Europe needs a definition of Carbon Dioxide Removal

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Examples provided by: HeidelbergCement, Fortum, Stockholm Exergi, Drax, Climeworks.

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Executive Summary

As the European Union works to formally adopt its 2050 target to reach net-zero greenhouse gas (GHG) emissions, there is still no definition for what constitutes a 'removal'. The legally binding European Climate Law for climate neutrality by 2050 acknowledges the role of carbon dioxide removals, stating that,

> "while greenhouse gas emissions should be avoided at source as a priority, removals of greenhouse gases will be needed to compensate for remaining greenhouse gas from sectors where decarbonisation is the most challenging"[1].

Against this background, there is still substantial confusion regarding what constitutes Carbon Dioxide Removal (CDR). Publications regularly confuse this with Carbon Capture and Storage or Utilisation, while others assume that Direct Air Capture alone constitutes Carbon Dioxide Removal. Some 'Natural Climate Solutions' also carry potential to qualify as CDR. This report seeks to remedy these confusions by providing clear and visual definitions of what is and what is not Carbon Dioxide Removal.

This paper provides clear and concise definitions of commonly used terms around Carbon Dioxide Removal, to give an overview of existing technologies and their potential for emissions reduction, to identify some examples of European industrial plants that could go carbon negative and to advocate for European CO_2 transport and storage infrastructure, a real enabler for large-scale carbon dioxide removals.

Four principles must be met for any practice or technology to be commonly considered as achieving "Carbon Dioxide Removal".

1. *Carbon dioxide is physically removed from the atmosphere.*
2. *The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent.*
3. *Upstream and downstream greenhouse gas emissions, associated with the removal and storage process, are comprehensively estimated and included in the emission balance.*
4. *The total quantity of atmospheric carbon dioxide removed and permanently stored is greater than the total quantity of carbon dioxide emitted to the atmosphere.*

[1] European Climate Law, 2019

Content

Introduction: Why do we need a definition for Carbon Dioxide Removal?

Currently, most of the world's carbon dioxide (CO_2) emissions come from carbon which has been geologically stored for millions of years (fig 1). Since the Industrial Revolution, we have been drilling and mining carbon at an increasing industrial scale from these ancient reserves, extracting the energy to power modern society, and emitting CO_2 into the atmosphere as a by-product. This carbon dioxide has the effect of trapping outgoing planetary heat. The rate of accumulation of this geological CO_2 in the atmosphere has accelerated such that CO_2 concentrations have gone up from 354ppm to 411ppm since 1990, accelerating average global temperature increases to approximately 1°C.[2]

European governments have begun to respond by formulating long-term targets aiming to halt human impacts on the climate. In Europe alone, Austria (2040), Denmark, Finland (2035), France, Germany, Iceland (2040), Ireland, Norway (2030), Portugal, Slovakia, Sweden (2045), Switzerland, the United Kingdom, and the European Union as a whole, are expected or already have a target to reach 'net-zero' emissions by 2050 at the latest.[3]

A key point is that achieving net-zero emissions requires a net balance between emissions and removals from the atmosphere.

All efforts to mitigate the worst impacts of climate change must therefore look at significantly decreasing CO_2 emissions as a priority, while also increasing removals from the atmosphere. All pathways analysed in the IPCC's Special Report on 1.5°C require negative emissions to some extent to balance out residual emissions, achieve overall net-negative emissions, and to accelerate the overall reduction of human impact on the climate.

The developments of European CO_2 transport and storage infrastructure is a strategic choice in support of EU's climate goals. Once CO_2 infrastructure is in place, industrial emitters will be able to dispose of captured CO_2, transporting and storing it safely in geological formations. This will enable the EU to unlock the large-scale decarbonisation that will be needed in order to achieve net-zero by 2050, while also providing the necessary infrastructure for Carbon Dioxide Removal.

This paper explains whether a process or project has the potential to qualify as Carbon Dioxide Removal, by providing clear and concise principles and illustrations of carbon flows.

[2] Intergovernmental Panel on Climate Change, 2018

[3] https://www.climatechangenews.com/2019/06/14/countries-net-zero-climate-goal/

What is Carbon Dioxide Removal/ Negative Emissions/Carbon Negative?

Terminology: CDR as the preferred term

The terms Greenhouse Gas Removal (GGR) and Negative Emission Technology (NET) have also been used to describe the same or similar processes. These terms are somewhat interchangeable.

Greenhouse Gas Removal refers to the removal of all greenhouse gases. However, the effect of CO_2 and other greenhouse gases on the climate are not entirely 'like-for-like' and the nature of their accumulation in the atmosphere is also quite different. Furthermore, efforts to remove other GHGs are less clear. To avoid confusion and possible loopholes, it is best to address the removal of CO_2 on its own.

Similarly, Negative Emissions refers to the concept of removals, which is the opposite of emissions. This term doesn't refer specifically to any greenhouse gas.

Negative Emission Technologies refers to specific technologies or processes which can be used to achieve Carbon Dioxide Removal.

To avoid confusion, this report only uses the term Carbon Dioxide Removal, explained below.

What does Net-Zero mean?

The target of the Paris Agreement, made effective in 2016, is to *"achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"*. "Net-zero" is the term which has come to represent this balance between emissions and removals. It is important to note that reducing emissions remains the absolute priority for the mitigation of climate change.

Any entity aiming for 'net-zero' emissions generally assumes some degree of Carbon Dioxide Removal. For example, an entity aiming for 'net-zero' and 80% reductions in emissions by the same date is implying that 20% of their 'net-zero' target will be met with Carbon Dioxide Removal.

What does Carbon Dioxide Removal mean?

There is no official or widely accepted definition of what 'Carbon Dioxide Removal' technically means. Conceptually, CDR entails taking CO_2 out of the atmosphere, where it contributes to climate change, and putting it someplace where it will not affect the climate for a long time. The aim is to reduce the concentration of CO_2 which is in the atmosphere. This can generally be achieved through both natural and technological means. The below definition of Carbon Dioxide Removal should be used for all proposed forms of Carbon Dioxide Removal.

There are four principles to bear in mind when assessing whether a process can be classified as Carbon Dioxide Removal. These are adapted from (Tanzer & Ramírez, 2019).

