REPORT

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Evaluating CCUS Technologies and their Potential Role in Accelerating Nigeria's Net-Zero Emissions Goal

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1. Abstract

This paper presents a techno-economic evaluation of Carbon Capture, Utilization, and Storage (CCUS) technologies within the context of global decarbonization efforts and their specific potential for accelerating Nigeria's net-zero emissions goal. Globally, CCUS is a critical component of net-zero pathways, with projections indicating a need for its capacity to grow over 100 times by 2050, capturing between 4 and 6 gigatons of CO_2 annually to decarbonize up to 20% of today's energy-related emissions. Nigeria has committed to achieving net-zero emissions by 2060, as outlined in its Energy Transition Plan and the Climate Change Act 2021. The nation's industrial sector accounts for a significant portion of its greenhouse gas emissions, and CCUS can play a vital role in abating these "hard-to-abate" sectors. While there are currently no operational large-scale CCUS projects in Nigeria, a recent high-level assessment identified 10,700 gigatonnes of prospective CO_2 storage resources, primarily in the Niger Delta, indicating significant geological potential. This report assesses the technical and economic viability of CCUS adoption across key Nigerian industries, models the potential of CCUS in contributing to the national climate target, and proposes a policy and regulatory framework to fast-track its deployment.

1. Introduction

1.1 Overview of Carbon Capture, Utilization, and Storage (CCUS) Technologies

CCUS involves the capture of carbon dioxide (CO_2), generally from large point sources like power generation or industrial facilities that use either fossil fuels or biomass as fuel. If not being used on-site, the captured CO_2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications, or injected into deep geological formations such as depleted oil and gas reservoirs or saline aquifers. CCUS is widely recognized as a key part of the toolkit of solutions needed to reach net-zero greenhouse gas emissions

1.2 Classification of CCUS Technologies: Point-Source and Direct Air Capture

Point Source Capture:

Point source carbon capture refers to the direct removal of CO_2 emissions from large stationary sources before they are released into the atmosphere. Typical sources include power plants, refineries, cement kilns, fertilizer plants, steel mills, and natural gas processing facilities. Point source capture involves post-combustion chemical absorption (e.g. amine scrubbing) can extract CO_2 from power-plant or industrial flue gases, pre-combustion capture (e.g. gasification) and oxy-fuel combustion (burning fuel in pure O_2 to yield concentrated CO_2). pre-combustion capture (e.g. gasification) or oxy-fuel combustion (burning fuel in pure O_2 to yield concentrated CO_2). Capture costs for point-source CO_2 are on the order of $100–300 per tonne of CO_2 (depending on scale and flue gas concentration) *(IEAGHG, 2024).*

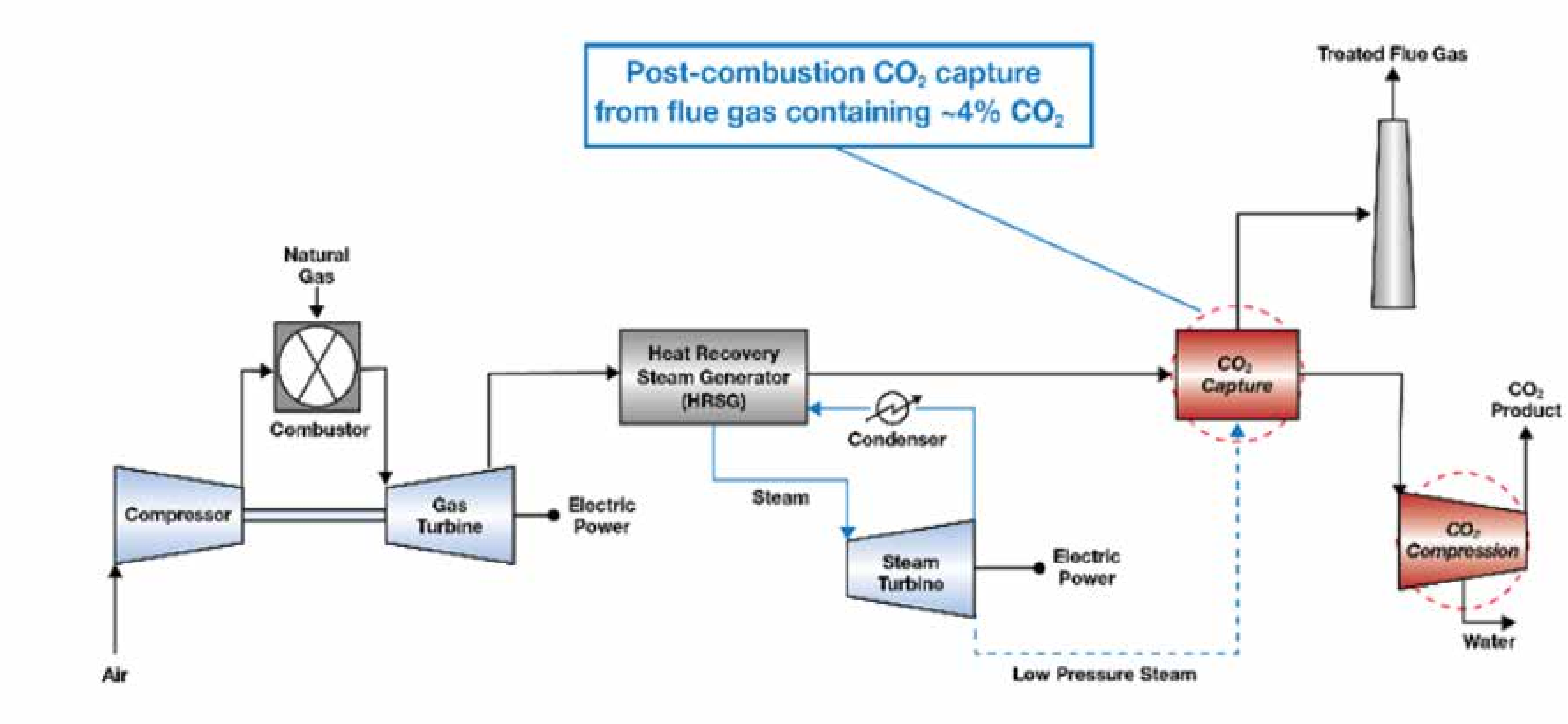

Fig 1.1 Point Source Capture

Direct Air Capture:

Air Capture (DAC) is an innovative technology that extracts CO_2 directly from the atmosphere, offering a vital tool to combat climate change by reducing greenhouse gas levels. DAC technologies represent a critical component of global strategies to achieve net-zero CO_2 emissions by 2050, addressing residual and historical atmospheric CO_2 concentrations that contribute to climate change. DAC uses chemical or physical sorbents to remove CO_2 from ambient air (approx. 0.04% CO_2) *(The Wall Street Journal),* unlike point sources, DAC can be sited flexibly but is much more energy-intensive and costly. Current DAC systems typically cost on the order of \$500–1,000 per tonnes of CO_2 *(Wissolutions)*. On capital cost basis, DAC significantly higher than point-source capture. Although there are optimistic projections that DAC costs possibly falling toward \$100–200 per tonnes by 2030 *(UN Regional Information Center),* but today DAC is feasible only at small scale (e.g. Climeworks' Orca plant in Iceland, Carbon Engineering's Canadian plant). DAC's ability to capture CO_2 anywhere, independent of emission sources, positions it as a versatile tool for negative emissions. The scalability of DAC technologies is constrained by several engineering and systemic barriers. Energy intensity remains a primary challenge, with solid sorbent systems requiring 1–3 GJ/ton CO_2 and liquid solvent systems up to 10 GJ/ton CO_2, compared to 0.5–1 GJ/ton for point-source capture.

