



Carbon Capture and Storage

Carbon Dioxide Emissions

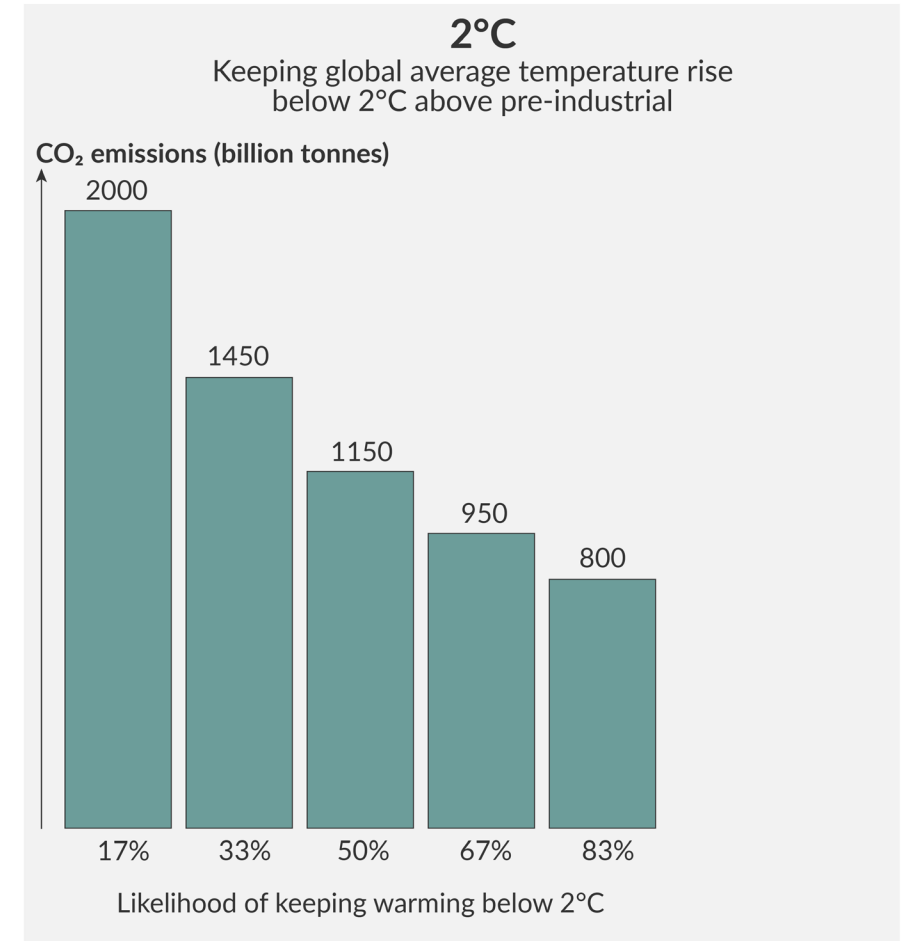
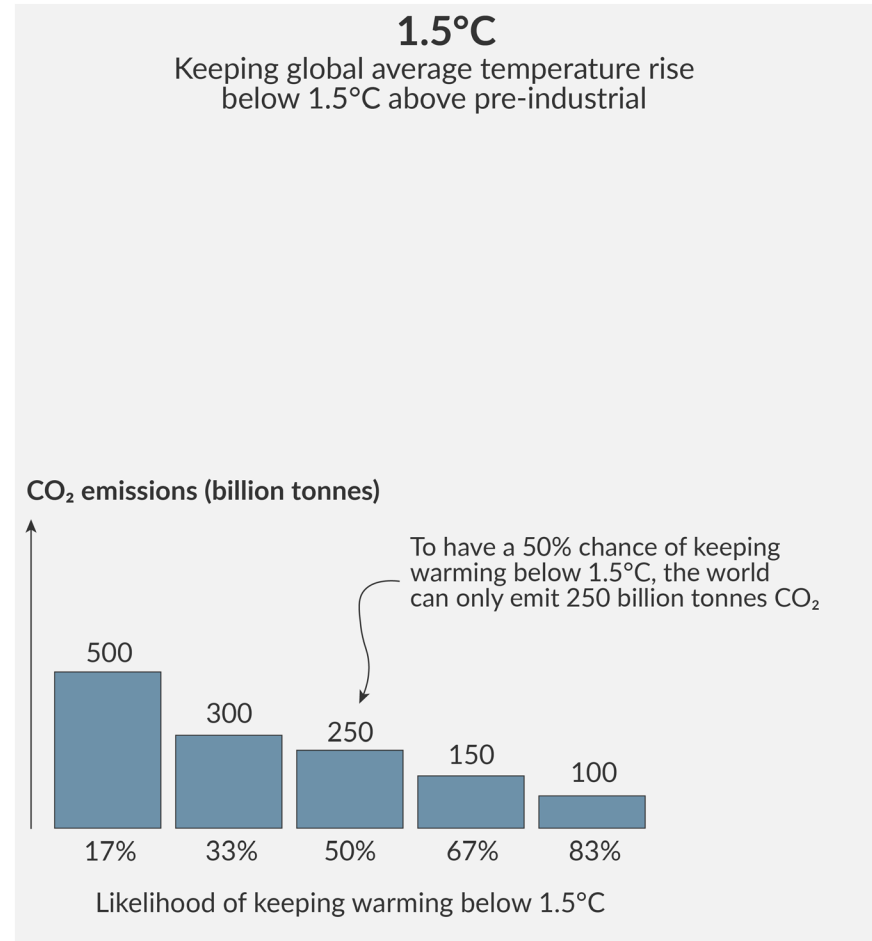


CO₂ emissions refer to the release of carbon dioxide (CO₂) into the atmosphere, primarily from human activities like burning fossil fuels (coal, oil, and gas), deforestation, and industrial processes.

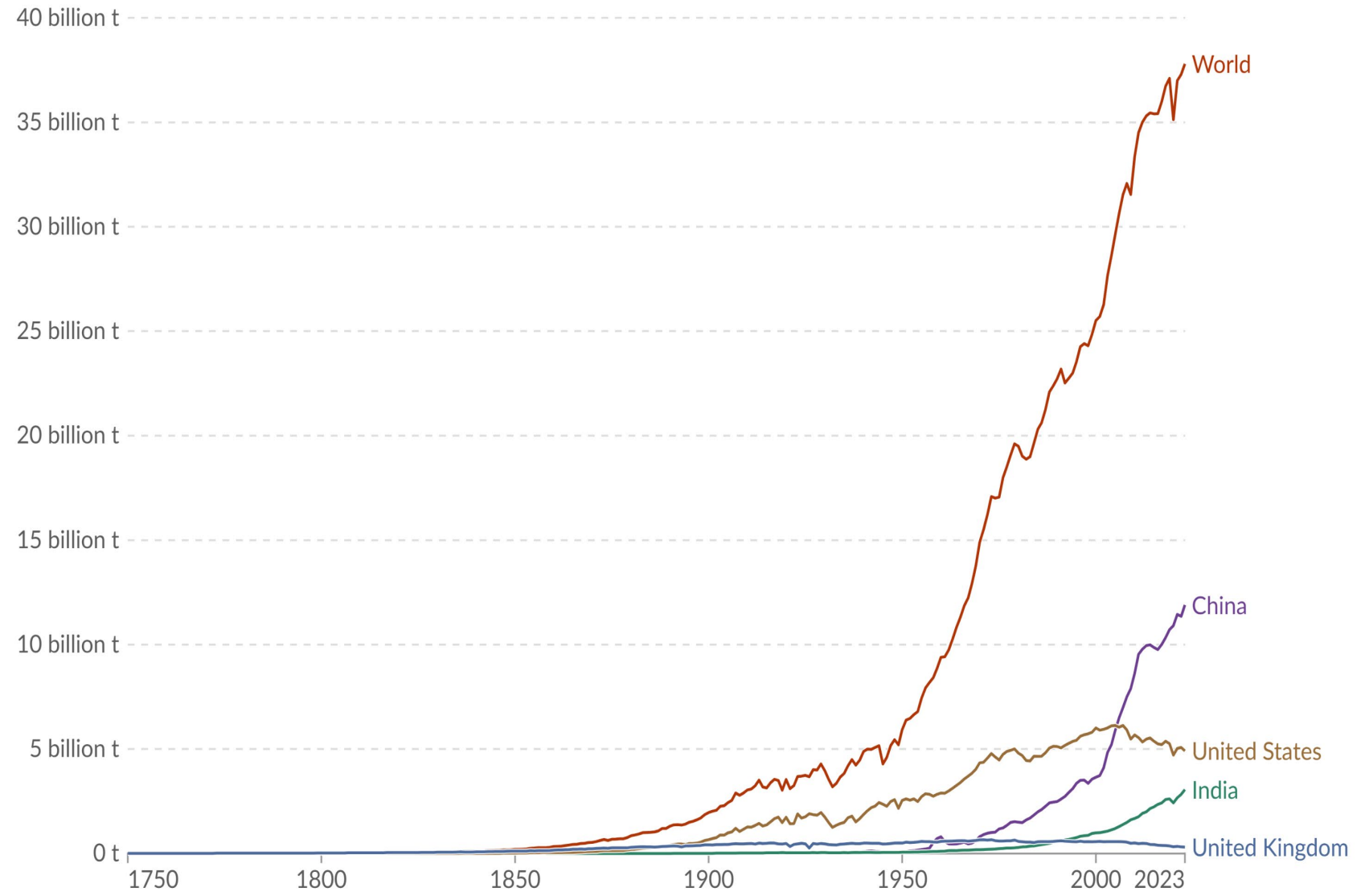
These emissions contribute to global warming and climate change by trapping heat in the Earth's atmosphere, leading to rising temperatures, extreme weather, and environmental disruptions.

