Future Leaders

The Role of Carbon Capture and Storage (CCS) in achieving Net Zero

Expertise Network: Climate Change

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Executive Summary

- With increasing C02 emissions worldwide there's a urgent need to control it due to it's harmful impact on climate, ocean chemistry, and ecosystems. **Carbon Capture and Storage** (CCS) is presented as a key solution capable of **reducing emissions by up to 90%**, particularly for hard-to-decarbonize sectors, and is essential for meeting **global net-zero targets by 2050**

- Carbon Capture, Utilization, and Storage (CCUS) is a **key technology** for achieving net zero by capturing CO2 emissions, storing them underground, and utilizing them in industries. It aligns with several **UN Sustainable Development Goals** (SDGs), including clean energy transition, industrial decarbonization, resource efficiency, and climate action, making it a crucial lever for reducing global emissions and fostering sustainable innovation

- CCS is set for a **12x capacity growth by 2030**, reaching over 500 MtCO2 annually, driven by power, hydrogen, and strong policy incentives in Europe and North America. Government tax credits and cost-saving hubs make CCS economically viable, with captured CO2 generating revenue through product conversion. CCS is essential for net-zero targets, particularly in **hard-to-abate sectors**, with global storage capacity lasting over 700 years

- To meet net-zero targets by 2050, **CCUS capacity must grow 120x**, reaching 4–6 gigatons of CO_2 annually, helping **decarbonize 15-20% of energy-related emissions**. Achieving this will require **$175 billion** in **annual investments**, with **70%** expected from ASEAN, China, India, and North America, targeting hard-to-abate sectors like steel, cement, and power

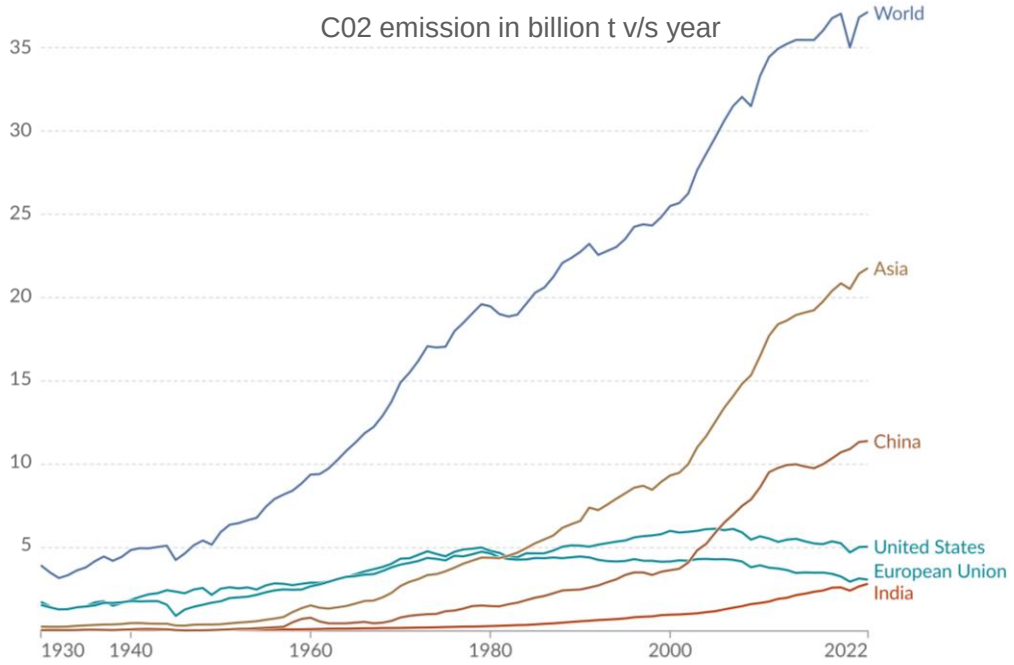
- Capture accounts for up to **70% of CCS costs**, especially in low-concentration sources, with key methods including **post-combustion**, **pre-combustion**, and **direct air capture (DAC)**. Innovations such as membrane systems, integration of **Artificial Intelligence**, and **CCS hubs** aim to reduce transport and storage costs, improving scalability and economic viability

- The development of CCUS hinges on **policy incentives**, market demand for green products, and industry collaboration for infrastructure. Strategic actions like **activating high-purity CO_2 hubs**, sharing risks across the value chain, and designing adaptable hub networks can accelerate deployment, reduce costs, and unlock significant investment opportunities

There is a Urgent Need to Control C02 Emissions on a Global Scale

Why CO2 Emissions Are Harmful:

- **Rise in CO2 Levels**
  - Since the 1960s, global CO2 emissions have increased more than **3fold**, reaching over **35 billion metric tons annually** by 2022 (as shown in the graph
  - The largest contributors are China (**30%**), the United States (**13%**), the European Union (**8%**)
- **CO2 and Temperature Correlation**:
  - A **1.2°C temperature increase** in global average temperatures has been recorded since preindustrial times, largely due to CO2 emissions
  - This increase in temperature is directly linked to more frequent **extreme weather conditions**, such as droughts, heatwaves, and hurricanes.
- **Impact on Ocean Chemistry**:
  - Oceans absorb approximately **25% of CO2 emissions** each year, leading to a **30% increase in ocean acidity** since the Industrial Revolution
  - This has detrimental effects on marine ecosystems, including the destruction of coral reefs which support **25% of marine biodiversity**



- **CCS as a Direct Response:**
  - As a technology can capture up to **90% of CO2 emissions** from industrial sources before they are released into the atmosphere
  - It has the potential to reduce global CO2 emissions by **14% by 2050**, as projected by the International Energy Agency (IEA)
- **Support for Hard-to-Decarbonize Sectors:**
  - Crucial for sectors like cement, steel, and chemical manufacturing, which account for **20% of global CO2 emissions** and are difficult to decarbonize through renewable energy alone
- **Enabling Carbon Neutral Goals:**
  - To achieve the net zero targets by 2050, CCS must be scaled up to capture about **510 billion metric tons of CO2 annually**
  - This technology plays a pivotal role in balancing emissions that cannot be eliminated through other means, making it essential for meeting global climate commitments

Source : Our World In Data – “Annual CO2 Emissions by World Region”

Carbon, Capture and Storage – A Decarbonization Lever to Achieve Net Zero

What exactly is CCS/CCUS?

A process that **captures** carbon dioxide (CO_2) emissions from sources like power plants, industrial processes, and direct air capture. The captured CO_2 is then transported and **stored** underground to prevent it from entering the atmosphere, and further **utilized** in industries

Carbon **Capture, Storage** and **Utilization** make up the three aspects of CCUS

Capture	Utilization	Storage
Capturing C02 means to **selectively separate** it from a different gas mixture where it is already present either at industrial plants or from the air around us	Utilization refers to the reality that **CO2 is needed** as a resource in many important areas of the economy. By recycling CO2 in a circular supply chain model, we can extract and reuse the CO2 already in the atmosphere and utilize it where it is actually needed.	Storage of CO2 is the **permanent removal of CO2 from atmosphere** – the captured CO2 will never make its way back into the the atmosphere until released

CCS Aligns with United Nation Sustainable Development Goals,

which addresses social concerns and showcases the environmental benefits of it's implementation

SDG 7: Affordable and Clean Energy

- Clean Energy Transition: CO_2 from fossil fuel plants, reducing emissions and supporting cleaner energy systems
- Scalable Decarbonization: Can cut emissions from energy production, crucial for scaling clean energy

SDG 9: Industry, Innovation, and Infrastructure

- Decarbonizing Heavy Industry: Reduces emissions in hard to abate sectors like cement and steel, fostering sustainable industrialization
- Circular Economy Boost: Captured CO_2 is utilized into products like fuels, driving industrial innovation and resource efficient

SDG 12: Responsible Consumption and Production

- Turning Waste into Resources: Captured CO_2 converted into useful products, promoting sustainable production
- Enhancing Resource Efficiency: Reusing CO_2 supports a circular economy and drives more efficient resource use

SDG 13: Climate Action

- Immediate CO_2 Reductions: CCUS can cut global emissions by 15% by 2050, making it essential for climate mitigation
- Key to Climate Targets: CCUS is critical to achieving net zero by 2050 and limiting warming to 1.5°C under the Paris Agreement