1. Carbon dioxide is physically removed from the atmosphere.
2. The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent.
3. Upstream and downstream greenhouse gas emissions, associated with the removal and storage process, are comprehensively estimated and included in the emission balance.
4. The total quantity of atmospheric carbon dioxide removed and permanently stored is greater than the total quantity of carbon dioxide emitted to the atmosphere.

Put simply, a process must permanently remove more CO_2 from the atmosphere than it emits. A good question to ask is: *will there be less CO_2 in the atmosphere after the process?*

If this relatively simple question is difficult to answer, then in all likelihood the process does not result in Carbon Dioxide Removal. This is due to upstream and downstream emissions, which are explained below.

The first and second principles, the combined removal and storage of CO_2, are the core element of any CDR process. These 2 principles should be used as an initial assessment. The third and fourth principles only need to be assessed if a process abides by the first two principles. As such, this report only illustrates the removal and storage elements of various processes which have been linked to Carbon Dioxide Removal.

Principle 1: Carbon Dioxide is physically removed from the atmosphere

The first step in creating a Carbon Dioxide Removal process is ensuring that the carbon comes from the atmosphere. Carbon which is taken from the biosphere or from the oceans can also, conceptually, be considered as having been removed from the atmosphere, however, detailed discussion of these approaches is not in the scope of this paper.

This first principle ensures that the source of the carbon dioxide remains a central element of any assessment of Carbon Dioxide Removal and ensures that a CDR process acts to reduce the concentration of CO_2 in the atmosphere.

Principle 2: The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent

The second principle of Carbon Dioxide Removal ensures that the CO_2 does not re-enter the atmosphere once it is removed. The CO_2 must be stored such that it is not intended to re-enter the atmosphere.

Geological storage is a proven method of storage which locks CO_2 away from the atmosphere for geological timescales. For all intents and purposes, geological storage is permanent.

Most other forms of CO_2 storage require management to ensure the carbon is kept away from the atmosphere. For instance, in biological organisms such as forests, these must be continuously managed such that the organism (and the carbon it retains) remain in place for as long as possible. Efforts must be made to reduce the 'reversibility' of the CO_2 storage. For agricultural practices which increase the carbon content of soil, this practice must be continued indefinitely, at risk of reemitting the stored carbon into the atmosphere. In some respects, "other" forms of CO_2 storage require much more active management than geological storage. This is not to exclude the fact that there are co-benefits to these storage methods, such as improvements to biodiversity and climate resilience.

Principles 3 & 4: Upstream and downstream emissions affect the carbon removal potential

Examining upstream and downstream emissions is critical in determining whether a process truly removes more CO_2 than it emits. Most of the ways to remove CO_2 from the atmosphere need some energy, transport, fertilisers, or other inputs, which tend to emit greenhouse gases. This third principle ensures these inputs are considered.

As shown in Tanzer & Ramírez (2019), to get an accurate picture of a whether a process removes more CO_2 from the atmosphere than it emits, a wide Lifecycle Assessment must be used. The wider the assessment (i.e. the more inputs it includes), the less a process is shown to permanently remove CO_2 from the atmosphere. Inputs that should be considered include: biomass origin, energy use, gas fate, and co-product fate.

For instance, in the deployment of Direct Air Capture, the CO_2 emissions from the energy required to power the facility must be considered.

Projects which rely on biomass to remove CO_2 from the atmosphere can have complex considerations when assessing carbon flows and accounting. Impacts of land-use change and indirect land-use change must be fully assessed to ensure that more carbon flows out of the atmosphere than into it. In addition to carbon flows, the sustainability and ecosystem-service of any biomass source needs to be accounted for.

The question of removing CO_2 with biomass can also include a temporal consideration. The EASAC indicates that there is a 'carbon payback period' for processes which use biomass.[4] Simply explained, if a tree is combusted then all the carbon it has accumulated over its years of growth would quickly be 're-released' into the atmosphere if not captured and stored.

Therefore, as a general rule of caution, if a process is shown to have only marginal CO_2 removal, it should not be considered as CDR.

The same can be said about processes which are conceptually carbon neutral. Since there are significant energy inputs in reusing CO_2, these must be taken account when assessing individual projects for their climate impact.

[4] EASAC website, Environment section

Does my project have Carbon Dioxide Removal potential?

Conceptually, Carbon Dioxide Removal is simple. The below graphs illustrate the carbon flows of various processes which potentially qualify as CDR, provided they abide by the first two principles cited above, namely:

1. Carbon dioxide is physically removed from the atmosphere.
2. The removed carbon dioxide is stored out of the atmosphere in a manner intended to be permanent.

These 2 principles can be used to rapidly assess whether a process or project has the potential to remove CO_2 from the atmosphere. The primary purpose of this exercise is to make the distinction between processes which can remove CO_2 and those which cannot.

Meeting both Principles 1 and 2 is the minimum requirement for a process to have CDR potential. Other emissions from the process chain will only need to be assessed if these first two conditions are met, to verify that the process truly results in Carbon Dioxide Removal.

Illustrated examples

The section below illustrates certain processes which comply with Principle 1 (CO_2 is removed from the atmosphere) and Principle 2 (CO_2 is stored permanently) and some which do not.

In the real world, processes which have the potential for Carbon Dioxide Removal will be dependent on the rigorous application of Principle 3 (upstream and downstream emissions) and Principle 4 (more CO_2 is removed than is emitted in the entire process).