Reducing CO₂ emissions is crucial for mitigating climate change and is a key goal of international agreements like the Paris Agreement.

Carbon Budget



Carbon Budget



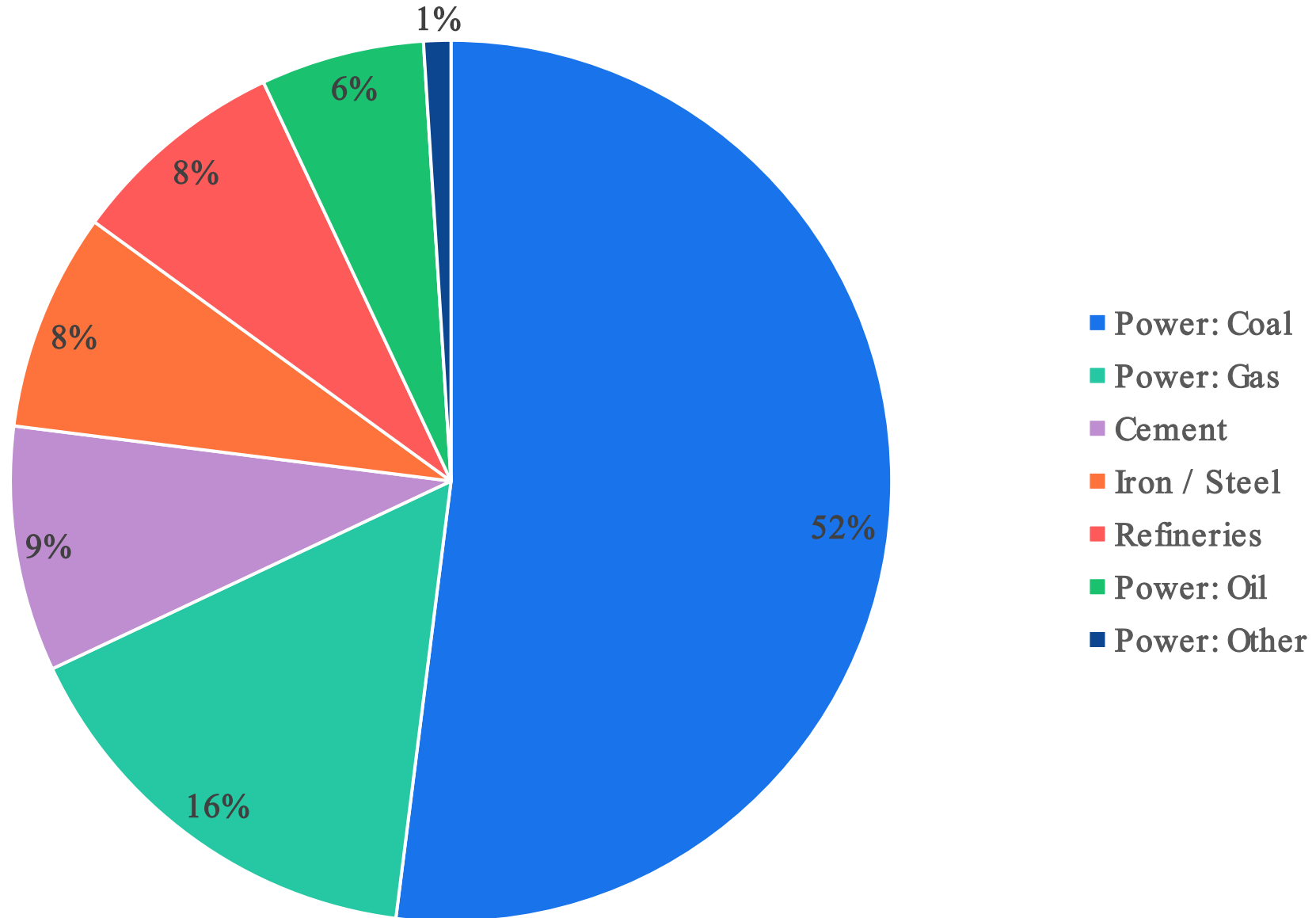
Net Zero



Net zero refers to balancing the amount of greenhouse gases emitted with the amount removed from the atmosphere, effectively reducing carbon footprint to zero.

Since eliminating all CO₂ emissions isn't feasible, solutions like renewable energy expansion, energy efficiency, carbon capture, and sustainable policies are necessary for a gradual transition to a low-carbon future.

CO₂ Emissions



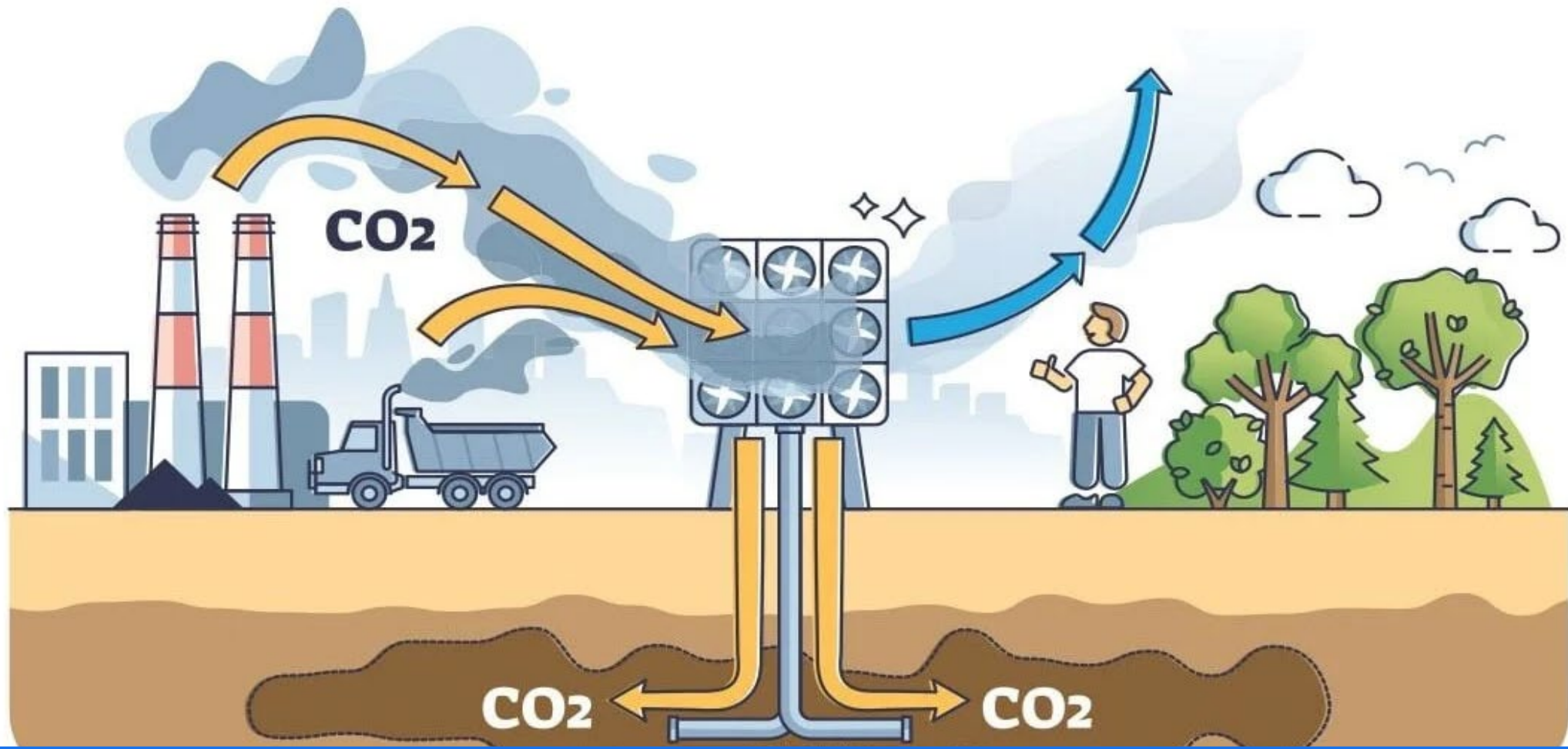
Most of the focus of CCS is on electricity production as this is the biggest stationary source of CO₂ production.

