INTRODUCTION TO CARBON CAPTURE AND STORAGE (CCS)

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OUR MISSION

TO ACCELERATE DEPLOYMENT OF CCS

WHO

WE ARE AN INTERNATIONAL CCS THINK TANK

OVER **200** MEMBERS ACROSS GOVERNMENTS, GLOBAL CORPORATIONS, PRIVATE COMPANIES, RESEARCH BODIES, NGOS

WHAT

FACT-BASED INFLUENTIAL ADVOCACY

CATALYTIC THOUGHT LEADERSHIP

AUTHORITATIVE KNOWLEDGE SHARING

WHERE

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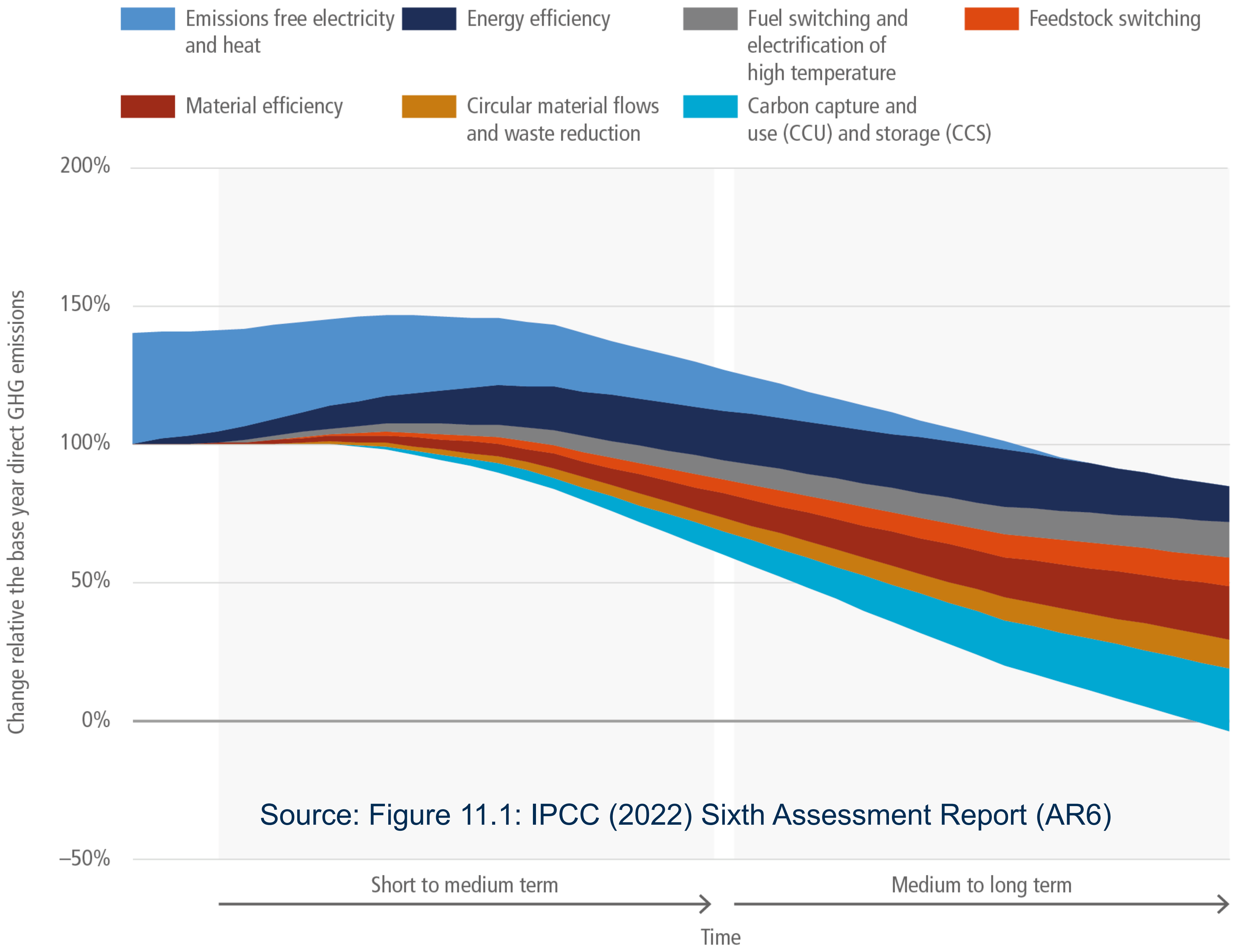
WHAT IS CCS?

Carbon Capture and Storage (CCS)

“A suite of technologies that captures the greenhouse gas carbon dioxide (CO_2) and stores it safely and permanently underground, so that it does not reach the atmosphere and contribute to climate change.”

WHY DO WE NEED CCS?



Source: Figure 11.1: IPCC (2022) Sixth Assessment Report (AR6)

There is no 'one-size-fits-all' solution to climate change. A combination of solutions is needed - with CCS essential to the mix.

- Limit global warming to below 1.5°C and avoid the worst impacts of global warming
- Cut greenhouse gas emissions to net zero by 2050

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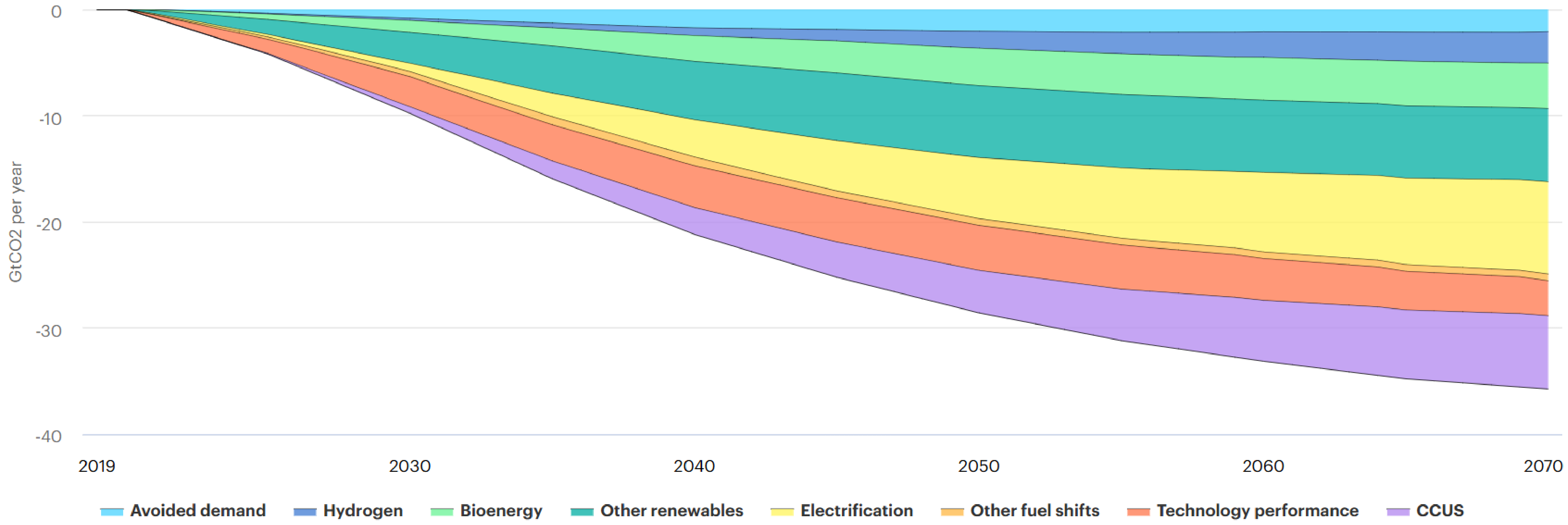
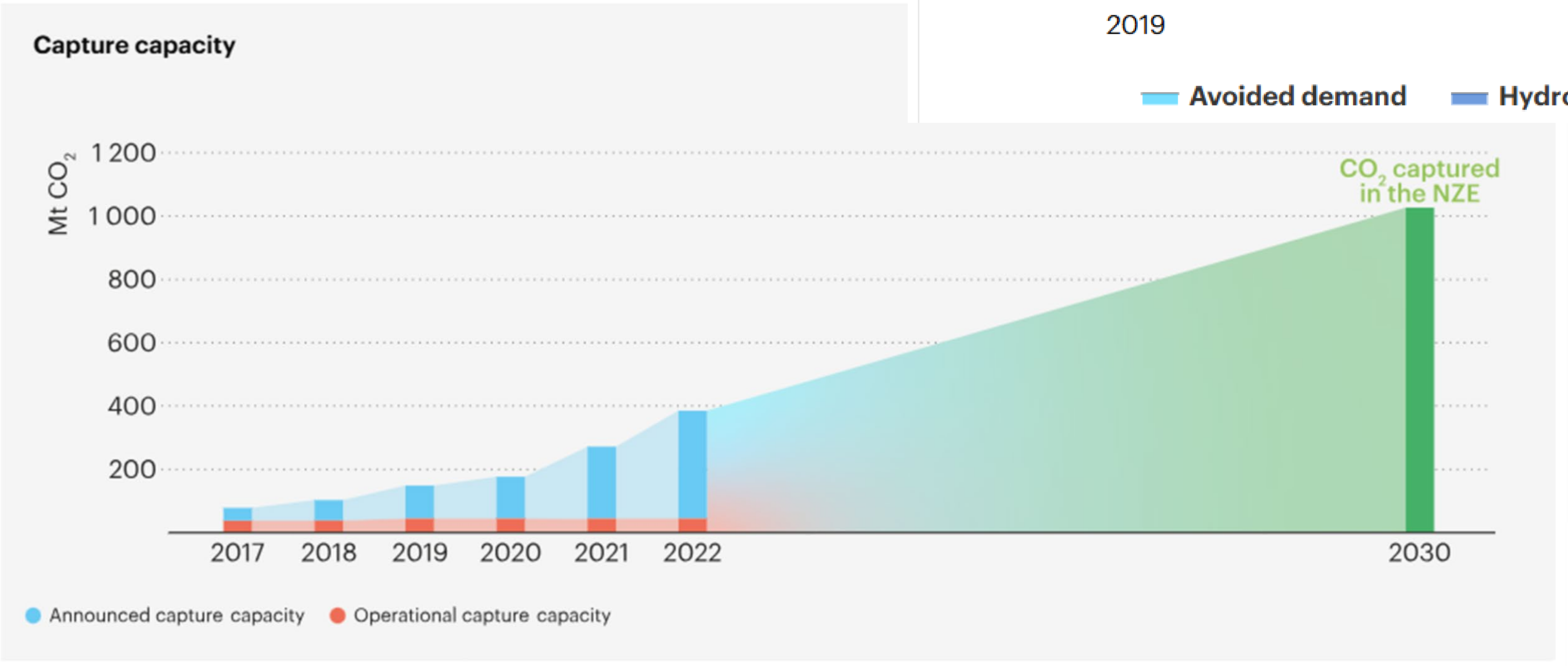
ROLE OF CCS



Source: IEA (2020), CCUS in Clean Energy Transitions



Milestones	2022	2030	2035	2050
Total CO_2 captured (Mt CO_2)	45	1 024	2 421	6 040

Source: IEA (2023),
Net Zero Roadmap

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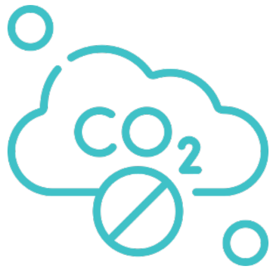
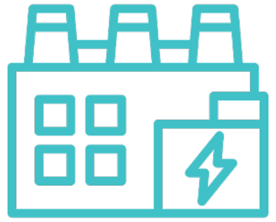
CCS FOR REACHING NET ZERO EMISSIONS

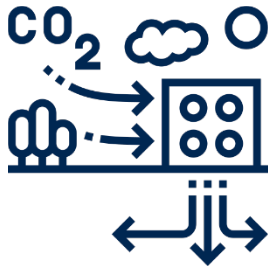


Achieving deep decarbonization in hard-to-abate industry.