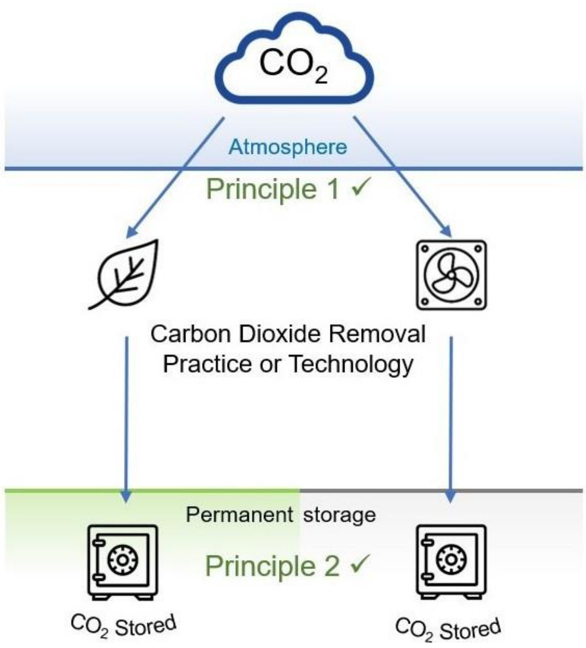


Fig 1. Carbon Dioxide Removal Practice or Technology

CO_2 is removed from the atmosphere and goes into geological storage or into the biosphere with the intention to keep it there for as long as possible. This process is the opposite of CO_2 emissions.

Principle 1 – Yes, the CO_2 the removed from the atmosphere.

Principle 2 – Yes, the CO_2 is stored in a manner intended to be permanent.

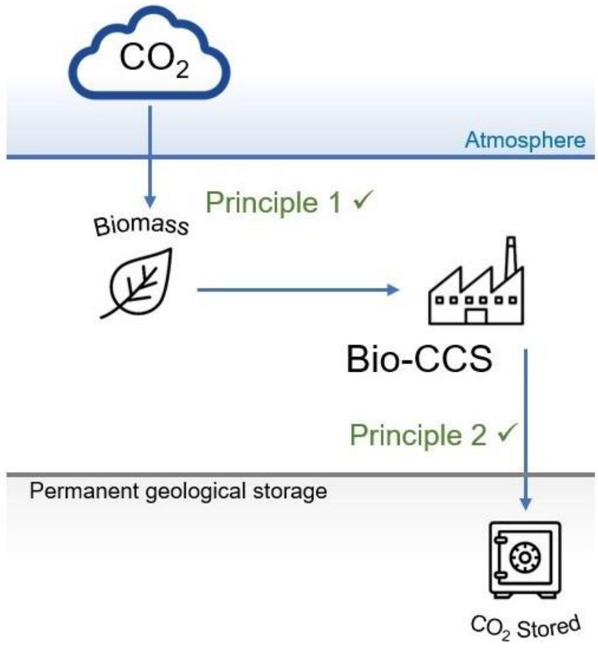


Fig 2. Bio-CCS has the potential to result in Carbon Dioxide Removal, however a further assessment of upstream and downstream emissions is necessary.

CO_2 is removed from the atmosphere by photosynthesis and bound as carbon in biomass. The biomass is combusted for energy or converted to a product or a gas with the carbon extracted. This carbon as CO_2 is captured and geologically stored.

Principle 1 – Yes, the CO_2 is removed from the atmosphere.

Principle 2 – Yes, the CO_2 is placed into geological storage.

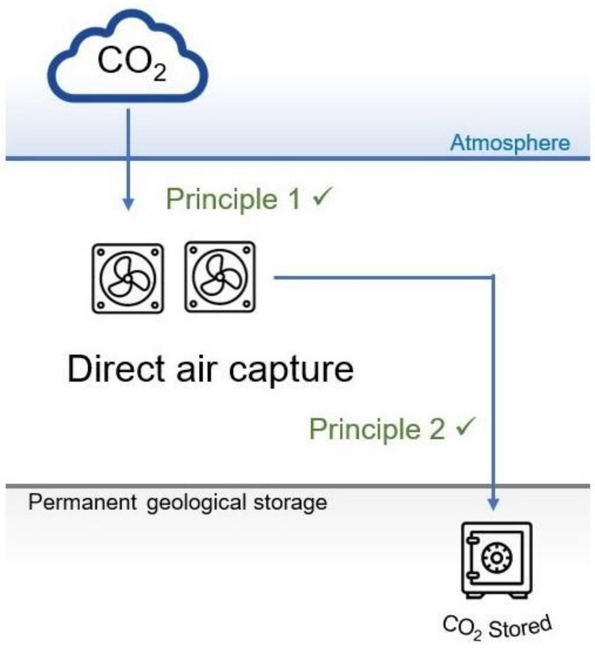


Fig 3. Direct Air Capture and Storage has the potential to result in Carbon Dioxide Removal, however a further assessment of upstream and downstream emissions is necessary.

Direct Air Capture units remove CO_2 from ambient air, removing it from the atmosphere. The CO_2 is then geologically stored. As with all CDR methods, for the DACS process to result in carbon removal, upstream and downstream emissions must be less than the CO_2 that is removed from the atmosphere.

Principle 1 – Yes, the CO_2 is removed from the atmosphere.

Principle 2 – Yes, the CO_2 is placed into geological storage.

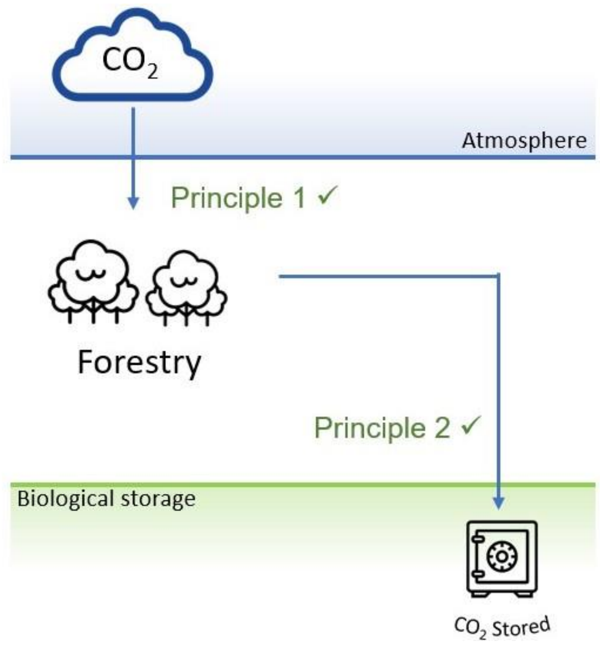


Fig 4. Forestry has the potential to result in Carbon Dioxide Removal, however a further assessment of upstream and downstream emissions is necessary.

The CO_2 is removed from the atmosphere by photosynthesis, where it becomes biomass. The forest is managed in such a way that more carbon is removed than is emitted. For storage of CO_2 to be permanent, the biomass must remain intact.