The production of cement is another important stationary source of CO₂ emission

Cement Production

- The production of cement is an important stationary source of CO₂ emission
- The total cement production is responsible for 9% of the global anthropogenic CO₂ emissions.
- It is not only an energy intensive process, but it also uses CaCO₃ as an ingredient and during cement production limestone is converted into CaO and CO₂.
- The CO₂ is emitted with the flue gasses





Carbon Capture

- Different options to try to reduce overall CO₂ emissions are being investigated, but the main way to reduce CO₂ emissions from large industrial sources is called Carbon Capture and Storage, or CCS.
- CCS involves capturing carbon dioxide (CO₂) at emission sources, transporting and then storing or burying it in a suitable deep, underground location.

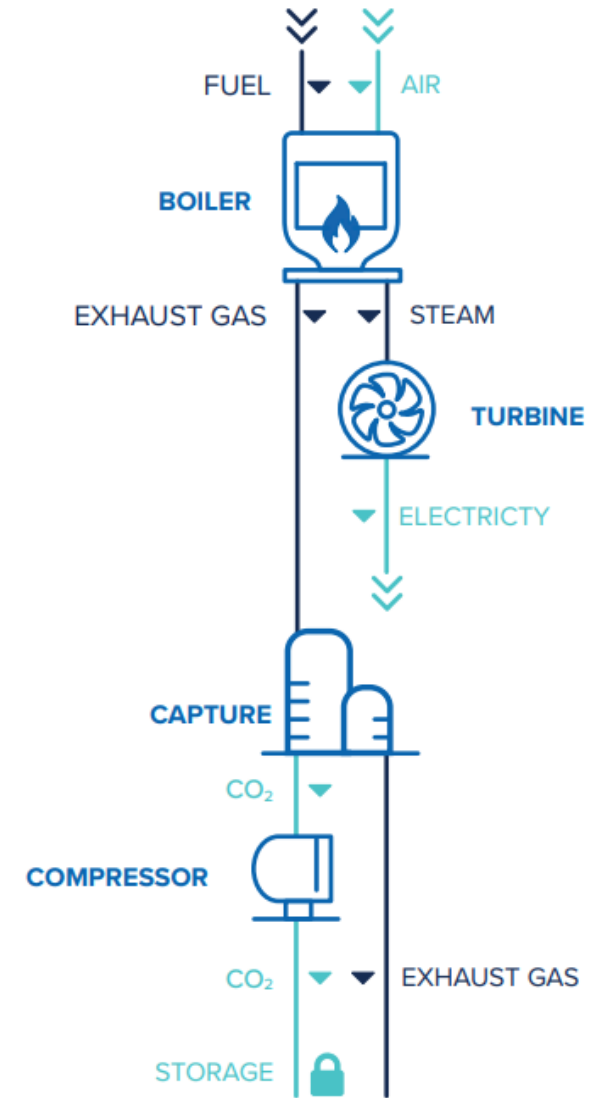
How do we capture carbon?

CO₂ must be separated, or captured, from the flue gas before it can be geologically stored. There are three main methods for capturing CO₂ from fossil fuel combustion:

- Post-combustion,
- Pre-combustion capture,
- Oxyfuel combustion.

Post-Combustion

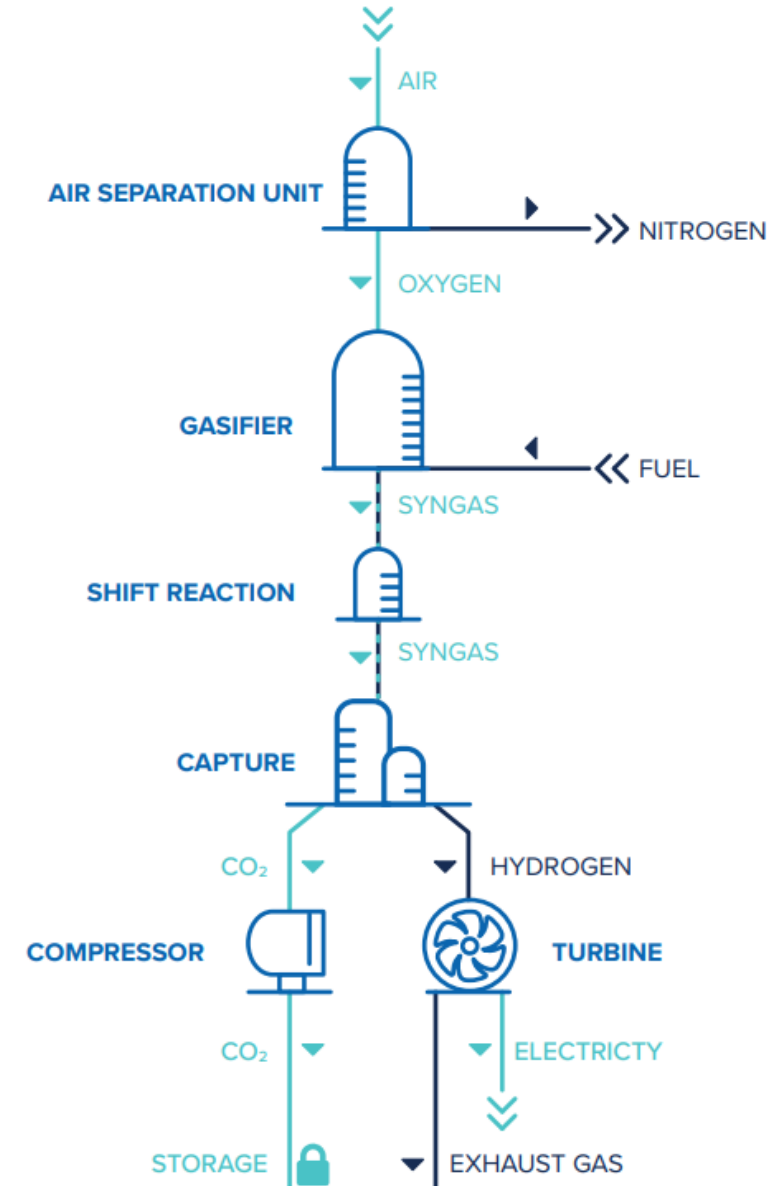
- In post-combustion capture, fuel is burned in a conventional power plant with minimal modifications.
- The most commercially developed technology for this process is chemical absorption.
- In this method, CO₂ is captured from flue gas using a solvent in a separation tower and later released by heating in a recovery column at temperatures exceeding 100°C.
- A key advantage of post-combustion capture is its suitability for retrofitting existing power plants, allowing for component replacements, upgrades, and improvements without significantly altering the plant's overall operation.