Enabling the production of low-carbon fuels at scale.



Providing emissions reductions in the power sector.



Delivering negative emissions.

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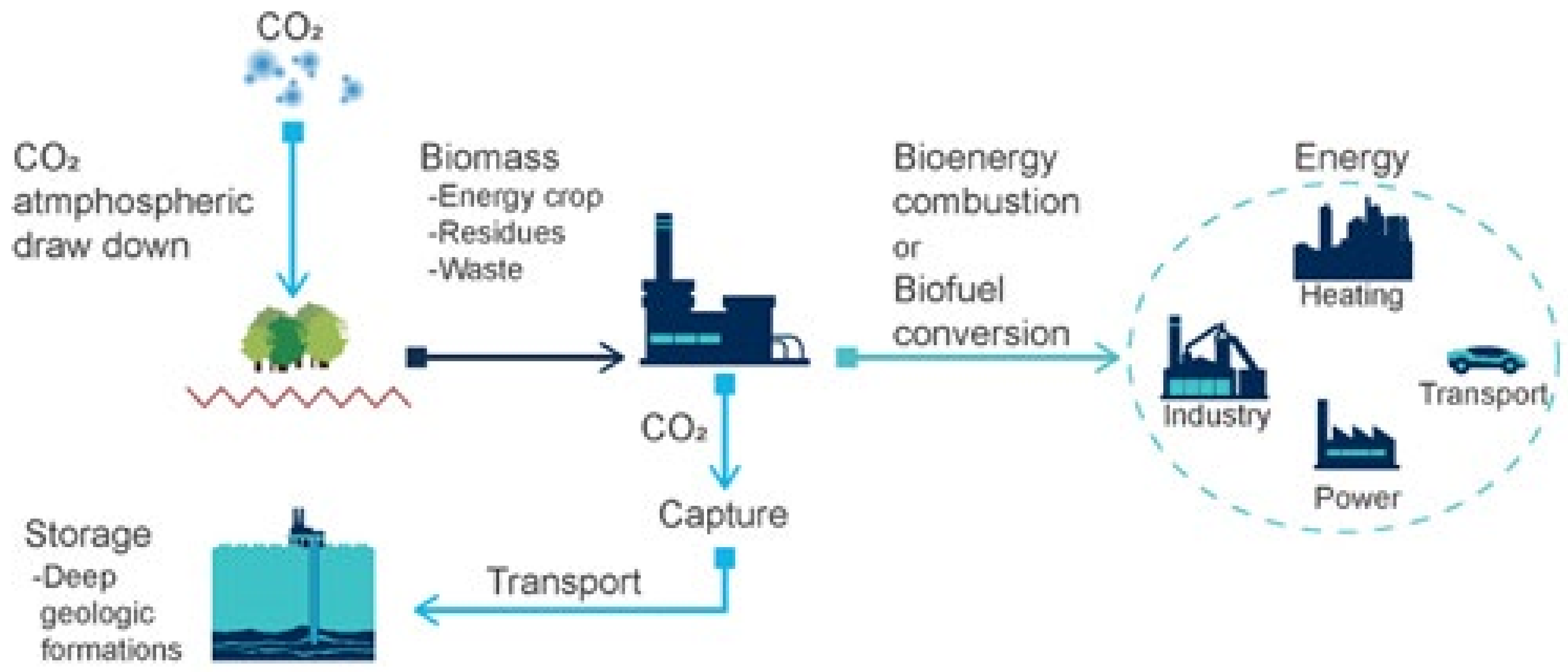
CARBON DIOXIDE REMOVAL (CDR)

- Carbon dioxide removal (CDR) is the process of removing CO_2 from the atmosphere – e.g., afforestation, reforestation, direct air capture (DAC) with CCS, and bioenergy with CCS, or BECCS
- BECCS applications include ethanol plants, biogas purification plants and biofuel power plants.
- **Negative Emissions** if CO_2 stored > CO_2 emitted during biomass production, capture, transport, storage and use
- Brazil has one of the greatest potentials for BECCS in the world, given its prominence in ethanol fuel production



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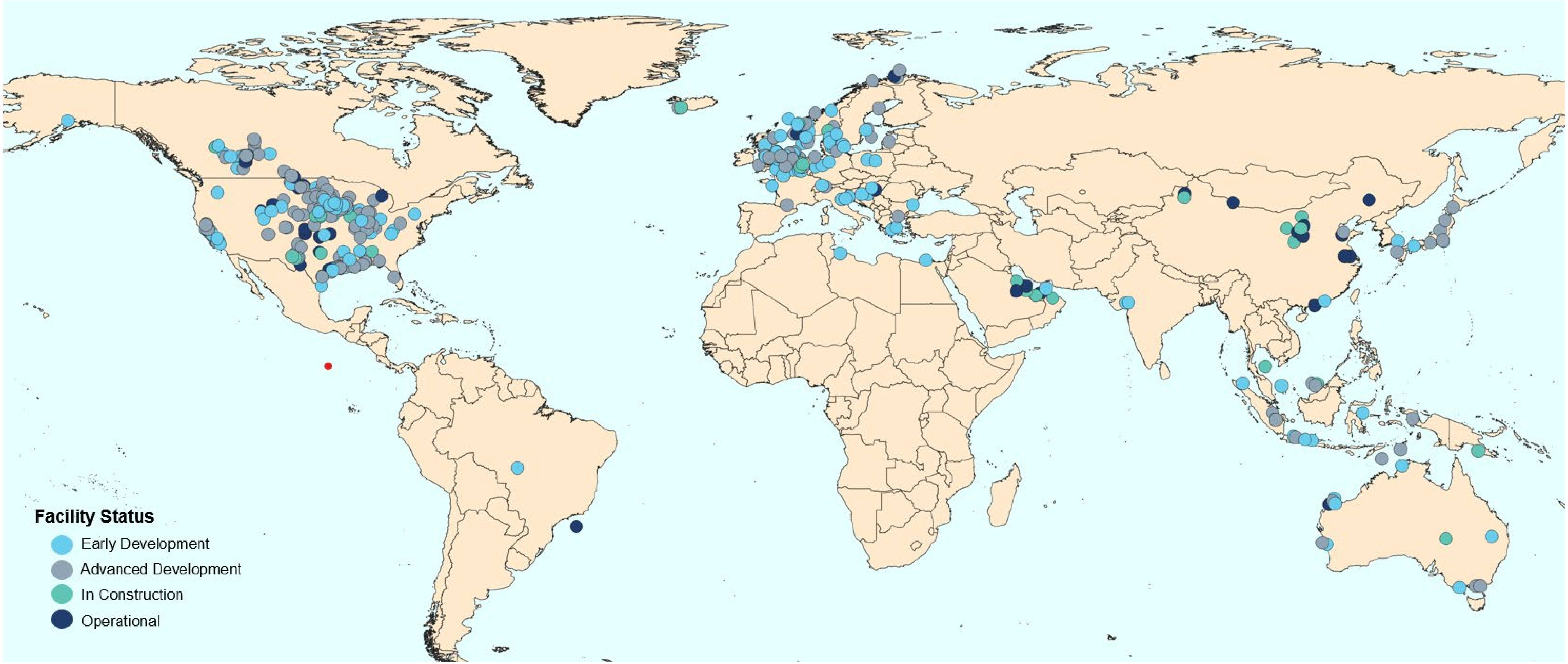
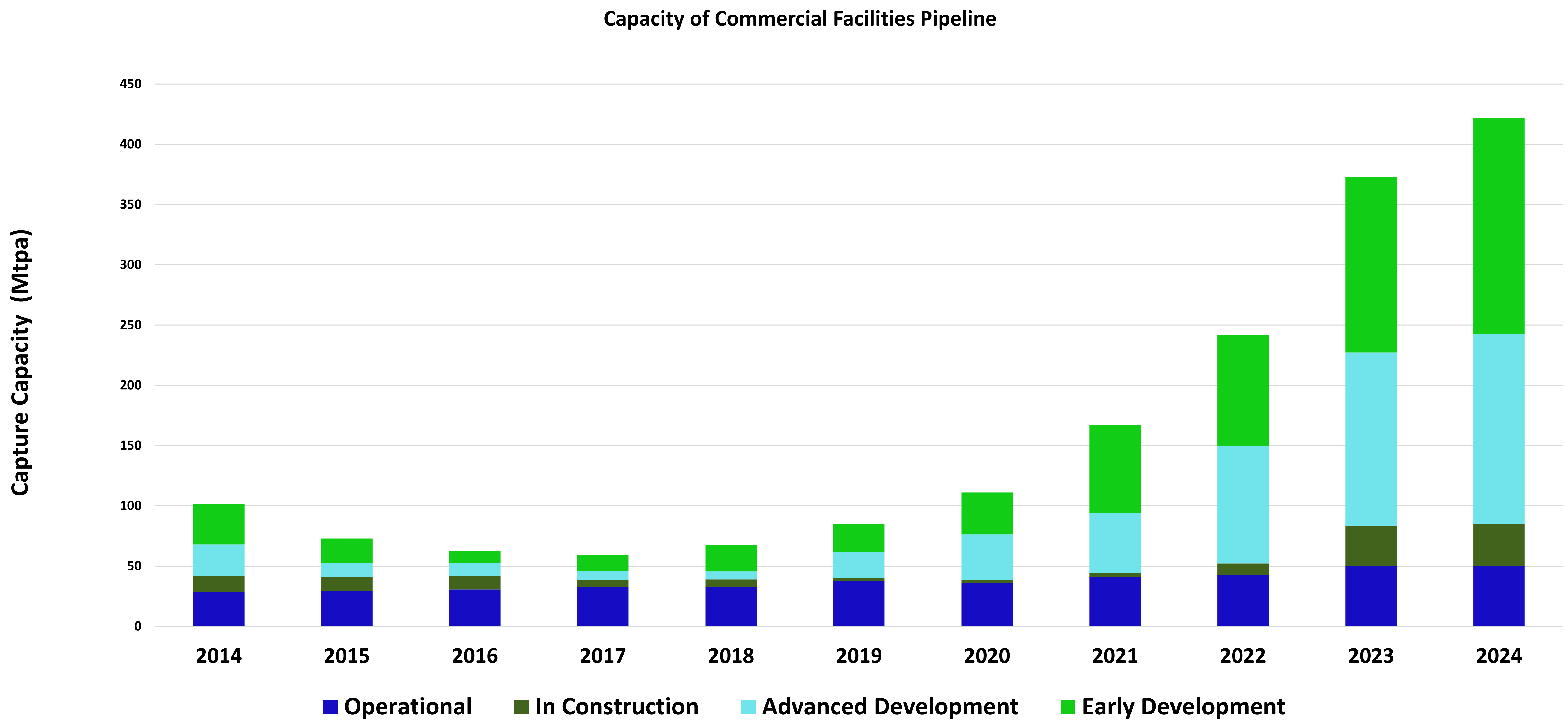
GLOBAL CCS FACILITIES



