Carbon Capture, Utilization, and Storage (CCUS)

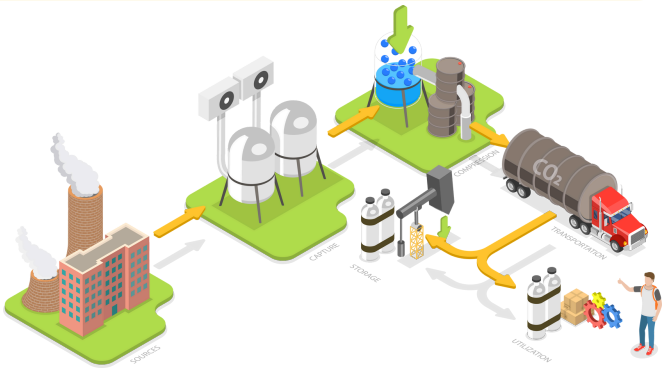
Carbon Dioxide in the Environment

Carbon dioxide (CO_2) is a gas produced by both natural and human sources. Human activity has added more carbon dioxide into the atmosphere, primarily from the burning of fossil fuels.

When fossil fuels are burned, the gas acts like an invisible blanket, causing the Earth to slowly warm up. Carbon dioxide has been building up in the Earth's atmosphere over the years as more and more fossil fuels are used.

What are Fossil Fuels?

Fossil fuels are non-renewable sources of energy like coal, oil, natural gas, and radioactive elements. These sources are considered non-renewable because they do not replenish at the same rate they are used.



The Effect on Climate Change

Fossil fuels will continue to be the most prominent source of energy until significant change is made. This will lead to an increase of carbon dioxide emissions in the atmosphere, which are a major contributor to climate change. Low-carbon technologies are crucial to reduce the negative impact of fossil fuels on the environment.

What are Low-Carbon Technologies?

Green energy technology that reduces carbon emissions, such as solar panels and wind turbines.

Carbon Capture, Utilization, and Storage (CCUS)

Carbon Capture, Utilization, and Storage (CCUS) is one of the most promising technologies for lowering carbon emissions. This process uses a combination of technologies that capture, transport, and utilizes or stores CO_2 safely underground. By storing the CO_2 underground, it does not contribute to overall global emissions. The captured CO_2 can be repurposed for various industries to produce goods and services.

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How Does CCUS Work?

There are three key steps to complete the process of CCUS: **Capturing, Transporting, and Utilizing or Storing**. Utilizing CO_2 can replace storing CO_2 where it can be repurposed, or it can be skipped as a step before storing.

