Technical and Business Aspects of Carbon Capture, Utilization and Storage

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Additional material provided by GaffneyCline Energy Transition Team

31 January 2023

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SPE International

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Attendees are urged to obtain independent advice on any matter relating to the interpretation of CO_2 storage and reporting.

Presenter

Drew Powell

- **Role and Experience**
  - GaffneyCline Projects’ & Energy Transition Director
  - Background in multiple disciplines, transactional, valuation, facilities, engineering, EPC, costs, commercial, hydrogen, CCS. Also CPRs, stock market listings, evaluation of both exploration and producing assets, reserves assessment.
  - A chartered chemical engineer with over 32 years’ industry experience.
  - Worked on several CCS projects including hubs, commerciality, SRMS assessments etc.
  - Based in Farnham, UK.

- **Professional Involvement**
  - SPE, AIEN, IChemE - Fellow
  - Regular presenter, media releases, across multiple topics and disciplines.

- **Education**
  - CEng. IChemE – since 1996.
  - B.Eng. Chemical Engineering, Aston University, UK.

Scene Setting - Global Carbon Perspective

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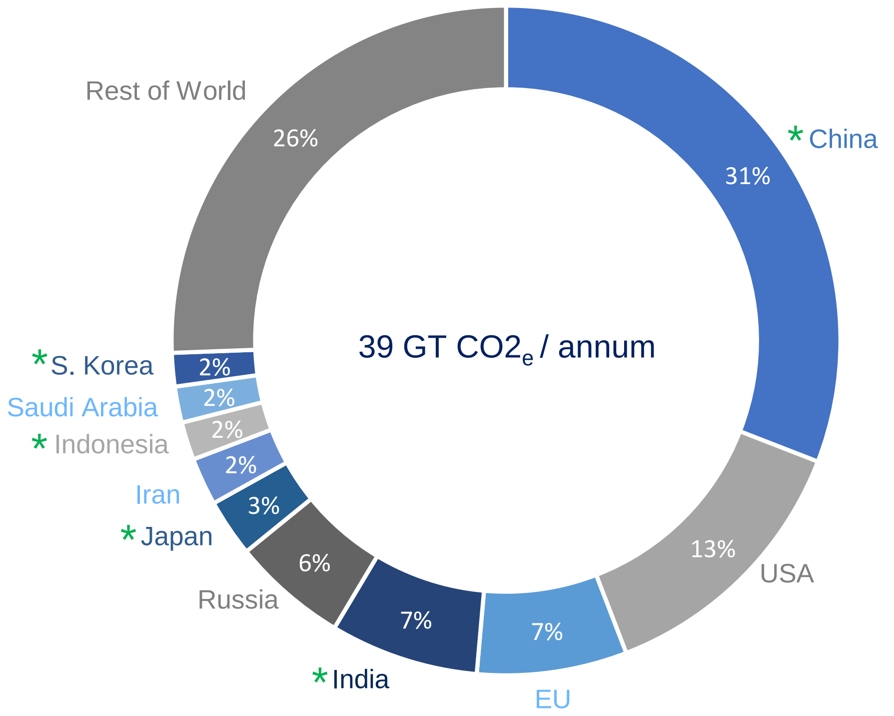
Top 10 Global CO_2 Emitters - Emissions, Targets and Policy

Global GHG Emissions - 2021



Net Zero Target Status of Top 10 Global Emitters

	2021 Emissions (MT)*	% Global GHG Emissions	GHG Emissions Global Ranking	Carbon Market	Net Zero Target	2030 Emissions Reduction Target	GHG Emissions Coverage	Legal Status	Utilisation of Carbon Offsets
China	12,040	31%	1	National ETS	2060	65%	< 95%	Proposed	Right Reserved
US	5,168	13%	2	State ETS + State Carbon Tax	2050	50%	100%	Proposed	Right Reserved
EU	2,826	7%	3	Regional ETS + Carbon Tax	2050	55%	100%	Legislated	None
India	2,797	7%	4	-	2070	45%	TBC	Public Pledge	TBC
Russian Federation	2,172	6%	5	Pilot ETS (Sakhaslin)	2060	30%	TBC	Legislated	TBC
Japan	1,082	3%	6	Carbon Tax	2050	46%	100%	Legislated	Right Reserved
Iran	897	2%	7	-	-	-	-	-	-
Indonesia	713	2%	8	National Power ETS	2060	41%	TBC	Proposed	TBC
Saudi Arabia	679	2%	9	-	2060	-	TBC	Public Pledge	Right Reserved
South Korea	629	2%	10	National ETS	2050	40%	TBC	Legislated	None

Top 10 emit ~ 75% of Global GHG emissions

5 of top global emitters in APAC = 44 % global emissions

9 x top global emitters set **Net Zero target**, 4 x top emitters legislated for Net Zero target

7 x top emitters plan to **cut emissions by >40% by 2030**

4 x top emitters with National/Regional **Carbon Compliance Market (CCM)**

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source: BP Statistical Review of World Energy 2022, Climate Action Tracker November 2022

Policies, Targets & Pledges: Overview

Key Global Developments in Policies, Targets & Pledges in 2021

CO_2 Emission Targets

45 out of 145 countries submitted stronger NDC at COP26

140 countries commit to Net Zero target covering 90% of global GHG emissions

16 countries have legislated for Net Zero Target, a further 34 countries implemented Net Zero government policy

International Maritime Organisation to halve emissions from shipping by 2050

Carbon Pricing

EU Allowances trade above US$90/T up from US$30/T at start of 2021

EU announces CBAM (Carbon Border Adjustment Mechanism) from 2026 impacting imports from 6 sectors (high intensity emitters like steel & cement)

China launches ETS became the largest global carbon market

COP26 reach agreement for global carbon mechanism

Carbon revenue collected increased by $31B to $84B

Voluntary carbon markets grew by 48% in 2021

Investment

45 countries pledge to phase down unabated coal by 2030 representing > 16% of global production

20 x countries commit to end by 2022 new direct public support for investment in unabated fossil energy sector

Methane Emissions

105 countries commit to cutting CH4 emissions by 30% by 2030

UNEP launch International Observatory (IMEO) to monitor and report on CH4 emissions

IMEO 2022 focus on CH4 emissions from fossil fuel production

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Scene Setting - Global CCUS and Project Pipeline

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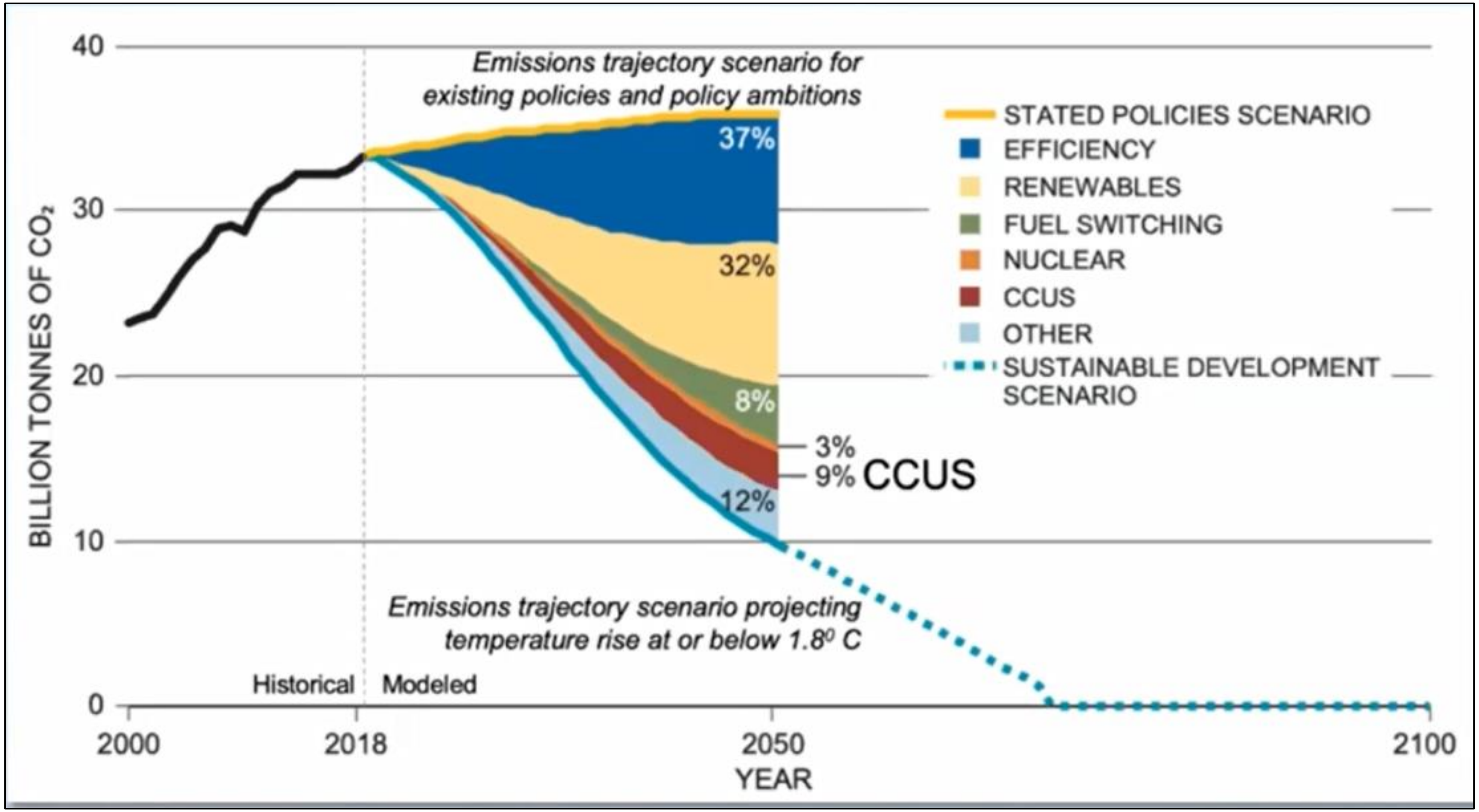
Global Emissions Projections: CCUS is a Key Part of the Solution (Previous SDS)



Global emissions projections for IEA's Stated Policies Scenario and the Sustainable Development Scenario with wedges to achieve CO2 reduction but current scenarios no different.