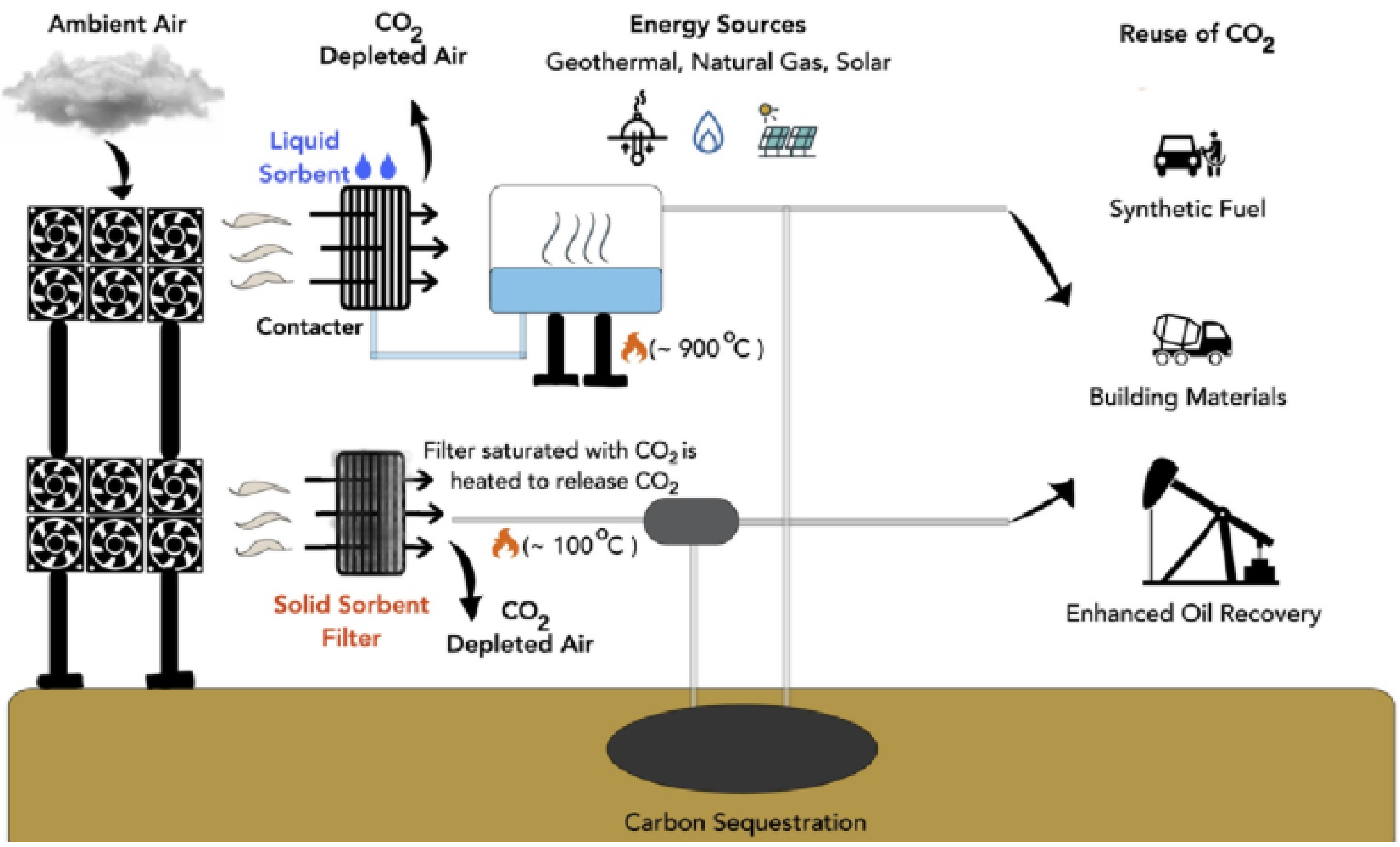

Fig 1.2 Schematic Overview of the Direct Air Capture Process with Sorbent Technologies and CO_2 Reuse Options

1.3. The Strategic Role of CCUS in Global Net-Zero Emissions Pathways

Carbon Capture, Utilization, and Storage (CCUS) is recognized as a critical technology in achieving global net-zero emissions targets by mid-century. While renewable energy, energy efficiency, and electrification address a large share of emissions, certain "hard-to-abate" sectors such as cement, steel, petrochemicals, and natural gas power generation cannot be fully decarbonized without CCUS. The International Energy Agency (IEA) projects that CCUS must account for nearly 15–20% of cumulative global emissions reductions required by 2050 to align with the Paris Agreement.

Strategically, CCUS plays four major roles. First, it enables emissions reduction at point sources, preventing large volumes of CO_2 from entering the atmosphere. Second, it supports the production of low-carbon fuels, particularly "blue hydrogen," which provides a scalable clean energy vector. Third, it allows carbon removal via Direct Air Capture (DAC) and bioenergy with CCS, offering negative emissions essential for offsetting residual emissions in aviation, agriculture, and other sectors. Finally, CCUS contributes to energy security and just transition by extending the use of fossil-based infrastructure while reducing its carbon footprint.

Globally, over 40 large-scale CCUS facilities are in operation or under construction, with notable projects in Norway, Canada, the United States, and the United Kingdom *(Carbon Capture Journal)*. These initiatives demonstrate that with the right mix of regulation, carbon pricing, and investment, CCUS can complement renewables to deliver a resilient and affordable pathway to net-zero.

Role Of CCUS In Global Net-Zero Roadmaps

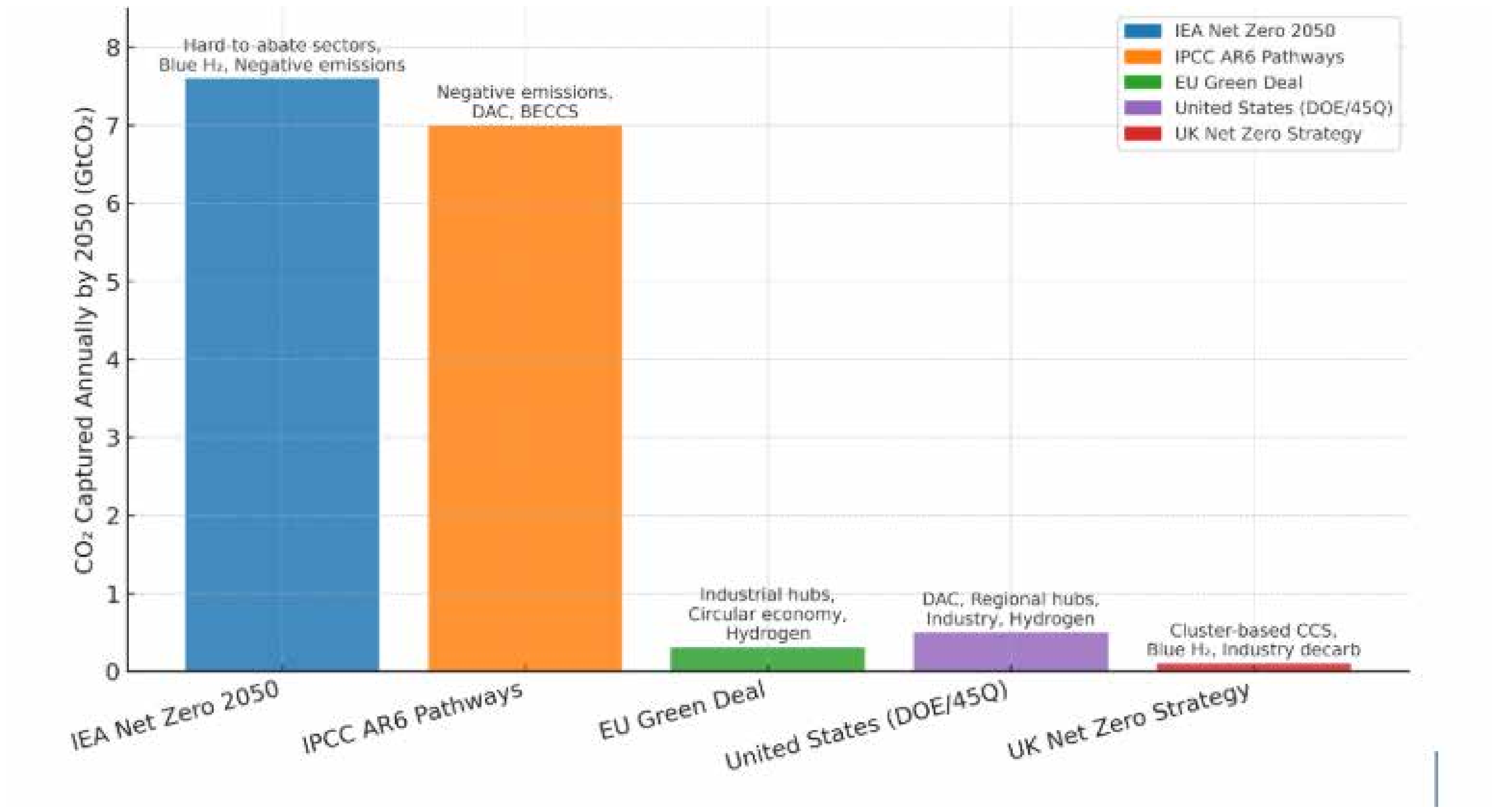

Figure 1.3 Role of CCUS in Global Net-Zero Roadmap *(IEA, Role of CCUS in Global Net-Zero Roadmaps)*

2.0 Global CCUS Outlook: Technical, Economic, and Decarbonization Potential

2.1 Technical and Operational Overview of CCUS Technologies

Carbon dioxide capture technologies encompass a diverse set of processes that enable the separation of CO_2 from flue gases or process streams, each operating on distinct physical or chemical principles. Mature technologies such as chemical absorption using amine solvents are already widely deployed across power, fuel transformation, and industrial facilities, while physical separation through adsorption, absorption, or cryogenic methods is commercially established in natural gas, hydrogen, and ethanol production. These approaches provide the backbone of current industrial CO_2 capture capacity.