CO_2 CAPTURE CAPACITY OVER TIME



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CCS IS PROVEN

1930s

First commercial CO_2 facility

First commercial CO_2 separation facility using amines commences operation in the natural gas industry

1972

First enhanced oil recovery project

First enhanced oil recovery project - in which CO_2 is geologically stored in the process – commences operation at the Terrell Gas Processing Facility

1996

First commercial geological storage

First commercial geological storage of CO_2 for climate mitigation purposes commences at Sleipner, Norway

2024

> 600 projects in the pipeline

- 50 in operation
- 44 in construction

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CCS PROJECTS TODAY

Ethanol & Hydrogen

- Decatur (Ethanol)
- Red Trail (Ethanol)
- Quest (Hydrogen)

Carbon Intensive Industry

- Al Reyadeh (Steel)
- Qingzhou Oxy-Fuel (Cement)
- Brevik (Cement, under construction)

Power

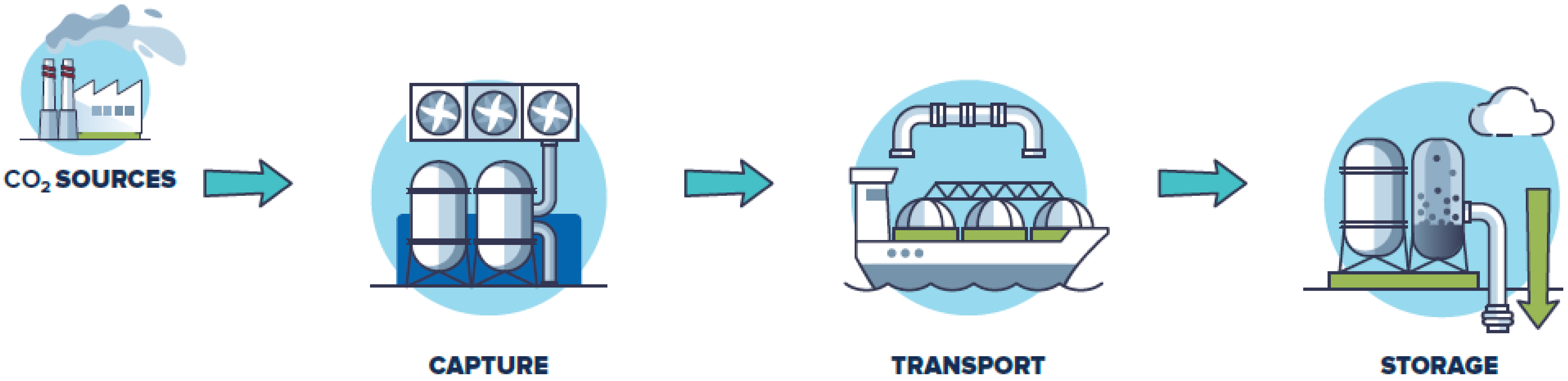
- Boundary Dam (Coal)
- Petra Nova (Coal)
- Net-Zero Teesside (Gas, under construction)

Direct Air Capture

- Orca
- Mammoth
- STRATOS (under construction)

HOW CCS WORKS

Three key steps



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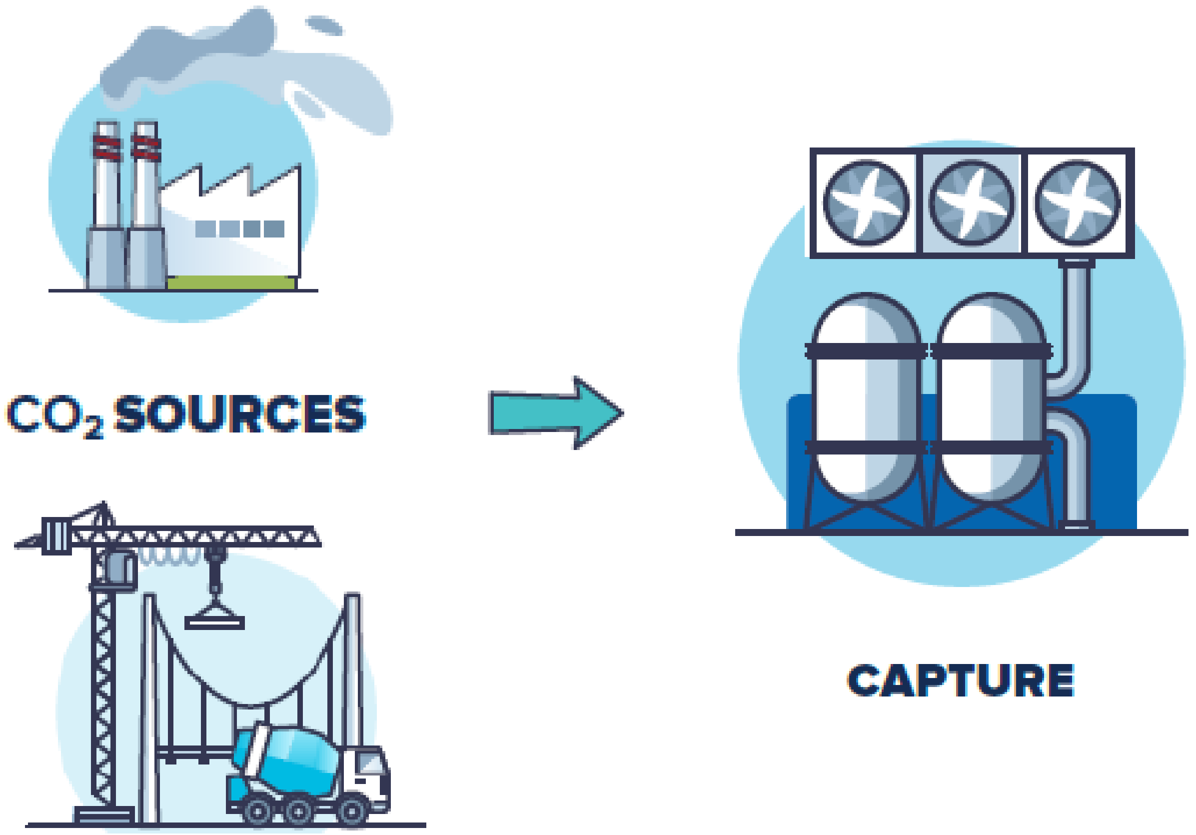
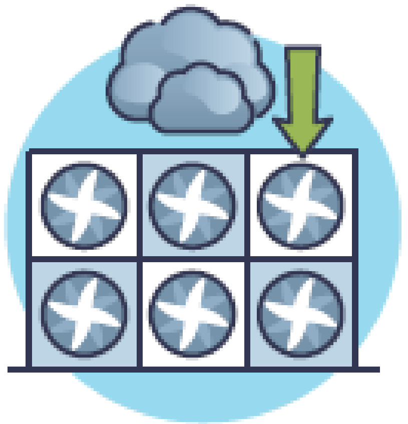
CAPTURE



Involves separating CO_2 from emissions produced by industrial processes such as cement or steel production, or from fossil fuel-based power generation.



CO_2 can also be removed directly from the air.

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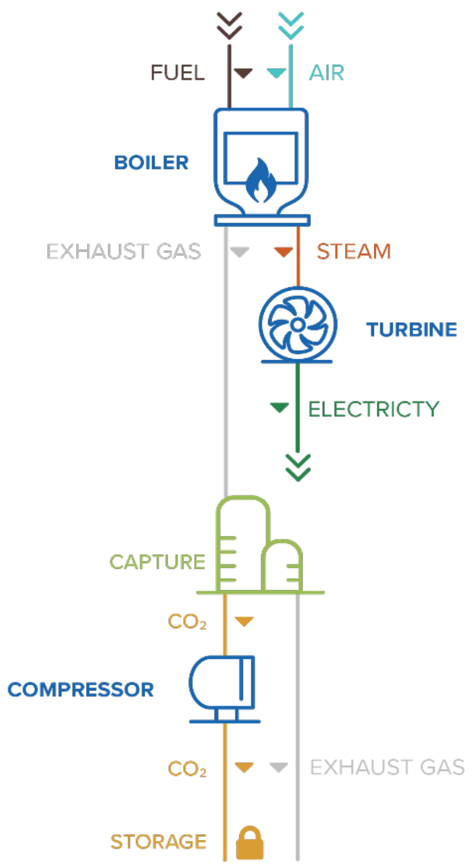
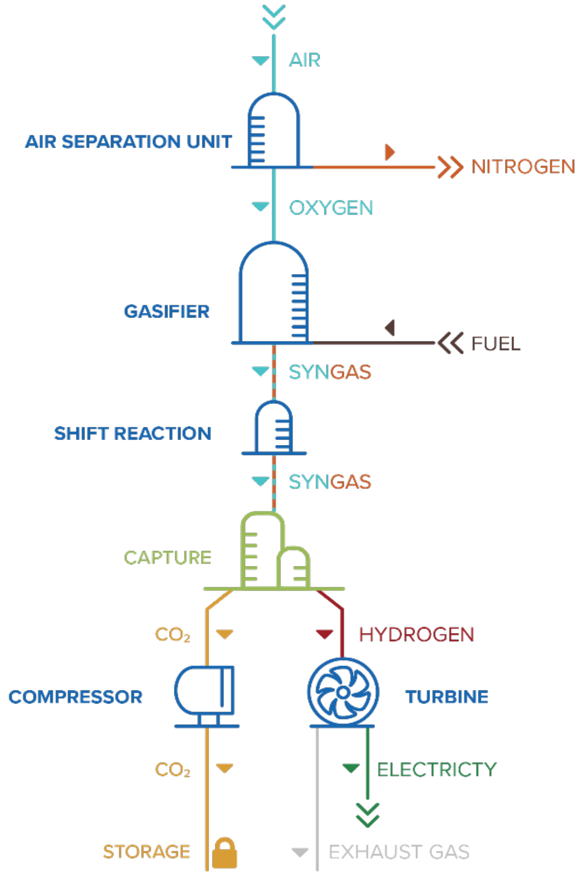
CATEGORIES OF CAPTURE SYSTEMS

POST-COMBUSTION CO_2 CAPTURE



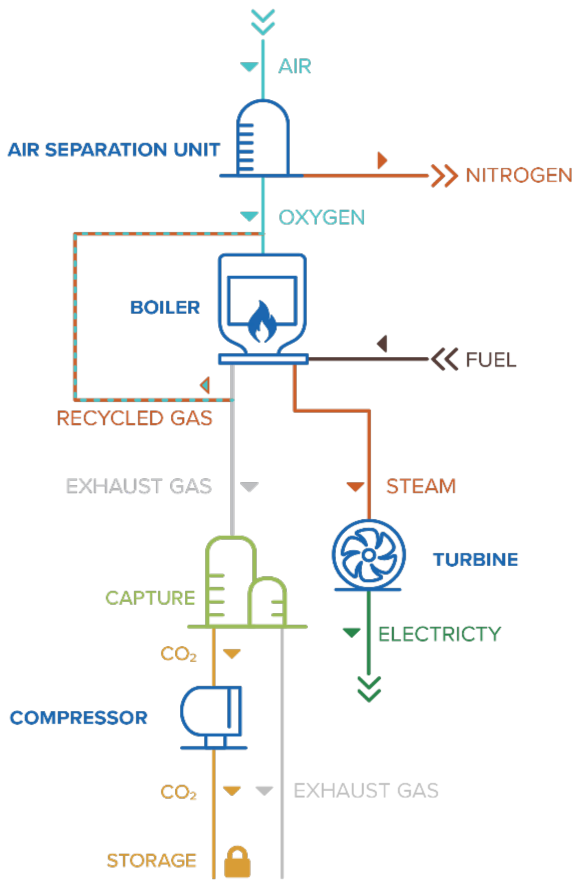
- Post-combustion capture refers to the removal of CO_2 from flue gases emitted **<u>after</u> fuel combustion** in industrial facilities.
- This method is ideal for capturing CO_2 from plants that use waste to generate energy (Mohammad et al., 2020).