Principle 1 – Yes, the CO_2 is removed from the atmosphere.

Principle 2 – Yes, provided the CO_2 is bound indefinitely to the biosphere.

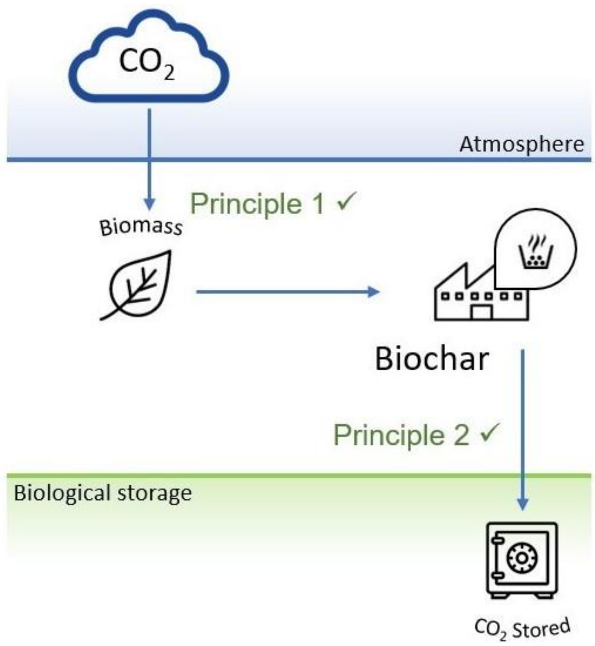


Fig 5. Biochar has the potential to result in Carbon Dioxide Removal, however a further assessment of upstream and downstream emissions is necessary.

CO_2 is removed from the atmosphere by photosynthesis and bound as carbon in biomass. The biomass is heated at high temperature without additional oxygen, transforming the carbon into a stable structure (e.g. charcoal). The biochar is then dispersed onto agricultural soils. Due to the stability of biochar, the CO_2 can remain stored for several hundred years.

Principle 1 – Yes, the carbon is removed from the atmosphere.

Principle 2 – Yes, provided that the biochar is used for applications that ensure long-term storage away in the biosphere.

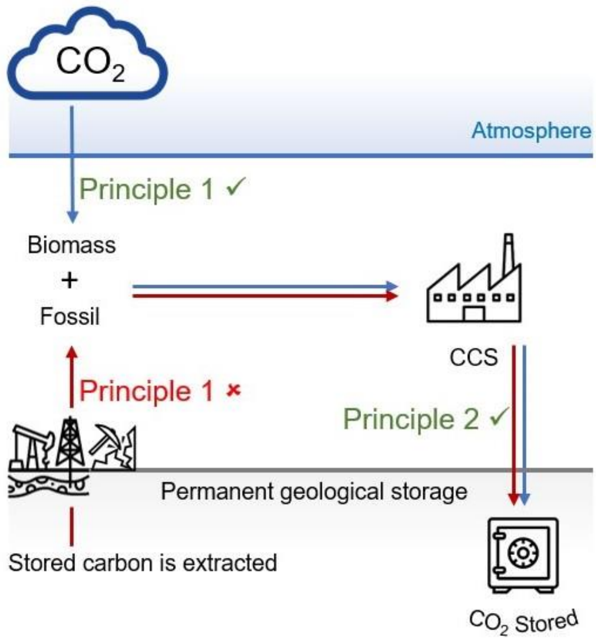


Fig 6. Combined feedstock with CCS shows how CCS can act as a transition from mitigation towards Carbon Neutrality or even Carbon Dioxide Removal when the feedstock is converted.

This process is a combination of the 'Bio-CCS' and 'CCS' processes and illustrates a facility which uses both fossil and non-fossil CO_2 with CCS. A typical example of this is a Waste-to-Energy plant with CCS, since both biogenic waste (food, paper) and fossil waste (plastic) is combusted.

In this process, CO_2 is extracted from both the atmosphere and from geological storage. This mixed CO_2 stream is captured and geologically stored. Depending on the share of atmospheric CO_2, this process has the potential to be Carbon Dioxide Removal.

Principle 1 – Yes, CO_2 is taken from the atmosphere. ***However, the captured CO_2 is a mixed steam of atmospheric and geological CO_2. The potential of CDR is directly related to the share of atmospheric CO_2.***

Principle 2 – Yes, the CO_2 is geologically stored.

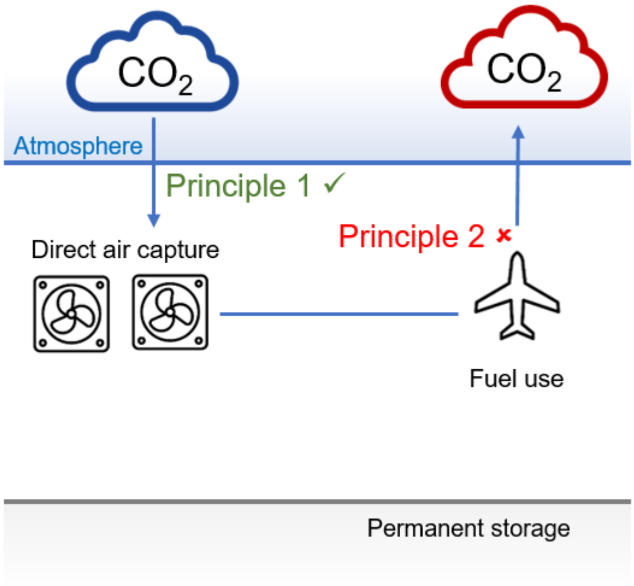


Fig 7. Direct Air Capture-to-fuels does not have the potential for Carbon Dioxide Removal.

CO_2 is removed from the atmosphere with Direct Air Capture facilities. The captured CO_2 is used to make fuels. The fuel is combusted, releasing the CO_2 to the atmosphere. This process does not store CO_2.

Principle 1 – Yes, CO_2 is captured from the atmosphere.

Principle 2 – No, the CO_2 is re-emitted into the atmosphere when it is burned as fuel.