Meanwhile, a range of emerging technologies is advancing toward commercialization. Oxy-fuel combustion and membrane separation are at demonstration scale, targeting coal power plants, cement kilns, and biogas upgrading, while calcium looping and chemical looping offer high-temperature, two-reactor cycles capable of reducing energy penalties compared with conventional methods. Pilot projects worldwide have validated their technical feasibility with fuels ranging from coal and natural gas to biomass.

At the frontier, direct separation technologies such as the LEILAC pilot in Belgium demonstrate the potential for integrated capture in cement manufacture, stripping CO_2 directly from limestone. Similarly, supercritical CO_2 power cycles, including NET Power's Allam Cycle in the U.S., showcase novel pathways that combine power generation with inherent CO_2 capture. Together, these technologies illustrate a progression from commercially mature systems to innovative concepts, underscoring the critical role of CO_2 capture in industrial decarbonization.

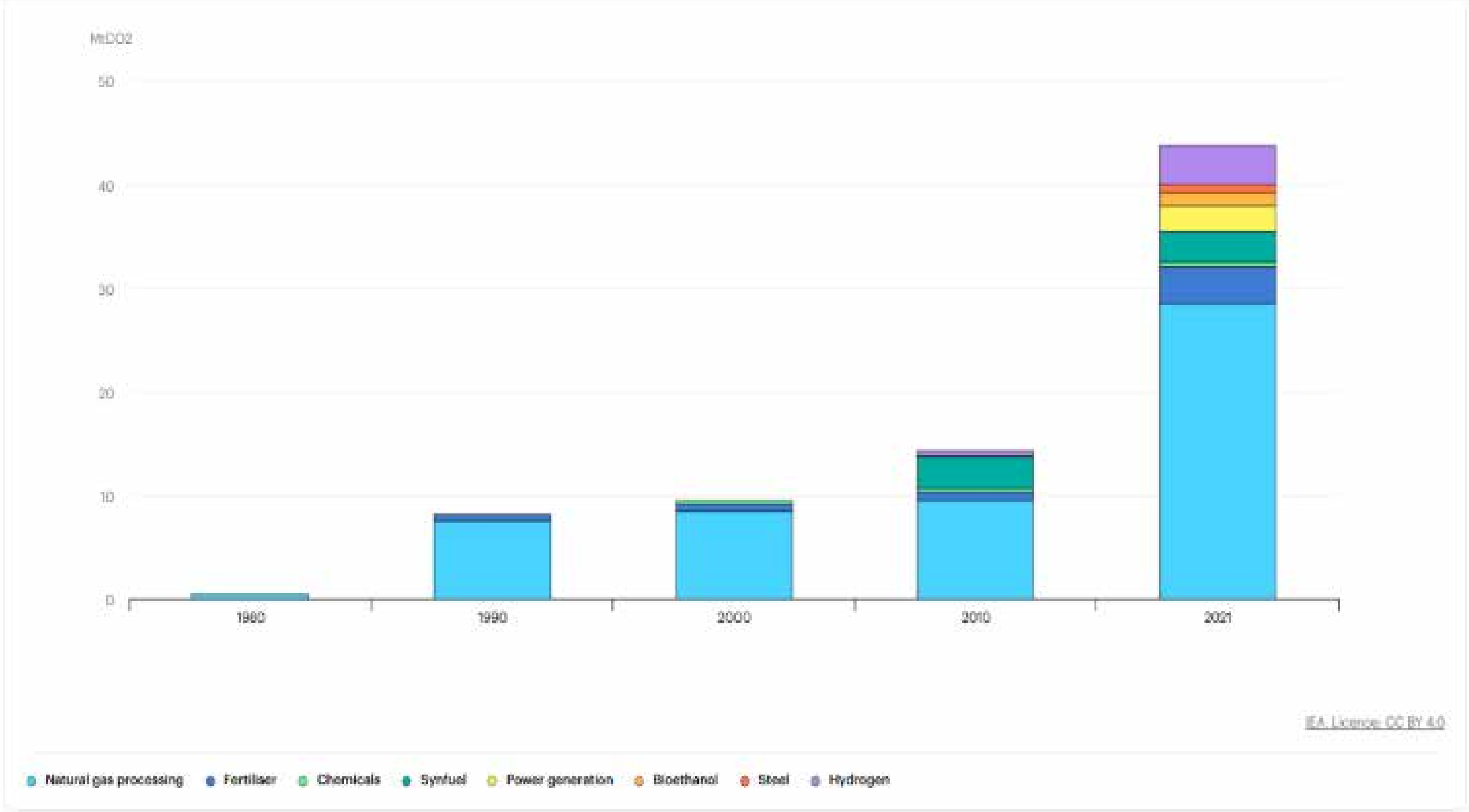

Fig2.1 CCUS facilities in operation by application, 1980-2021

Today, CCUS facilities around the world have the capacity to capture more than 40 MtCO2 each year *(IEA 2023)*. Some of these facilities have been operating since the 1970s and 1980s. Since these early projects, CCUS deployment has expanded to more regions and more applications. The first large-scale CO2 capture and injection project with dedicated CO2 storage and monitoring was commissioned at the Sleipner offshore gas facility in Norway in 1996. The project has now stored more than 20 MtCO2 in a deep saline formation located around 1 km under the North Sea.

2.2 Cross-Industry Adoption and Applications of CCUS

Carbon Capture, Utilization, and Storage (CCUS) has progressed from pilot demonstrations into early commercial deployment across a range of industrial sectors, though the scale of deployment remains modest relative to global climate targets. Current operational facilities capture approximately 50–51 $MtCO_2$ per year, while the project pipeline exceeds 400 $MtCO_2$ per year by 2030. However, less than 20% of the announced 2030 capacity has reached either Final Investment Decision (FID) or operation, underscoring significant delivery and execution risks (*IEA, Global CCS Institute).*

The sectoral outlook highlights CCUS as a critical lever for decarbonizing hard-to-abate industries such as gas processing, refining, fertilizer, chemicals, cement, and iron and steel. Collectively, the cement and steel industries alone account for nearly 13.5% of anthropogenic CO_2 emissions (Fennell et al., 2022). For cement, emissions are unavoidable both from fossil fuel combustion and from process chemistry during clinker production. Accordingly, CCS is uniquely positioned as the only scalable technology to mitigate these process emissions. Currently, more than 30 cement-sector CCS projects are in various stages of development, with flagship examples including the Brevik Cement Plant (Norway), which will capture approx. 0.4 $MtCO_2$/yr for storage via the Northern Lights project *(IEA, Global CCS Institute).*

In the steel sector, CCUS offers two primary pathways: retrofitting blast furnaces with post-combustion capture and supporting the development of hydrogen-based direct reduction ironmaking through low-cost blue hydrogen production. While operational capacity remains limited (e.g., Al Reyadah, UAE), multiple projects are advancing in Asia Pacific and North America.

Fig 2.2 Brevik CCS facility in Brevik, Norway.

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Beyond industry, CCUS applications extend to power generation (e.g., Petra Nova, USA), natural gas processing (e.g., Sleipner, Norway), and bioenergy with CCS (BECCS) at the ADM Decatur facility, USA. Moreover, Direct Air Capture (DAC) is rapidly gaining traction, with commercial projects like Climeworks' Mammoth (Iceland) advancing alongside large-scale US DOE-backed hubs.

2.3 Economic Viability and Cost-Benefit Analysis of CCUS Deployment

The economic viability of CCUS depends on balancing high upfront capital costs with long-term climate and operational benefits. Typical capture costs vary by sector and technology, ranging from US\$15–25 per tonne of CO_2 in natural gas processing, to US\$40–120/tCO_2 in power generation and cement, and up to US\$200/tCO_2 for emerging Direct Air Capture (DAC) systems. Transport and storage add an additional US\$10–20/tCO_2, making integrated CCUS chains highly capital-intensive *(IEA, Global CCS Institute)*.

Business models are evolving to address these costs. Tax incentives and carbon pricing have proven effective where applied: in the United States, the 45Q tax credit offers up to US\$85/tCO_2 stored (and US\$180/tCO_2 for DAC), underpinning projects such as Petra Nova (power) and ADM Decatur (bio-CCS) (*DOE, 2023).* Similarly, the UK's Contract for Difference (CfD) model for industrial clusters guarantees revenue stability for projects like HyNet North West and the East Coast Cluster, de-risking investment in shared CO_2 transport and storage networks *(DOE, 2023; IEA, 2023)*.