- Broad acceptance among scientific community and policy makers that CCUS is a key part of reducing carbon emissions
- Need "all of the above", not "either/or"
- Amount of projected emissions reduction from CCUS varies, with different projections suggesting contribution between 10-30%

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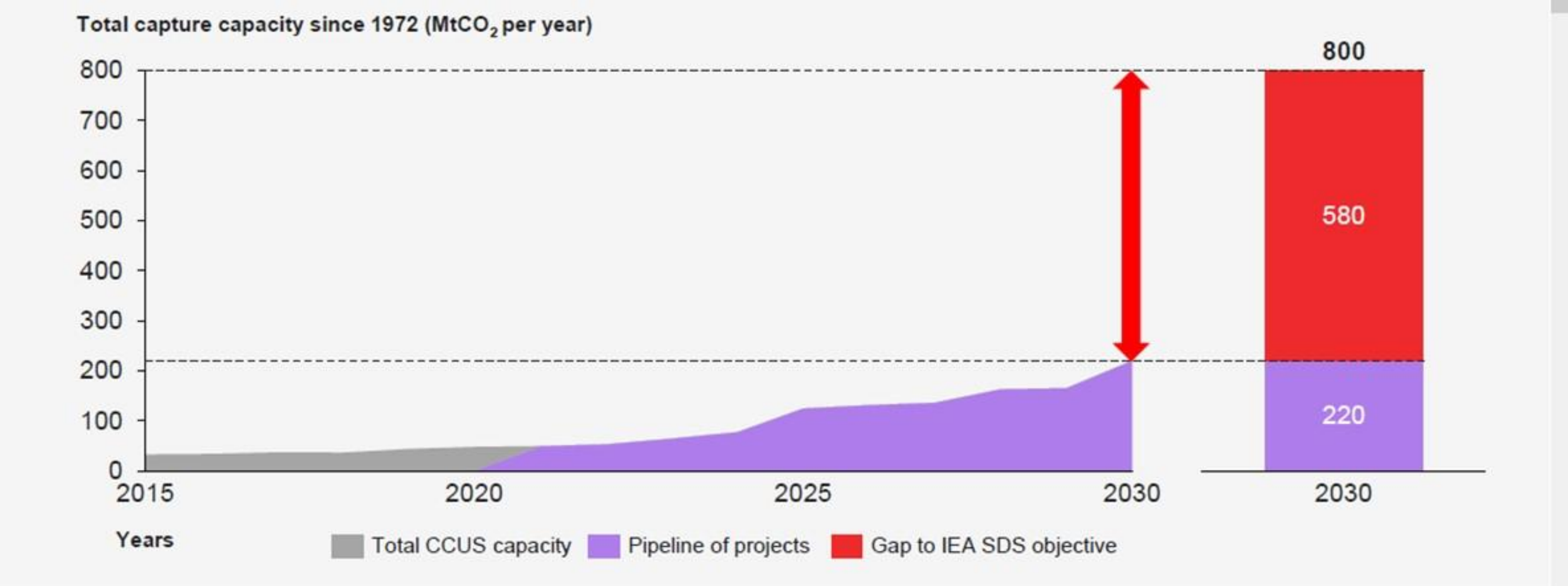
Source: IEA, 2019 from NPC, 2019

Status of CCUS Projects vs What's Required



- The SDS, created by the IEA, is a roadmap with guidance and advices in order to follow the energy transition and to respect the Paris Agreement, to keep temperatures well below 2°C above pre-industrial era. Replaced by NZE and APS – Announced Pledges Scenario.
- Current and Planned CCUS Developments are far below the required targets to achieve "Net Zero".
- Global CCUS capacity remains low relative to IEA objectives in the Sustainable Development Scenario (SDS).
- The capture capacity of the current pipeline of projects needs to be multiplied by ~4-fold by 2030.

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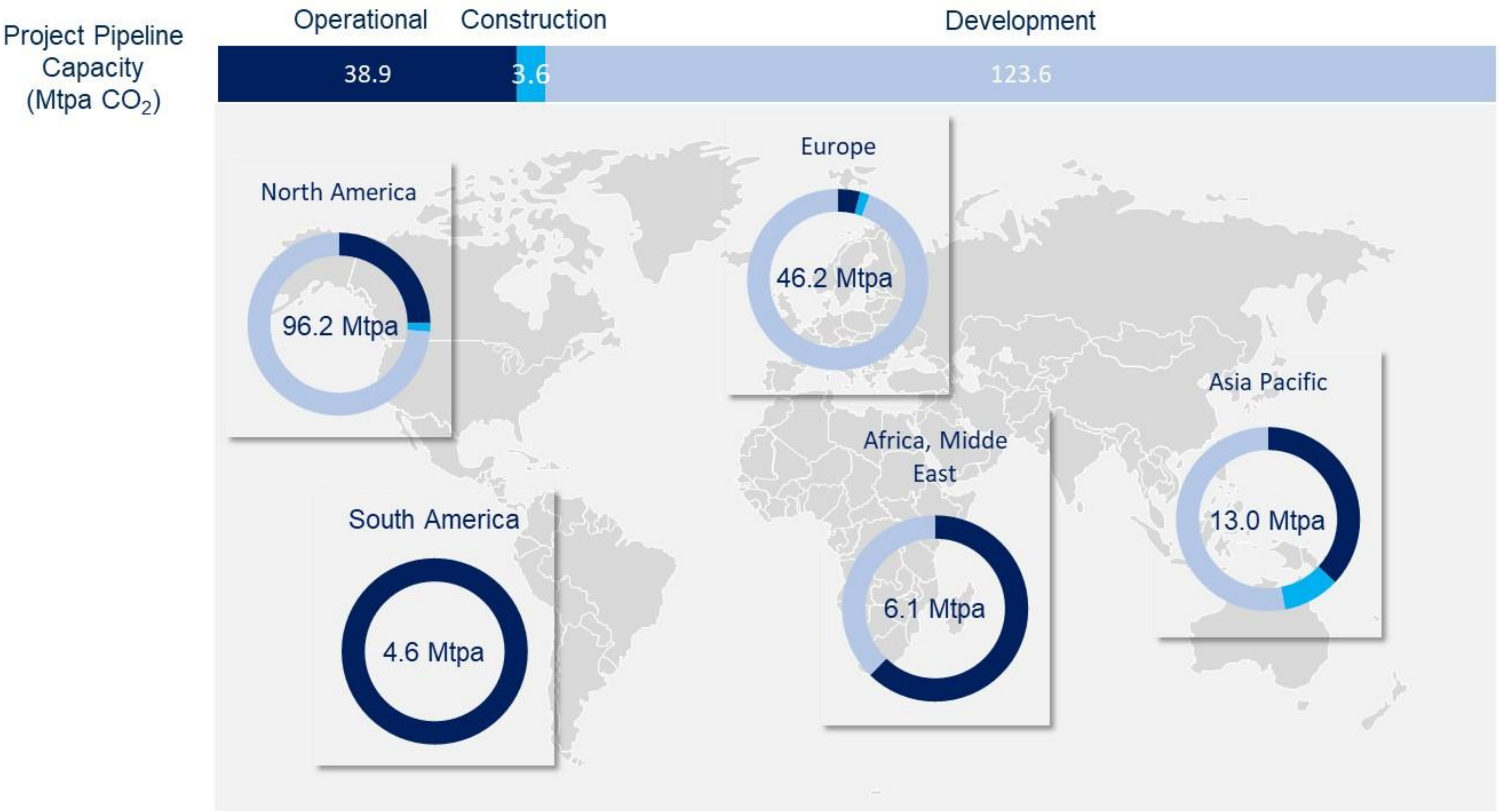
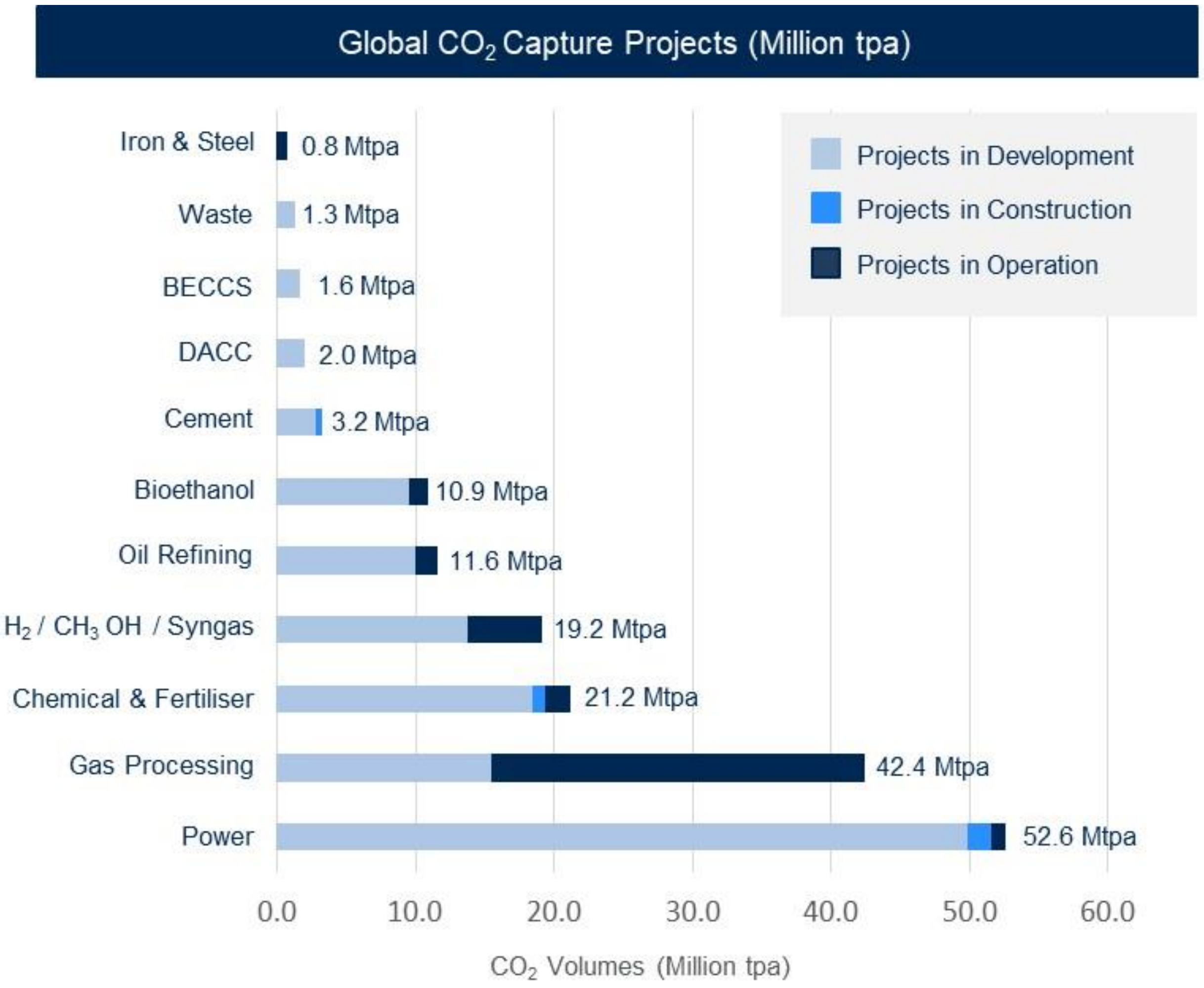
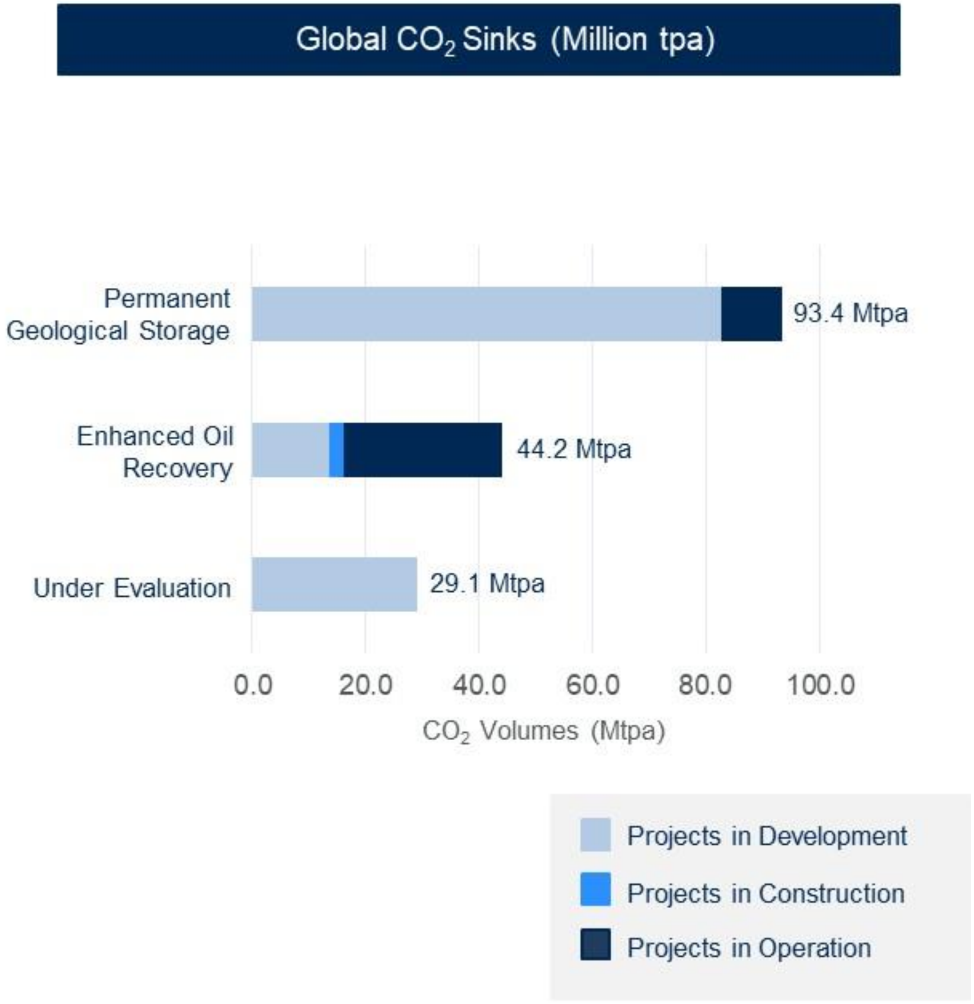
Source: IPCC, IEA, Food and Agriculture Organization, Kearney Energy Transition Institute