Pre-Combustion

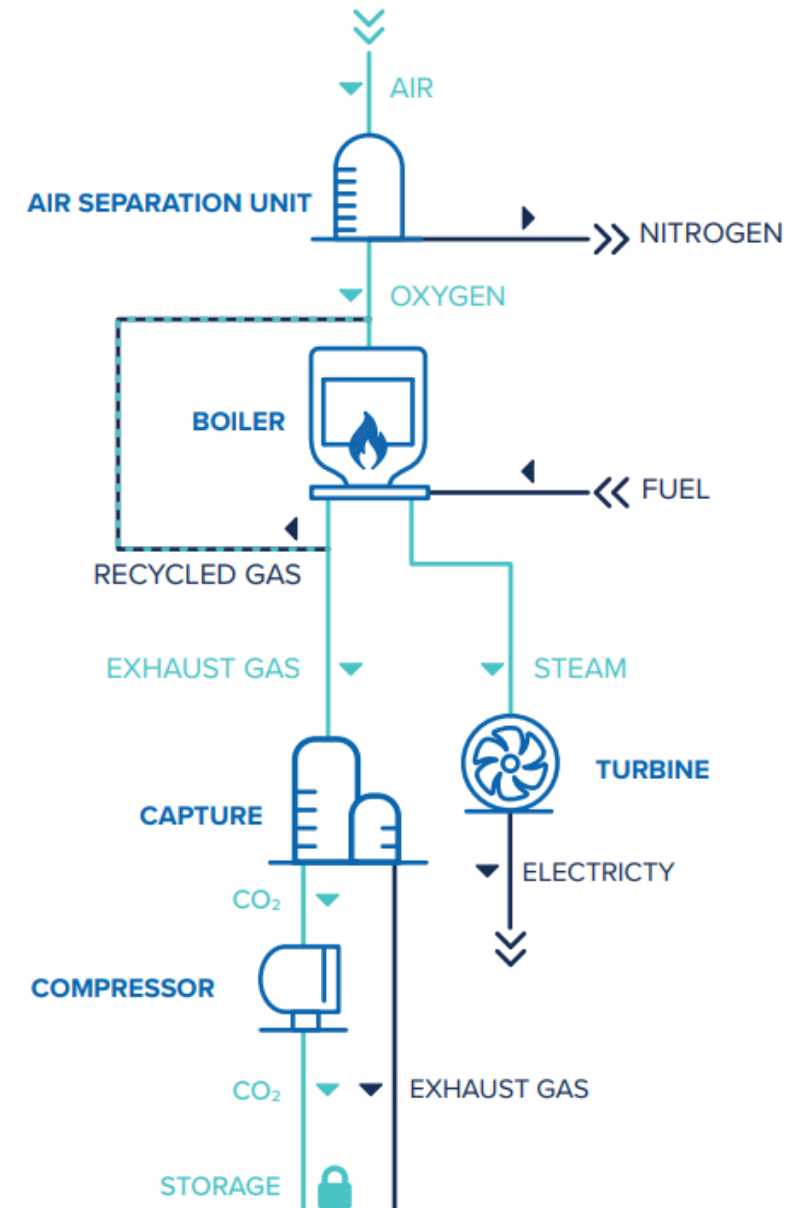
- Pre-combustion capture, commonly used in Integrated Gasification Combined Cycle (IGCC) systems, involves gasifying and partially oxidising fuel to produce a mixture of CO₂ and hydrogen.
- These gases are then separated, typically through physical absorption. The resulting hydrogen is combusted in a modified gas turbine or fuel cell, generating power and water.

PRE-COMBUSTION CO₂ CAPTURE



Oxyfuel Combustion

- Oxyfuel combustion relies on established cryogenic methods to separate oxygen from air before burning coal or gas in a mixture of pure oxygen, often combined with recycled flue gas to control combustion temperature.

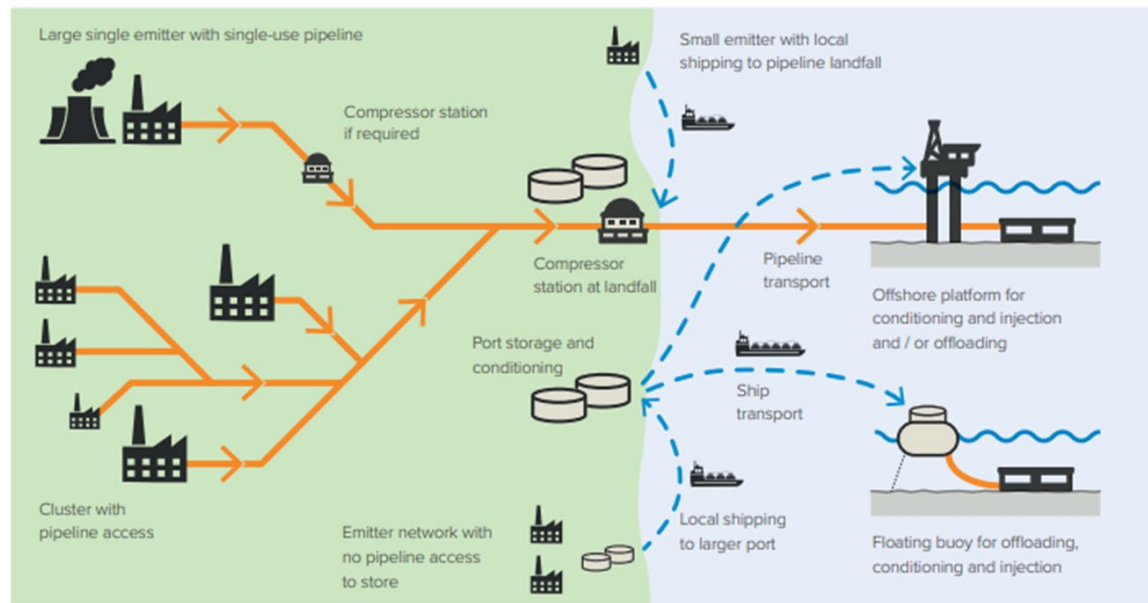


Transportation

- The design of the transport, wells and injection infrastructure is a major part of the post-CO₂ separation system which supplies the storage reservoir.
- CO₂ can be transported via trucks or ships, but the most common and efficient method is by pipeline

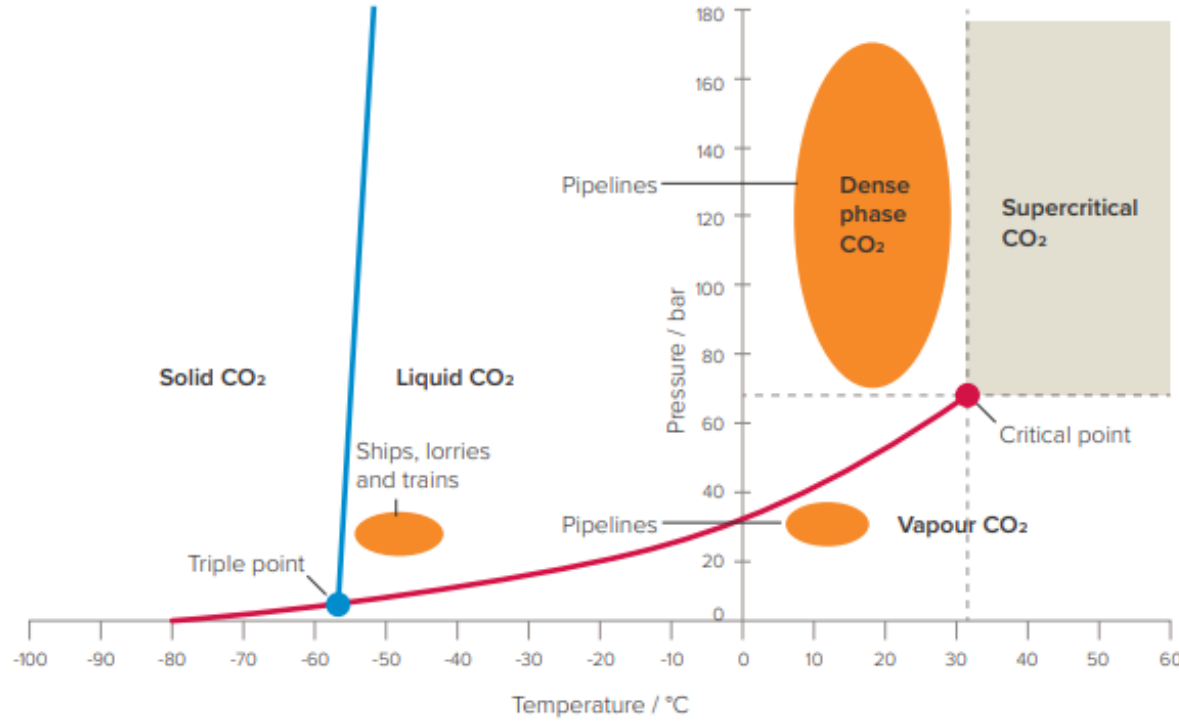


Transportation



- For CCS applications, the transportation method for the CO₂ from the capture site to the storage site (if they are not co-located) is dictated by:
 - the mass of CO₂ to be transported,
 - the distance of transportation,
 - the terrain (for example onshore or offshore),
 - the phase or state that the CO₂ is in during transportation