PRE-COMBUSTION CO_2 CAPTURE



- Pre-combustion capture removes CO_2 **<u>before</u> fuel combustion** in industrial processes or facilities.
- Gasification reactions produce “syngas” stream that can be split into CO_2 and H_2 streams in the capture unit.

OXYFUEL CO_2 CAPTURE



- In oxyfuel combustion capture, the fuel is **combusted in the presence of nearly pure oxygen** (approximately 98%) to ensure complete combustion, which makes CO_2 capture easier.
- Separates nitrogen from combustion air

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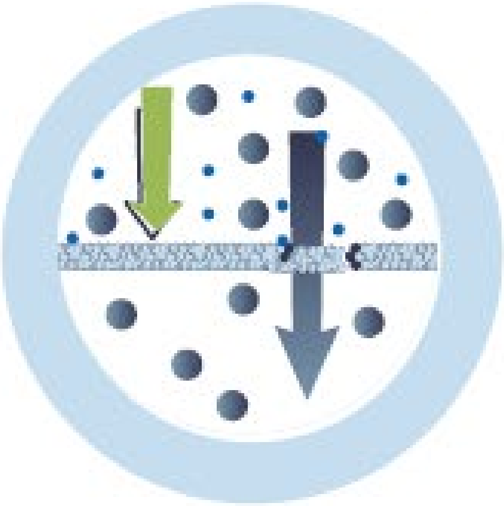
TECHNOLOGIES USED DURING CAPTURE

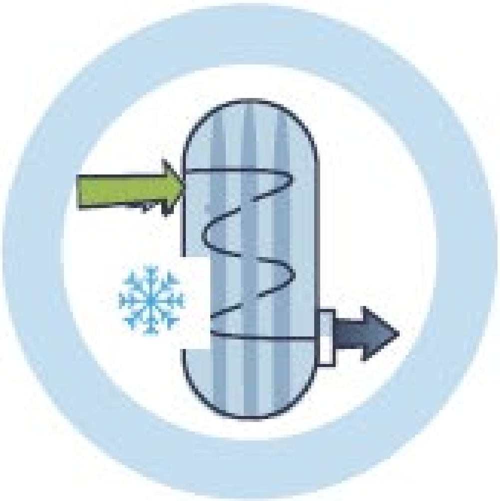
CCS technologies can capture over 90% of CO_2 emissions from industries – CO_2 that would otherwise have been released into the atmosphere.

ABSORPTION BY LIQUID SOLVENTS

ADSORPTION ONTO THE SURFACE OF SOLID SORBENTS

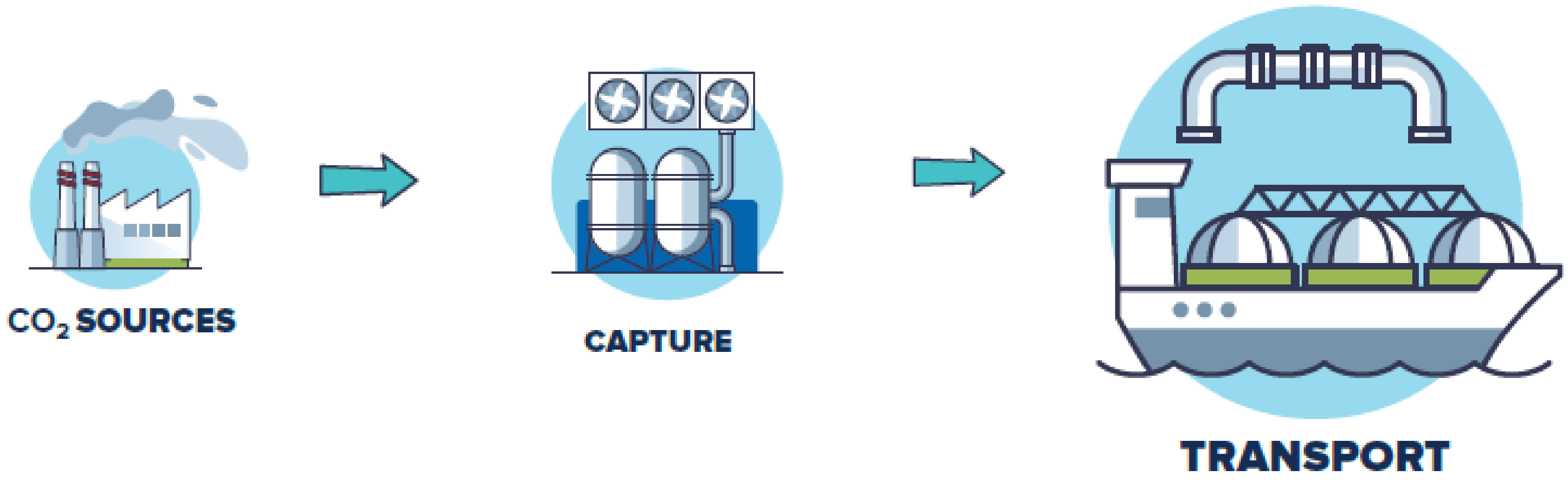


SEPARATION USING MEMBRANES THAT ACT LIKE SIEVES



CRYOGENIC SEPARATION

TRANSPORT



CO_2 transportation is regulated and closely managed under national and international laws and standards.

CO_2 is safely and securely transported in countries around the world every day.

MODES OF CO_2 TRANSPORT

COMPARISON OF CO_2 TRANSPORT MODES

CURRENT CAPACITY
MT = MILLION TONNE

PIPELINE

- Most common mode of CO_2 transportation.
- Can move large, commercial-scale quantities over long distances with lower operational cost.

~110 $MTCO_2$ PER YEAR

SHIP

- Offers flexibility in scale and destination.
- Is a good alternative for regions without close access to storage sites.
- In some cases, can be a cheaper option than pipelines for transport over long distances.

>2 $MTCO_2$ PER YEAR

TRUCK

- Best suited for transport of small quantities of CO_2 (2-30 tonnes per batch).

>1 $MTCO_2$ PER YEAR

RAIL

- More advantageous over medium and long distances, using existing rail lines.

>1 $MTCO_2$ PER YEAR

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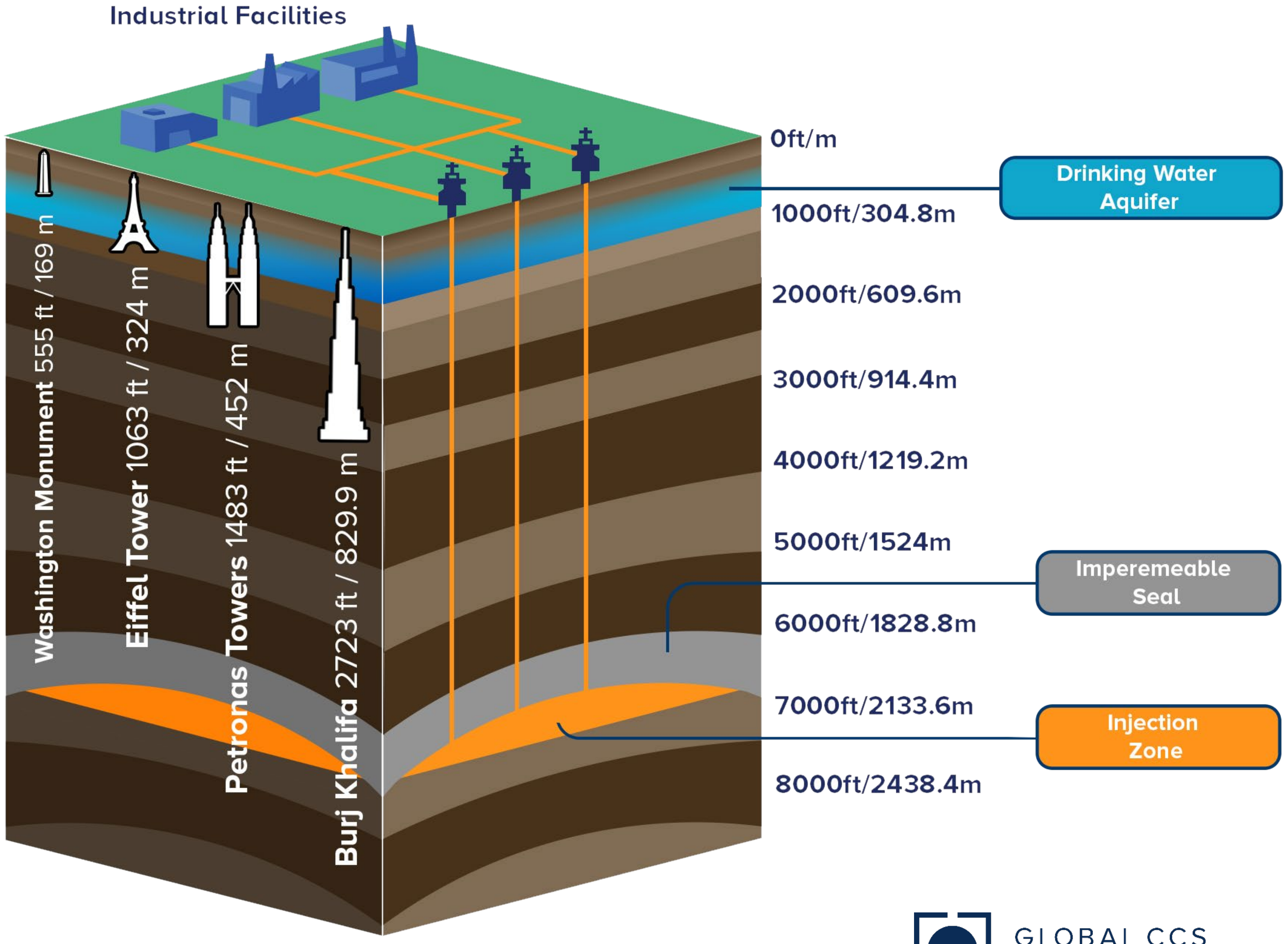
GEOLOGIC STORAGE

Captured CO_2 is injected into carefully selected porous rock formations (**storage formations**).