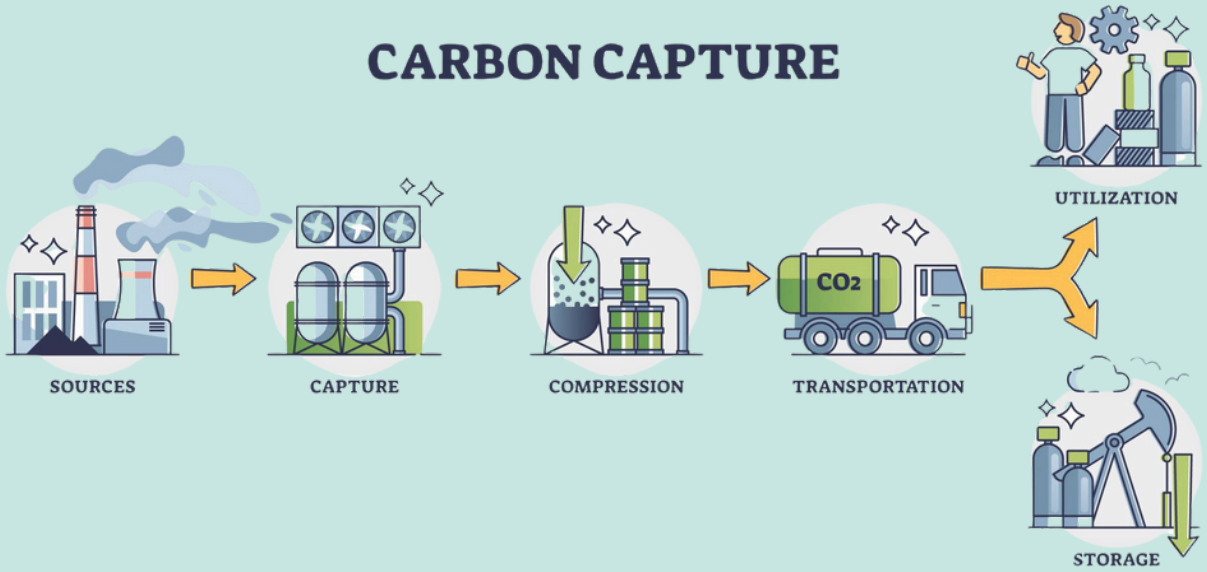

Figure 1: The general process of CO_2 capture, utilization, and storage, courtesy of Pathways: Shaping your Energy Future.

1 Capture

Capturing carbon dioxide is the first step in CCUS. It can occur before or after the combustion process, or alongside the burning of fuels. Using a specific method to capture CO_2 depends on what emissions sources are being used.

Key Terms

Pre-Combustion - occurs before the fuel is burned into the atmosphere

Post-Combustion - occurs after the fuel is burned into the atmosphere

Flue Gas - the exhaust gas produced from the combustion process

Absorber - cylinder column used to separate gases in post-combustion capture

Pre-Combustion Capture

CO_2 is isolated from other gases and removed directly from fossil fuels (i.e. coal and gas) before combustion occurs.

Post-Combustion Capture

CO_2 is absorbed from fossil fuels after combustion occurs by using an absorber with chemicals to separate it from the flue gas.

Oxy-Fuel Combustion Capture

Fossil fuels are burned alongside pure oxygen rather than air to produce higher CO_2 concentrations to capture.

Membrane-Based Capture

CO_2 can permeate through the membrane, while it blocks other gases from entering. This can be used for pre-, post-, or oxy-fuel combustion capture.

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2 Transport

Once the CO_2 is captured, it is transported by pipelines, ships, railways, and trucks.

Pipelines are commonly the most cost-effective and safest option for large-scale projects. The transportation through pipelines is controlled by pressure differences in gases. Gases move from areas of high pressure to areas of low pressure. By changing the pressure of CO_2 in pipelines, it can then be transported to different locations.

CO_2 is captured from facilities and transported to areas suitable for storing or utilizing carbon dioxide. This is sometimes across large regions, making pipelines the most efficient option to transport captured CO_2. Pipelines have the lowest climate impact out of all the options for CCUS transportation, but it will still have some sort of negative environmental impact. Pipelines can damage the surrounding habitats and vegetation, and if it leaks or ruptures, there is a higher risk of damage.

3a Utilizing

Captured CO_2 can be utilized in several ways. One of the most common is for enhanced oil recovery. It can also be used for carbonation in soft drinks and in the production of dry ice.

Enhanced Oil Recovery

Enhanced oil recovery is when CO_2 is injected into mature oil reservoirs, increasing the pressure and improving the oil flow. This allows more oil to be extracted from depleted wells. This can extend the life of oilfields while also being safely stored underground.

Did you know?

More than 5,000 miles of CO_2 pipelines across the U.S. transport approximately 80 million metric tons of CO_2 per year (American Petroleum Institute).

3b Storing

Once the CO_2 is transported to its destination, it is then injected into deep rock formations. This allows the CO_2 to be safely stored underground without contributing to harmful emissions in the atmosphere.

The rock formations used are similar to what has held oil and gas underground for millions of years. Possible storage sites could include depleted oil reservoirs (for enhanced oil recovery) or saline aquifers where it then dissolves into the rock.