Transportation



- Gas takes up less volume when it is liquefied, solidified, or hydrated.
- Therefore, before being transported, captured CO₂ is often compressed and liquefied until it becomes a supercritical fluid.
- In a supercritical state, CO₂ has the density of a liquid but the viscosity of a gas and is, therefore, easier to transport through pipelines.

Pipeline Design

There are several special design aspects that must be carefully considered including:

- **Composition of the CO₂**
 - Impurities can affect the critical pressure of the gas and hence the required operating pressure of the pipeline, the corrosion behaviour, the mode of failure in the unlikely event that the pipeline fails, and the impact of a release of CO₂ from the pipeline
 - The composition of the CO₂ from different emitters and processes will vary and therefore the compositional mix in a pipeline network, in which CO₂ is being transported from several different emitters, needs to be tightly specified
-

Pipeline Design

There are several special design aspects that must be carefully considered including:

- Composition of the CO₂
 - **Material Properties of the Pipeline**
 - Low-carbon steel is the most economical material from which to construct long distance CO₂ pipelines. However, it is vulnerable to corrosion if water is present with the CO₂, therefore it is critical that water is removed prior to transportation
 - The toughness of the steel needs to be tightly specified to ensure fracture control during decompression of the CO₂.
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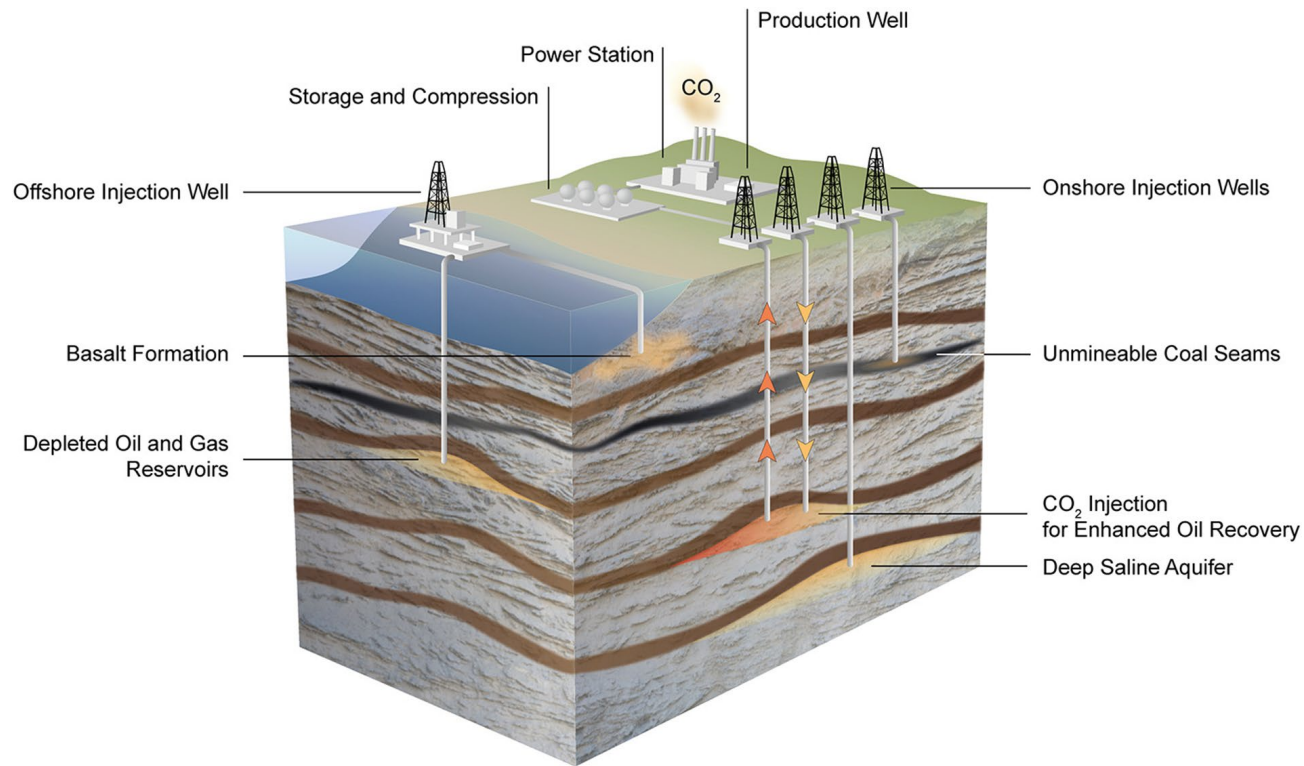
Pipeline Design

There are several special design aspects that must be carefully considered including:

- Composition of the CO₂
- Material Properties of the Pipeline
- **Safety and Risk Criteria**
 - High concentrations of CO₂ can lead to asphyxiation. Therefore pipelines must be routed such that there is a safe distance between the pipeline and human population in case of leakage.