Empirical cases highlight both successes and challenges. Quest (Canada) has safely stored over 7 MtCO_2 since 2015 with transparent annual reporting, while Norway's Longship/Northern Lights provides a state-backed "open-access" storage model expected to handle up to 5 MtCO_2/yr. in its initial phase. Conversely, the Gorgon CCS project (Australia), designed for approx. 4 MtCO_2/yr. has underperformed significantly due to injectivity issues, achieving only about 30% of intended capture between 2016–2024 *(IEA, Global CCS Institute).*

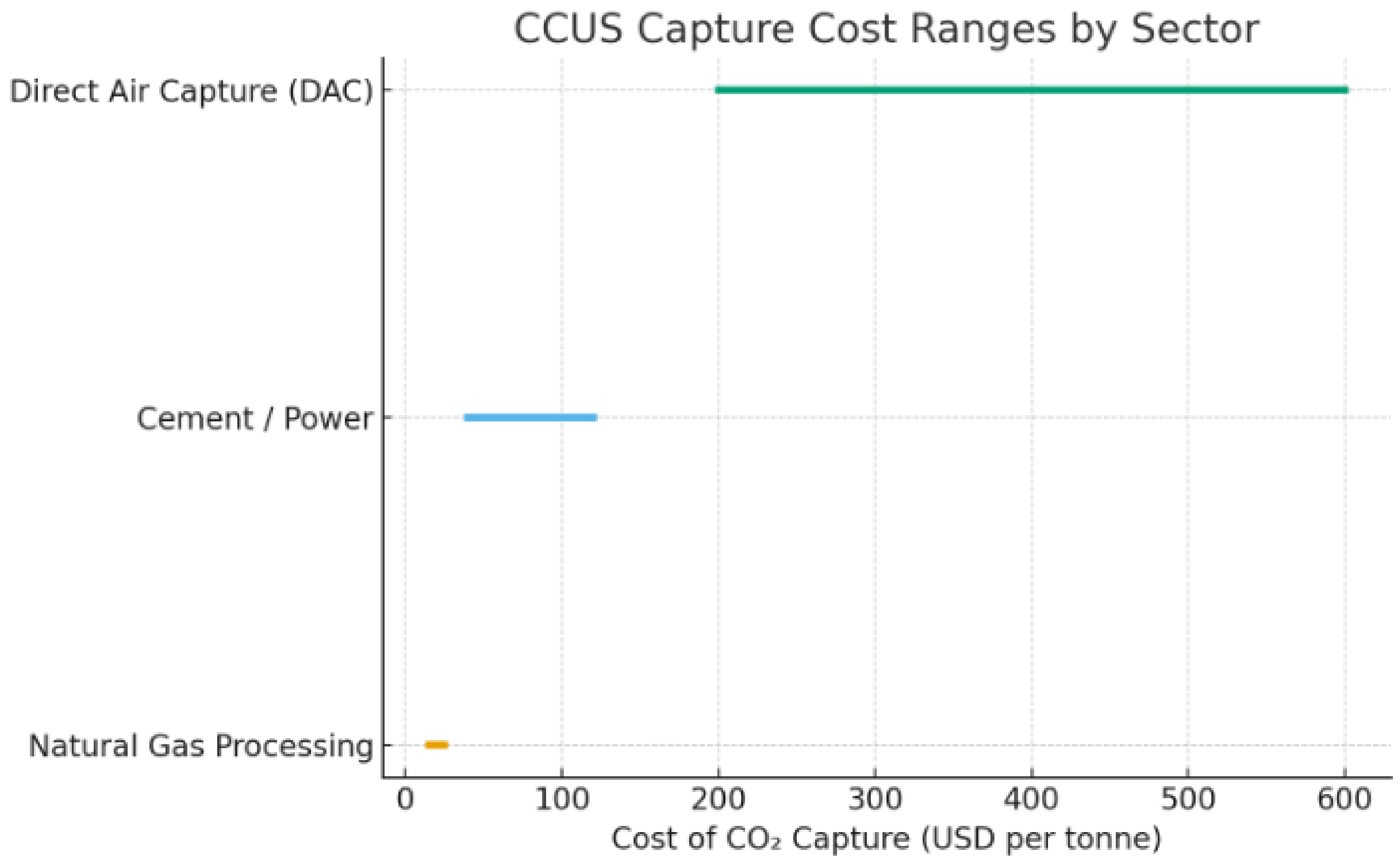

Fig 2.3 CCUS Capture Cost Ranges by Sector

The broader cost-benefit analysis positions CCUS as a least-cost pathway for hard-to-abate sectors (cement, steel, refining) where alternatives are limited. Avoided emissions translate into compliance cost savings in regulated markets (e.g., EU ETS ~€90/tCO_2 in 2024). Additionally, shared infrastructure clusters lower unit costs and generate network externalities. However, financing gaps remain: fewer than 20% of announced CCUS projects to 2030 have reached final investment decision, underscoring the need for policy certainty, stable carbon prices, and innovative financing mechanisms to accelerate deployment.

2.4 Major Contributions of CCUS to Global Decarbonization and Net-Zero Targets

Reducing global carbon emissions requires more than relying on traditional solutions like energy efficiency improvements and renewable energy expansion.

The decarbonization of hard-to-abate sectors, like steel and cement, demand the deployment of new and improved carbon capture and storage (CCS) and carbon capture, utilization and storage (CCUS) technologies.

Carbon Capture, Utilization, and Storage (CCUS) stands as a central pillar in global strategies to meet net-zero emissions, especially for hard-to-decarbonize sectors. The International Energy Agency (IEA) projects that CCUS will contribute between 15% and 40% of cumulative emissions reductions in heavy industries such as cement, steel, and chemicals through 2070 in its Sustainable Development Scenario, and will account for nearly 40% of cumulative CO_2 mitigations across these sectors. Notably, up to 90% of CO_2 in cement, 75% in steel, and under 80% in chemicals could be captured by mid-century..

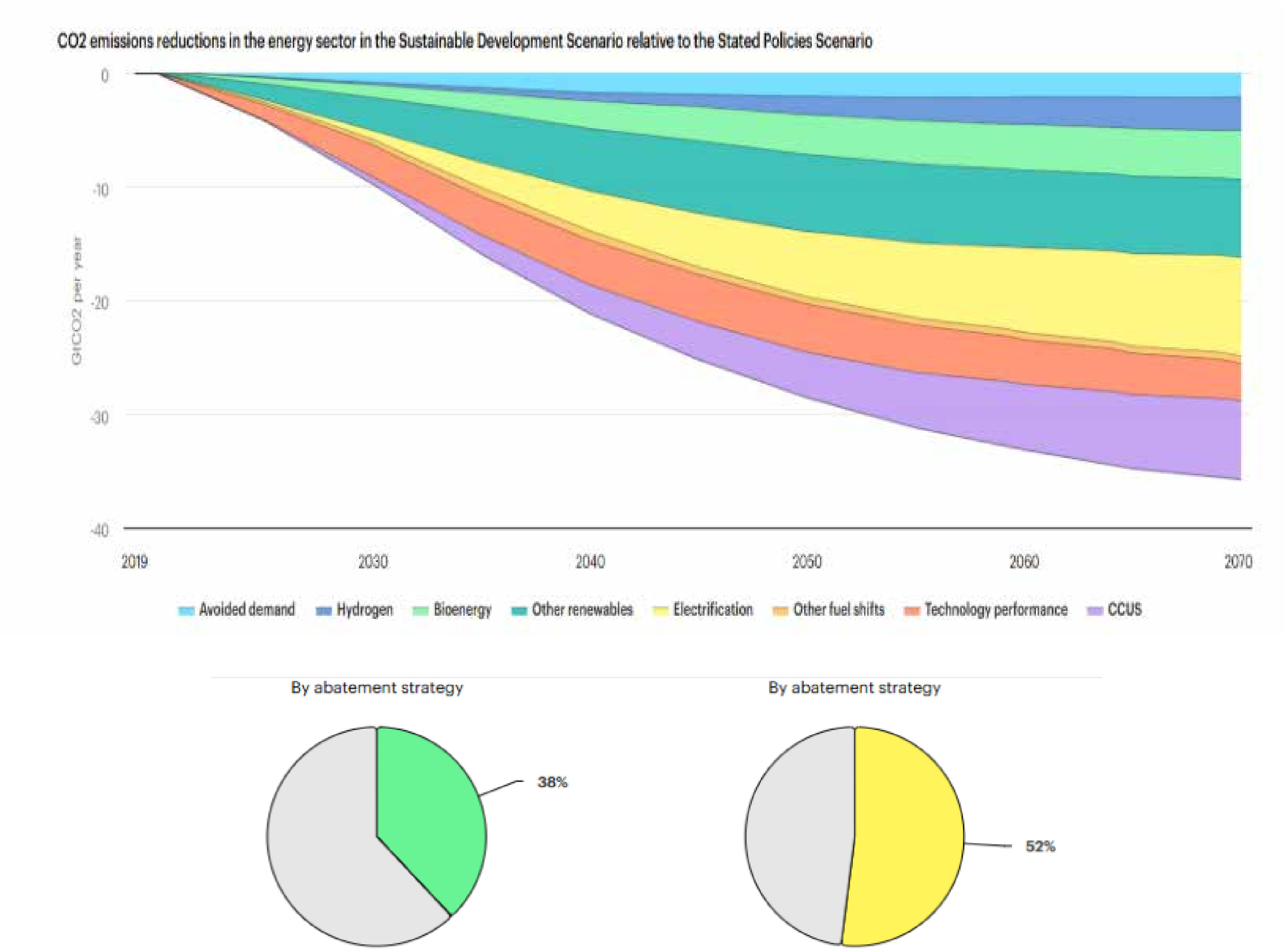

Fig 2.4 Cumulative Emission Reduction, 2020 – 2070

Climate modeling emphasizes the scale: CCUS capacity must expand by over 100 times to reach 4–6 gigatonnes of CO_2 annually by 2050, covering 15–20% of current energy-sector emissions. Similarly, OGCI's analysis forecasts development of about 100 CCUS hubs globally, each potentially capturing 7.5–10 $MtCO_2$/year, together delivering up to 1 $GtCO_2$/yr. by 2030, a contribution comparable to removing emissions from hundreds of coal power plants or tens of millions of vehicles

2.5 Policy and Regulatory Mechanisms Driving Global CCUS Adoption

The successful deployment of CCUS is strongly contingent on robust policy and regulatory mechanisms that reduce investor risk, incentivize capture and storage, and establish clear long-term liability rules. Across jurisdictions, governments are strengthening frameworks to provide certainty and attract capital.