These can be depleted oil and gas reservoirs, or porous rock filled with unusable, saline water – either onshore or offshore.

Storage formations are always underground, typically at depths 2-3 kilometers or more below the earth's surface.



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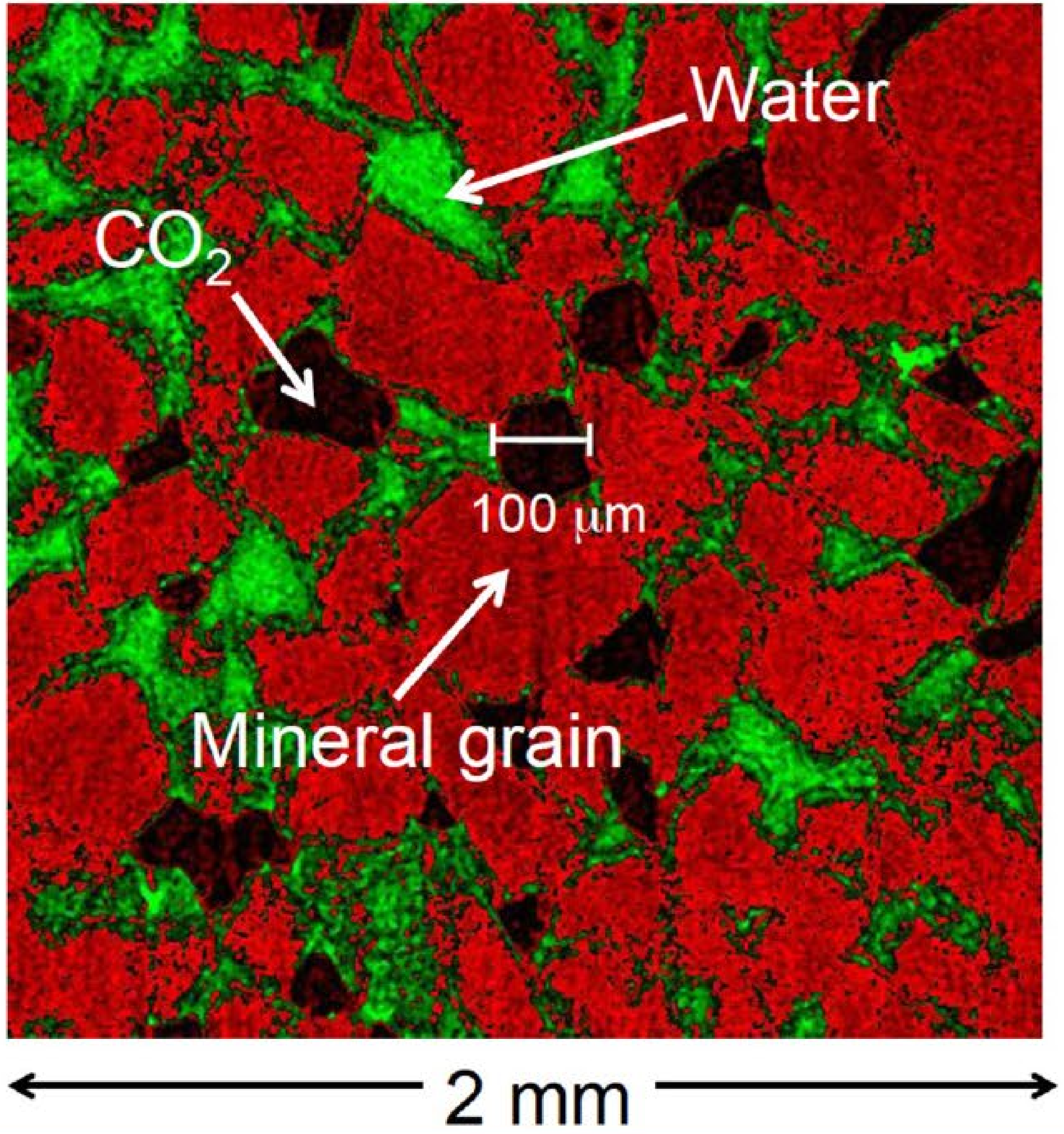
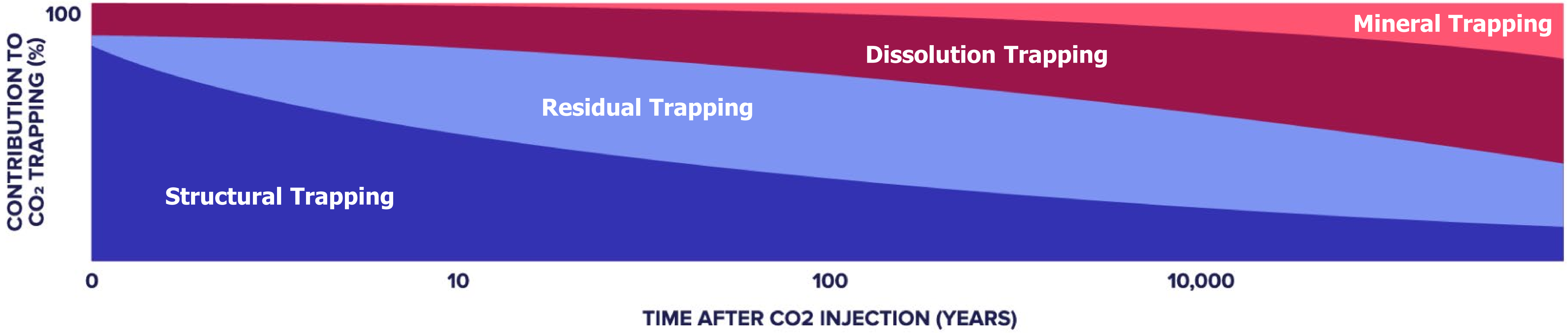
What Does CO_2 Look Like In a Rock?

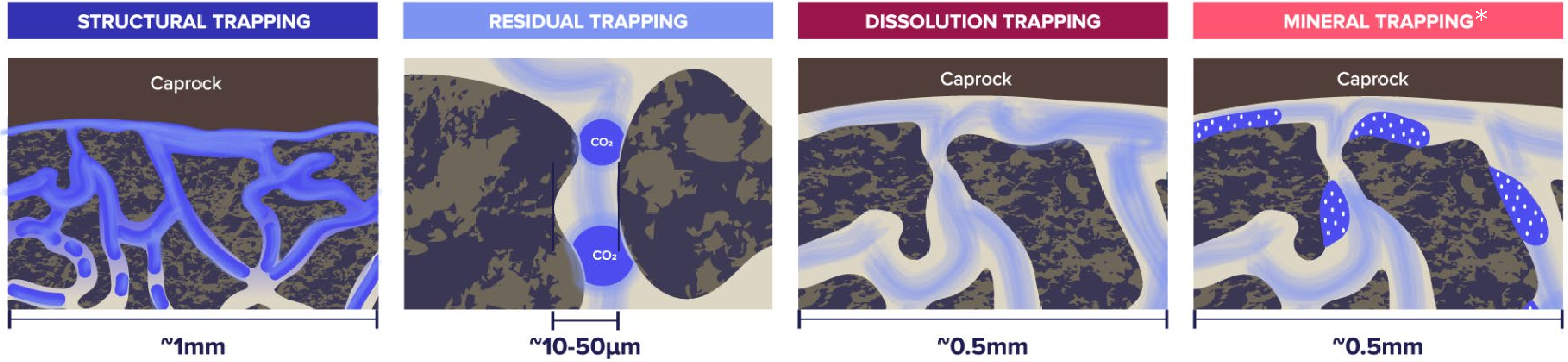
- 2-dimensional image of a sandstone (common reservoir rock) with water and CO_2 in the pore space
- Wells are often drilled > 1 mile underground.
- Sandstones are sedimentary rocks where the pore structure is formed from the space between the mineral grains
- Oil and gas are produced in these pores, and are the same that ultimately store CO_2
- Courtesy of the Advanced Light Source at LBNL! Strand of hair is roughly 70 microns



TRAPPING MECHANISMS

Geologic storage mechanisms – how is CO_2 trapped?





*Mineralization in Basalt occurs MUCH faster – 95% of injected CO_2 mineralized in 2 years (CarbFix)

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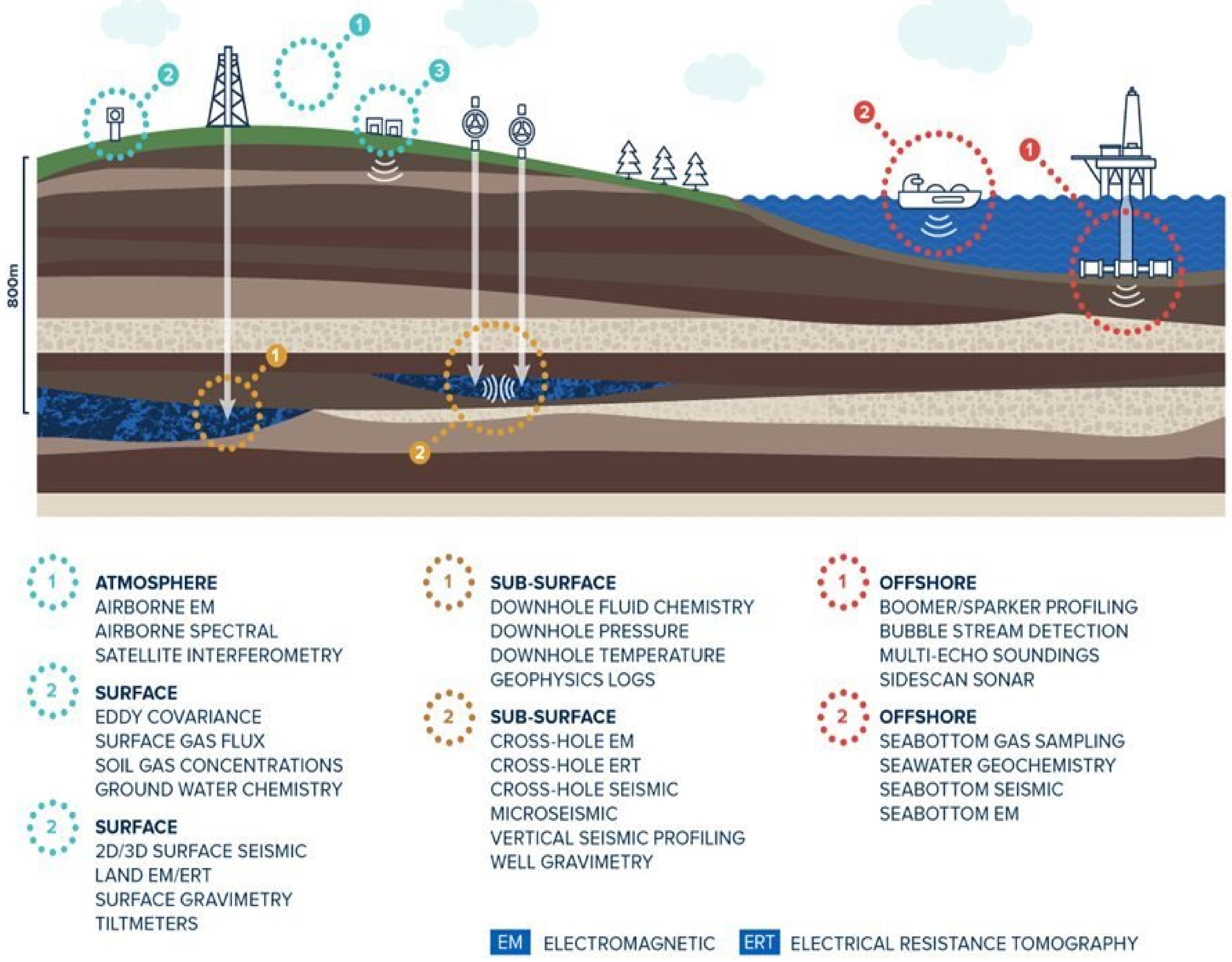
MEASUREMENT, MONITORING AND VERIFICATION (MMV)