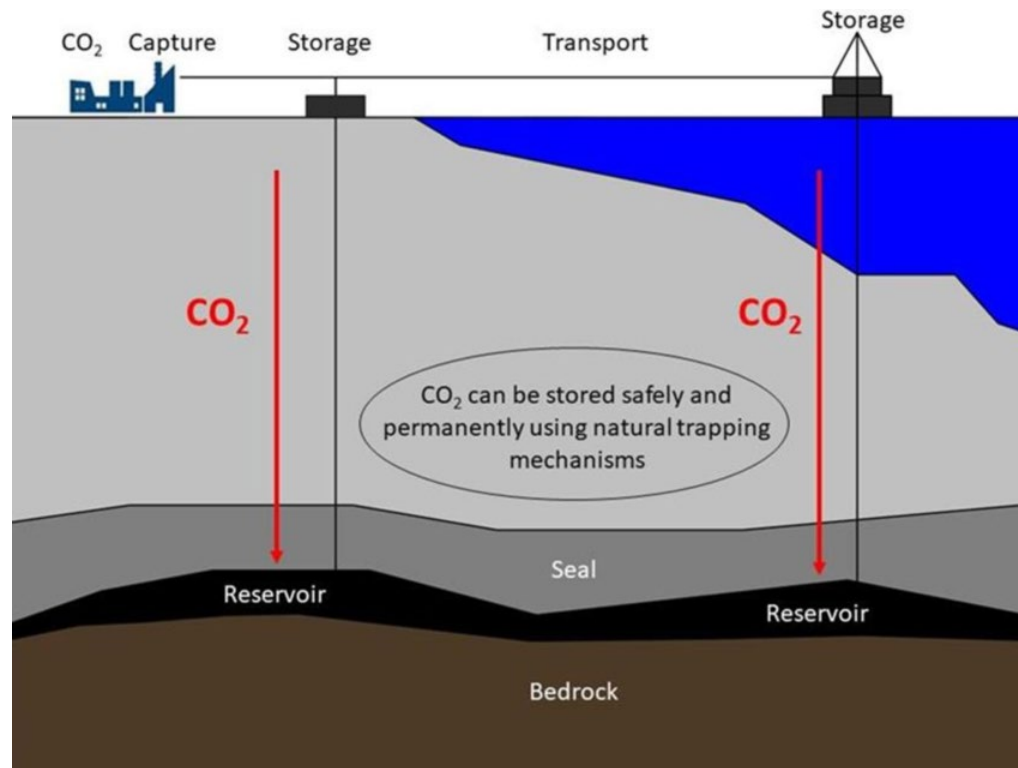


Geological Sequestration



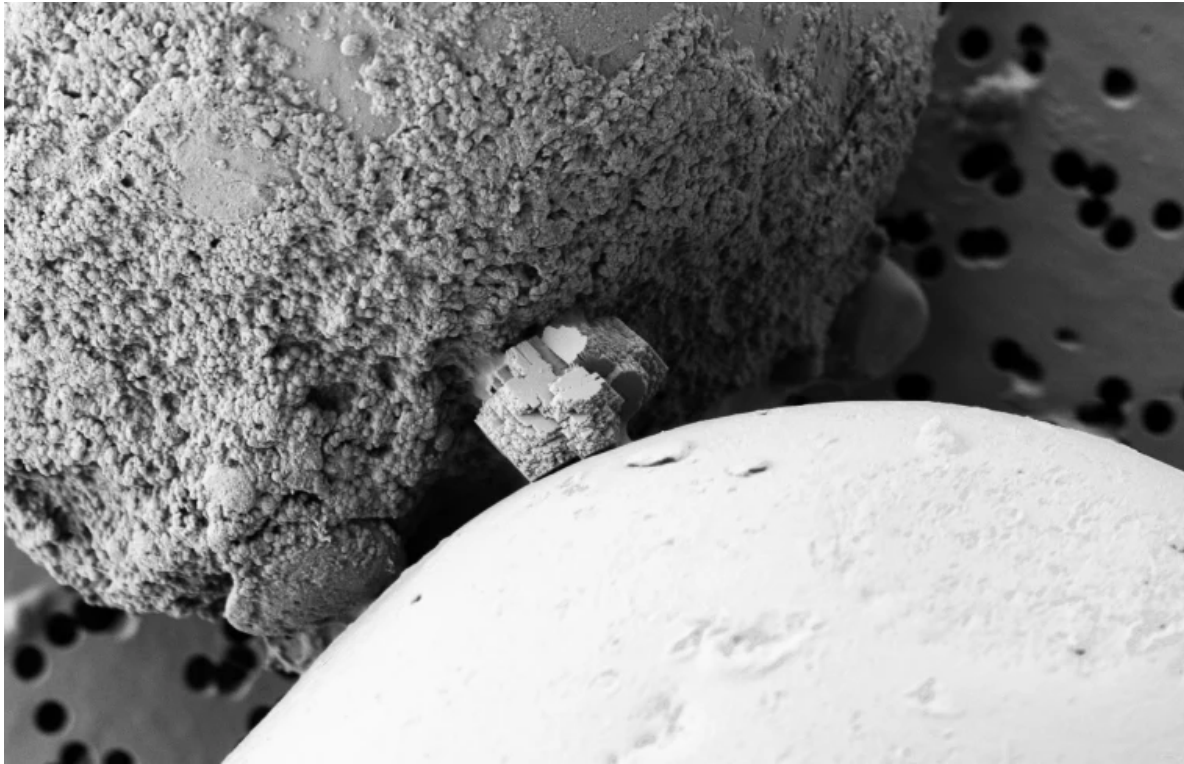
- The most well-developed approach to storing CO₂ is injecting it underground into naturally occurring, porous rock formations such as former natural gas or oil reservoirs, coal beds that can't be mined, or saline aquifers.
- This is a process called geological sequestration.

Geological Sequestration



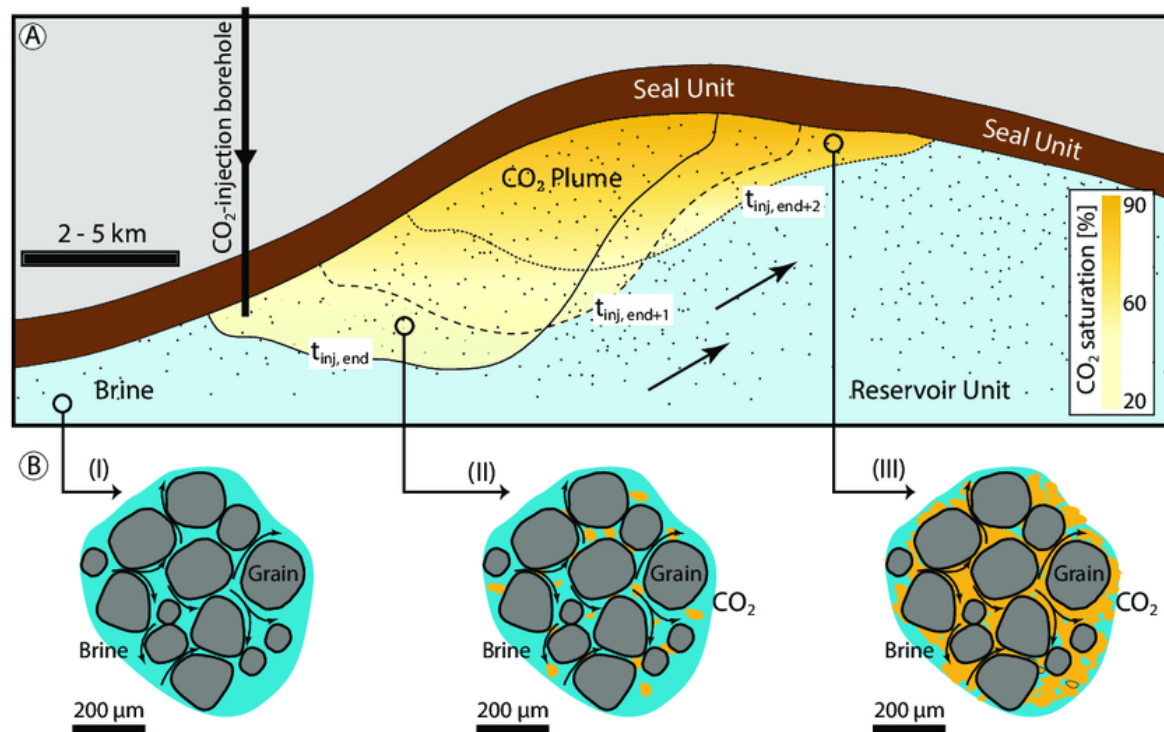
- The most straightforward way underground reservoirs store CO₂ is through the solid impermeable rock that typically surrounds them.
- Once CO₂ is injected into a reservoir, it slowly moves upwards through the reservoir until it meets this layer of impermeable rock, which acts like a lid the CO₂ cannot pass through.
- This is what's referred to as 'structural storage'