In the United States, the Inflation Reduction Act (2022) and the Infrastructure Investment and Jobs Act (2021) have significantly advanced CCUS deployment by enhancing the 45Q tax credit, providing up to US\$85/tCO_2 stored and US\$180/tCO_2 for DAC and offering billions in grants and low-interest loans. These measures underpin projects such as Wabash Valley Resources, a zero-carbon fertilizer facility, which secured US\$38 million in DOE funding for FEED studies and is advancing toward FID with federal loan guarantees.

In Europe, regulatory tools such as Carbon Contracts for Difference (CCfDs) have been introduced in Denmark, Germany, and the Netherlands to bridge the gap between volatile carbon prices and the higher costs of CCS deployment. These schemes guarantee revenue streams even when EU ETS carbon prices fall, ensuring predictable investment conditions. The EU's Industrial Carbon Management Strategy (2024) further commits to capturing 450 MtCO_2 annually by 2050, embedding CCUS into the bloc's climate governance architecture.

Emerging economies are also advancing frameworks. Indonesia introduced Presidential Regulation 14/2024, which mandates permitting, safety monitoring, and post-closure liability for CCS while integrating fiscal incentives such as tax breaks and storage fees. In Australia, the Petroleum Legislation Amendment Bill 2023 established comprehensive oversight for onshore and offshore CCS, while federal legislation aligned with the London Protocol to enable cross-border CO_2 trade.

Ultimately, these mechanisms underscore that CCUS deployment depends on predictable legal frameworks, strong fiscal incentives, and clear liability regimes. Case studies in the US and EU show that where governments provide sustained derisking, projects advance rapidly toward commercial scale.

Conversely, jurisdictions with policy uncertainty such as fluctuating EU ETS prices or delayed Canadian carbon tax reforms face stalled or cancelled projects

2.6 Future Projections and Trends in CCUS Technology Development

The trajectory of CCUS technology shows strong momentum, with projections forecasting dramatic scale-up by mid-21st century. IDTechEx anticipates global CCUS capture capacity reaching 2.5 $GtCO_2$ per annum by 2045, representing a CAGR of about 18.5% between 2025 and 2045. IDTechEx also highlights the long-term trend toward shared CO_2 transport networks, enhancing cost-efficiency through infrastructure synergies

In the nearer term, the IEA Sustainable Development Scenario projects annual CO_2 capture of greater than 450 Mt by 2030, driven significantly by retrofitting 20 coal-based power and industrial facilities per year, largely concentrated in Asia. This retrofitting is expected to prevent over 70 Gt of cumulative emissions across the life of the plants. By 2030, advanced capture tools, including CCUS-enabled hydrogen production are expected to contribute significantly, with 18 MtH_2/year forecast from CCUS-equipped facilities.

Market dynamics reflect accelerating project development: by mid-2025, there were over 474 CCUS projects announced, suggesting 812 Mtpa potential capacity by 2030, with 67.5% already beyond feasibility. North America is projected to hold 35% of global CCUS capacity by 2030, while a global pivot toward long-term geological storage is underscored by a projected 59% CAGR in standalone storage capacity from 2025 to 2030. Notably, post-combustion capture is expected to dominate capture technologies by 2030 (accounting for about 73% of capacity)

In summary, the future of CCUS looks promising, with rapid expansion anticipated across capacity, technology, and deployment pipelines. Key themes include retrofits, hydrogen CCUS, DAC growth, and shared infrastructure hubs, all supported by policy impetus and diminishing cost curves

3.0 CCUS in Nigeria: Prospects, Challenges, and Policy Implications

3.1 Current State of CCUS Development and Readiness in Nigeria

The CCS Readiness Index *(CCS-RI)* is an evaluation criteria set by the Global CCS Institute to assess the readiness of countries for full-scale commercial CCS deployment. Using this approach, countries are evaluated based on certain criteria, which have been grouped under the following key indicators:

i. Country's inherent interest in CCS
ii. Development of relevant policies
iii. Legal and regulatory frameworks
iiv Development of geological CO2 storage assessment

1. Country's inherent interest in CCS

Nigeria's economic backbone remains fossil fuels, oil and gas dominate exports and government revenues. At the same time, Nigeria emits approximately 28 million tonnes of CO_2 annually from industrial sources, with this figure rising 3–5% yearly *(IFC,2025).* Facing mounting climate risks including desertification and flooding Nigeria has signaled its commitment to a low-carbon future through a net-zero pledge by 2060 and a 20% GHG emission reduction target by 2030. This dual pressure and opportunity underpin a strong inherent interest in deploying CCS.

2. Development of Relevant Policies

Nigeria's regulatory framework is gradually evolving to support the deployment of Carbon Capture, Utilization, and Storage (CCUS), although it remains at an early stage compared to global leaders. Several landmark policy instruments signal a growing recognition of CCUS in the country's decarbonisation pathway.

a. ***Petroleum Industry Act (PIA, 2021)*** – This Act introduces environmental management requirements for upstream operations, mandating CO_2

mitigation plans for licensees. By embedding decarbonisation obligations into petroleum regulation, the PIA establishes a foundation for integrating CCUS into oil and gas operations.

b. ***Climate Change Act (2021)*** – This Act creates Nigeria's national carbon budgeting framework and a governance structure for long-term emission reduction. The law formally aligns Nigeria with net-zero ambitions and provides a legislative anchor for adopting mitigation technologies, including CCUS (Wikipedia).

c. Decarbonisation Requirements for Oil Licensing – From 2025, new oil license applicants must present low-carbon strategies and decarbonisation plans. The Upstream Petroleum Decarbonisation Template specifically requires operators to demonstrate pathways for emission reduction, implicitly creating space for CCUS integration.

d. Political Signaling and Capacity Building – Nigeria hosted its first CCUS-focused national workshop in 2023, demonstrating intent to integrate carbon management into its energy transition strategy. This mirrors international trends where first-mover nations combine technical workshops with policy roadmaps to derisk early investments.

e. Comparison with Global Trends – While Nigeria's policies are foundational, they are less mature than frameworks in countries like Indonesia, Japan, and Canada, which have introduced CCS-specific legislation, storage permitting processes, and fiscal incentives.

3. Legal and Regulatory Frameworks

Although Nigeria has begun embedding environmental mandates within its legal structure, no dedicated CCUS regulatory framework currently exists. Below is an analysis by key legal components impacting CCUS readiness:

I. Conceptual Recognition Without Dedicated Legislation: Existing laws like the Petroleum Industry Act *(PIA,2021)*and Climate Change Act *(CCA,2021)* provide a conceptual basis for CCUS primarily by embedding environmental management and net-zero goals into national policy. However, they do not explicitly articulate CCUS-specific provisions such as pore space ownership, storage liability, or long-term monitoring and verification (MRV). The lack of clear mandates on subsurface rights remains a central legal gap.

II. Regulatory Ambiguity and Licensing Permissions: A draft regulation from the Nigerian Upstream Petroleum Regulatory Commission *(NUPRC)* allows operators to conduct CCS within leased areas only "with the consent of the Commission." This provision signals a willingness to accommodate CCUS under existing legal frameworks but falls short of establishing a fully regulated system

III. Pore Space Ownership Unresolved: Nigeria, like most countries, has not legislated pore space ownership the subsurface volumes required for CO_2 storage. Without clear legal title, developers face high uncertainty in securing storage rights and managing long-term liability, which is essential for investor confidence. In contrast, jurisdictions like Alberta (Canada) legally vest pore space in the state to enable CCUS deployment

IV. Institutional Capacity & Governance Gaps: Analyses by *Ogbo, Onuoha, and Odoh (2024)* identify fragmented regulatory responsibility and limited institutional readiness as major barriers to CCUS progress in Nigeria. The absence of a unified regulatory body or coordination among key agencies hampers effective governance and investor assurance.