Emerging Global CCUS Project Pipeline



Global CCUS Project Pipeline – Sources + Sinks





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Hubs and Clusters

- Cross-industry hubs and clusters already starting to develop and likely to increase:
  - especially in Europe and North America
  - Potential in other regions e.g. Middle East, China.
- Collect CO_2 emissions from an area with several high emitters.
- Smaller CO_2 volumes can be collected by gathering with larger economies of scale.
- Creates commercial synergies.
- Uses shared infrastructure.
- Potential challenges include:
  - Public policies e.g. CCS/CCUS laws to assist development.
  - Financial support from governments.
  - Complexity of projects e.g. shared pipelines can increase time of project.

- A **Cluster** is a geographic concentration of related industries, facilities, factories etc.
- A **Hub** is a central CO_2 point to capture emissions from a cluster.

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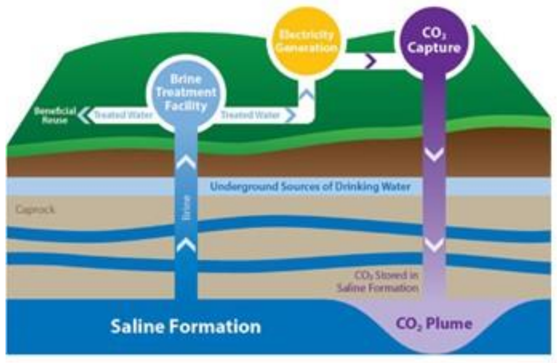
Source: Modified from Kearney, 2021

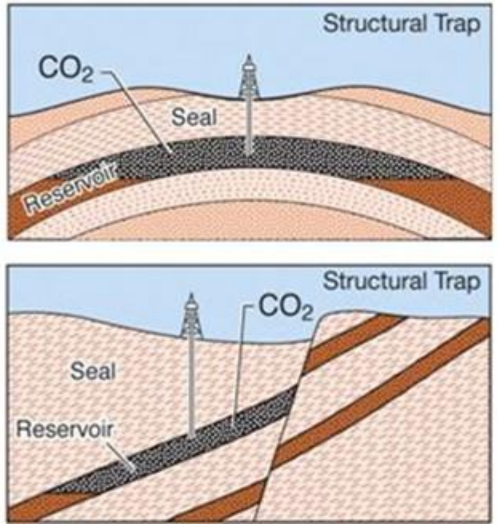
Potential Storage Types for Geological CO_2 Storage



Deep Saline Formations

Biggest potential for large-scale CO_2 storage

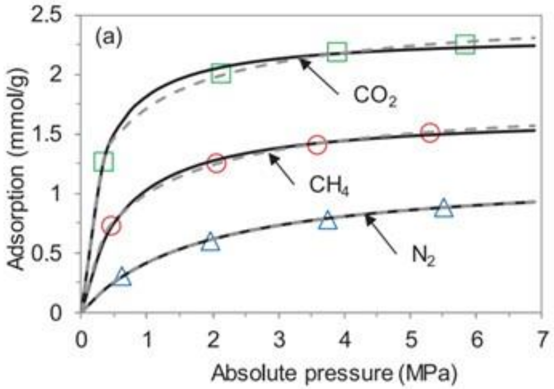
Large density difference between supercritical injected CO_2 and brine may lead to fast buoyancy segregation



Oil & Gas Reservoirs

Depleted oil and gas fields can be used to trap CO_2 using some of the same mechanisms as hydrocarbons

Enhanced oil recovery by CO_2 injection can also be used to enhance production at the same time



Coal Seams

Coals are potential CO_2 sequestration sites because of the adsorption characteristic of coal to preferentially capture CO_2

Can also be used as an enhance recovery technique

Some organic shales have similar properties to coal allowing adsorption

Basalts

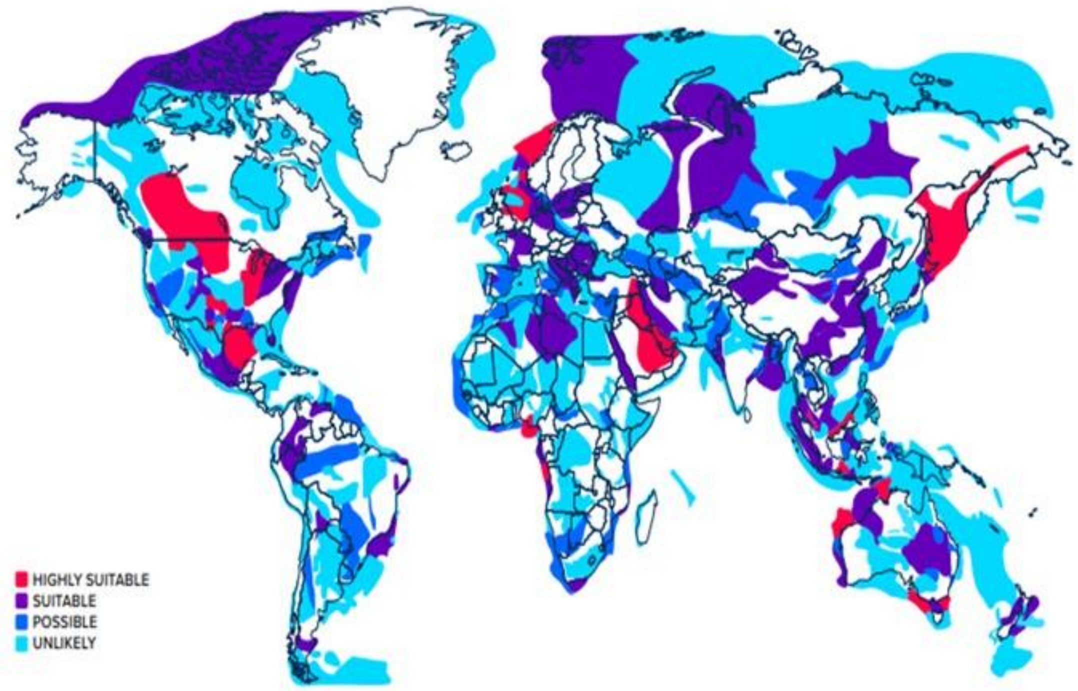
Basalts allow injected CO_2 to react chemically with Mg and Ca to form stable minerals

Hellisheiði, Iceland

Source: National Energy Technology Laboratory

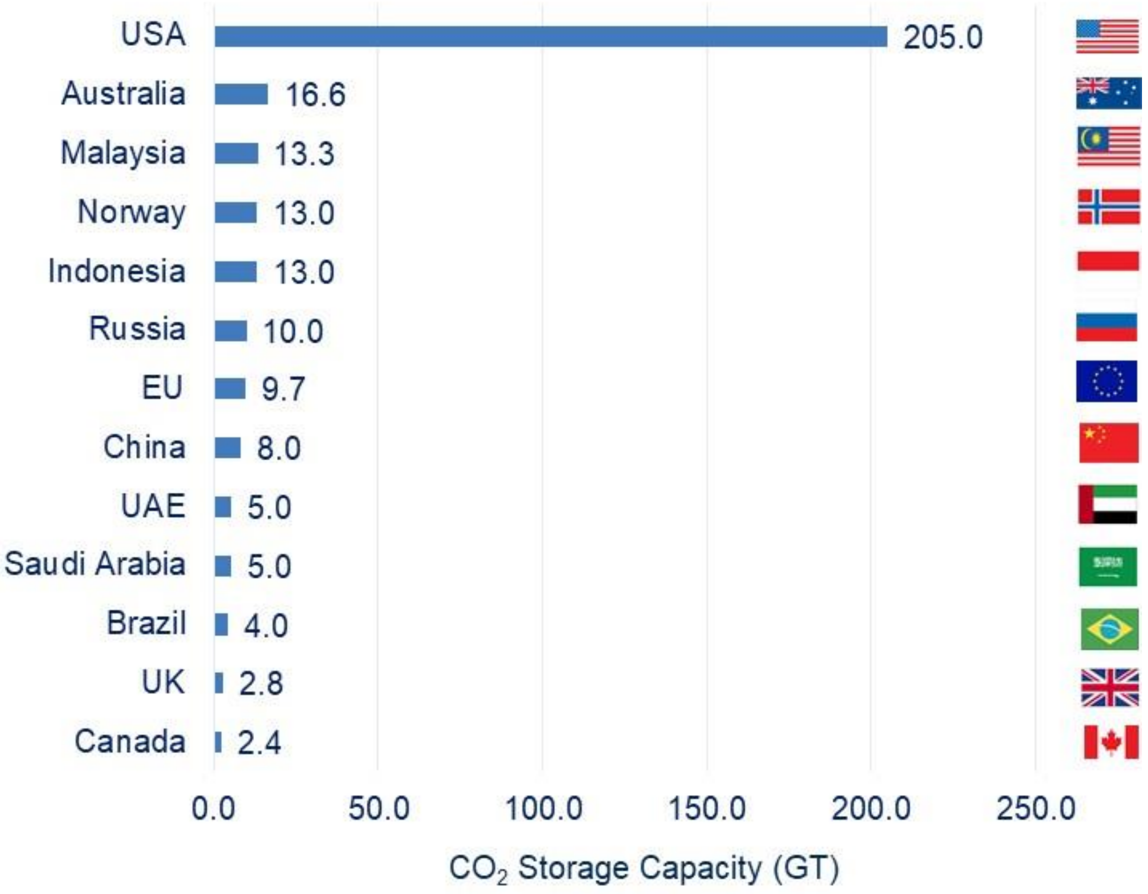
Global Carbon Dioxide Storage Potential

Global Storage Potential of Sedimentary Basins - Aquifer



Source: GCCS Institute

Estimated Storage Potential of Depleted Hydrocarbon Fields



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Aquifers Offer Significant CO_2 Storage

Storage in Depleted gas reservoirs

- Analytical methods provide a good basis for benchmarking estimates of storable quantities.
- Dynamic model sensitivity analyses can provide insight into the effect of different processes.
- Dynamic models - not automatically reliable CCS forecasts.
- Storable quantities can be estimated accurately, usually with a relative low range of uncertainty.

