ROLE OF CARBON AND LONG-TERM MITIGATION STRATEGIES BEYOND 2050 THROUGH CARBON CAPTURE AND USE (CCU) AND CLOSING THE CARBON CYCLES (C³)

ISSUES PAPER

Prepared by the ICC Commission on Environment and Energy

This issues paper is a technical background paper aimed for discussion. It is not an ICC position and does not reflect a consensus on this topic.
Key messages and aspects at a glance

CCS (Carbon Capture and Storage) and CCU (Carbon Capture and Use) seem to be nearly the same at first glance…
… but are very different and a clear distinction should be made in discussions and decision making.

Business needs to focus on the here and now…
… but also looks far into the future and well beyond current boundaries.

Most of the global mitigation challenges are energy related and can be addressed by fuel switching…
… but indispensable use of carbon requires alternative approaches in certain applications.

It is not the use of carbon or the occurrence of CO₂ that is dangerous…
… but only the emission of GHGs into the atmosphere that is causing climate change.

CO₂ is a chemically very stable molecule causing serious climate challenges…
… but sufficient amounts of renewable energy can transform it into valuable input materials for many industrial processes – both as an energy carrier and a material resource.

In the short-run potential still exists to improve current processes…
… cross-industry approaches and CCU are important steps in the medium-run over the next decades…
… but in the long-run closing the carbon cycle (C³) is essential after 2050.

CCU only seems to be a niche application and a researcher’s dream today…
… but current developments show that its long-term CO₂ transformation potential is only limited by the provision of adequate infrastructure.

Widespread CCU including Closed Carbon Cycles (C³) is expected to be fully operational post 2050…
… but initial steps need to be taken today to reach this goal in time.

Business will continue its efforts on R&D and deployment …
… but this must be accompanied by stimulating regulatory frameworks and acknowledging the role of business and other stakeholders.

CCU and Closing the Carbon Cycle (C³) indeed are capital-intensive approaches…
… but globally efficient market mechanisms, adequate climate financing and strengthening of existing technology mechanisms (such as under the UNFCCC) can support their wide-scale deployment and global availability; including to developing countries..

COP 21 is not the time or the place to discuss such issues in detail as technology neutrality and support of all promising mitigation solutions is called for …
… but COP 21 must keep the door open also to this promising approach by enabling the right framework or addressing unforeseen barriers.

¹ This paper focuses on CCU only and does not assess or evaluate CCS.
Background and outline of ideas

Effective climate protection requires a significant reduction of greenhouse gas emissions including CO₂. Additionally, we need to maintain economic growth and development, provide an adequate standard of living for a growing and ageing world population in a sustainable manner. A major strategy is the use of renewable energies instead of fossil-fuel based energy, which is the predominant source of carbon emissions today. Other strategies especially in the short to medium term include using more gas and other fuels lower in GHG emissions, and focusing on energy efficiency to reduce energy demand or also CCS where appropriate.

But not all greenhouse gas emissions can be avoided by a fuel switch. When carbon is used for its chemical properties or where carbon is an unavoidable component of an indispensable input material, then it cannot be readily substituted. There are many examples of such cases which are essential for our modern society. Examples include the manufacturing of chemicals and pharmaceuticals (carbon is an integral part of the product), or the production of cement or lime (the raw materials contain CO₂).

For such non-energy applications, an alternative mitigation strategy is CCU (carbon capture and use) which in the long-run needs to be embedded in a truly circular economy. CO₂ can be captured and reused as a valuable raw material. This can be carbon-neutral if the required energy is provided from renewable sources or other energy sources without GHG emissions. However, the technologies, business models and infrastructure will take decades to be developed and installed. But in order to have it ready when it is needed, political attention and the appropriate policies and regulatory framework are needed today. This focused discussion could start at COP 21 with enhanced recognition of CCU as a valuable option in a global climate agreement—rather than yielding to pressures to ban the use of carbon as such completely.

There is a major difference between carbon-free and carbon-neutral. Neither life nor prosperity without carbon is possible – but it is possible to avoid releasing fossil CO₂ emissions into the atmosphere.