Moreover, the Natural Resource Governance Institute (NRGI) and others have flagged wider transparency and enforcement deficits in Nigeria's governance echoing challenges that if unaddressed, can derail future CCUS enforcement and oversight.

4. Development of Geological CO2 Storage Assessment

The Nigerian CO_2 Storage Atlas *(IFC / World Bank / IEA collaboration)* provides the first country-scale public mapping of prospective storage and identifies about 10,700 gigatonnes (10,700 Gt) of prospective CO_2 storage resource across Nigeria, with major early opportunities concentrated in and around the Niger Delta and three industrial hubs (Lagos, Port Harcourt, Warri). Some of the basin is Highlighted below

Niger Delta Basin: multiple field assessments

The region hosts multiple candidate reservoirs (depleted fields + saline aquifers) with demonstrably suitable petrophysical properties at the field scale; however, most estimates are initial/theoretical and require dynamic simulation, pilot injectivity tests, and caprock/leakage pathway analysis before classifying as commercial storage capacity. Some of the field evaluated are;

a. ***CRK Field (onshore Niger Delta):*** Static 3-D reservoir modelling mapped two reservoir sands (D10C0, D6200). Average porosity 20–29%; permeability 250–890 mD; water saturation 8–75%. Theoretical storage capacity is approximately 24.85 Mt CO_2, median effective capacity is approximately 6.22 Mt for the mapped sands. Study concluded reservoir and caprock properties are broadly suitable for CO_2 storage pending dynamic simulation and integrity checks.

b. ***HAN Field (Niger Delta):*** Site characterization reported favorable injectivity and sealing; a field-level estimate of about 50 Mt CO_2 storage capacity (noted as a confirmed suitable candidate for pilot injection).

c. ***Aida, J, Gabo, Z, Maje and other Niger Delta fields:*** Several studies used well logs, 3-D seismic and petrophysical analyses to map reservoir continuity, porosity/permeability, caprock integrity and compute volumetric and effective storage estimates for both depleted hydrocarbon reservoirs and saline aquifers. Examples include J-Field saline aquifer volumetric assessments and injectivity/index evaluations for Gabo and Z fields. These studies typically report reservoir porosities in the high-teens to mid-20s (%) and permeabilities from 100s to 1000s of mD in cleaner sands parameters favorable for injection but requiring dynamic modelling and well integrity assessment.

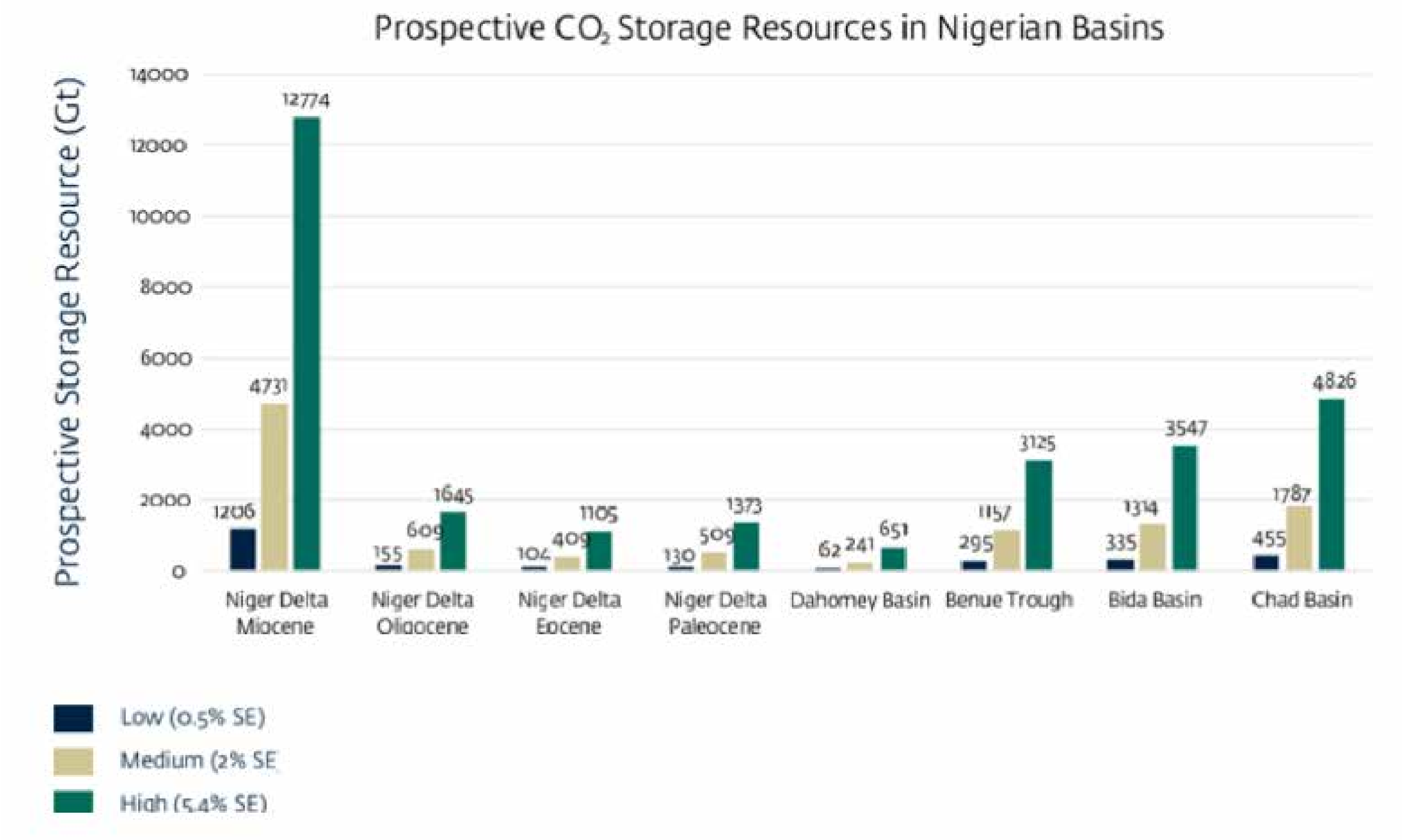

Fig 3.1 Prospective CO_2 Storage Resources in Nigeria Basin *(IFC / World Bank / IEA collaboration)*

I. Benue Trough (Northern Benue / Bima Formation)

Recent work identifies the Bima Formation and other Benue units as potential reservoir targets for CO_2 storage (outcrop and subsurface studies). Research highlights reservoir heterogeneity risks but also demonstrates candidate sand bodies with adequate porosity and lateral continuity. The Benue assessment is at a preliminary prospect/screening stage and requires targeted subsurface data (wells, seismic) to mature capacity estimates.