Storage in Saline Aquifers

- Analogs are limited for reliable basis for estimating storable quantities.
- Simulation is important, supported by analytical end-points.
- For large open aquifers in particular, storable quantities are determined by the development plan rather than subsurface estimate.

Depleted gas reservoirs offer relative low risk opportunities, but in the long run aquifers will provide the storage space that we need to make a material difference to CO_2 emissions.

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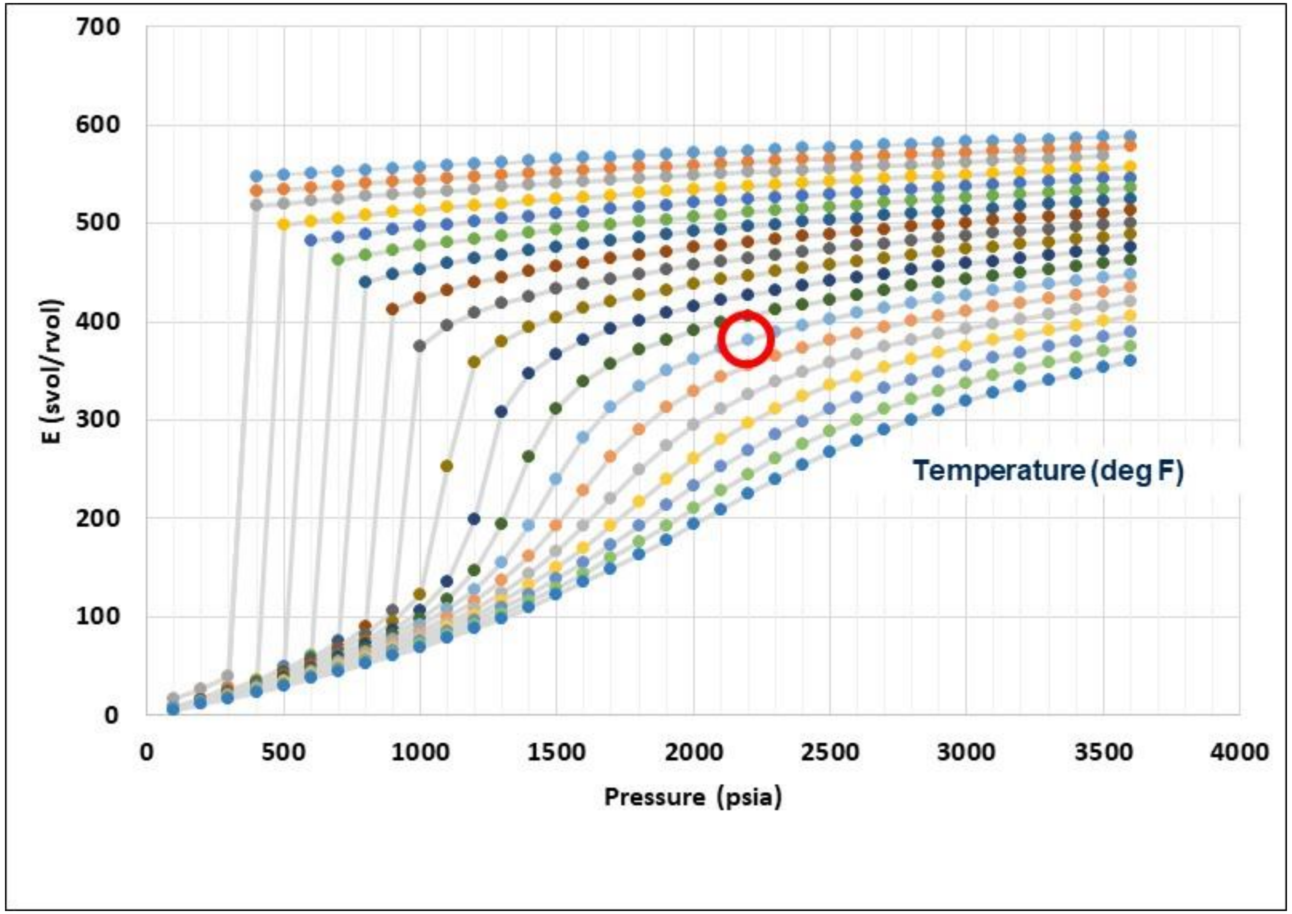
CO_2 Expansion Factor - More CO_2 than produced HC's



Gas expansion factor

$$E = \frac{\rho_{reservoir}}{\rho_{surface}}$$

CO_2 density at 60 °F and 14.7 psia is 0.00184 t/m^3

Example

In a depleted gas reservoir, it is not unreasonable to store a much larger volumes of CO_2 (expressed at surface conditions) than the volumes of natural gas

Depth: 5,000 ft, p = 2,200 psia, T = 120 °F

Natural gas expansion factor ~ 150 scf/rcf

CO_2 expansion factor ~ 380 scf/rcf

Ratio: 2.5 : 1

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CO_2 Storage International Standards Developing in Support of Sector

- SRMS
  - Released in 2022
  - Includes suggestions for the application of the SRMS with the intent of including details of the processes of quantification, categorization, and classification of storable quantities so that the subjective nature of subsurface assessments can be consistent between storage resource assessors.
  - Available for download from SPE Bookstore
- Similarly ISO 27914 – other ISO standards
- CarbonSAFE in US etc.

Carbon Capture Methodology

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CCUS Capability

Source
- Gas processing
- Power plants
- Ammonia, hydrogen
- Steel, iron, cement
- Industrial processes

Capture
- Absorption
- Membrane
- Adsorption

Processing & Transport
- Purification
- Liquefaction
- Pipelines
- Ships
- Trucks

Use or Storage
- EOR storage
- Sequestration
- Chemical

- Let us discuss further – key part of process train – firstly Capture .

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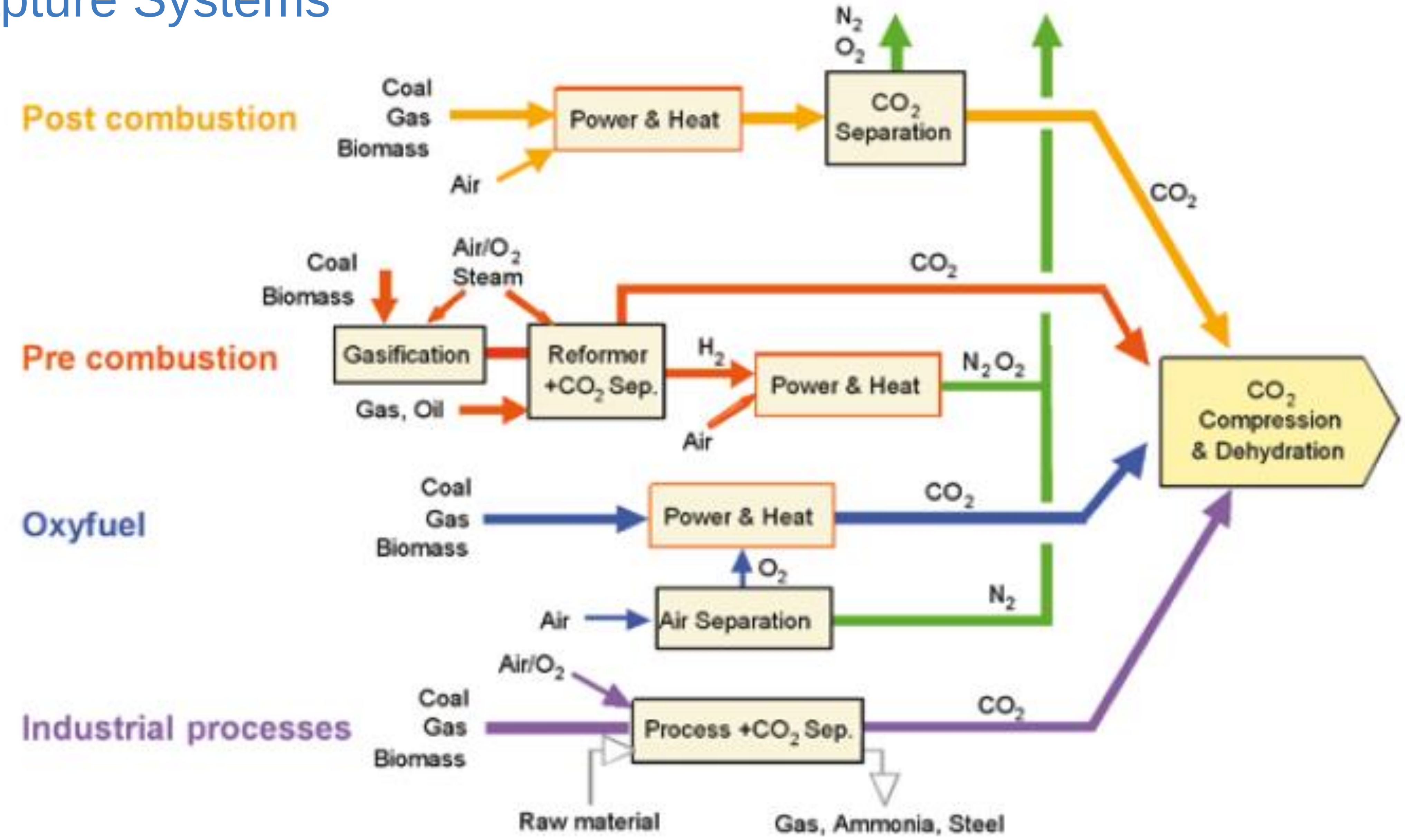
CO_2 Capture Systems



Source: IPCC Special Report on Carbon dioxide Capture and Storage, 2005, Chapter 3 “Capture of CO2” (image adapted from BP)