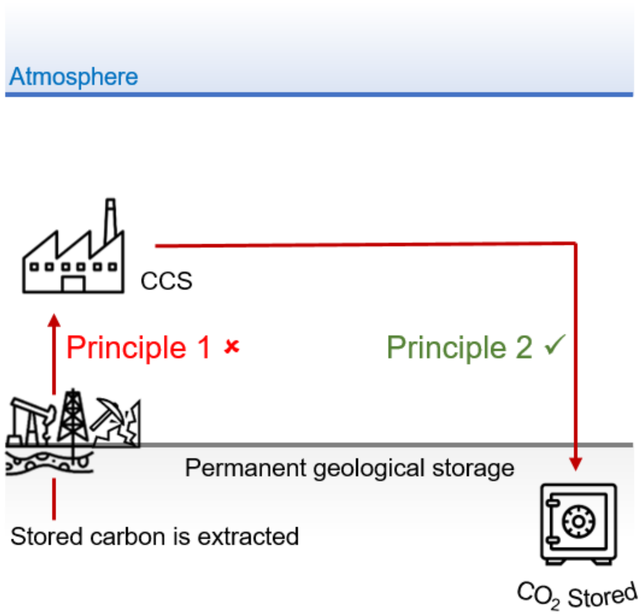


Fig 8. Carbon Capture and Storage typically reduces emissions by around 95%.

Geological carbon, such as fossil fuels and limestone, is removed from geological storage, and used, releasing CO_2 which is captured from the flue gas. The captured CO_2 is then geologically stored. The process alone cannot result in Carbon Dioxide Removal since no CO_2 has been removed from the atmosphere.

Principle 1 – No, the CO_2 is removed from geological storage.

Principle 2 – Yes, the CO_2 is geologically stored.

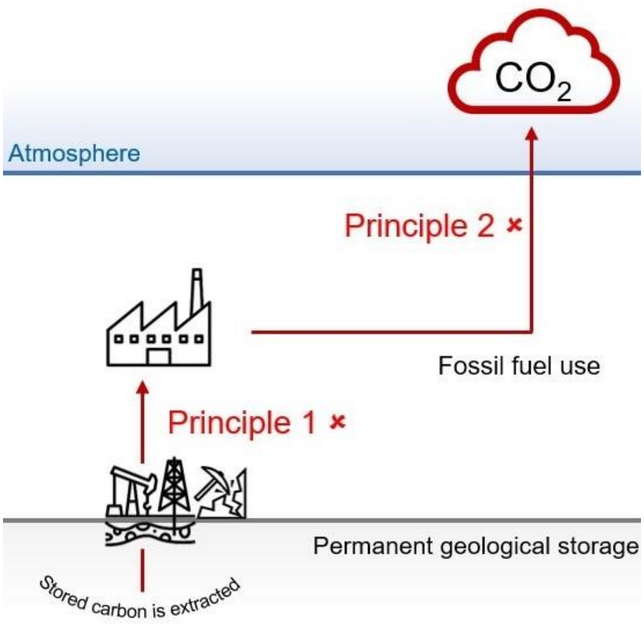


Fig 9. CO₂ emissions resulting from carbon mining and disposal in the atmosphere

Carbon is extracted from geological storage and combusted, adding CO_2 into the atmosphere. This process is the principal cause of climate change. It is the industrial acceleration of this process which has changed the atmospheric composition of greenhouse gases to the extent that we see today.

Principle 1 – No, the CO_2 is taken out of geological storage.

Principle 2 – No, the CO_2 is emitted into the atmosphere.

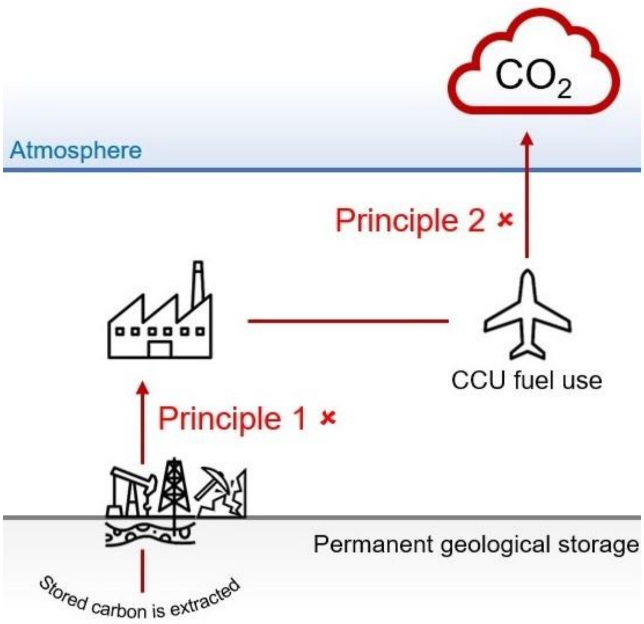


Fig 10. CO_2 Utilisation-to-fuels results in an increase in carbon dioxide in the atmosphere.

Fossil fuels, containing carbon, are removed from geological storage, and combusted, releasing CO_2 which is captured and converted to fuels. The fuels are used, and CO_2 is released into the atmosphere. This process does not remove or store CO_2, therefore adding CO_2 to the atmosphere.

Principle 1 – No, the CO_2 is extracted from geological storage.

Principle 2 – No, the CO_2 is emitted into the atmosphere.

European CO_2 transport and storage infrastructure – the enabler for carbon removals

The development and large-scale deployment of cross-border, European CO_2 transport and storage infrastructure is crucial to reach the European Union's objective of net-zero GHG emissions by 2050. This infrastructure will enable clean, competitive energy and industrial sectors, early large-scale clean hydrogen and not least the delivery of significant volumes of carbon emission reductions and removals.

As outlined in previous sections, permanent geological storage of CO_2 is the key component of the definition of carbon removal, where CO_2 is permanently removed, and it is a necessary dimension to deliver climate change mitigation. CO_2 transport and storage networks are urgently needed to aid large scale emissions reductions, especially from European industrial clusters. These same CO_2 transport networks and permanent geological storage have the potential to also contribute to numerous Carbon Dioxide Removal processes.