- Once CO_2 is safely stored, MMV programs must validate the CO_2 plume is behaving as expected.
- Techniques used in monitoring are:
  - **Seismic Monitoring:** Using acoustic (sound) waves to image the subsurface and detect CO_2 plume movement.
  - **Surface and Subsurface Monitoring:** Installing sensors at various depths to monitor CO_2 levels, pressure, and other parameters.
  - **Soil Gas Monitoring:** Measuring CO_2 concentrations in the soil above the storage site.
  - **Aerial and Satellite Monitoring:** Using remote sensing technologies to monitor large areas for CO_2 emissions.
- A numerical model is needed to model CO_2 behaviour and should be updated based on new monitoring data.



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POLICIES DRIVING GROWTH

Greater recognition of role of CCS in NDCs, National Roadmaps

Creation of international CCS ambition: Carbon Management Challenge

Strengthening general climate policy

Strengthening fiscal incentives – capital and operating support

Establishment of national CCS targets

Development of CCS regulations

POLICY SUPPORT

Government policy is a critical driver of CCS investment and deployment

Carbon pricing
Emissions Trading Schemes (ETS), carbon taxes

Subsidies
Tax credits/tax incentives, grants and direct investment, loans, offtake agreements, carbon contracts for difference (CCfDs)

Laws and regulations
Permitting regimes, domestic and international legal frameworks or agreements

REGULATORY SUPPORT

Law and regulations are essential for CCS

CCS-specific legislative and regulatory frameworks:

- Reduce risks and promote safety
- Provide certainty to investors
- Give communities long-term assurance
- Ensure environmental protection
- Enable transboundary developments

US EPA: CLASS VI REGULATIONS

- U.S. Environmental Protection Agency (EPA) is responsible for protecting public health by regulating and overseeing the nation's public drinking water supplies
- Safe Drinking Water Act (SDWA), administered by EPA, prohibits underground injection of fluids without a permit
- EPA regulates underground injections through the Underground Injection Control (UIC) program
- Class VI regulations/wells specific for CO_2 injection into deep rock formations – designed to protect underground sources of drinking water (USDWs) by preventing the movement of contaminants out of injection formations and into USDWs
- Class VI regulates all aspects of the injection wells including:
  - Project siting
  - Injection operations, testing and monitoring
  - Financial responsibility
  - Well construction requirements
  - Emergency response and remedial plans
  - Plugging and closure of wells and injection sites
- Ensuring compliance through permitting, site inspections, required reporting, and compliance reviews

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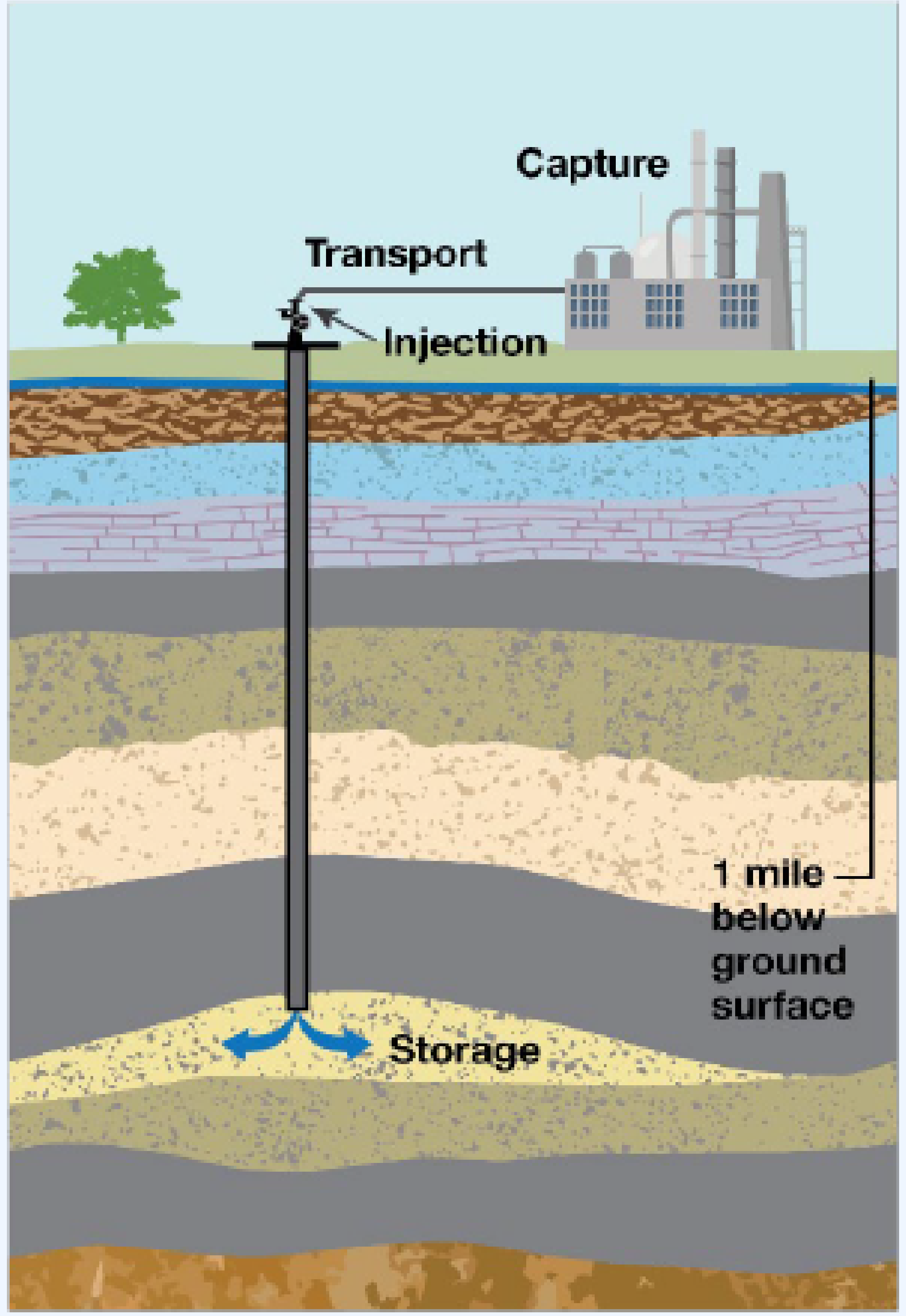
Geologic Sequestration of CO_2 and the Safe Drinking Water Act



The Safe Drinking Water Act requires permits <u>with protection and mitigation measures</u> for the Geologic Sequestration of CO_2

UIC Class VI regulations are designed to protect underground sources of drinking water (USDWs) by preventing movement of CO_2 out of the injection formation

Protective aspects of UIC Class VI regulations include:

- Multiple safeguards to protect USDWs (described later in this presentation).
- Development of written plans for operating a GS project based on EPA technical guidance.
- Adaptable and evolving - revisions made to plans if new data indicate the need.
- Tracking the movement of the "plume" of CO_2 and any other potential changes in the subsurface

Siting (Selecting Project Location)

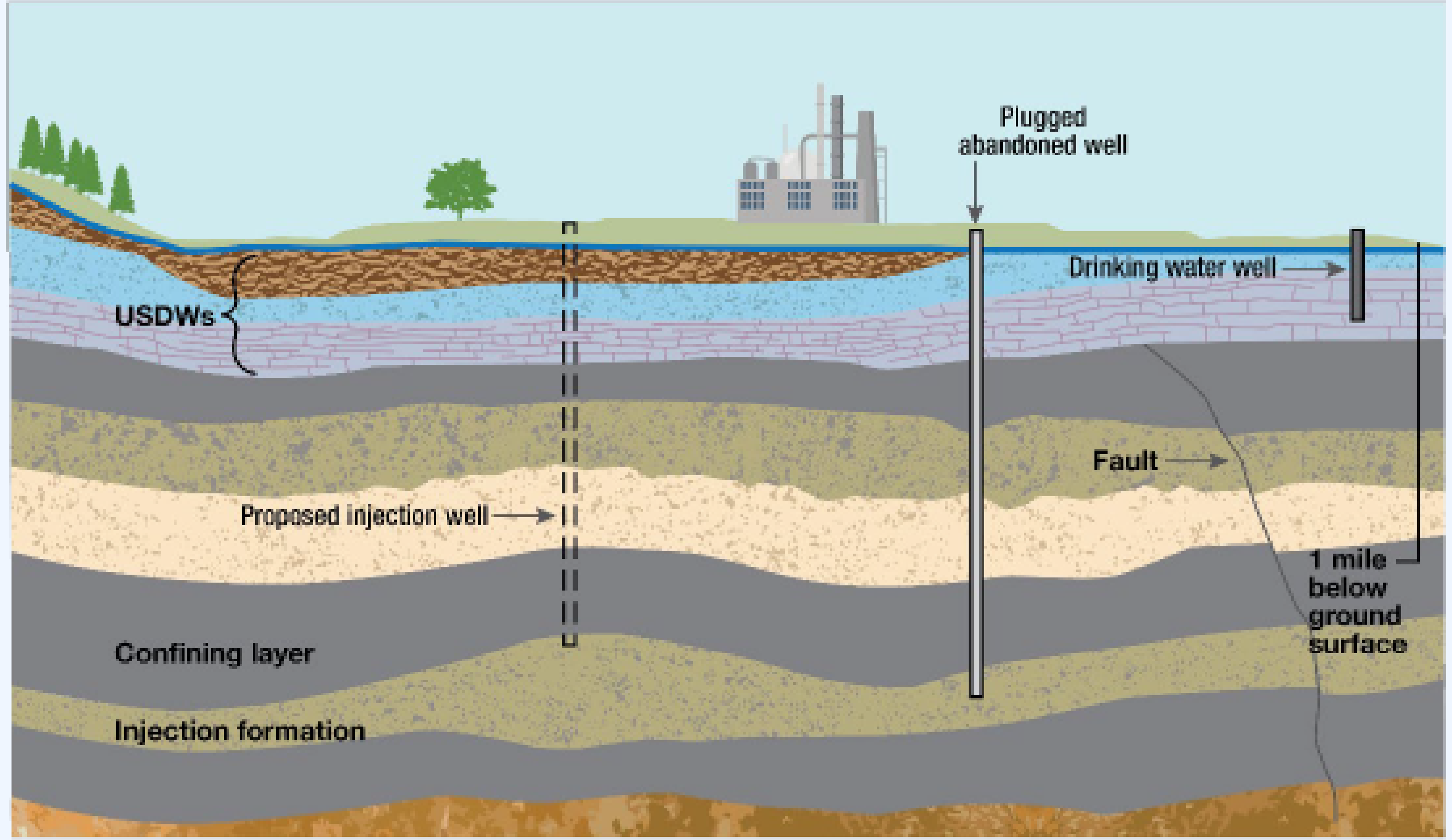
Proper site characterization and selection focuses on the geologic setting of the injection well.