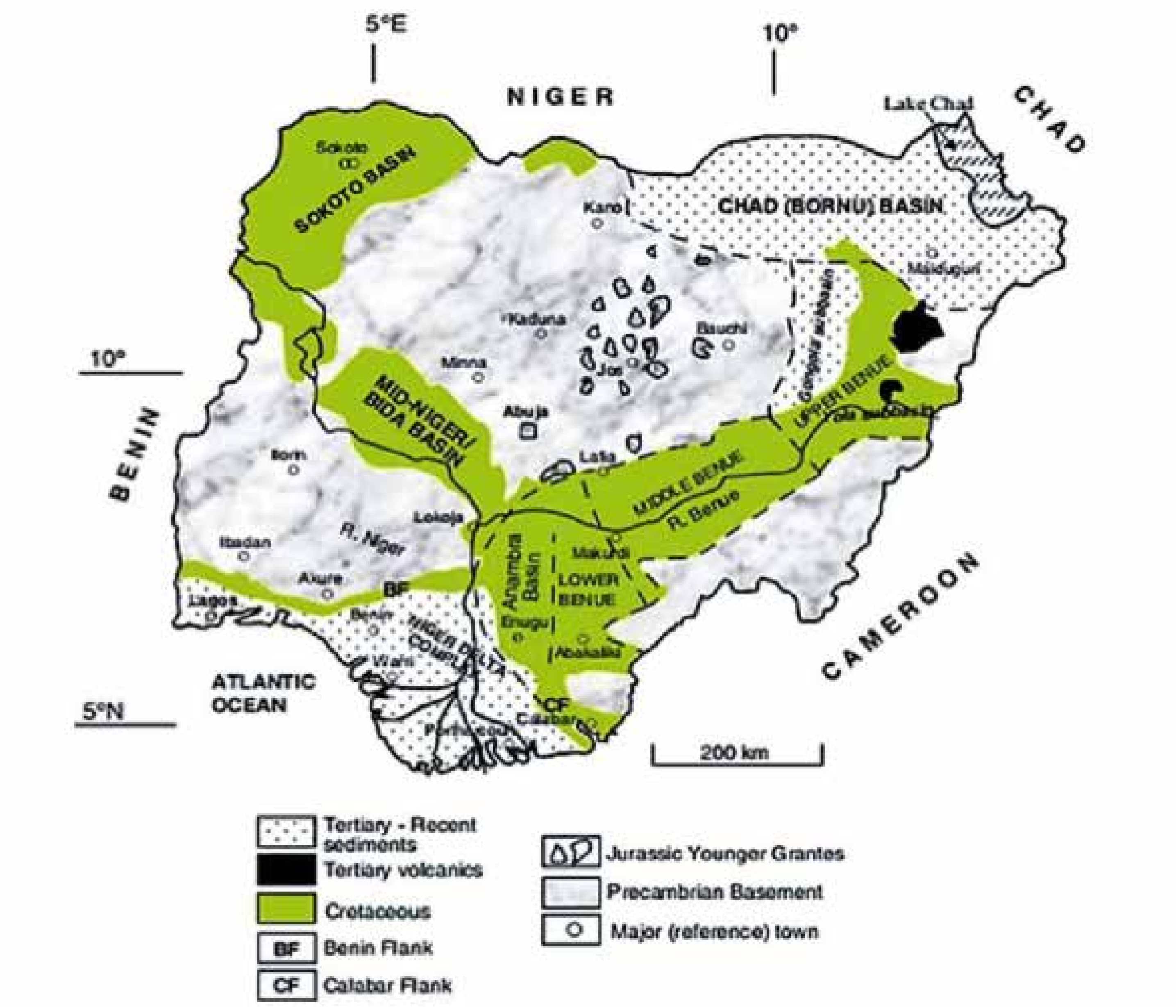

Fig 3.2 Map Showing Different Basin in Nigeria *(IFC / World Bank / IEA collaboration)*

II. Chad Basin

Screening and ranking work (Bachu-style criteria) has placed the Nigerian sector of the Chad Basin as a basin of interest. Studies have applied multi-criteria screening (depth, seal presence, basin maturity) and flagged parts of the basin for follow-up prospect characterization. These are still early-stage, requiring more well/seismic data

III. Lullemmeden, Bida, Dahomey and Other Basins

Some formations (e.g., in Iullemmeden) have potential stacked sand-aquifer targets, but data sparsity (few wells, limited modern seismic) means these basins remain low-to-moderate confidence until new data are acquired.

3.2 Techno-Economic Assessment of CCUS in the Nigerian Industrial Landscape

CCUS deployment is strongly influenced by techno-economic feasibility. High capital expenditure (CAPEX), operating expenditure (OPEX), and energy intensity currently limit widespread adoption in Nigeria. The techno-economic assessment shows that CCUS can play a vital role in Nigeria's industrial decarbonization strategy. While current CAPEX and OPEX are significant barriers, targeted deployment in low-cost capture sectors (gas processing, refineries) and integration with Enhanced Oil Recovery (EOR). provides near-term economic viability. Hydrogen production with CCUS offers a strategic pathway for diversification and global competitiveness. Compared to advanced economies, Nigeria faces higher financing and infrastructure risks, but the abundance of geological storage potential and synergies with oil and gas operations present unique opportunities.

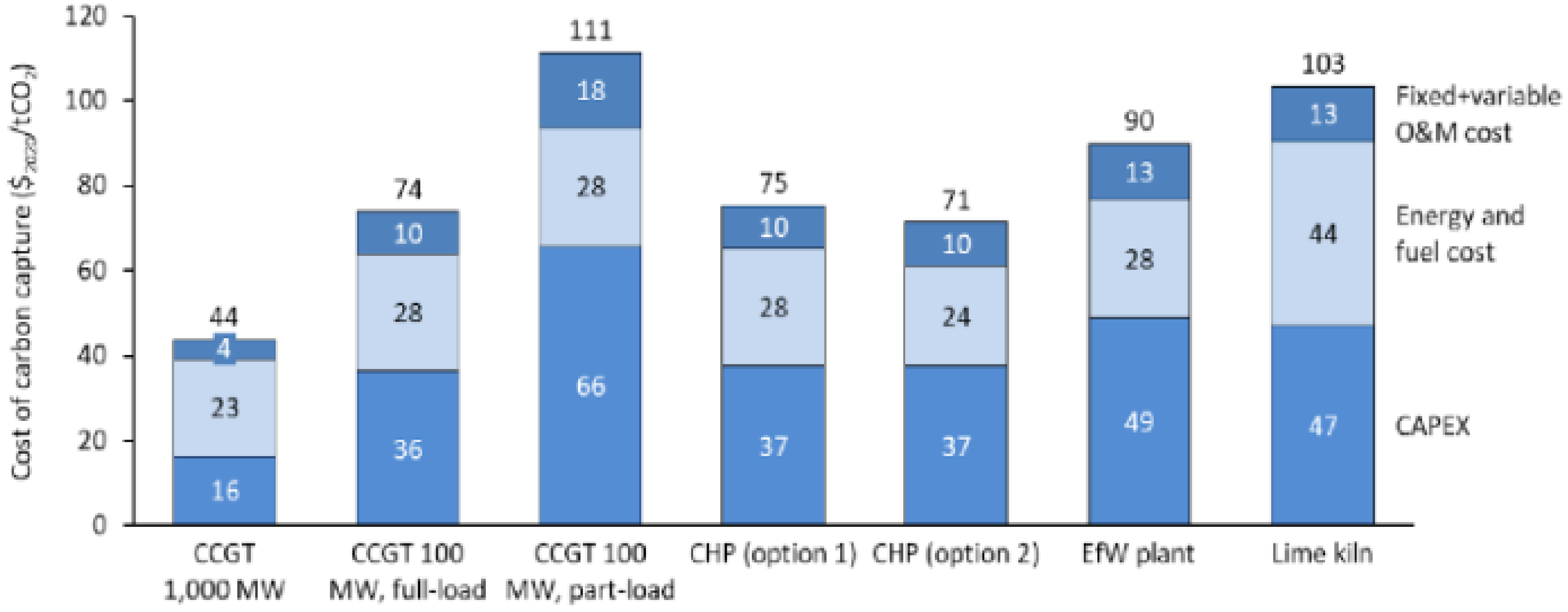

Fig 3.3 Cost Analysis of CCUS

3.2.1 Geological & EOR Opportunity (Why Nigeria matters)

Nigeria has very large prospective geological CO_2 storage resources and existing oilfield infrastructure that make CCUS + EOR an attractive near-term pathway. Public mapping and national atlases identify large storage volumes in the offshore and onshore Niger Delta and adjacent basins order-of-magnitude resource estimates exceed what Nigeria's current emissions demand, making long-term storage feasible. This favorable geology, combined with many mature oilfields that could receive CO_2 for EOR, creates both a storage sink and a revenue stream (incremental oil) that can materially improve CCUS project economics.

3.2.2 Enhanced Oil Recovery (EOR): Techno-Economic Prospects

I. Technical fit: The Niger Delta contains numerous depleted and declining fields. CO_2 injection can increase recovery factors; typical EOR uplift globally ranges from about 5% to >15% of original oil in place depending on reservoir characteristics and flood design *(IFC / World Bank / IEA collaboration).* Nigeria's onshore/offshore geology and existing well networks lower incremental CAPEX for well tie-ins compared with undeveloped basins.

II. Revenue model: Incremental oil sales provide direct cashflow that can offset capture CAPEX/OPEX; the EOR revenue stream combined with carbon credits or future carbon pricing can make investments attractive to national oil companies (NOCs) and IOCs.

III. Constraints: EOR requires sustained CO_2 supply, well integrity upgrades, and careful reservoir surveillance. Transport logistics (pipelines from capture points to injection hubs) and permitting are critical. Field-by-field feasibility studies and pilot injections are recommended before scale-up.

3.2.3 Hydrogen production opportunities (Blue hydrogen) in Nigeria

I. Feedstock and pathway: Nigeria's abundant natural gas reserves make steam methane reforming (SMR) + CCUS (blue hydrogen) the most immediate hydrogen pathway. The government and industry have articulated ambitions to develop a hydrogen sector to support domestic industry and exports. Blue hydrogen can be lower cost than green hydrogen in the near term given

Nigeria's low gas feedstock costs but competitiveness hinges on capture cost and energy inputs.

II. Representative economics: Blue hydrogen costs in Nigeria's context roughly in the global blue range ($2.8–$3.5/kg) under favorable assumptions; green hydrogen costs remain higher until renewable capacity and electrolyser supply chains scale. Key drivers for blue hydrogen LCOH are natural gas price, capture rate and capture cost (CAPEX/OPEX), and the price obtainable for hydrogen exports or domestic use *(Sustainable Energy Research, 2024)* .

III. Integration synergies: Co-locating SMR units with existing refineries or petrochemical clusters reduces transport costs for feedstock and product. Captured CO_2 can be routed to nearby EOR hubs, creating a circular value chain (H_2 revenues + EOR offsets). Long-term, hybrid models blending blue and green hydrogen (powered by renewables as they scale) can reduce lifecycle emissions.

3.2.4 CCUS technology options: costs and energy attributes

Below is a concise comparison of primary capture technologies with their cost/energy characteristics and relevance to Nigeria.