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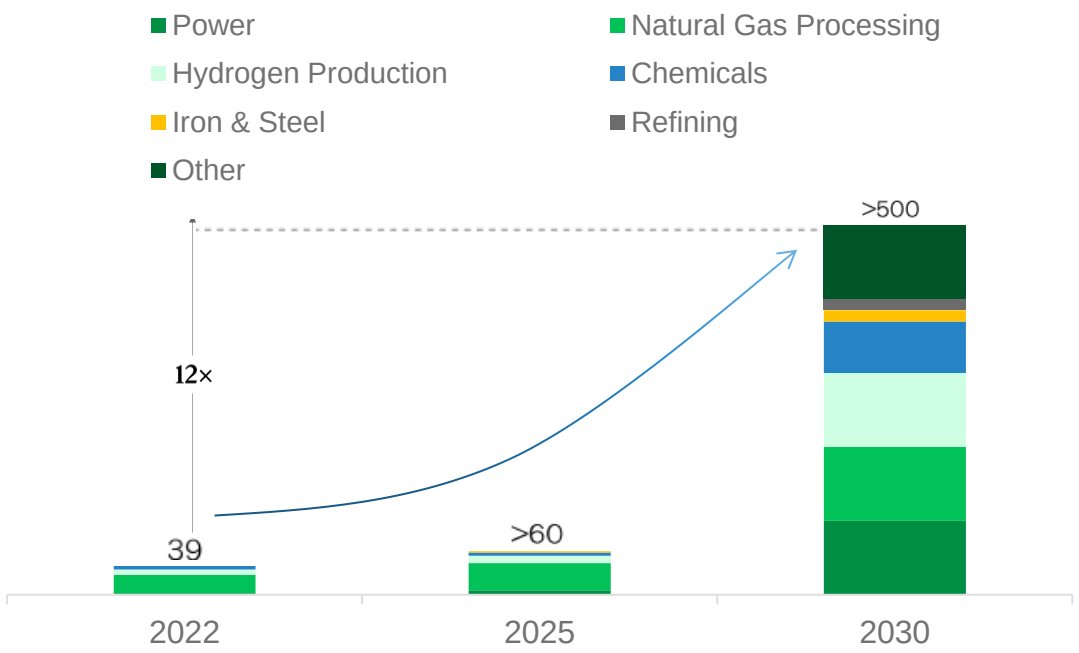
Source: Global CSS Institute – "Global Status of CCS 2023 – Report & Executive Summary"

How Economically Viable is CCS and What are the Market Dynamics

Capacity of announced CCS Projects MtCO2 per year



Step change in planned market projects over the last two years

- **12x Growth by 2030:**
  - CCUS capacity is set to soar from 39 $MtCO_2$/year in 2022 to over **500** $MtCO_2$/year by 2030
- **Sector Leaders:**
  - Power leads growth with a **64% CAGR**, followed by hydrogen production (**43%**) and iron & steel (**51%**)
- **Regional Dominance:**
  - Europe and North America account for **80% of announced capacity**, driven by strong policy incentives
- **Widening Scope:**
  - CCUS is expanding to sectors like cement, blue hydrogen, and chemicals, showing broader applicability
- **Robust Pipeline:**
  - 68 projects are operational, 39 under development, and **533** are in **planning stages**, reflecting strong momentum
- **Net-Zero Enabler:**
  - CCUS is crucial for meeting net-zero targets, especially in ha**rd-to-abate** sectors, positioning it as an economically viable solution

Revenue from Carbon Utilization
Captured CO2 can be converted into products like fuels and materials, offsetting costs

Cost Reduction via Hub
CCUS hubs can lower costs by sharing transport and storage infrastructure

Government Boosts
U.S. tax credits ($85/ton for sequestration, $180/ton for direct air capture) make CCUS viable in key industries

Global Hub Development
700 potential hubs globally, 60% within 50 miles of storage sites.

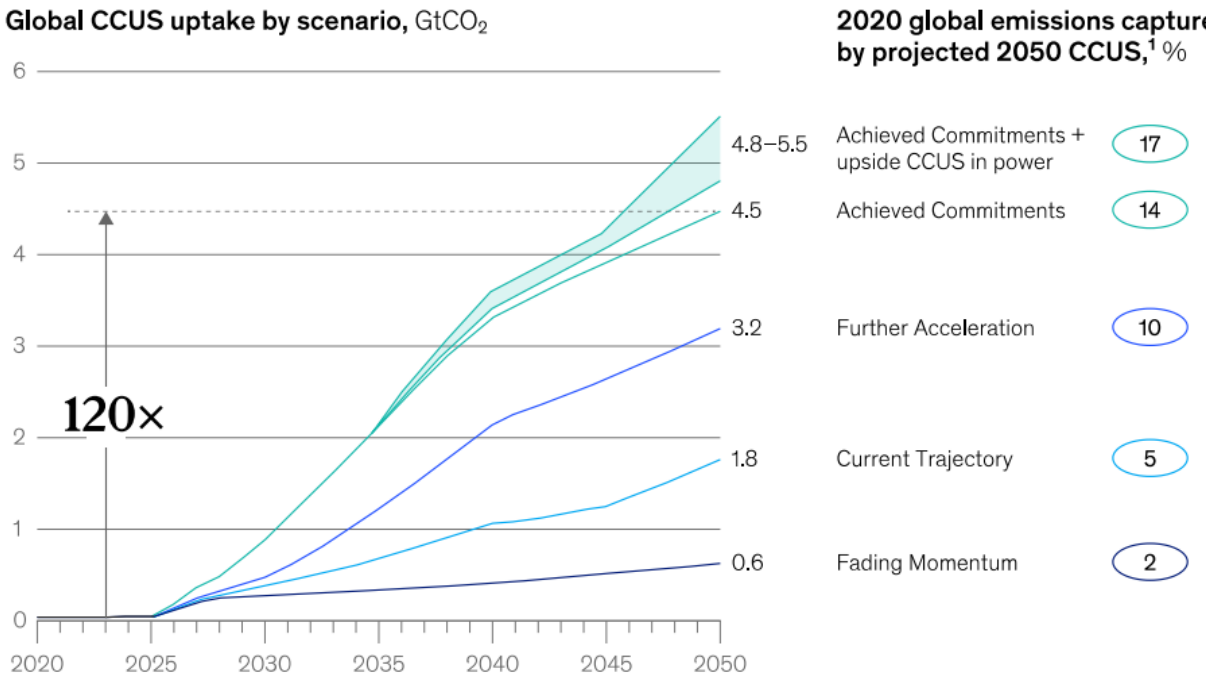
High Costs for Low-Concentration Sources
Cement and power generation are costly due to low CO2 concentrations