Goals: Protect USDWs by confirming that the site is suitable for GS – that it can hold the CO_2 and that CO_2 will not leak through geologic pathways.

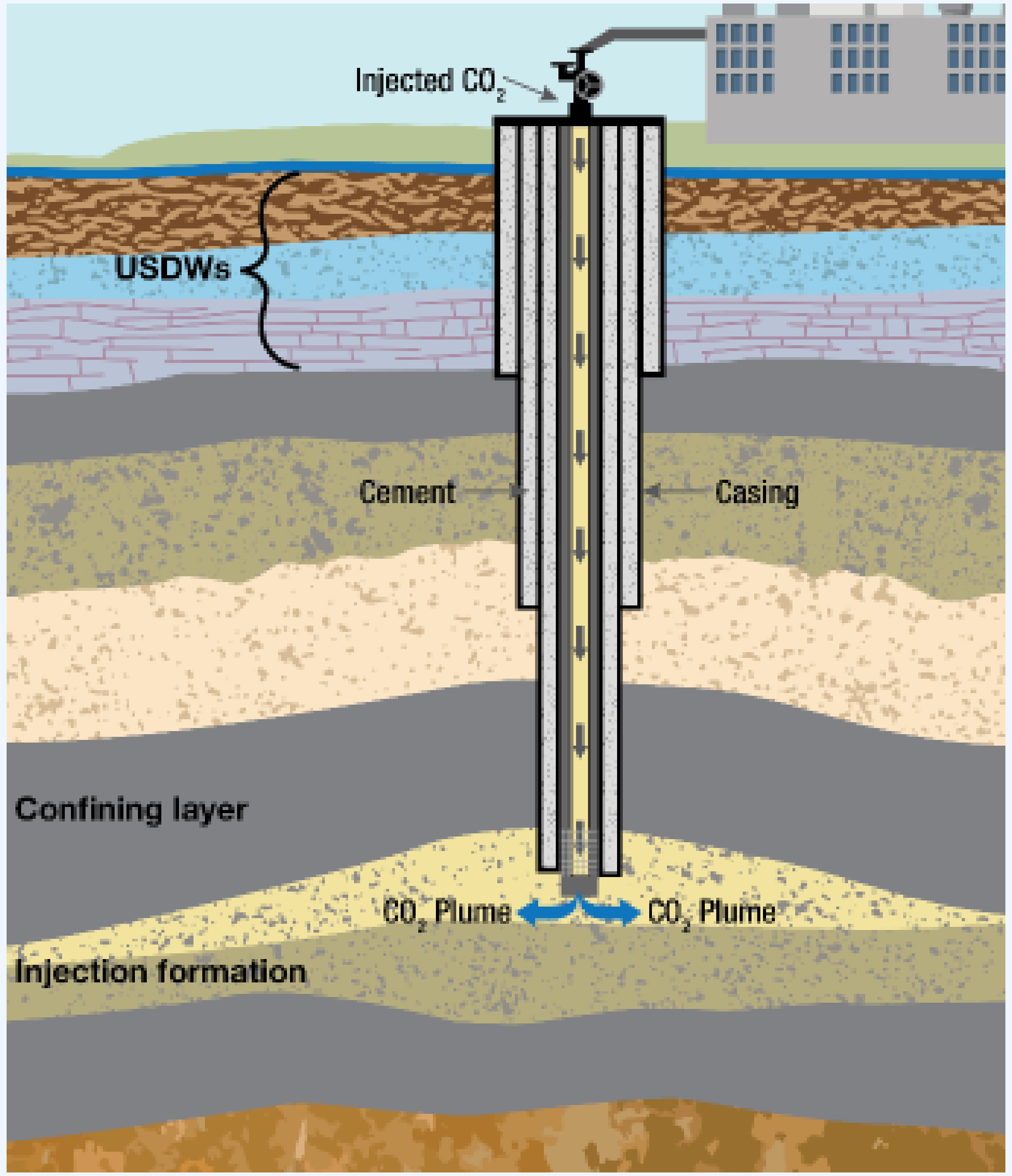
How this is done:

Testing, data collection, and analysis to show the following:

- **Injection Zone**—can hold the injected CO_2. Thousands of feet deep.
- **Confining Layer**—prevents CO_2 from moving upward.
- **Faults**—if present, test to verify they are inactive and will not allow movement of CO_2.
- **Seismic history**—confirm seismic stability in the area.
- **Compatibility**—verify that there will be no unanticipated reactions between the CO_2 and the existing chemical composition in injection zone.



Injection Well Construction



Class VI wells are constructed to protect USDWs.

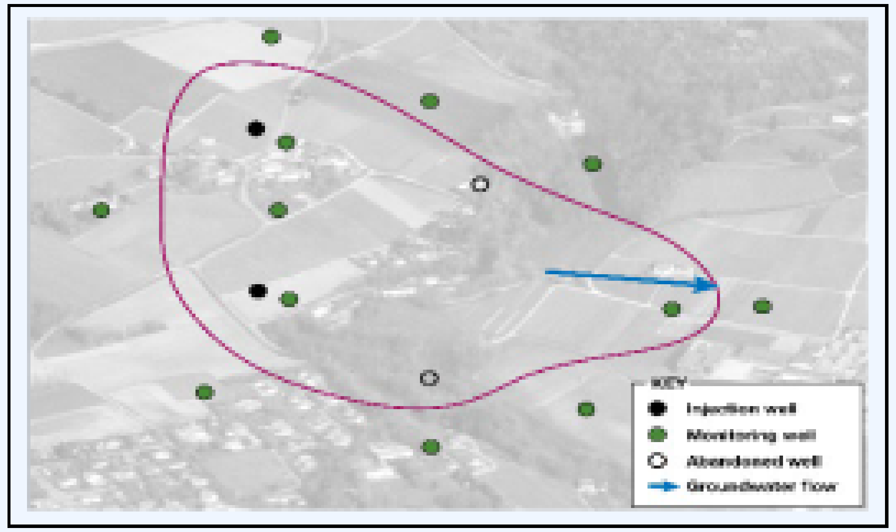
Goals: Protect USDWs by preventing injected CO_2 or other naturally occurring fluids in deep formations from reaching USDWs. Isolate geologic formations from each other. Ensure the well will tolerate the subsurface conditions it will encounter.

How this is done:

- To prevent fluids from entering USDWs, wells are constructed with multiple protective layers of casing and cement to ensure:
  - Injected CO_2 does not leak from injection wells.
  - Deep formation fluids do not move along the outside of the well casing and migrate upwards.
- High-quality cementing is key to preventing fluid movement and protecting USDWs.
- Well materials are corrosion-resistant.
- Cement around the long metal tube ('long strong casing') must extend all the way from surface to the bottom of the well to isolate formations and prevent CO_2 movement between formations along the well.
- After construction and before injection, wells are tested to:
  - Verify structural soundness.
  - Check cement quality.
  - Check for leaks in tubing and casing.

Testing and Monitoring

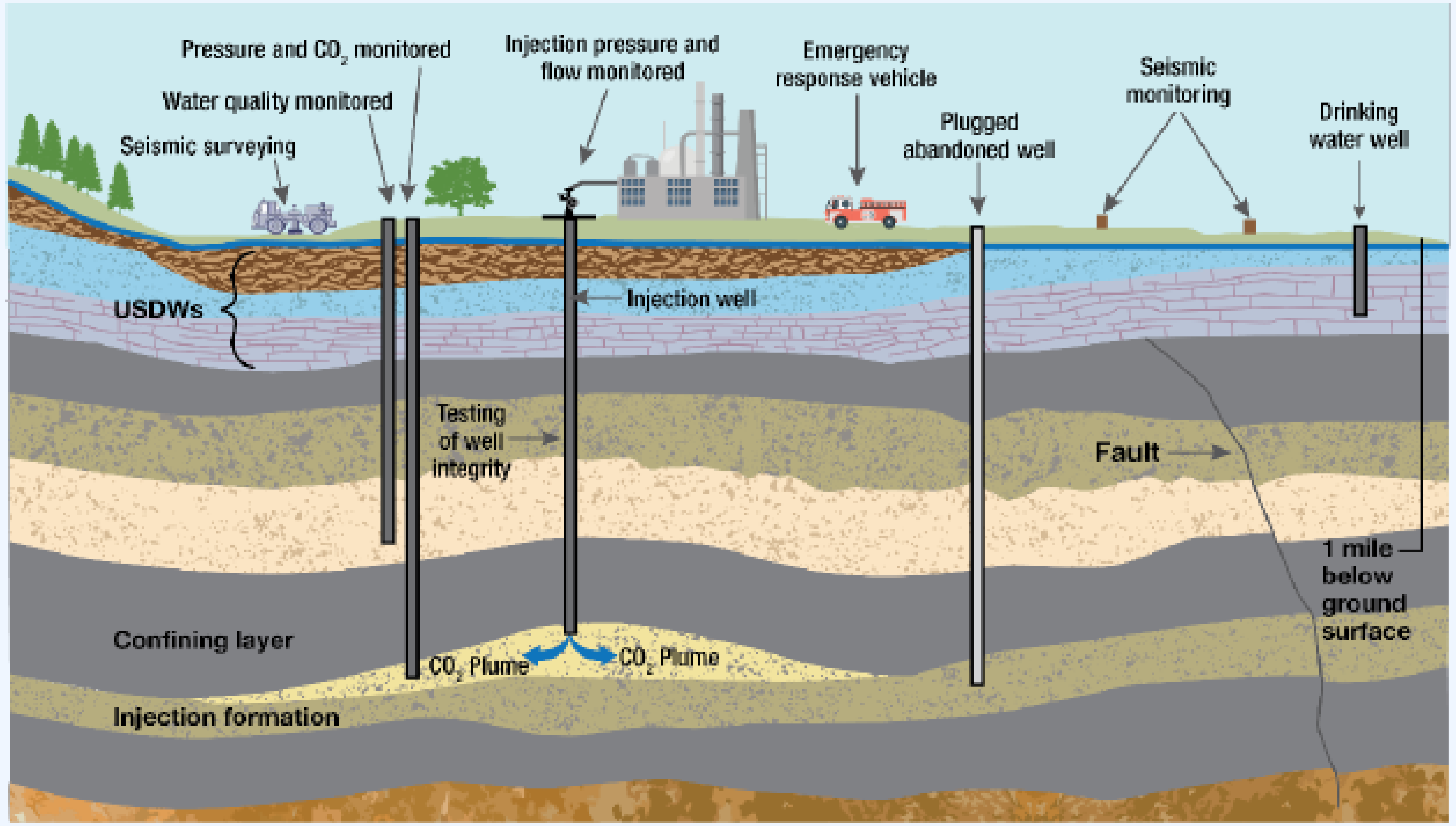
Multiple types of testing and monitoring are done to support safe injection and storage of CO_2 during injection and through to site closure.