CO_2 Capture Stream Categorization

	High Pressure	High Purity	Dilute	Very Dilute	Extremely Dilute
CO_2 Concentration	Variable	40-100%	10-25%	3-8%	0.04-1%
Sources	**Gas processing** 2 to 65% CO2 (Sour/acid gas) ~100-1000 psia 1% of total emissions **Synthesis Gas** 45% CO2 After gasification ~500psia <<1% of total emissions	**Ethanol Plants** >99% CO2 (Fermentation), 17.4psia n/a (0.1%) **Ammonia Plants** 97% CO2, 29psia <1% of total emissions **Petchems** 100% CO2 (EO), 43psia 2% of total emissions **Hydrogen** 45% CO2 20psia 4% of total emissions	**Coal Power Plants** 11-14% CO2 14.8psia 58% of total emissions **Cement Plants** 22.4% CO2 (Kiln off gas) 14.7psia 7% of total emissions **Refinery Crackers** 10-18% CO2 (FCC) 14.5psia 2% of total emissions	**Natural Gas Turbines** 4-6% CO2 14.8psia 11% of total emissions **Industrial Furnaces** 8% CO2 14.5psia 13% of total emissions	**Confined Spaces (submarines, spacecraft)** 0.2-1% CO2 14.5psia n/a **Ambient Air** 0.04-0.06% CO2 4.4-14.5psia

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Categorization adapted from Howard Herzog, MIT Energy Initiative

CO_2 Capture Technology

Absorption	Adsorption	Membrane	Cryogenic	New Tech
Uptake of CO_2 into the bulk phase of another material	Uptake of CO_2 onto the surface of another material	Selectively separate CO_2 based on differences in solubility or diffusivity	Gas stream is cooled to separate CO_2	e.g. Oxyfuel combustion technology utilising a metallic oxygen carrier

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CO_2 Capture Technology

Physical Absorption – How It Works

- CO_2 molecules dissolve into a selective liquid solvent.
- CO_2-rich solution is sent to desorber.
- Heat is applied to release the CO_2 from the solvent.
- CO_2-lean solution cooled and recycled.
- Only technology currently available for widespread commercial deployment.
- Energy intensive, up to 50% of OPEX.

CO_2 Capture Technology

Physical Separation – How It Works

Adsorption

- CO_2 molecules adhere to a selective surface.
- Packed bed or fluidised bed systems.
- Adsorbent regenerated by decrease in pressure or increase in temperature in a cyclic process.

Cryogenic Separation

- Uses low temperatures for condensation and separation of CO_2 from flue gases.
- CO_2 can also be separated as a solid or liquid phase.

CO_2 Capture Technology

Membranes – How It Works

- Pressure driven process.
- Driving force dictated by pressure of gas stream.
- Increased separation performance when CO_2 concentration in the feed mixture increases.
- Variety of chemical and/or physical mechanisms for separation.

CO_2 Capture Technology Types

	Chemical Absorption	Physical Separation	Membranes
Description	Reaction between a chemical solvent and CO2 within a gaseous process stream occurs in an absorption column. Chemical solvent is recovered in a desorption column operating at higher temp.	Either makes use of a solid surface (adsorption), liquids (absorption), cooling and liquefaction (cryogenic), or dehydration.	Based on devices (membranes) with high CO2 selectivity. CO2 passes through but other gases are retained in the gas stream.
Types	Amines • MEA • Other Amines Ammonia Caustics Amino Acid Salts Ionic Liquids Catalysts with Chemical Absorbents Enzymes Other catalysts	Absorption • Organic Solvents • Selexol • Rectisol • Purisol Adsorbents • Zeolites • Activated carbon • Si/Al Gels • Metal Organic Frameworks • Supported Amines • Metal oxides (chemical looping) Cryogenic	Organic • Polymeric • Size selective • Liquids Inorganic • Metallic • Ceramic • Other

- Other non-principal types include Calcium looping, direct separation, electrochemical, algae-based, mineral-based, and mixed or hybrid systems.
- **Absorption is both in chemical and physical types because all chemical absorption includes some component of physical adsorbtion and is therefore a mixed technology.**

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CO_2 Capture Technology Characteristics

	Chemical Absorption	Physical Separation	Membrane Separation
Availability	Many providers for gas processing, but 2 stand-outs in Power CO2 Capture (MHI KS-1 and Shell Cansolv).	Many providers for absorption based solvents for gas processing, but 3 standout Dow (Selexol), Linde (Rectisol).	A few key providers including Schlumberger, MTR.
Application	Retro-fits or New-builds. Gas processing or Post-combustion	Retro-fits or New-builds. Gas processing, ethanol, methanol, hydrogen, or post combustion	Retro-fits or New-builds.
Advantage	Commercially available, wide application.	Wide application. Modular (adsorbents and absorbents).	Wide application, compact, modular. Efficient. Cost reduction potential with hybrid processes. Other potential separation applications.
Disadvantage	Energy required to regenerate solvent, limited cost reduction potential.	Not as economical in comparison to amines for low CO2 concentrations / partial pressures	Operating performance and lifespan. Requires additional differential pressure across membrane.

- However Technical Readiness Levels vary.

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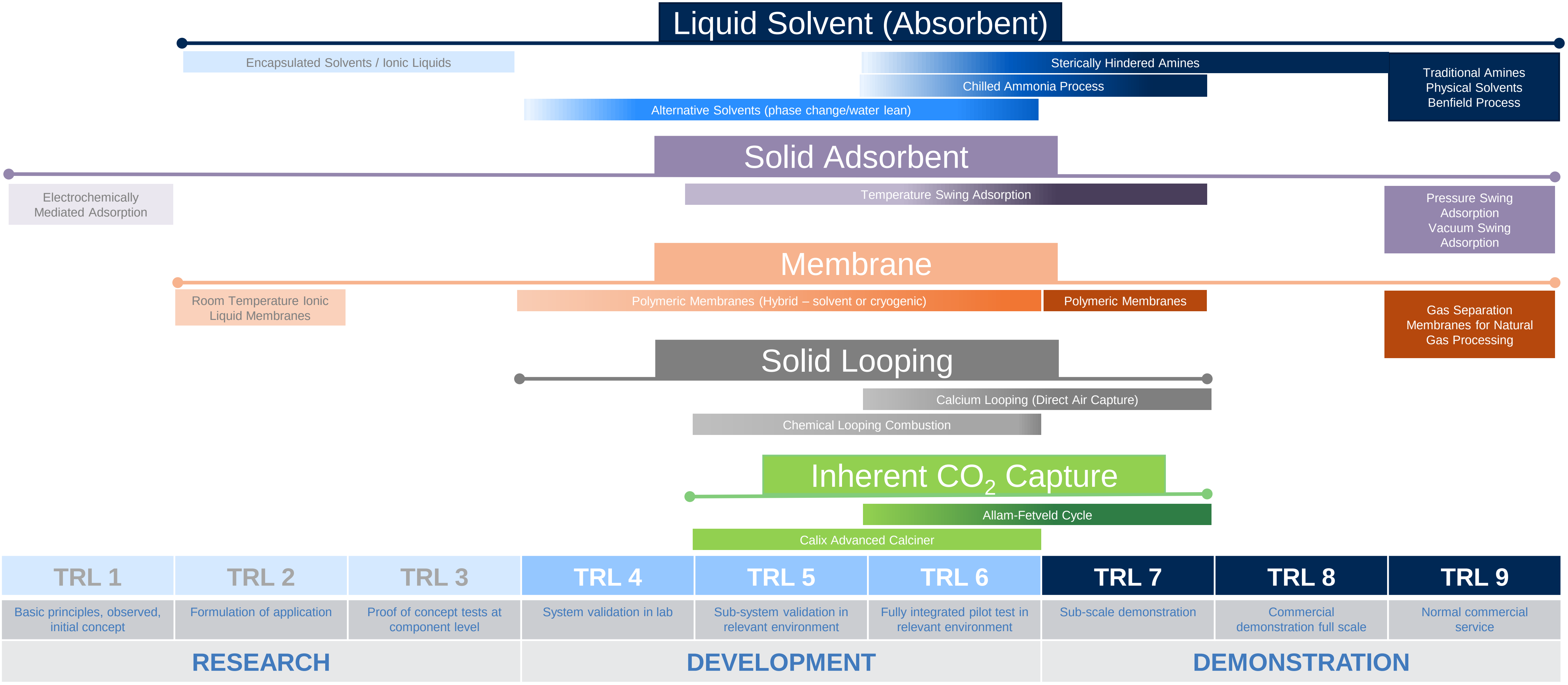
Capture Technology Maturity



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Readiness level diagram developed based on Global CCUS Institute data March 2021

CO_2 Capture Challenges

Existing Facilities

There are a number of challenges when developing CO_2 capture on existing plants, typically:

- CO_2 emission source pressure, temperature and impurities.
- Source stream CO_2 concentration.
- Land availability.
- Facility layout.
- Plant integration.

Low CO_2 partial pressures impact equipment size, energy consumption, and capture technology choices.

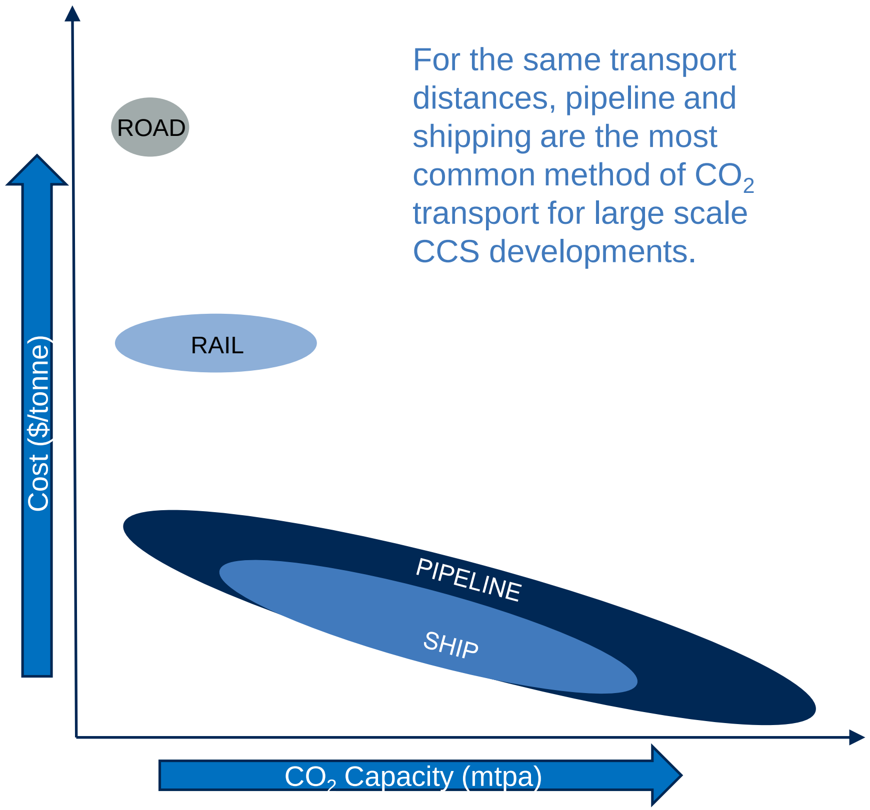
CO_2 Transportation
Comparison

PIPELINE
- High CAPEX, low OPEX
- Excellent for both point-to-point and hub based developments
- Large capacity, current largest single pipeline up to 16 mtpa capacity
- Proven for large scale CCS
- Low fugitive emission losses

SHIP
- Lower CAPEX than pipeline, higher OPEX
- Normally combined with some pipeline infrastructure for developments
- Provides flexible commercial opportunities for developments and breaks the value chain
- Current ships are designed for up to 10,000m^3 , but large scale ships are being developed
- Low fugitive emission losses

RAIL
- Limited capacity
- Only viable if rail networks exist between source and sink for CO_2
- More suited for CO_2 supply to industrial users
- Higher fugitive emission losses than pipelines and shipping
- Limited suitability for CCS developments

ROAD
- Only suitable for very small capacities
- More suited for CO_2 supply to small industrial users
- Higher fugitive emission losses than pipeline and shipping
- Not suited to large scale CCS developments



For the same transport distances, pipeline and shipping are the most common method of CO_2 transport for large scale CCS developments.