The European Union benefits from a world class storage region – the North Sea basin. This basin has tens of billions of tonnes (Gt) of CO_2 storage capacity and has the advantage of being offshore, thereby reducing the public acceptance barrier. Offshore development, however, has a higher capital cost than onshore but benefits from the cost savings delivered by economies of scale. Onshore CO_2 storage will also be important and is already proven in Canada and in the USA. Public acceptance has proven to be more challenging in Europe, due to population concentration and location. It is, therefore, likely that offshore storage will precede onshore storage[5]. The legally binding climate objective of net-zero GHG emissions by 2050 will require large volumes of CO_2 to be stored, therefore there is a strong need to increase storage appraisal in Europe.

CO_2 transport and storage infrastructure is essential to enable carbon removals, linking CO_2 emitters to storage sites and Europe is well positioned to develop cross-border, shared CO_2 transport and storage infrastructure[6]. Many of Europe's largest carbon emitters (both power plants and industrial facilities) are already clustered together around major ports and industrial regions[7]. Importantly, some industrial clusters are also close to excellent and extensive geological CO_2 storage opportunities.

Connecting a capture site to storage requires the transportation of CO_2 either via pipeline or by other modalities such as ship, barge, truck, and rail. Investments to retrofit existing natural gas pipeline networks into CO_2 pipeline networks can be advantageous and cut initial costs of infrastructure. In this respect, the European Taxonomy for

[5] ZEP report, "Identifying and Developing European CCS Hubs", 2016
[6] ZEP report, "CO2 Capture and Storage (CCS) in energy-intensive industries", 2013
[7] Such as Rotterdam, Amsterdam, Antwerp, Hamburg, Le Havre, Humberside, Teesside, Ruhr area, et al.

Sustainable Finance[8] has included the retrofit of gas pipelines for low-carbon gas transportation as a sustainable investment in a net-zero economy. This approach would pave the way to cross-border, regulated asset-based CO_2 transport and storage infrastructure, to which industrial emitters and power plants can plug in and decarbonise their production.

However, a clear signal from policy makers will be needed to support and incentivise the deployment of CO_2 infrastructure. Large public investments will be needed in the initial stages, and a favourable policy framework ought to be put in place on a European level to support industries, energy companies and Members State governments:

- The incumbent revision of the Trans-European Network for Energy regulation[9] (TEN-E) should be based on the European Green Deal and encompass the principle of climate neutrality by 2050. It should enable CO_2 transportation by several modalities (ship, barge, truck, rail), and include CO_2 storage – an essential component of a CCS full chain project – as a part of the Trans-European Network;

- The retrofitting of existing gas pipelines should be promoted and facilitated;

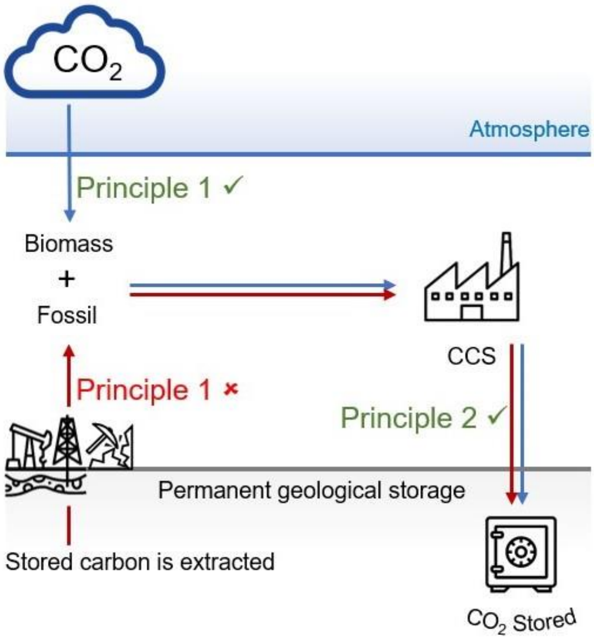
- More funds must be mobilised in addition to the Connecting Europe Facilities and the Innovation Fund[10]. The CO_2 transport and storage infrastructure should also be a crucial part of the post-pandemic green recovery stimulus package;

- The national decarbonisation pathways outlined in the National Energy and Climate Plans (NECP) should include deployment of CO_2 transport and storage infrastructure. They should also be aligned and coordinated with the upcoming European clean hydrogen strategy. Clean hydrogen produced from natural gas with CCS is a viable option for industrial decarbonisation that will require this CO_2 infrastructure.

[8] European Commission, Annex to Technical Report, 2020
[9] More on TEN-E Regulation: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=celex%3A32013R0347
[10] Zero Emissions Platform, Input to the Secretary General, 2019

Proposed or existing CDR projects in Europe

Combined feedstock with CCS – NorCem



Cement production contributes to climate change by combusting fossil fuels for heat and due to the chemical process of the calcination of the clinker. The main component of clinker is limestone, which is a geological source of carbon.

The NorCem cement plant in Norway has a proposed project that has the potential to achieve Carbon Dioxide Removal in the industry. By adding Carbon Capture and Storage, thereby capturing the process and flue gas CO_2 and permanently storing it, emissions can be abated by around 90 to 95%. Subsequently, by replacing fossil fuels with sustainable biomass to generate the necessary heat, the CO_2 which is captured will have originated from the atmosphere, leading to physical removal of CO_2 from the atmosphere. This process would thereby remove CO_2 and permanently store, while producing the essential building block that is cement.

This project meets both Principles 1 and 2 (see Combined Feedstock with CCS graph).