Geological Sequestration

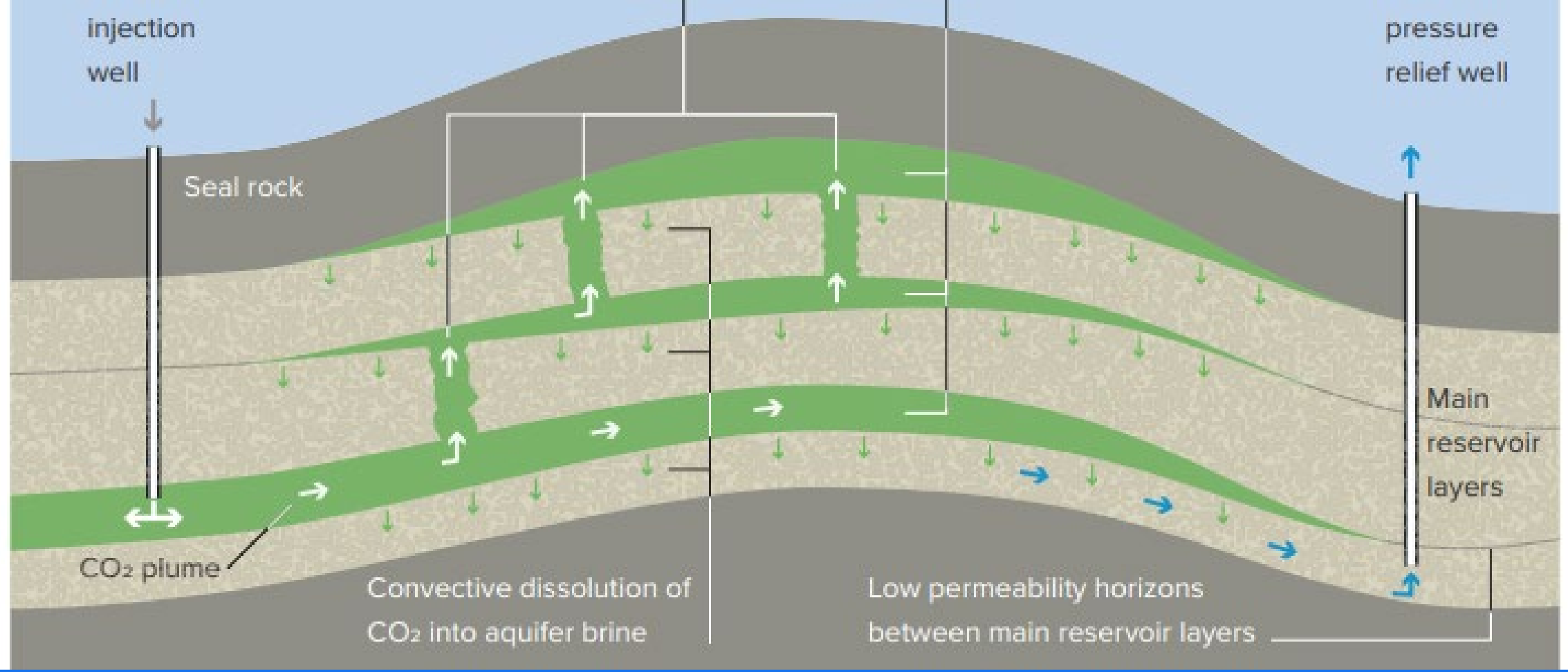


- Over time, the CO_2 trapped in reservoirs will often begin to chemically react with the minerals of the surrounding rock.
- The elements bind to create solid, chalky minerals, essentially locking the CO_2 into the rock in a process called 'mineral storage'.

Geological Sequestration



- In the case of saline aquifers, as well as structural and mineral storage, the CO₂ can dissolve into the salty water in a process called ‘dissolution storage’.
- Here, the dissolved CO₂ slowly descends to the bottom of the aquifer.





Geological Storage System

The design and development of a CO₂ storage reservoir in layers of permeable rock below the ground surface involves several scientific and technological inputs. These include:

1. **The assessment of the size, shape and mineralogy of the geological reservoir, and of the way fluid flows through the rock at both the pore scale and the reservoir scale;**



Assessment

Before CO₂ can be stored underground, a detailed assessment of the geological reservoir is required to ensure it can safely contain the injected gas over long timescales. Key factors include:

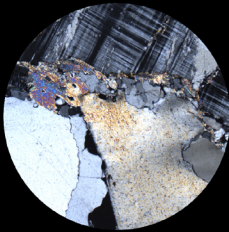
- **Size and Shape**



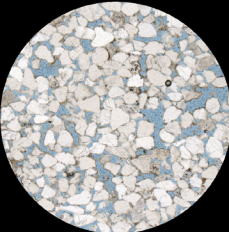
U.S. Geological Survey studies underground rock layers. Scientists identify those that are most suitable for trapping and those that are good for storage. One consideration is space.

Microscope Views of Rocks:

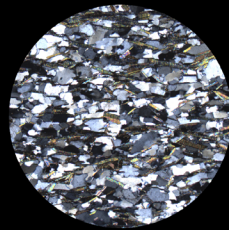
No empty space, good for trapping CO_2 below



Blue color represents empty space, good for storing CO_2

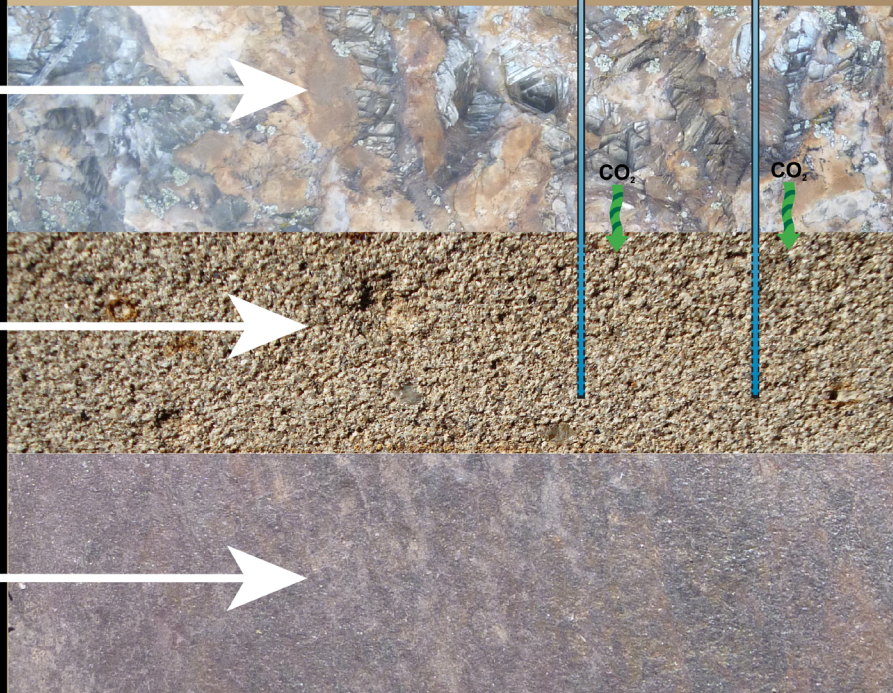
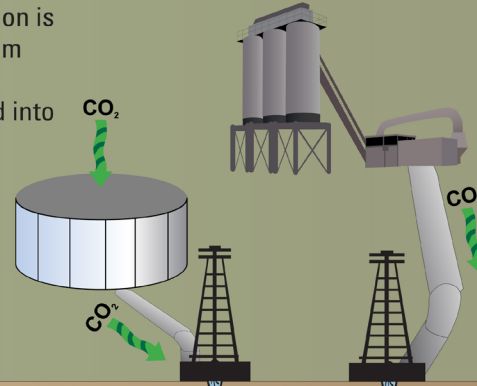


No empty space, good for sealing CO_2 above



Geologic Carbon Sequestration

Geologic carbon sequestration is capturing carbon dioxide from industrial processes and the atmosphere. It is then turned into a liquid and injected deep underground.



- A typical site selected for subsurface CO_2 storage will have permeable rocks that lie 1.0 – 2.5 km below the surface where the pressure is sufficient that the CO_2 is a dense and supercritical fluid, increasing the mass stored per unit volume of rock.
- Such rocks typically have a porosity of around 10 – 20% of the volume of the formation.



Assessment

Before CO₂ can be stored underground, a detailed assessment of the geological reservoir is required to ensure it can safely contain the injected gas over long timescales. Key factors include:

- Size and Shape
- **Mineralogy**

Assessment

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- Size and Shape
- Mineralogy
- Fluid Flow



Geological Storage System

The design and development of a CO₂ storage reservoir in layers of permeable rock below the ground surface involves several scientific and technological inputs. These include:

1. The assessment of the size, shape and mineralogy of the geological reservoir, and of the way fluid flows through the rock at both the pore scale and the reservoir scale;
2. **The assessment of the mechanical response of the reservoir to pressurisation associated with the injection;**



Assessment

Injecting CO₂ into a reservoir increases pressure, which can induce mechanical changes, including:

- **Rock Deformation**



Assessment

Injecting CO₂ into a reservoir increases pressure, which can induce mechanical changes, including:

- Rock Deformation
- **Induced Seismicity**



Assessment

Injecting CO₂ into a reservoir increases pressure, which can induce mechanical changes, including:

- Rock Deformation
- Induced Seismicity
- **Caprock Intensity**

Geological Storage System

The design and development of a CO₂ storage reservoir in layers of permeable rock below the ground surface involves several scientific and technological inputs. These include:

1. The assessment of the size, shape and mineralogy of the geological reservoir, and of the way fluid flows through the rock at both the pore scale and the reservoir scale;
2. The assessment of the mechanical response of the reservoir to pressurisation associated with the injection;
3. **The design and drilling of CO₂ injection and pressure relief wells, which pass through the overlying rock and into the target geological formation**