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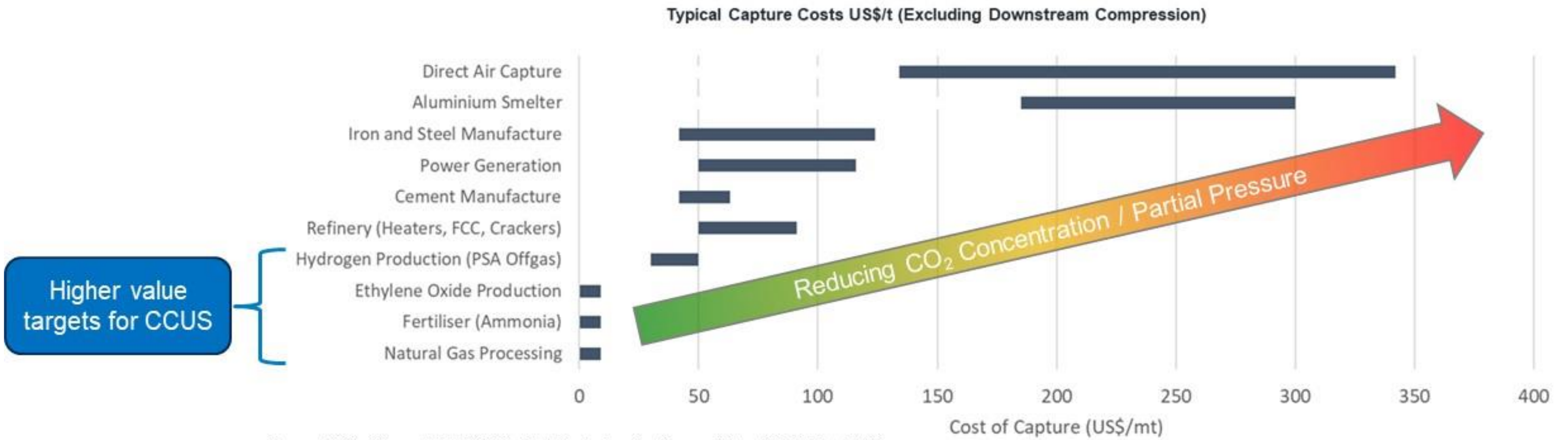
Comparative Costs of Capture, Transport and Storage



Source – GaffneyCline and Global CCUS Institute "Technology Readiness and Costs of CCUS", March 2021

- Within the value chain, costs will vary, but typically:
  - Onshore transportation costs are 3-14 US$/t CO_2
  - Offshore transportation costs are 10-15 US$/t CO_2
  - Storage site costs are 3-13 US$/t CO_2
- Variation in capture cost driven by CO2 partial pressure.
  - For high pressure and high purity, capture cost can be relatively small.
- For most point sources, capture will account for the majority of the overall cost of CCUS.
- Careful evaluation of the value chain technical elements is required to drive costs down. This combined with the tax credits and/or grants available can provide positive outcomes for CCUS opportunities.

Oil and Gas Facility Re-Use for CCS

- Existing oil and gas facilities infrastructure have the potential to be re-used for CO_2 transportation and storage but must be evaluated on a case by case basis.
- Elements of infrastructure can include:
  – Pipelines
  – Platforms, including jackets
  – Subsea Manifolds
  – Umbilicals
  – Onshore facilities and pipelines.
- Reduces CAPEX and OPEX.
- Some considerations though – see next slide.

Oil and Gas Facility Re-Use for CCS

- Pipeline considerations:
  - Sufficient size and pressure rating
  - Pipeline integrity and life extension study – including detailed internal and external inspection.
- Subsea manifold suitable for re-use provided its location and pipework configuration (including valving, materials, pressure rating, etc.) is appropriate
  - Requires a full integrity and life extension study to confirm technical feasibility.
- Platforms re-use considerations:
  - Original design life / remaining life expectancy.
  - Topside equipment weight required for injection of CO_2 – generally lighter than for oil/gas.
  - Complexity of removal of existing oil/gas production equipment and other brownfield modification work.
  - Practicalities and costs of modification work carried out offshore.
- Umbilicals re-use highly dependent on individual asset – requires case by case assessment incl:
  - Conditions and maintenance
  - Capacity
  - Remaining design life.
- Onshore facilities limited, but potential for re-use of existing site footprint, supporting infrastructure and utilities.
  - Existing skilled workforce could reduce upfront investment costs.

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Commercial Aspect of CCUS – Project Risk Overview

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CCS Business Model Risk Overview

High Risk — Capture of CO_2

- Structural risk arising from lack of economic support for capture.
- Emitters unlikely to give a contractual commitment for CO_2 supply.
- Significant liability issues surrounding impact of capture on emitting plant operations.

Medium Risk — Take delivery of already captured CO_2

- Limited quantities available, and lack of economies of scale.
- Economics are challenging in many situations.
- Contractual volume commitments may be low, given variability of CO_2 stream.

Lower Risk — Aggregation and transportation

- Provided contractual arrangements for CO_2 inputs and outputs are clear, risks are similar to gas pipeline model.
- Higher technical risks arising from long term CO_2 transportation / corrosion.
- Long term investment requires long term CO_2 throughput commitments from gathering zone.

Lower Risk — EOR and other forms of CO_2 usage

- EOR business well proven.
- E.g. Class II well permit applications are well proven.
- Limited sequestration potential compared to permanent measures.
- incentives may have downside risk (e.g. 45Q)

Medium Risk — Sequestration in Aquifer or depleted HC reservoir / other

- Very new / emerging technology.
- Regulatory and technical uncertainty exist.
- Long term liabilities are a major consideration.
- Agencies may be slow to provide required permits.
- Significant cost differences exist between storage mediums.

- Generally, each project will be unique and will require bespoke Business Model Risk Assessment

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Snapshot Segment Risk Analysis - Capture

High Risk

Capture of CO_2

Primary Risks	Possible Mitigations
• Insufficient economic rent to support costly capture equipment. • High tariff for aggregations / sequestration adding to economic burden. • Take or pay commitments to aggregation and storage providers. • Third party consequences from capture equipment (high opex, lower efficiency, facility owner exposed to other indirect costs). • Technology risk. • Liability and insurance.	• Increased incentive/carbon price and / or stacking potential from eg Low Carbon Fuel Standard (LCFS), Hydrogen or Canadian Clean Fuel credits. • Aggregation and storage tariff guaranteed through very low cost route. • Optionality on volume commitment. • Limited liability / indemnity from plant owner. • Evolutionary development plan, incorporating new technologies as needed. • Performance guarantees from EPC contractor / equipment provider.

Snapshot Segment Risk Analysis – Geological Sequestration

Medium Risk	Primary Risks	Possible Mitigations
Geological Sequestration	• Ongoing regulatory uncertainty concerning long term liabilities for secure storage • Rights to pore space • Schedule risk arising from well permits and other features • Technical features of sub-surface performance (injectivity, capacity and integrity) • CO_2 plume movement and monitoring	• Further regulatory clarification / development and /or investment where State guarantees are offered • Clean surface/mineral rights covering entire sequestration site • Conditions Precedent regarding regulatory approvals and permits • Detailed technical due diligence and ongoing monitoring to amend development plan if needed

- Different projects may carry differing Business Model Risk Assessment

Commercial Aspect of CCUS - Carbon Pricing

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Carbon Pricing/Valuing Mechanisms

- A carbon tax puts a direct price on GHG emissions and requires entities to pay for every ton of carbon pollution emitted.

- An emission trading system (ETS)—also known as a cap-and-trade system—sets a limit (“cap”) on total direct GHG emissions from specific sectors within the jurisdiction and sets up a market where the rights to emit (in the form of carbon permits or allowances) are traded.

- Under a crediting mechanism, emissions reductions that occur as a result of a project are assigned credits, which can then be bought or sold.

- Under a results-based climate finance (RBCF) framework, entities receive funds when they meet pre-defined climate-related goals, such as emissions reductions.

- Under internal carbon pricing, entities assign their own internal price to carbon use and factor this into their investment decisions.

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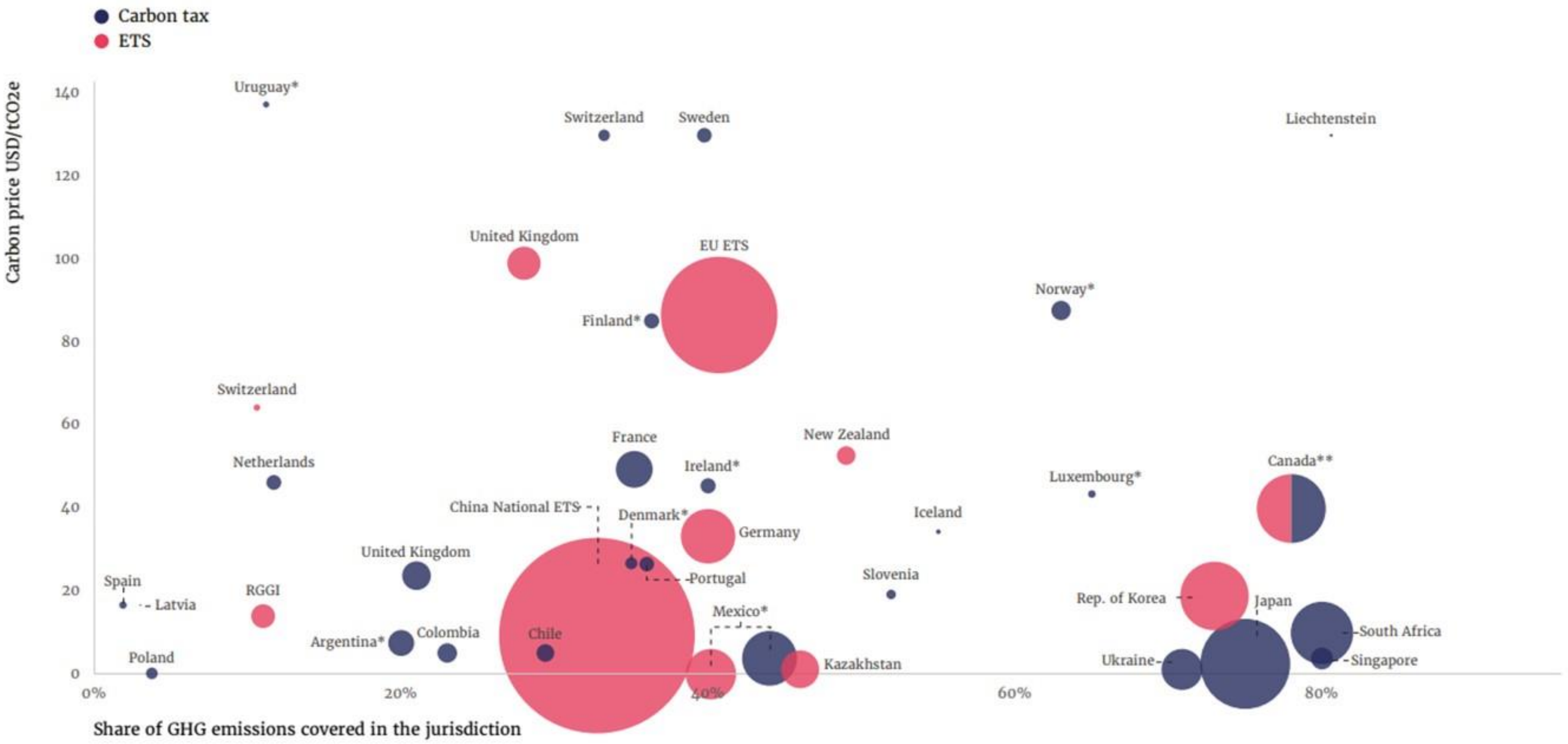
Source: https://www.carbonpricingleadership.org/what