Requests for political support

- Acknowledge Carbon Capture and Use (CCU) and Closing the Carbon Cycle (C³) as a suitable and an environmentally sound mitigation strategy for select cases of indispensable carbon use and ensure general political support.
- Include this technology option (amongst other suitable ones) in relevant considerations, documents and strategies at UN and national levels including Intended Nationally Determined Contributions (INDCs) and other national climate policies where appropriate.
- Develop enabling regulatory frameworks and foster socio-political dialogues to inform and assist public acceptance of these technologies.
- Generate funding and financial risk-mitigation mechanisms for necessary R&D, deployment and infrastructure; including adequate market mechanisms on a global scale.
Closing the carbon cycle to mitigate climate change sustainably in the long term

Closing the carbon cycle means **using carbon and avoiding release of CO₂ by capturing it to use it again** (and again and again...). Initial bits and pieces such as CCU units can start locally. But it is not sufficient to just use CO₂ once in production processes, because the products most likely release that embedded CO₂ at the end of their lifetime. We need to expand current CCU approaches into a truly circular approach based on renewable energy only. Ultimately, in a few decades, an integrated system of processes, uses and infrastructure is needed. This ensures that **carbon can be used efficiently where needed**, while at the same time **climate relevant net-CO₂ emissions are avoided effectively**. Any use of CCU that does not operate in a closed system (that is, where all CO₂ is re-captured and ultimately permanently isolated from atmosphere) already contributes by **delaying CO₂ emissions** and reduces CO₂ in the atmosphere for decades.

The ultimate goal should be to strive for net-zero emissions by closing the carbon cycle completely. This requires **cross-sectoral approaches**. One example could be the capture of CO₂ emissions from one process (e.g. steel-making) and their use as an input in the next process (e.g. polymer production). The circle is closed by capturing CO₂ from final end-of-life emission sources such as waste incinerators and making CO₂ again available as a raw material. Such a circular economy would result at the end in **zero net emissions and an overall CO₂ emission-free system**, if **decarbonized energies are used** throughout. Such zero net emissions can equally be achieved if not all emissions are captured -- as long as there are “net-negative emissions” from capturing more CO₂ than is being released in a particular reference frame.

**Today: separated quadrants**

**Tomorrow: Closing the carbon cycle**

Source: Dr.-Ing. Hans-Jörg Weddige, thyssenkrupp

The **limitation is not on the side of using CO₂**, but on the **availability of sufficient decarbonized energy** to turn CO₂ into a useful carbon raw material again. But it is not necessary to convert CO₂ always fully back to carbon. **Intermediate carbon compounds** (such as CO) are often sufficient. And this reduces the energy demand significantly.

**Closing the carbon cycle** is a **long-term option** for a **specific part of our common climate change challenge**. We are not talking about science fiction as individual building blocks are already under development and can begin to make contributions on a much shorter time horizon. However, it is a grand design and this far-reaching transition will take decades to complete.
A closer look on the challenges.

There are several hurdles to be overcome before a widespread deployment of CCU will be possible. This requires activities and engagement from all stakeholders in society and can only work if adequate political decisions support such approaches.

Scientific and technical obstacles certainly are still to be overcome. Tackling these obstacles will require engineering ingenuity paired with investments in Research and Development (R&D) to address especially cross-industry process-chains. The deployment of CCU and closing the carbon cycle also requires the development of new business models so that it becomes economically viable. This is the inherent responsibility of industry and business, provided that governments put in place the required framework. It still needs substantial discussions and work within the value chain over the next decades.

Such a redesign of industry and business requires access to affordable capital. Many uncertainties make investments in industrial-scale and long-lived assets very risky, both for actual CCU installations as well as for required renewables. This calls for considerable risk capital financing. To enable a swift diffusion and adoption worldwide, adequate financing mechanisms are needed, including investment and deployment support. In particular, risk mitigation for ‘first to third of its kind’ installations will be crucial to accelerate their deployment. Lack of capital seems currently not to be the issue since there is lots of finance looking for investment opportunities. Given an adequate policy and regulatory framework, investment uncertainty can be reduced and a huge potential exists to generate significant growth across industries.

Using CO$_2$ as a carbon resource is very attractive where there are large and concentrated CO$_2$ sources on the one hand and users of carbon on the other in interconnected industrial clusters. This allows a new view on optimizing processes across sectors, for example in the value chain energy – steel – chemistry – automotive – municipal services. This can also have significant effects on regional planning. Provision of required infrastructure to capture and transport CO$_2$ and the intermediate raw materials and products is a further challenge.

A suitable regulatory framework supporting CCU and closed carbon cycles is needed to stimulate growth and investments. Adopting the MRV (monitoring, reporting and verification) rules to include CO$_2$ exports to CO$_2$-using installations as carbon-neutral can be an important step towards this. A meaningful LCA (life cycle assessment) is required to identify the actual potential and contribution of any suggested activity.

Another example is the land-use and forest sector, which is key for the accomplishment of many national climate policies – but also to close carbon-cycles. It is estimated that 20-25% of the INDCs delivered for COP 21 rely on the land-use sector. As such, it is important to ensure the availability of resources and proper means of implementation. Reducing emissions from deforestation and forest degradation (REDD+) and market mechanisms deserve special attention as they build on current
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Efforts and could have a major impact on forest related mitigation actions, covering deforestation, degradation, conservation and the enhancement of forest carbon stocks for multiple purposes, including restoration and finally closing the carbon cycle to achieve zero net carbon.