Assessment

Effective well design ensures safe and efficient CO₂ injection while maintaining reservoir stability. Key aspects include:

- **Well Placement**



Assessment

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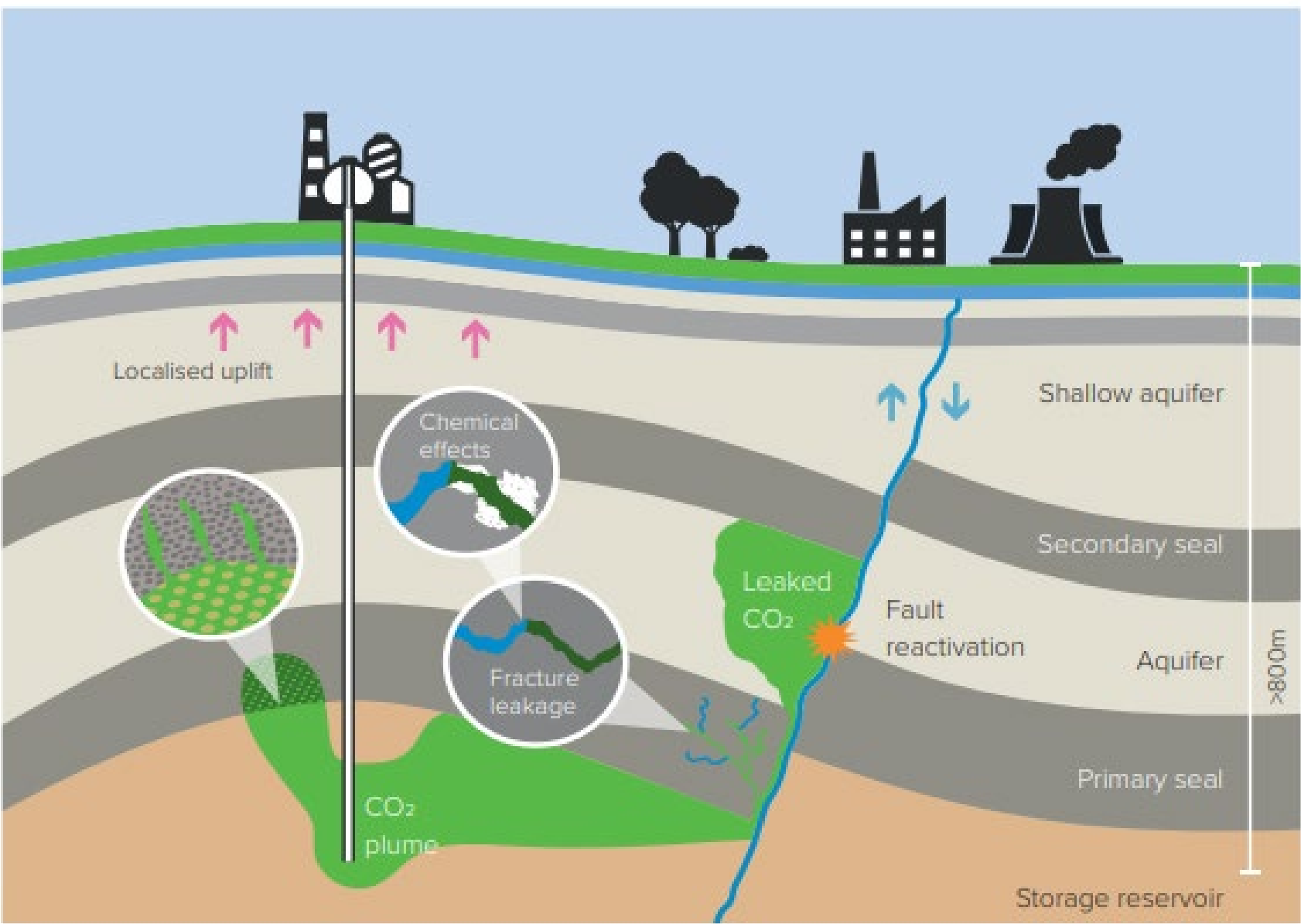
- Well Placement
- Well Construction



Assessment

Effective well design ensures safe and efficient CO₂ injection while maintaining reservoir stability. Key aspects include:

- Well Placement
- Well Construction
- **Injection Strategies**



- The injection rate may need to be limited to avoid the pressure at the injection well becoming too large, and fracturing rocks near injection wells or activating pre-existing faults within or possibly below the storage zone



Geological Resource and Capacity

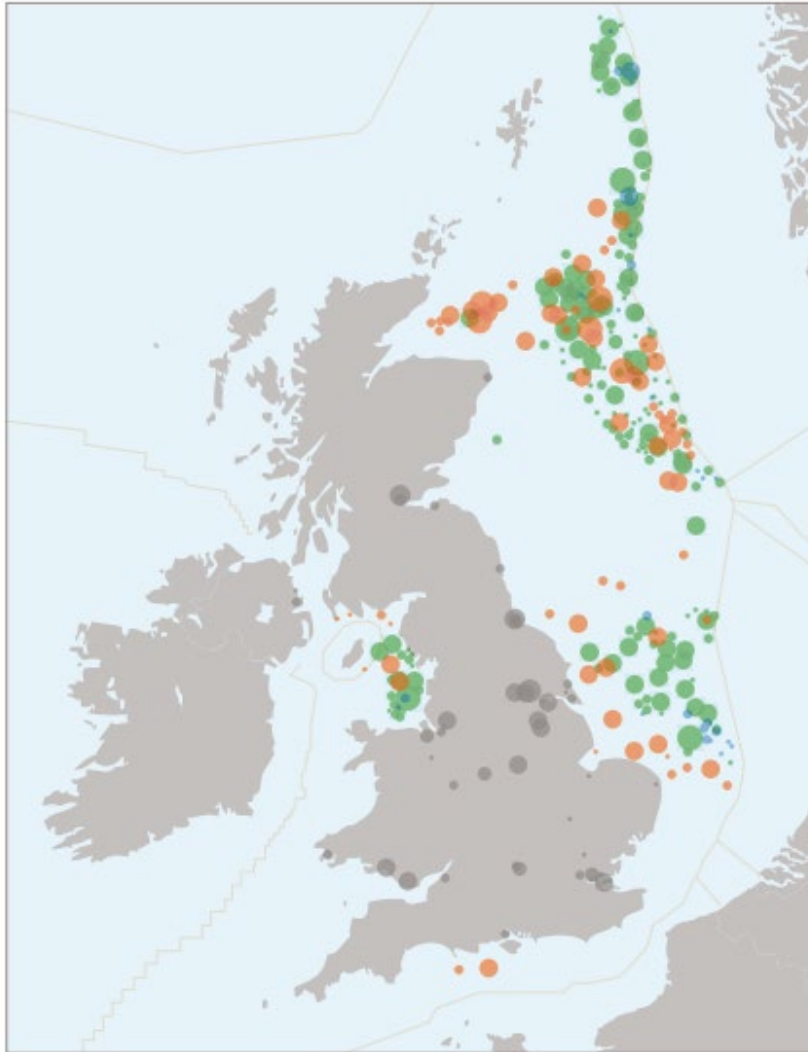
- The storage capacity is an estimate of the amount of CO₂ that can be safely and permanently stored.
- The theoretical storage capacity is calculated by estimating the overall volume of the rock strata, the total volume of pore space within the strata and the proportion of that pore space that can be reasonably expected to be utilised for CO₂ storage.
- The mass of CO₂ is calculated by estimating the density of the CO₂ at the temperatures and pressures of the subsurface.

KEY

- CO₂ sources (top 50)
- Saline aquifer (confined trap)
- Saline aquifer (open)
- Hydrocarbon fields

Capacity (P50)/Emissions (megatonnes):

- <10
- 11 – 100
- 101 – 1000
- <4000



Geological Resource and Capacity

- In the UK, the total theoretical storage capacity has been estimated to be at least 78 GtCO₂ in over 50% of model predictions carried out to explore the impact of uncertainties in rock
- Of this total theoretical storage capacity, around 60 GtCO₂ occurs in saline aquifers, 8 GtCO₂ in chalk aquifers and a further 8 GtCO₂ in depleted oil and gas fields.
- A further 2 GtCO₂ is contained in small units of less than 20 MtCO₂ each.