Coverage of Global Carbon Markets & Pricing Mechanisms



source: World bank 'State and Trends of Carbon Pricing 2022'

Comparison of Carbon Pricing Mechanisms

ETS / Cap & Trade most complex to implement but should lead to most efficient carbon pricing

	Carbon Tax	ETS / Cap & Trade	Carbon Credit
Principle	• Predefined tax rate targeting specific emission sources	• Market based allowances traded around emissions limit or Cap	• Market based verifiable credits issued which can be monetised to generate income for certified projects
Market Type	• Compliance	• Compliance	• Voluntary
Pricing Certainty	• Pre-defined tax rate • Stable price • Strong signal for investment	• Market driven price => volatility • Price reflects gap between emissions and cap • Hedging may increase volatility	• Highly dependent upon project quality • Largely dependent upon Corporate demand and project availability
Emission Level Predictability	• Uncertain - difficult to predict emission reduction with predefined tax rate.	• Good, controlled cap determines upper limit on emissions.	• Dependent upon the quality of the project and ongoing management of the Carbon sink.

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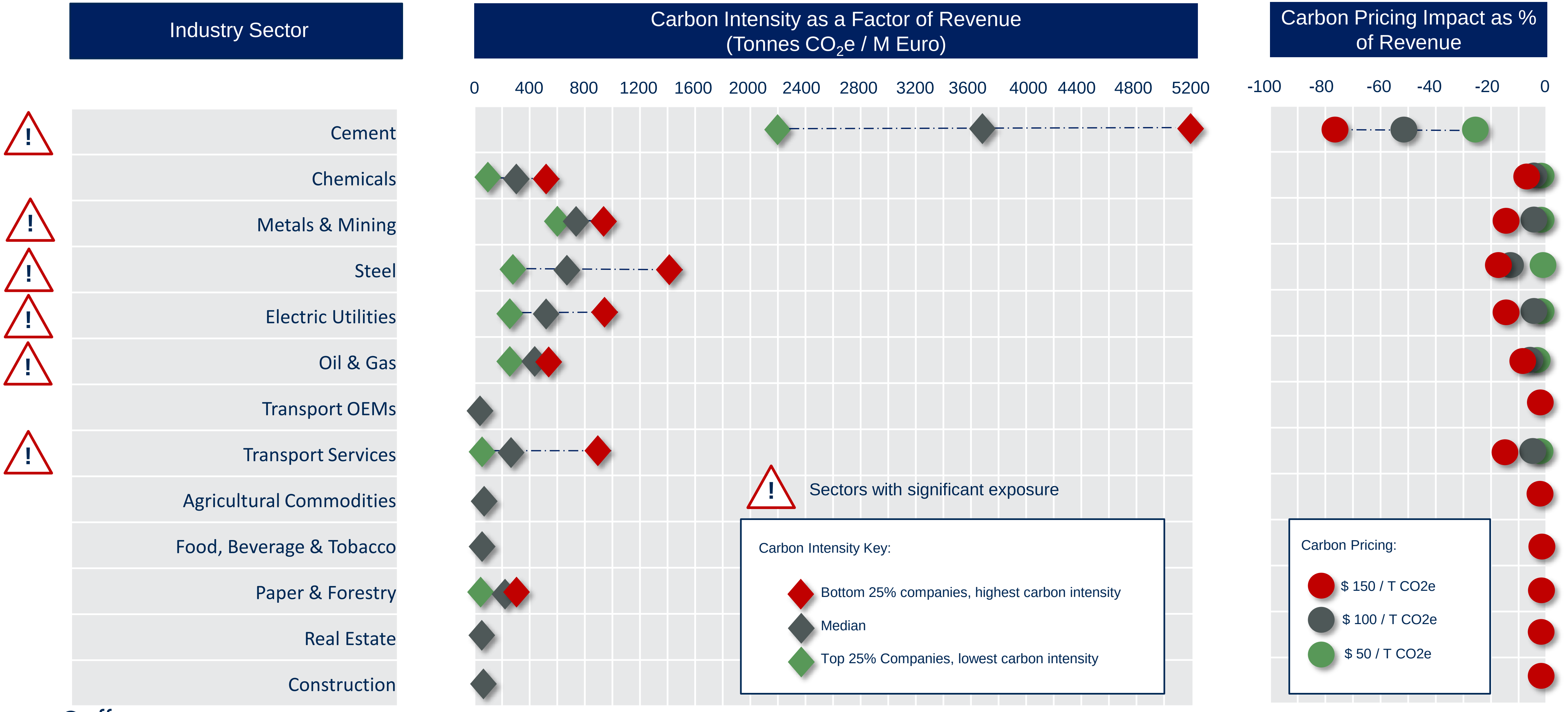
Industry Readiness for Carbon Pricing

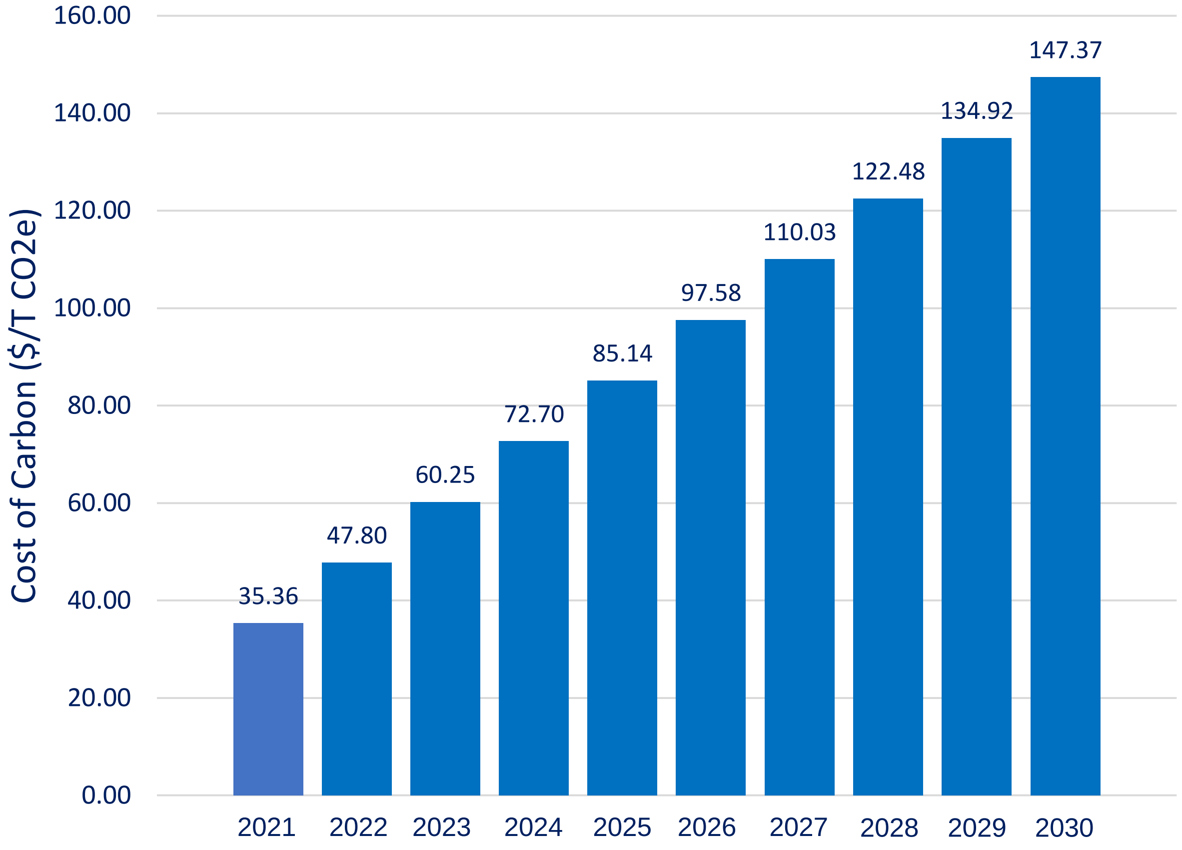
Heavy Industrial players most highly exposed to future Carbon Pricing



Netherlands Industry Carbon Tax

NL first to introduce Carbon Tax on Industry which has largely lagged on decarbonisation

Overview	
Established	2021
Coverage	Netherlands
Sectors	235 x Industrial Companies
Scope	Decarbonisation of large Industrials
Principle	> Complementary to EU ETS > Emissions capped as per EU ETS > Tax rate predefined and indexed up to 2030 > Tax paid is difference between EU ETS and NL Industry Carbon (indexed) rate
Target	Reduction of 14.3 M CO2e by 2030



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Carbon Pricing – Key Conclusions

- Geographic coverage of Carbon Pricing limited but growing.
- Range of approaches.
- Heavy Industrial energy consumers most highly exposed to future Carbon Pricing.
- Only a small amount (< 4%) of Global Emissions is within 2030 Carbon Price Corridor recommended by IPCC. Increases in carbon tax likely.
- Increasingly, Carbon pricing integral to Client decision making.
- Emerging investment case for carbon mitigation including CCUS.