There are many challenges to overcome for which there are not yet ready-made, clear cut solutions. Long-term economic feasibility is necessary to pursue such ideas.

However, while economic enabling conditions and benefits are important, societal acceptance will be fundamental. Initial resistance to such approaches can be a socio-political challenge. It must be explained that such approaches are evidence of industry’s willingness to change its production processes and traditional ways of doing business. Such changes can lead to a broad range of environmentally sound solutions for future generations. Open dialogue and honest discussions about options, challenges and opportunities are needed. This paper is a first step in this direction. But to reach this goal adequate political support is needed.

It is indispensable to build credibility for such ideas. Without that, it will not be possible to mobilize researchers’ ideas, process engineers’ implementation skills and the willingness of boards to provide financing.

It is essential to identify and address these challenges today in order to deliver solutions tomorrow.

Only through gaining political support and momentum can CCU go forward rapidly as one of the solutions to climate change. The process can and should start at COP-21.

More detailed information can be found in the two technical appendices on the following pages.
Appendix 1 on General Background: Strategies for avoiding CO\textsubscript{2} emissions and the role of closing the carbon cycle (C\textsuperscript{3})

In spite of the impressions often given, the use of carbon as such does not causing climate change as long as there are no greenhouse gas emissions released into the atmosphere. Climate change is fueled by releasing additional greenhouse gases, including CO\textsubscript{2} from fossil sources into the atmosphere, in addition to the “natural emissions” from bioactivities including human breathing.

To avoid climate relevant CO\textsubscript{2} emissions four options exist in principle:

I. Do not use carbon at all, hence no CO\textsubscript{2} can be produced (decarbonization)

II. Only use carbon from renewable sources, hence a balance between CO\textsubscript{2} emissions and CO\textsubscript{2}-uptake for renewal is obtained (“bio-carbon”)

III. Use carbon, but capture and lock away the CO\textsubscript{2} safely (CCS – carbon capture and storage)

IV. Use carbon, and then reuse the CO\textsubscript{2} as a valuable raw material and source for carbon and carbon compounds without releasing GHG into the atmosphere (closing the carbon cycle with CCU – carbon capture and use)

I. As indicated the option of avoiding (fossil) carbon might be applicable for a majority of today's CO\textsubscript{2} emissions. This seems to be the solution for most if not all energy-related use of carbon. However, there are essential chemical applications of carbon where carbon is indispensable if society does not want to significantly reduce its standard of living. A world without using carbon at all is not possible. Carbon chemistry is literally at the heart of life and prosperity on this planet.

II. Using carbon from renewable sources can be an option for certain applications, but this approach has its limitations. It cannot substitute all carbon-bearing inputs, such as limestone in cement or lime making. Since this approach requires sustainable forestry to be acceptable, huge areas of land are needed, which is expected to cause serious conflicts of use. Calculations estimate for example the amount of land required to produce “bio-coal” for just 10 million ton of steel to equal the size of the Kingdom of Belgium. Further, the physical and chemical properties (such as energy densities, flame temperatures, transportability or physical strength) of “bio-coals” might not be sufficient to be a true substitute for some important carbon uses in the foreseeable future.

III. The role of CCS and its contribution to climate change mitigation are strongly disputed by many NGOs, but accepted by major economies, the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC), as well as leading intergovernmental agencies such as the International Energy Agency and the Organisation for Economic Co-operation and Development. CCS does not close the carbon cycle, but it avoids a loose end by “trapping” CO\textsubscript{2} in geological formations. Therefore there is strong debate about the availability of storage sites, safety of enclosure, conflicts of interest regarding other uses such as water or mining, etc. The IPCC notes in its latest Assessment Report that all of the components of integrated CCS systems exist and are in use today in various parts of the fossil energy chain; and that total practical geologic storage capacity is large and likely sufficient to meet demand for CO\textsubscript{2} storage over the course of this century, albeit the capacity is geographically unevenly distributed. But the general acceptance of CCS in society is still sometimes lacking. It could play a role as a bridge technology or in closing the carbon cycle by acting as an intermediate storage before the entrapped CO\textsubscript{2} is used again later.
IV. CCU is the approach of capturing CO₂ and using it as an input to produce other products. Two different “uses” of CO₂ can be distinguished:

a. “Molecular use of CO₂”: There are certain polymers, in which CO₂ can be embedded as part of the molecular structure. Or CO₂ can be used as such; for example in greenhouses to speed up plant growth or for cleaning applications. Such uses are very limited and will only be able to contribute a minor part to solving the CO₂ problem.

b. “CO₂ as a raw material for carbon”: CO₂ can be used to provide – together with renewable energies – a source of carbon for further processes. This can include classical chemical processes as well as bio-chemical approaches and other novel inventions.