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CCUS Projects Around the World

Canada is a global leader in advancing Carbon Capture, Utilization, and Storage (CCUS) technologies. Learners can find multiple examples in this **Reference Material**. Globally, North America and Europe have the most CCUS projects in operation and under construction. In this section, two examples will be highlighted from Canada and the United States to showcase the work that has been done.

Alberta Carbon Trunk Line

The Alberta Carbon Trunk Line stands as the world's most extensive carbon capture and storage initiative. It encompasses a 240-km long pipeline created to collect and compress CO_2 and then inject it into depleted oil reservoirs. This project aims to mitigate carbon emissions and advance sustainable carbon management practices.

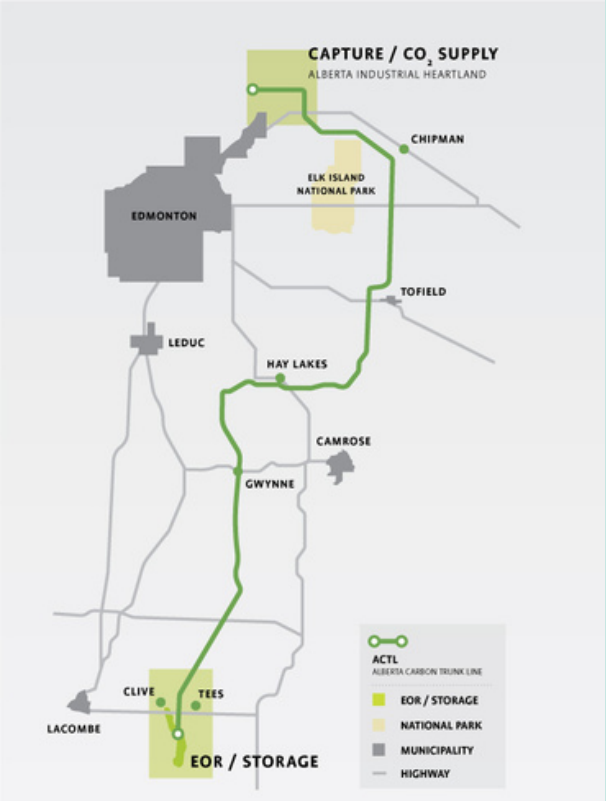

Figure 2: Map of the Alberta Carbon Trunk Line system, courtesy of Enhance Energy.

Illinois Industrial Carbon Capture and Storage Project

This is a large-scale commercial project that aims to collect 3,000 tonnes of CO_2 per day for storing underground. This equates to 1 million tonnes of CO_2 annually. The CO_2, is captured from the fermentation process used to produce ethanol at an industrial corn processing plant in Illinois. The CO_2 is then transported to a geological site to be properly stored.

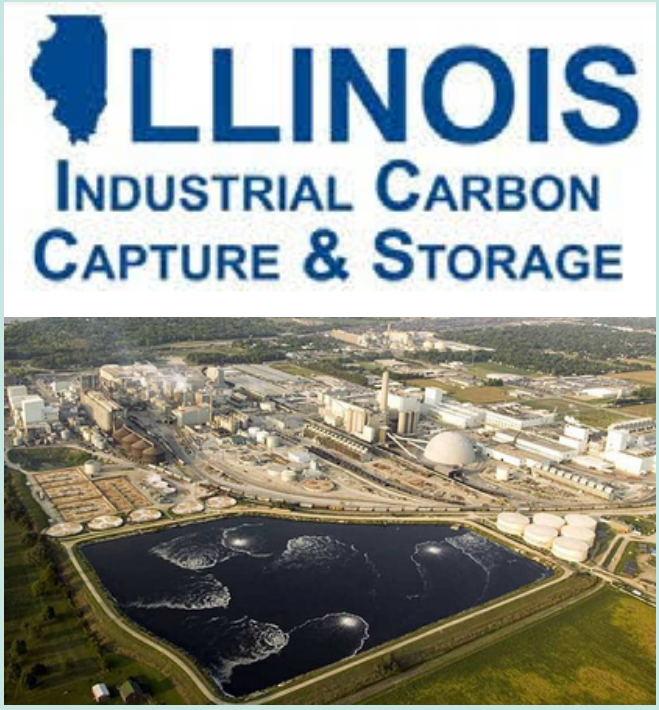

Figure 3 and 4: Aerial photo of the Illinois industrial Carbon Capture and Storage Project, courtesy of NETL.