Commercial Aspect of CCUS - Legal Framework & Regulation

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Global Overview – CCS Policies and Instruments

GHG Emissions Policy and Targets

Implementation of clear and binding National emissions targets to deliver on Paris Climate goals

Examples

- Nationally Determined Contributions (NDCs)
- EU Fit for 55

CCS Legal and Regulatory Framework

Legal and regulatory framework governing the selection, injection, transportation and storage of CO_2

Examples

- UK Oil & Gas regulation of CO_2 storage
- Amended IMO 'London Protocol'

Carbon Pricing Policy and Mechanism

Establishing a cost for CO_2 emissions through Carbon 'Cap and Trade', Carbon Taxation of Carbon Credit

Examples

- EU Emissions Trading Scheme
- US 45Q Tax Credit

Carbon Accounting and Verification

Establishing verifiable reporting, accounting and verification of avoided emissions captured and permanently stored

Examples

- EU Certification of Carbon Removals
- CCS+ Initiative

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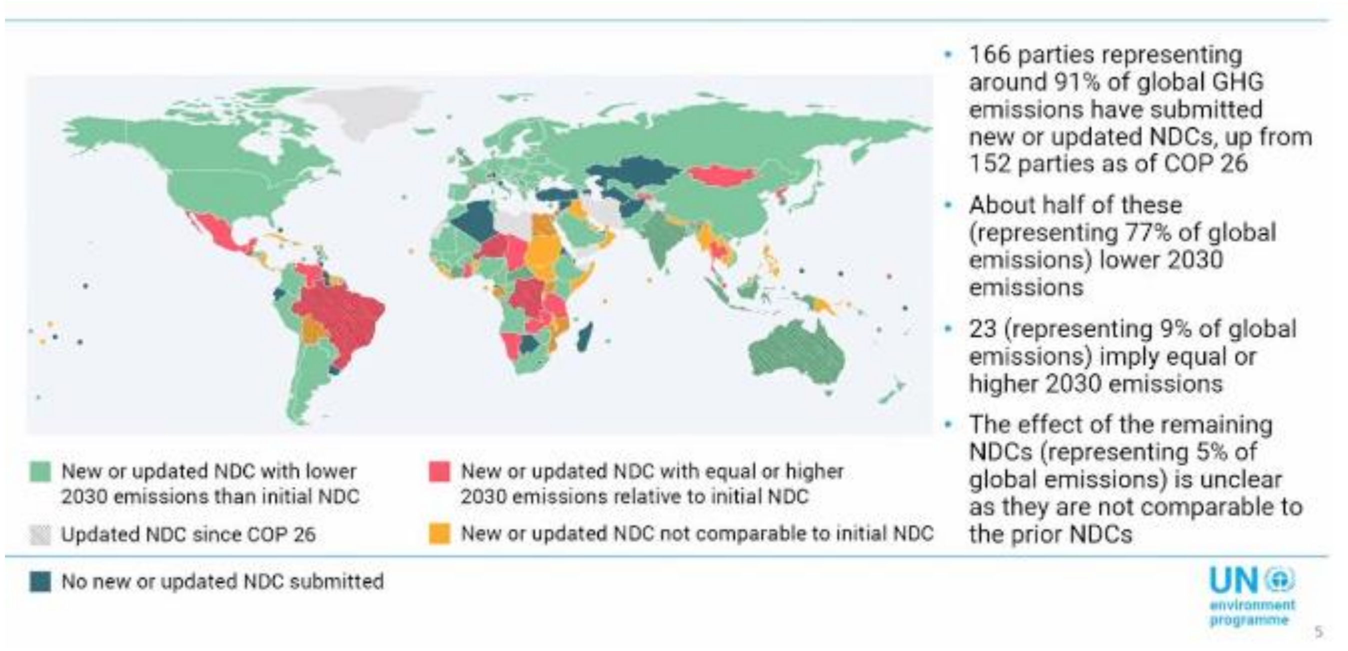
Global Overview – CCS Legislation and CCS in NDCs

- CCS part of NDC plans.
- Multiple different strategies
- No country has exactly same approach.
- Detail is extensive.



Countries' NDCs presented at UNEP's press conference. Graphic: UN Environment Programme.

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e.g. EC Legal Framework, CO_2 Storage

Scope

Geological storage (of more than 100ktpa) of CO_2 in EU member states (excludes EOR)

Regulatory framework designed to; minimise risk of leakage, monitoring and reporting regime, ensure adequate remediation

Complete project lifecycle from exploration permit to post closure

Key Principles

Member States retain rights to decide if storage of CO_2 and determine where storage maybe selected

CO_2 sites selected only if no risk of leakage confirmed through technical characterisation and assessment

Operators shall make adequate provisions for financial liabilities

Member States shall ensure third party access to storage in transparent and non-discriminatory manner

Key Stakeholders + Responsibilities

European Commission review and advise on licence and permit applications at 'Early Phase' development

Member States implementation of directive, issuing of penalties for infringement

National Competent Authority governing regulation, issuing of licences and permits, maintain register

Operator of CO_2 storage site until transfer to Competent Authority

Status

Entered into force in 2009 (amendment made to the previous directives 2000 – 2008)

Every 3 years Member States submit a report on implementation of Directive, next report due 2023

Framework implemented by 19 countries Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Lithuania, Luxembourg, Malta, Netherlands, Portugal, Slovakia, Spain, Sweden and UK

Key Activities of Project Lifecycle - EC Legal Framework, CO_2 Storage

Exploration

- Suitability of geology.
- **Characterisation of storage.**
- Assess storage capacity.
- Injection testing.
- Site selection.

Storage

- CO_2 stream acceptance.
- CO_2 stream analysis.
- **Routine annual inspection of surface and injection facility.**
- Non-routine inspection by Authority.
- **Monitor storage.**
- Monitor surrounding environment.
- Annual reporting.

Closure

- Sealing storage.
- Removal of injection facility.
- **Monitor storage.**
- **Monitor surrounding environment.**
- Reporting every 3 years.

Transfer

- Monitor storage.
- Monitor surrounding environment.
- **Reporting every 5 years**.

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Key Permit & Operating Obligations - EC Legal Framework, CO_2 Storage

Exploration

- Open to all entities possessing the necessary capacities.
- No admission criteria set by EU Directive for granting of Exploration Permits.
- **Exclusive permit rights issued for limited volume area and limited time.**

Storage

- **Priority to Exploration licence holder.**
- **Operator financially sound.**
- **Operator technically competent.**
- Implement financial security.
- Authorisation of storage technical limits.
- Approved operating plans.
- Approved of conditions for closure.
- Ongoing analysis and registration of CO_2 composition & properties.

Closure

- **Financial security valid.**
- Conditions of Storage Permit met.
- **Approved post closure plan**.
- Site sealed and injection facilities removed.

Transfer

- **Evidence CO_2 completely and permanently stored.**
- Minimum of 20 years elapsed.
- Conformity of actual with modelled behaviour of CO_2.
- No detectable leaks & site evolving to long term stability.
- **Financial contribution to Authority for 30 years cost post transfer.**

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Obligations and Liabilities - EC Legal Framework, CO_2 Storage

Exploration

- Member State retains right to determine if and where CO2 storage locations maybe selected.
- Member State shall decide if Exploration required.

Storage

- **In the event of leakage Operator shall take corrective actions and forfeit Carbon allowances under ETS.**
- **In event Operator fails to act, Competent Authority shall; withdraw the permit and take over operational and legal responsibilities.**
- **Operator shall responsible for inspections, monitoring, reporting & corrective action.**

Closure

- Operator responsible for sealing storage site and removing injection facility.
- **Operator continues responsibility for and financial provision of inspections, monitoring, reporting & corrective action until transfer.**

Transfer

- **Authority responsible for inspections, monitoring, reporting & corrective action.**
- **Operator shall make financial contribution to cover Authority's costs for inspections, monitoring & reporting.**

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Licencing Overview - 2022

- Equinor and BP awarded licences in UK.
- UK launched first CCS storage licence round. Awards in 2023.
- 3 storages licences awarded in Norway.
- Class VI wells in US – primacy moving to States from EPA – accelerated approvals expected.
- Danish defined area CCS applications opened. Award in 2023.
- Storage permit awards in Australia for CCS acreage.
- Globally – progressing.

Final Comment – Progress is being made but much still to do.

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Back-Up Slides

GaffneyCline - CCUS Project References

UAE CO_2 Storage Assessment

Location: UAE
Client: NOC
Year: 2021

Project Description:
Assess and estimate CO2 storage potential of depleted hydrocarbon reservoirs, shallow unconventional gas reservoirs or saline aquifers in Abu Dhabi. Provide recommendations for the subsequent in-field injection and related operations.

Services Provided:

- Screening and identification of reservoirs and aquifers for safe CO_2 storage
- Assess storage capacity, injectivity and containment risks
- Conceptual engineering of CO_2 storage pilot
- Recommendation on monitoring and risk mitigation
- Economic analysis of utility type model

National Strategic Planning of CCS

Location: Middle East
Client: NOC
Year: 2021

Project Description:
Assess overall unit cost of Carbon Capture and Storage of emissions from major sources within the country

Services Provided:

- Screening and identification of aquifers for safe CO_2 storage
- Assess storage capacity, injectivity and containment risks
- Estimation of capture, transportation and storage costs
- Recommendation on optimized phased project development approach

US Gulf CO_2 Storage Facility

Location: US Gulf Coast
Client: Confidential
Year: 2021

Project Description:
Assess viability of CO_2 storage facility

Services Provided:

- Technical due diligence on CO_2 storage facility
- Estimation of CO_2 storage supply/demand scenarios
- Establish storage merit curve to assess relative economic viability of the facility

US Industrial CO_2 Cluster

Location: US
Client: Investor
Year: 2021

Project Description:
Project Due Diligence for industrial capture, aggregation and sequestration of CO_2 emissions

Services Provided:

- Estimation of capital costs across entire CO_2 value chain from source to sink
- Assessment of alternative technologies and estimated costs
- Assessment of availability of support from tax credit and impact on investment case

GaffneyCline – CCUS Project References

UK CO_2 Storage Project Technical Advisor

Location: UK
Client: Government - DECC
Year: 2016

Project Description:
Technical assurance to enable Department of Energy and Climate Change (DECC) to evaluate the two bids and to take a Final Investment Decision on the Peterhead and White Rose Carbon Capture and Storage projects.

Services Provided:

- Review of the geoscience, reservoir engineering, wells and offshore facilities and pipeline
- Review of the design basis, monitoring and review of the FEED and evaluation of bids

CCUS Project Diligence

Location: Europe
Client: Industrial
Year: 2021

Project Description:
Technical assessment of CCUS project taking CO2 from several refinery and petrochemical facilities including 'blue' Hydrogen Steam Methane Reformers (SMR's) to offshore CCS in depleted gas field in the North Sea.

Services Provided:

- Review of subsurface and surface data
- Assess storage capacity, injectivity and containment risks
- Recommendations on project viability and development risks

Russia CO_2 Storage Assessment and Development

Location: Russia
Client: Oil & Gas Major
Year: 2021

Project Description:
Screening and selection of depleted reservoirs and aquifers for storage of CO_2 captured from adjacent gas processing plants and proposed blue ammonia project

Services Provided:

- Screening reservoirs and aquifers for safe CO_2 storage
- Review subsurface data in accordance with ISO27914
- Development of reservoir conceptual engineering
- Developed client CO_2 storage plan for permit and licensing submission

Indonesia Assessment of CO_2 Storage in depleted Gas Field

Location: Indonesia
Client: Mid-Size Independent
Year: 2021

Project Description:
Assess viability of depleted gas field as a potential store for CO_2 captured from coal fired power plant

Services Provided:

- Assess reservoir storage capacity, injectivity and containment risks
- Review subsurface data in accordance with ISO27914
- High-level estimate assessment of the unit cost of CO_2 capture, transportation and sequestration