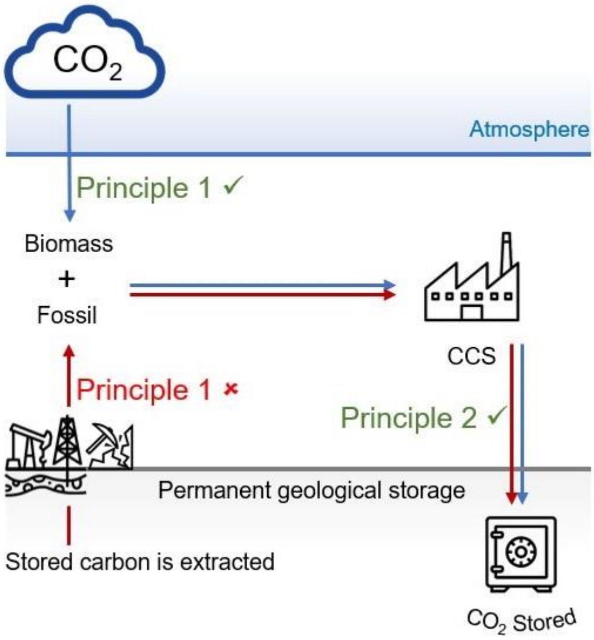
Combined Feedstock with CCS – Stockholm Exergi

Stockholm Exergi operates one of the most advanced urban multi energy systems in the world and is the main supplier of energy to the Stockholm region. The utility is co-owned by the Fortum group and the City of Stockholm. In 2019, annual energy production was approximately 8 TWh of district heating, 1.4 TWh of electric power and 0.5 TWh of district cooling. Production is mainly based on Combined Heat and Power fuelled by waste (900 000 tonnes), biofuels (mainly residues from forestry), large scale heat pumps recycling heat from sewage treatment facilities, and recycling of heat from data centres, office space and grocery stores. The last fossil CHP facility was decommissioned during beginning of year 2020.

Stockholm Exergi is developing a Bio-CCS project at the Värtan site, as a retrofit to the bio-fuelled KVV8-plant. The Bio-CCS plant will be based on the 'Hot Potassium Carbonate' (HPC) technology with a capture-rate of 80-95%. The Bio-CCS facility would result in about 800 000 tonnes of Carbon Dioxide being removed every year. The project is currently in the pre-study phase with forecasted start FEED in Q1/2021 and FID in Q2/2022. The scope for the project is a capture plant, liquefaction and intermediate storage in the harbour area.

In 2019, a test-facility based on the HPC technology was commissioned, with a capacity to capture up to 700 kg CO2/day. The test facility operates on actual flue-gases from the KVV8 unit and the test program focuses mainly on topics related to evaluating kinetic of reactions and degradation of the sorbent. The test program has proven the applicability of the HPC technology and from autumn 2020 it is intended to be re-designed and expanded for continued R&D.

This project meets both Principles 1 and 2 (see Combined Feedstock with CCS graph).



Combined feedstock with CCS – Klemetstrud Waste-to-Energy

Fortum Oslo Varme (FOV) owns and operates a Waste-to-Energy plant at Klemetsrud in Oslo, and burns household and industrial waste that cannot or should not be recycled. The plant processes around 400 000 tons of waste per year, with plans to increase capacity, and emits about 450 000 tons of CO_2 annually. Waste heat from the incineration is recycled to electricity and district heating/cooling to buildings in Oslo. Along with sorting and recycling, energy recovery of residual waste is a necessary part of the circular economy that removes unwanted, toxic components from the material cycle and allows resources from the remaining waste to be recycled.

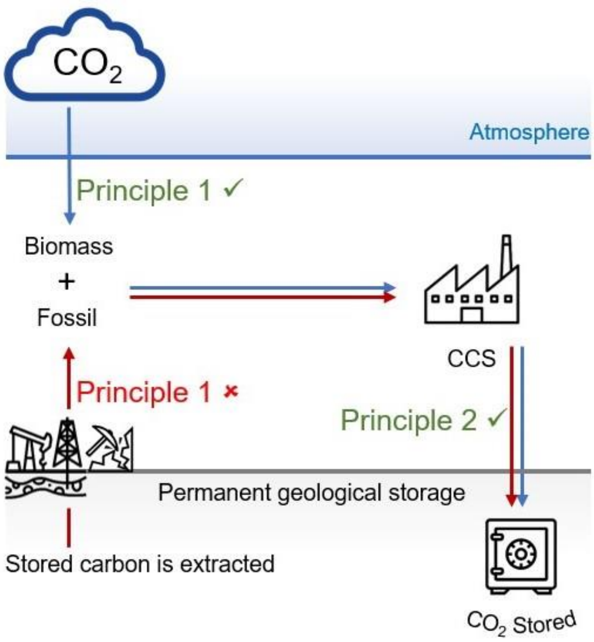
In 2015, FOV started a feasibility study to investigate the possibility of capturing CO_2 from the flue gas, and has completed both a concept study and a FEED study as part of Norway's commitment to establish a full value chain for CO_2 capture and storage. Captured CO_2 will be transported and stored permanently under the seabed in the North Sea with the Northern Lights transport and storage project.

As part of the FEED study FOV built and operated a pilot plant testing the chosen amine technology on the plant-specific flue gas. The pilot plant captured about 3 tons per day and tested for nine Months and 5500 hours with very good results regarding emissions and degradation of amine. DNV GL qualified the technology for Waste-to-Energy in 2019, with direct transfer value for coming capture projects in the Waste-to-Energy business.

The link between carbon capture, energy recovery and district heating is important from a resource perspective, which results in low energy loss because the available excess heat from the capture process can be reused in the existing district heating system using a heat pump. There is also a significant BIO-CCS (BECCS) potential in the Waste-to-Energy industry, and energy recovery with CO_2 capture can thus help achieve carbon dioxide removal. About 50% of the waste incinerated at the Klemetsrud plant in Oslo is of biogenic origin (including food waste, textiles, wood and paper/cardboard), which means that half of the CO_2 emissions from the incineration will be part of the natural CO_2-cycle. Thus, CO_2 capture on energy recovery will in effect remove CO_2 from the atmosphere.

Waste-to-Energy is also closely linked to urban infrastructure. Large emissions cuts must be taken in the cities, where populations are growing and both waste and emissions must be handled. In many cities, Waste-to-Energy facilities are the largest point emissions of CO_2, and the FOV CO_2 capture project demonstrates how CCS on Waste-to-Energy can be a key factor for cities' ability to achieve their climate targets and cut emissions effectively, including significant amounts of Carbon Dioxide Removal.

This project meets both Principles 1 and 2 (see Combined Feedstock with CCS graph).