Goals: Track CO_2 injection, CO_2 movement, and pressure. Be alerted to leakage, problems with the injection well, or other unexpected changes in the subsurface.

How this is done:

- Pressure and CO_2 tracked in the injection formation.
- Groundwater quality monitored above the confining zone.
- Seismic surveys done to image the location and size of the CO_2 plume.
- Physical integrity of the well tested routinely.
- Testing for corrosion of the well required.
- Records retained for 10 years after site closure.
- Guided by plan approved by the UIC Director.



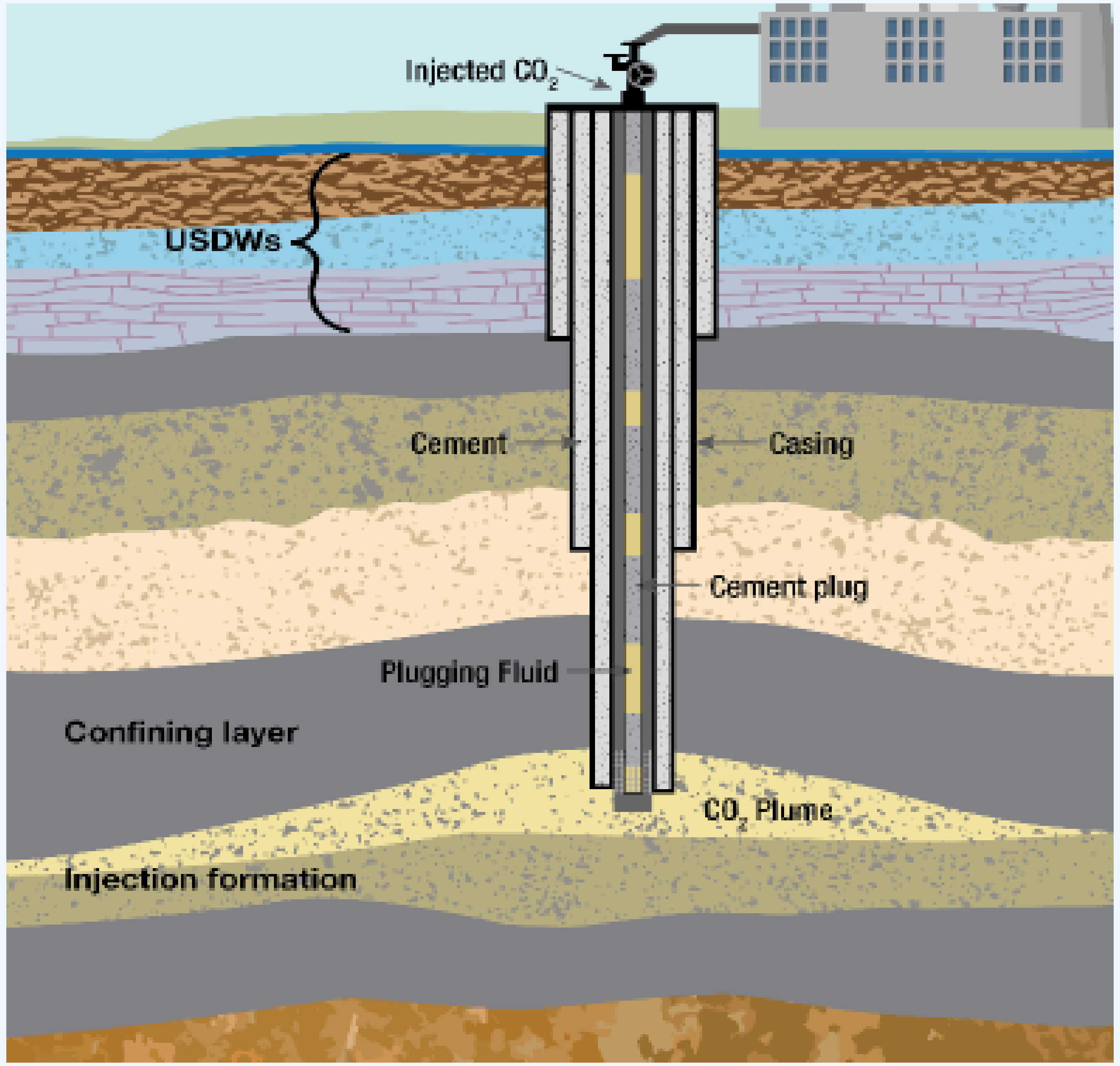
Post-Injection and Site Closure

Project sites must pose no danger to USDWs in order to be closed.

Goals: Demonstrate to the UIC Director that the project site will pose no danger to USDWs in the future. Close and restore the project site.

How this is done:

- After injection ceases, monitoring continues according to approved post-injection site care plan.
- Well is plugged according to approved well plugging plan:
  - Long-term prevention of CO_2 moving into USDWs.
  - Keeping formations isolated.
- To prepare to close the project site:
  - Demonstrate the plume and pressure in the injection formation are stable.
- Site closure—remove surface equipment and restore site to condition approved by UIC Director.



Adapted from: U.S. EPA, 2016. Geologic Sequestration of Carbon Dioxide Underground Injection Control (UIC) Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance. https://www.epa.gov/uic/final-class-vi-guidance-documents.

Carbon Management Challenge

Global carbon management initiative aligned with the Paris Agreement and high-level ministerial at COP, building on existing global collaborations (i.e. CEM CCUS, MI CDR), with a stakeholder mechanism launching soon.

Advancing projects by 2030 to manage

1 gigaton of CO_2 annually

22

Countries plus the European Commission

Workstream 1

Developing Country Project Finance

Co-Leads
Kenya
Indonesia
US

Workstream 2

Project Deployment and Tracking

Co-Leads
Brazil

Workstream 3

Strategic Comms and Engagement

Co-Leads
Saudi Arabia
UK

CCS IN BRAZIL

Capture potential

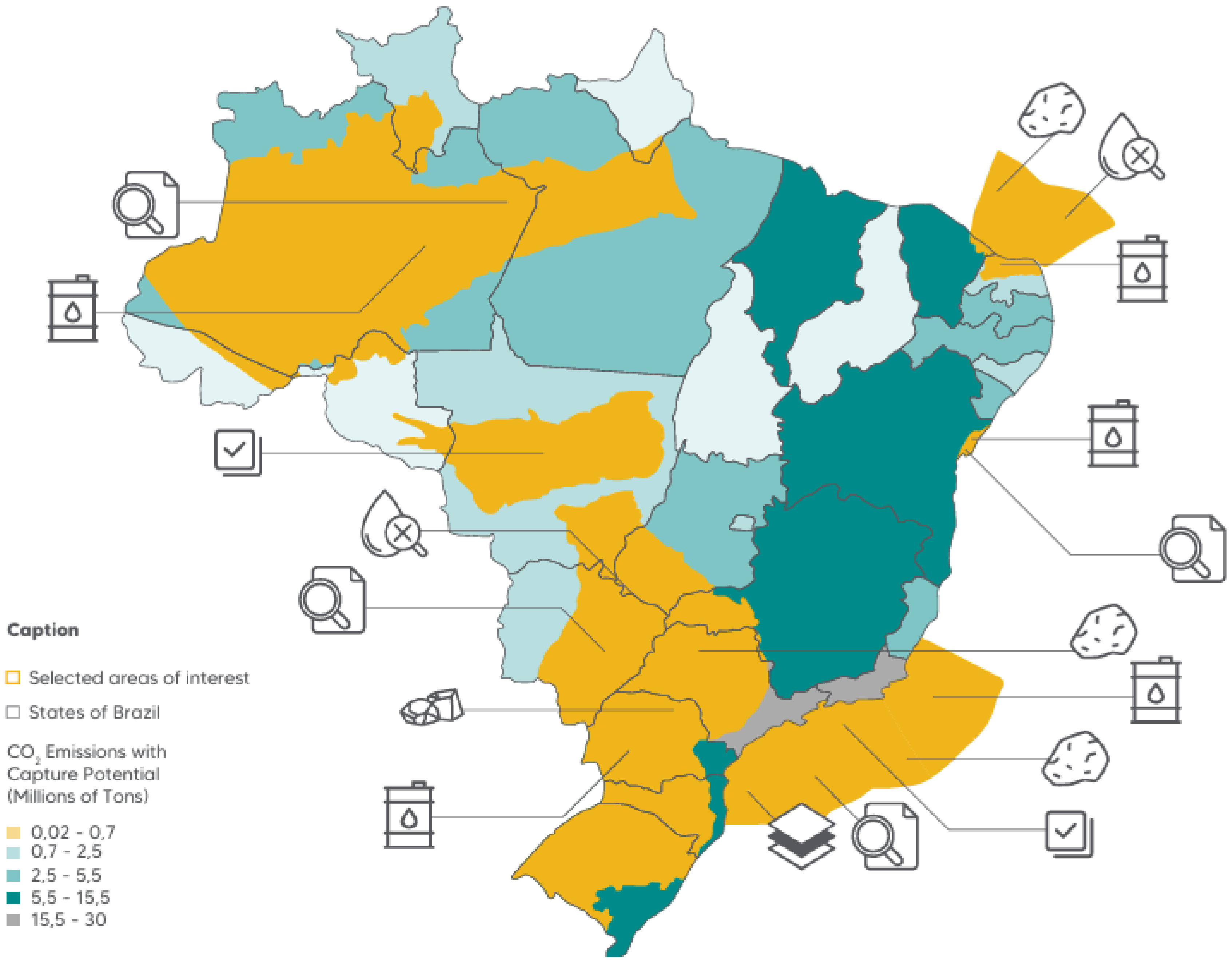
Brazil has the potential to capture 190 million tons per year of CO_2, according to CCS Brasil

Storage potential

Several areas Brazil have favourable geological characteristics for CO_2 storage in saline formations and depleted oil and gas reservoirs

Economic benefit

The successful implementation of eight potential CCS hubs could contribute up to US$3.2 billion per annum to Brazil's GDP and stimulate the creation of 210,000 new jobs, initially in construction, then in operational roles, according to S&P Global modelling



Source: CCS Brasil (2022/2023), 1st Annual CCS Report in Brazil

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THANK YOU

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