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Positive and Negative Impacts

CCUS has both positive and negative impacts on the climate, the environment, the economy, and the surrounding communities. It can be challenging for companies to install efficient and cost-effective pipelines while also considering the environmental impact or risks involved. As more research becomes available, it becomes easier to understand the benefits and costs of the technology.

Did you know?

According to the Global CCS Institute, the injection and storage of CO_2 has been working effectively in the US for over 50 years, successfully storing close to 300 million tonnes underground (Loria & Bright, 2021).

Advantages of CCUS

- CCUS extracts CO_2 from already produced sources (non-renewable sources) of fossil fuels, effectively cutting down existing emissions.
- Pipelines can be built above ground or underground, making it adaptable.
- CCUS has proven to be successful in reducing emissions in sectors that are typically challenging to reduce, specifically industrial emitting ones like cement, steel, and chemical plants.
- CCUS can be used for different purposes: it can limit emissions from fossil fuels, or it can speed up emission reduction and reduce temperature if combined with bioenergy or direct air capture technologies.

Disadvantages of CCUS

- Pipeline installation often results in the decrease of native vegetation, habitat loss for animals, poor water quality, and eroded soils in the surrounding area.
- Air quality can be affected during construction and from the combustion of fossil fuels at emitting facilities.
- Indigenous communities are often unfairly impacted by pipeline leaks and have a hard time protecting their own land and rights.
- Risk of leaks or ruptures in CO_2 pipelines can lead to health concerns due to carbon dioxide being a dangerous gas to inhale
- There is limited capacity for carbon dioxide to be stored globally.
- The current CCUS global deployment is still not sufficient enough to reach the anticipated net-zero CO_2 emissions target by 2050.

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The Global Impact of Carbon Capture

There are around 50 operational CCUS projects globally, with 44 under construction and more than 500 in the planning stage.

More than 50 million tonnes of CO_2 is currently captured annually, which accounts for around 0.1% of all global emissions. If all projects in development were complete, the estimated total CO_2 capturing would be between 400 and 550 million tonnes per year. This would account for ~1% of today's greenhouse gas emissions.

The 2023 International Energy Agency (IEA) Roadmap to Net Zero estimates that CCUS would have to contribute ~8% of the total CO_2 mitigation of emissions to reach net-zero by 2050 in the energy sector. Considering the projected impact of CCUS technology, the role of CCUS would likely be a smaller percentage of total mitigation.

Did you know?

Almost 80% of all human-produced carbon dioxide emissions come from the burning of fossil fuels (ECCC, 2024).

The Role of Carbon Management

Canada's climate plan aims to reduce greenhouse gas emissions by 40-50% by 2030, and aims to reach net-zero by 2050. This means there is a balance of removed and produced emissions from the atmosphere. This is globally recognized as a critical component to climate action. There is no credible path to net-zero emissions without the role of carbon management technologies like CCUS.

In this climate plan, CCUS plays a significant role in the deployment of other carbon capture technologies. This could include Carbon Dioxide Removal (CDR) via direct air capture and storage, and bioenergy with carbon capture and storage.

Next Steps in Carbon Capture Technology

CCUS faces technological, economic, environmental, and socio-cultural barriers that limit the current rate of deployment needed for reaching net-zero by 2050. However, it can be an essential technology for lowering and mitigating emissions in already-produced industries with large emissions. The biggest component to CCUS success is time and more research. With over 500 CCUS projects in the planning stage and over billions invested into these projects globally, CCUS will become more widely known.

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