis. Valuable substances can be extracted from the algae mass. Another example of CCU without electrolysis is carbonation, i. e. the absorption of CO_2 by rocks or industrial residues (slag, ash). Carbonation is a natural process in rock formations. It can be greatly accelerated for industrial applications to produce building materials.

Research is being supported in a variety of ways and funding for climate-friendly technologies is generally on the rise. When deciding on financial backing, the priority should be the extent to which the proposed project can actually contribute to climate neutrality and the elimination of fossil raw materials.

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