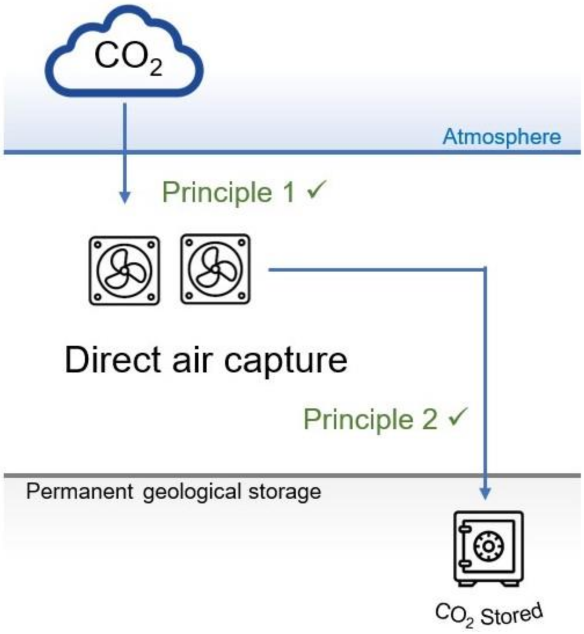


Direct Air Capture and Storage – Climeworks

The direct air capture technology, as an example of CLIMEWORKS, allows to physically capture CO_2 from the atmosphere using an adsorption filter. Ambient air is drawn into the direct air capture plant and the carbon dioxide is bound to the filter. When the adsorption filter is saturated with CO_2, the filter is heated up to approx. 100 °C (using mainly low-grade heat). The CO_2 is released and collected as concentrated CO_2 gas. CO_2-free air is released back to the atmosphere. This continuous cycle is then ready to start again.

In Iceland, the principle of negative CO_2 emissions has been realised in the EU-funded project "CarbFix2" in the vicinity of one of the world's largest geothermal power plants. There, CO_2 is taken from the atmosphere using Climework's technology and currently injected into the geothermal source, bounded to water and pumped more than 700 m into the underground. There the CO_2 will be mineralised within several years. The heat used to release the CO_2 from the filter is provided by the geothermal power plant, an abundant source of carbon-free energy in Iceland.

This project meets both Principles 1 and 2 (see graph DACS)



Bioenergy and Carbon Capture and Storage – Drax

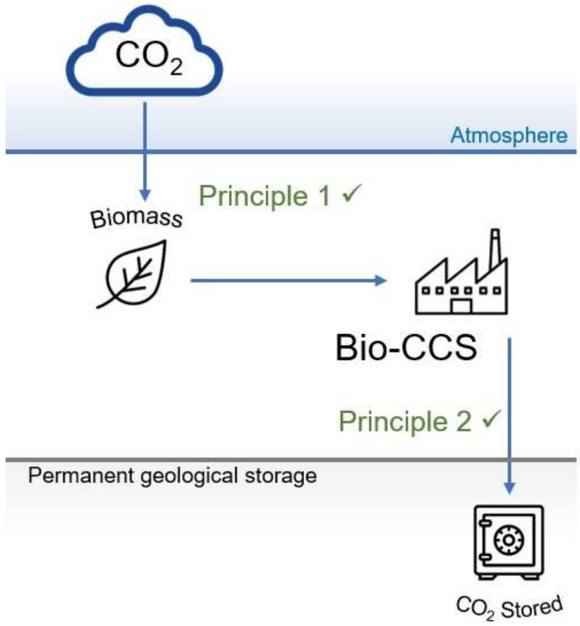
In recent years the Drax Power Station in Yorkshire has undergone a fundamental decarbonisation transition to operate on sustainably sourced biomass wood pellets in place of coal, converting four of its six generation units. The addition of carbon capture and storage to Drax's biomass units (BECCS) will allow the production of electricity with net-negative emissions.

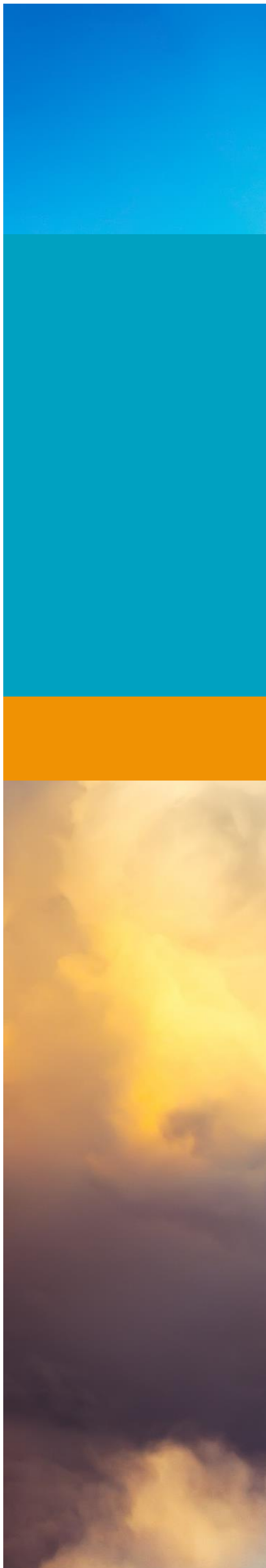
In February 2019, Drax announced the operation of a BECCS demonstration plant, to capture a tonne of CO_2 a day during the pilot phase. This is the first-time carbon dioxide gas has been captured from the combustion of a 100% biomass feedstock anywhere in the world. The project then received £5 million from the UK government to scale this up to capture 100 tonnes of CO_2 per day in Norway which will provide valuable technical data about the scalability of the project.

If scaled up each one of Drax's four 660 MW biomass units will be fitted with carbon capture and storage to capture 4MtCO_2 per year. Upon completion of this process, the four units will provide 2.4GW of clean 'firm' power on the system, whilst capturing 16MtCO_2 per year creating the world's first negative emissions power station. Conversion of the first unit could occur as early as 2027 subject to suitable policy frameworks, with the remaining units converting every other year until 2033.

The deployment of BECCS at Drax Power Station could act as an 'anchor project' for wider Carbon Capture and Storage (CCUS) deployment in the Humber region enabling the development of a CO_2 transport and storage network. This network unlocks decarbonisation of industry in the region through the deployment of CCUS and could enable the development of hydrogen production at scale for use in decarbonising of a range of sectors.

This project meets both Principles 1 and 2 (see Bio-CCS graph).





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