# Technology trends for $CO_2$ reduction

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## Introduction

Industry still dominates the share of greenhouse gas emissions affecting climate change. Emissions are still high despite the urgent need to address the primary causes of climate change. The Paris Agreement seeks to pursue efforts to restrict the increase to 1.5°C while limiting the global average temperature increase to well below 2°C above pre-industrial levels. This has also been incorporated into the crucial Sustainable Development Goals for Energy. In order to achieve climate targets, a highly adaptable system that can handle significant amounts of variable renewable energy sources must be developed. Benefits of system flexibility have been provided by coal- and gas-fired facilities, which are a significant source.

These facilities are able to continue offering these advantages and satisfy demands for long-term flexibility because to carbon capture, storage, and utilization. However, reluctance to change, a lack of knowledge, high investment costs, and failure anxiety all contribute to the delayed adoption of such technologies. The rapid rate at which technologies become outdated and the constant flow of new discoveries make this even more challenging. Moreover, a common basis for evaluating the impact of CCUS technologies is not available. To this end, all the techniques for the CO2 reduction were gathered and categorised based on the technology pathways and CO2 source of emission.

## Results & Discussion

The classification of these innovative and emerging techniques for combatting climate change has not been established yet, mainly due to the numerous combinations available. To this end, all the techniques for the CO2 reduction were gathered and categorised based on the technology pathways and CO2 source. Each of the technology provided was accompanied by its Technology Readiness Level (TRL). The techniques can be mainly categorized on the techniques applied at the source of emission and on the atmosphere (Fig. 1).

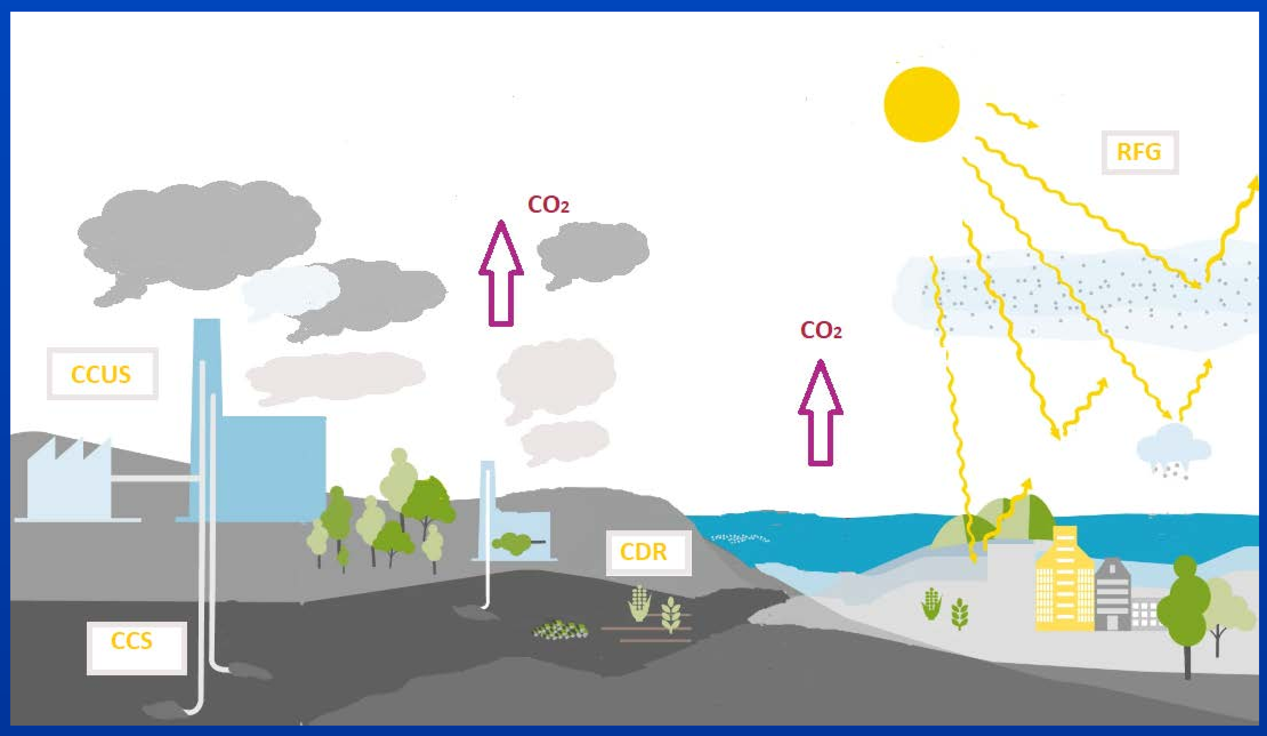


Figure 1: Schematic diagram of different pathways for reducing CO2

**Geoengineering techniques for CO2 after it has been emitted into the ambient atmosphere**

Climate geoengineering refer to the removal of atmospheric CO2 or extensive interventions on Earth's radiative energy budget. Although some research suggestions proposed refer to interventional procedures, they are still under development, carry a significant amount of uncertainty and risk, and provide moral and political quandaries:

- Radiative Forcing Geoengineering Techniques (RFG) reduce the amount of absorbed solar energy in the climate system by increasing the amount either of solar shortwave radiation or terrestrial longwave radiation.
- Carbon Dioxide Removal (CDR) increase the removal of CO2 from the atmosphere by using sinks to alter climate. The characteristic of these techniques is that they amplify natural processes and integrate the steps of CO2 capture and sequestration. The main inseparable processes included in this category are:
  - Land management techniques.
  - Accelerated weathering on land and in the ocean.
  - Ocean iron fertilization.
  - Bioenergy with carbon capture and sequestration (BECCS)

  This approach refers to the extraction of energy from biomass through oxidation or gasification (ie.. bioenergy) combined with the capture and sequestration of the CO2 generated during oxidation and gasification.
  - Direct air capture and sequestration (DACS)

  This technique incorporates chemical separation methods that directly capture CO2 from the ambient air combined with long-term CO2 disposal.

**Mitigation measures**

Mitigation measures refer to the CO2 reduction by removing CO2 directly at source prior to emission. The amount of CO2 captured is either stored in the subsurface or re-utilised in several long-lived materials or directly after treatment. Due to the separate techniques involved for capture and disposal (i.e. storage and/or utilization), there are numerous combinations available tailored to the industry applied.

- Carbon Capture and Storage, CCS incorporates the chemical separation and removal of CO2 from the plants and its storage in a relevant subsurface.
- Carbon Capture Storage and Utilisation, CCUS refers to the use of the CO2 emitted as feedstock for new products. The main difference for these techniques is the use of the CO2 as a carbon resource. The two (2) main routes of CO2 utilisation are:
  - Direct use of the CO2, where a percentage of the CO2 stays in the reservoir. CO2 is a key component in enhanced oil and gas recovery, for the enhancement of plant growth, wastewater treatment etc. CO2 is also used in products, such as carbonated beverages and fire extinguishers and as a solvent.
  - Indirect use of CO2 based on a biological or chemical process of CO2 into a new product. CO2 can be biologically transformed by algae into new organic compounds. In chemical transformation, CO2 is converted to chemical building blocks for the industry or synthetic fuels for the transport sector. It can also be used for mineralisation, e.g. for making building materials.

## Conclusions

The transformation and/or use of CO2 provides routes for substituting fossil fuels and introduces renewable energy into the production processes. Technologies with reference to CO2 are advancing rapidly with many being emerging for the commercial market. The categorization of these emerging technologies can pave the way for conducting solid comparative assessments thus introducing them for commercial operation.

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