Long-Term Storage Potential
Global storage capacity for over 700 years of emissions at current rates

McKinsey & Company – "Global Energy Perspective 2023: CCUS outlook & Scaling the CCUS industry to achieve net-zero emissions"; McKinsey & Company – "The world needs to capture, use, and store gigatons of CO2: Where and how?"

A Key to the Energy Transition but there's Need of Investment to Reach its Potential

Required Growth of CCUS capacity to achieve net-zero targets by 2050

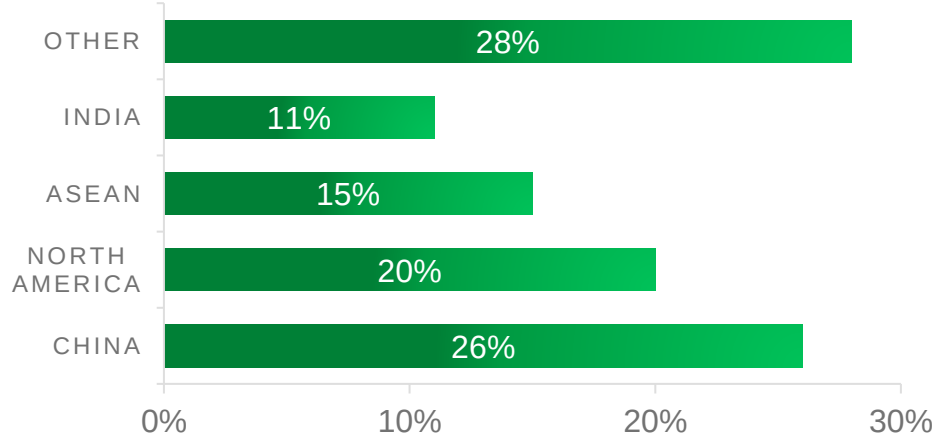


- To meet net-zero targets, CCUS capacity must grow over **100 times**, reaching **4 to 6 gigatons** of CO_2 by 2050
- Achieving this net-zero target would help **decarbonize 15-20%** of today's energy-related emissions.
- To achieve this, significant acceleration is required beyond the **Current Trajectory scenario**

Projected Investment parameters in CCS/CCUS by 2035

$175 Billion is the predicted **Annual Investments** in CCS projects; which shows along with the growth and **diversification** of the CCUS market, investment into CCUS is also growing

70 % of these Investments are expected to be concentrated in regions of **ASEAN**, **China**, **India**, and **North America**



A significant portion of these investments will target **hard-to-abate sectors**, such as cement, iron, steel, and potentially the **power sector**

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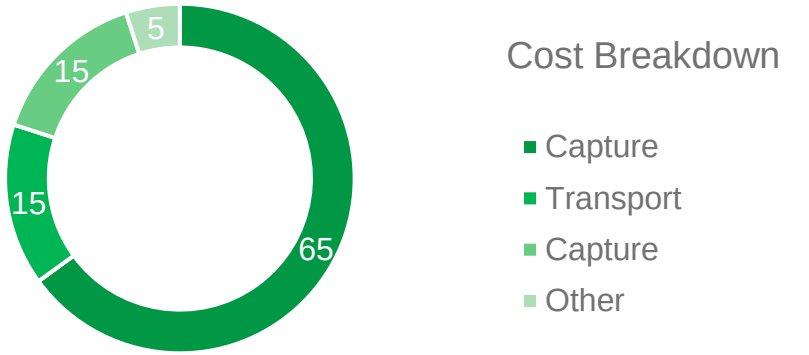
Overview of Technologies and Methods involved in CCS and How They Work