There are two different options to transform CO₂ into a carbon raw material again. On the one hand, it can be transformed to obtain pure carbon, which is very energy-intensive. On the other hand, for many applications it is sufficient or even more desirable to provide carbon compounds such as CO, as an important precursor to many chemical reactions. This offers a wide range of opportunities for CO₂ use and broadens the scope for CCU considerably in the medium to long run.

At first glance, the two approaches CCS and CCU might appear similar as they both start with capturing CO₂ from off-gases. But there are important technical, economic and socio-political differences which require a careful distinction between the two approaches. For example, when using CO₂ as the raw material for carbon, it is not required to have a very pure CO₂ at the beginning as is normally the case for CCS. In certain applications it might even be beneficial not to have pure CO₂ but a more suitable gas mixture instead: for example, in fertilizer production a mixture of CO and N₂ is much more desirable than pure CO₂. This paper does not deal with CCS, which would require its own detailed assessment.

In the long term, closing the carbon cycle (C³) in a truly circular economy is a very promising strategy to combine effective climate change policy with continued industrial activity and the preservation of societies’ wellbeing and standard of life.

As outlined in this paper, achieving this goal is not just a technical issue, but also requires careful socio-political discussions on needed infrastructure, location of CO₂ sources and users, possible intermediate storage facilities, and many other issues.
Appendix 2 on Technical Background: How to transform CO$_2$ from a perceived threat into a valuable input for a climate friendly industry

Ideas and suggestions for approaches to close the carbon cycle are quite plentiful in academic and research circles. They can be grouped into several key categories, such as:

- **Artificial photosynthesis**, biochemistry, CO$_2$ electrolysis and other means of decomposing CO$_2$ into carbon and oxygen, which can be then used again as feedstock (or be discarded without any negative impact on climate or environment)
- **Mineralization**, i.e. embedding CO$_2$ in artificial “rocks” which could potentially be used for construction applications
- **CO$_2$ valorization**, i.e. using CO$_2$ as a feedstock for chemical or biochemical processes replacing fossil raw material to produce fuels, base chemicals or other products are. This approach can be based on:
  - embedding CO$_2$ directly in products such as in certain polymers (“molecular use”), using it as a “fertilizer” in greenhouses, using it as a cleaning agent or in air-conditioning devices, etc.; or
  - breaking up the CO$_2$ molecule to obtain other valuable precursors for subsequent products (“CO$_2$ as a raw material for carbon”).

In all cases significant amounts of **energy** are required, sometimes in very large amounts. Therefore, these ideas rely on the availability of affordable and climate-friendly energy. In actual processes this is normally done by adding **hydrogen** as an energy carrier, which in itself is quite energy-intense its production. A limiting factor might be the enormous amount of electricity to produce the hydrogen needed.

Today there are **three main approaches to CO$_2$ valorization**:

- **Power to gas**: using renewable electricity to obtain artificial natural gas which then can be reused in various ways, including for electricity production or fed into the gas infrastructure. This is very much a buffer function and creates a storage opportunity for renewable energies.
- **Power to liquid**: using renewable electricity to produce fuels such as methanol, which then replace fossil-based fuels.
- **Power to chemicals**: using renewable energy and CO$_2$ to provide precursors for polymer materials. This can be achieved by directly using the CO$_2$ or by breaking up the CO$_2$ and using the resulting components.
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Other approaches under the umbrella of CCU such as artificial photosynthesis and mineralization do require much less energy theoretically. However, in reality it is extremely difficult to get these chemical reactions started and to proceed in sensible time scales -- in nature such processes normally takes thousands or even millions of years.

This explains why one of the most important questions regarding CCU is less the issue of CO₂ containing gas provision and treatment, but the provision of adequate catalysts to make reactions proceed fast enough to be of any value or commercial interest. Provision of sufficient hydrogen will be the limiting factor for industrial up-scaling.

Such ideas are not just scientific thought experiments. There have been many actual activities including industrial research and demonstration of such concepts.

But reliable solutions on an industrial scale do take time. Therefore this is not a short-term solution and it cannot replace on-going activities or mitigation efforts in existing production technologies. Extensive basic research followed by intensive applied research will be necessary to further develop and test those concepts, before they are market-ready.

The energy issue also determines why this approach cannot work for maintaining energy production from fossil fuels, because the energy required to break-up the resulting CO₂ afterwards is about three-times larger than the energy obtainable from burning carbon to CO₂ in the first place. Hence such approaches are useful when carbon is required for its chemical benefits and the expense of additional energy is justified, but not merely as an energy carrier.

Source: Dr.-Ing. Hans-Jörn Weddige, thyssenkrupp
The International Chamber of Commerce (ICC)

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