Different capture technologies vary in efficiency, energy use, and industry suitability, with potential for cost reduction

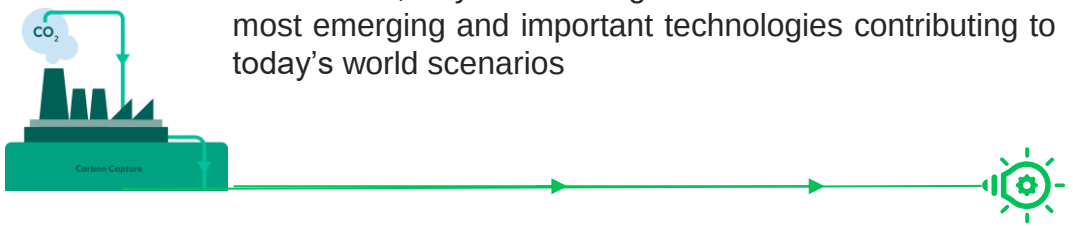
- **Capture** alone can account for up to **70% of the total cost**, particularly for low-concentration sources like power generation, where CO_2 concentration is often between 5-15%



- In **Transport** CO_2 is essentially compressed and moved via pipelines, ships, or trucks to storage sites. Costs vary based on **proximity to storage sites** and can be minimized through shared infrastructure in CCS hubs
- **Storage** costs depend on the type and geological characteristics of the storage site, with offshore options being more expensive due to additional infrastructure needs. Limited availability of suitable underground storage sites can hinder deployment in certain regions, especially in regions like Europe.
- Reducing these costs is essential for making CCS economically viable at scale

Methodology of separating CO2 from source:

- CO_2 is separated from emissions sources, such as power plants, cement factories, or chemical production sites
  - **Post-combustion:** Capturing CO_2 from flue gases (common for existing plants)
  - **Pre-combustion:** Extracting CO_2 before fuel combustion.
  - **Direct Air Capture (DAC):** Extracts CO_2 directly from ambient air, key for net-negative emissions. One of the most emerging and important technologies contributing to today's world scenarios



Emerging Innovations in CCS:

Membrane-based systems and chemical solvents: Improving the efficiency and economics of capturing CO_2 from dilute sources using relevant chemical solvents to achieve maximum efficiency and accuracy of extraction

AI and advanced materials: Increasing **monitoring** reliability using new hotspot technologies is improving overall **safety concerns**, and cost-effectiveness of the process by minimizing the **reliance on manual processes**

CCS hubs: Concentrating emissions from nearby industries is **reducing transport costs** and promoting efficiency of the entire CUS process

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Strategic Drivers and Actions to Accelerate CCUS Development

Key Drivers and Uncertainties for CCUS

Policy Incentives: Tax credits, subsidies, and regulatory standards in regions like Europe and North America are crucial for driving CCUS growth and decarbonizing sectors such as steel and cement.

Industry Collaboration: Coordinated efforts in building CCUS infrastructure (pipelines, storage) can accelerate projects by up to 30% and lower capital costs.

Market Demand: Sectors like steel and cement may see 10-20% price premiums for CCUS-enabled green products, making CCUS financially viable.

Monetizing CO_2: Utilizing captured CO_2 as feedstock in industrial processes can offset capture costs by 20-30%, offering new revenue streams.

Voluntary Carbon Markets: Negative-emission pathways, like BECCS and DAC, could unlock a $50 billion market by 2030, providing funding for decarbonization efforts.

Actions to Accelerate CCUS Hub Development To Achieve Net Zero Targets:

Activate No-Regret Projects: Focus on initial hubs around high-purity CO_2 sources to lower capture costs and accelerate learning. Hubs designed for scalability could **reduce capture costs by 15-25%** as economies of scale improve

Establish Market Mechanisms for Risk and Value Sharing: Develop frameworks to equitably distribute risk and value across the CCUS value chain (capture, transportation, storage). Standardization in CO_2 monitoring and governance can improve investor confidence, potentially unlocking $50-100 billion in capital by 2030

Design Resilient and Flexible Hub Networks: Develop adaptable networks (e.g., trunk lines for centralized storage or **multi-sink models**) to ensure scalability. Collaborative efforts between industries could reduce infrastructure costs by **20-30%**, leading to faster deployment

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