1. Post-combustion solvent (amine) capture

Applications: Retrofitting thermal plants, cement kilns, refineries.

Energy requirement: Typical thermal reboiler duty of about 2.8–3.4 GJ/ton CO_2 (recent advances report down to approximately 2.7 GJ/t for optimized systems). Electricity for compression and auxiliaries adds further demand *(RSC Publishing)*

Costs: CAPEX and OPEX moderate for concentrated point sources; capture cost ranges (global): approximately $40–120/t for dilute industrial streams *(NETL)*; lower for concentrated streams.

Nigeria relevance: Good fit for refineries, combined-cycle gas plants (where heat/electricity supply is stable), and cement plants. Energy-intensive regeneration makes co-location with reliable heat sources or waste-heat integration important.

2. Pre-combustion (gas-shift + physical absorption)

Applications: Integrated gasification or SMR with capture (used for blue hydrogen).

Energy requirement: Capturing CO_2 before combustion reduces regeneration energy relative to post-combustion per unit captured but requires process integration (shift reactors, pressure-swing units).

Costs: Higher CAPEX but can reach lower OPEX per tCO_2 for high-concentration CO_2 streams. Suitable for new hydrogen plants.

Nigeria relevance: Good for new blue hydrogen plants using SMR with high capture rates; integrating with existing gas processing hubs reduces transport needs.

3. Oxy-fuel combustion

Applications: New power plants and some industrial furnaces.

Energy requirement: Requires air separation (ASU) which is energy-intensive; eliminated N_2 simplifies compression and storage.

Costs: High CAPEX for ASU; limited to new builds due to integration challenges. Nigeria relevance: Less attractive for retrofit in Nigeria's existing fleet; potential in new, dedicated hydrogen or industrial plants.

4. Solid sorbent and modular capture (incl. certain DAC approaches)

Applications: Small modular point sources, potential for low-temperature regeneration.

Energy requirement: Sorbent regeneration energy can be lower (depending on sorbent) useful where low-grade heat or waste heat is available. DAC solid sorbents often report lower electrical demand than solvent DAC but still significant

Costs: Emerging; modularity can reduce CAPEX for smaller projects.

Nigeria relevance: Potential niche role if sorbents can be regenerated using waste heat (refineries, petrochemicals) or low-cost thermal energy.

5. Direct Air Capture (DAC)

Applications: Negative-emissions or offsetting legacy emissions.

Energy requirement & cost: Very energy-intensive, liquid solvent DAC 6–10 GJ/tCO_2 ; current costs global \$200–600/tCO_2. Cost reductions likely but still long-term *(IEAGHG 2021; ORNL 2024)*.

Nigeria relevance: Not near-term priority because high energy intensity collides with grid reliability constraints; can be considered medium/long term if cheap renewable power becomes available and storage/transport logistics are solved.

3.2.5 CAPEX & OPEX attributes: What drives cost in Nigeria

CAPEX drivers: capture plant hardware, civil works, CO_2 compression and dehydration, pipeline or shipping infrastructure, monitoring/well retrofits for injection, and permitting. Offshore storage (subsea injection) CAPEX is higher but may be appropriate in the Niger Delta offshore.

OPEX drivers: energy for regeneration and compression, solvent/sorbent replacement, maintenance, monitoring and verification (M&V), and CO_2 transport tariffs. In Nigeria, additional OPEX factors include increased logistics costs caused by security/vandalism risk mitigation, fuel supply volatility, and higher insurance/contingency charges.

Financing & policy: Higher cost of capital in Nigeria relative to OECD markets increases levelized cost; lack of robust carbon pricing reduces revenue certainty and lengthens payback period. Public-private finance, concessional loans, and policy levers (tax credits, production incentives for blue hydrogen) are therefore essential for bankability.

3.2.6 CO_2 transport: options and Nigeria's constraints

A. Transport modes & costs (global benchmarks):

1. ***Pipelines:*** Most economical for large, continuous volumes; levelized transport cost often ranges from a few cents to a few tens of cents per tCO_2-km depending on scale and terrain. Published ranges of per-tonne-km costs commonly used in modelling are roughly \$0.01–\$0.10/tCO_2-km; network effects (shared trunk lines and hubs) lower unit costs at scale. Tools such as NETL's CO_2 transport model provide detailed cost curves.
2. ***Road/rail tankers:*** Only economic for small volumes or where pipeline

construction is infeasible; unit costs are much higher per t-km.

3. Shipping (liquid CO_2 carriers): Viable for export or when pipeline is not feasible across water; economies of scale depend on port handling and liquefaction CAPEX.

4. Solid State Transport: CO_2 is captured and converted into a solid form – e.g. dry ice (solid CO_2), CO_2 clathrate (hydrate), or chemically bound to a solid carrier or mineral – then moved by truck, barge or ship to storage wells. The main solid carriers include:

i. Cryogenic solid (dry ice): Cryogenic solid CO_2 (dry ice) transport involves compressing and cooling CO_2 into pellets or blocks shipped in insulated containers (~20 t capacity). It eliminates high-pressure systems, with minimal leakage (~0.3%/day) and energy use of ~150–200 kWh/t. Compared to costly liquid CO_2 trailers (€660k), insulated dry-ice containers offer a safer, lower-capital alternative for CO_2 transport *(Danish Energy Agency, 2022).*

ii. CO_2 Hydrates (Clathrates): CO_2 hydrates form under moderate pressure (5–30 bar) and low temperatures, trapping 150–180 SCM CO_2 per m^3 but storing far less CO_2 than liquid form, making them bulky and inefficient. While cheaper in refrigeration and equipment, hydrate transport requires cooled, pressurized vessels. In Nigeria, limited cold-chain infrastructure and long distances make large-scale hydrate transport impractical, suitable only for small or short-haul applications *((Kaur et al, 2021)*

iii. Adsorption on Solids (Sorbents or Carriers): Solid sorbent CO_2 transport involves capturing CO_2 on materials like activated carbon, zeolites, or MOFs and regenerating them at the injection site. Though effective in CO_2 adsorption, low bulk density and high regeneration energy reduce efficiency. Studies show trucks with solid sorbents carry less CO_2 than liquid carriers, making the method uneconomical for large-scale transport. In Nigeria, limited local production, high fuel use, and logistics challenges restrict feasibility to small or pilot-scale applications *(IEA, 2023; Truck-energy model, 2024).*

iv. Mineral Carbonation: Mineral carbonation captures CO_2 by reacting it with CaO- or MgO-rich materials (e.g., basalt, serpentine, or industrial wastes) to form stable carbonates like $CaCO_3$ and $MgCO_3$, creating permanent, leak-free CO_2 storage *(Nwali et al., 2024).*

While feasible using cement and steel industry wastes in Nigeria, achieving high conversion (~80%) requires high temperature and pressure, making it energy- and cost-intensive. Given Nigeria's limited basalt formations, mineral carbonation is best suited for small-scale, site-specific CO_2 capture rather than large-scale transport or storage.

B. Nigeria-specific transport constraints:

i. Geography & hubs: Many large CO_2 sources (refineries, gas plants) are concentrated near the Niger Delta and southern coastal basins, close to likely offshore or onshore storage sites; clustering capture points could make pipelines an efficient option. Public CO_2 storage atlases already identify potential hubs

ii. Infrastructure & security: Pipeline construction in Nigeria faces challenges: right-of-way acquisition, community engagement, vandalism and sabotage risks, and higher security and maintenance costs. These factors increase CAPEX and raise insurer/financing requirements. Recent persistent issues in the broader oil and gas pipeline sector (vandalism, theft) imply CCUS pipelines will require additional safeguards, raising lifecycle costs and OPEX.

3.2.7 Energy requirement & Nigeria's power landscape

I. Capture energy needs: Typical solvent post-combustion capture need is approx. 2.7–3.4 GJ thermal per tCO_2 plus electricity for compression; DAC and some solvent processes demand substantially more (DAC up to 6–10 GJ/tCO_2 for some liquid solvent designs). Electricity may be needed for blowers, fans, compressors, pumps, and control systems.

II. Nigeria's grid realities: Nigeria's grid is dominated by natural gas generation with chronic under-generation relative to installed capacity and frequent outages. Transmission losses, vandalism, and gas supply interruptions are ongoing challenges. Despite abundant gas reserves, domestic gas infrastructure and reliable power dispatch remain bottlenecks. Recent policy moves and concessional financing are improving the sector but reliability remains lower than OECD norms.

III. Implication for CCUS projects:

i. High on-site energy reliability required: Capture plants need reliable thermal and electrical energy. Unreliable grid increases OPEX (diesel or on-site generation) unless the capture plant is integrated with its own gas-fired cogeneration or waste-heat supply.

ii. Opportunity for cogeneration / process integration: Co-locating capture on gas processing sites or refineries permits use of process heat and reduces incremental energy and cost (improves CAPEX/OPEX). For blue hydrogen, integration with SMR and shared utilities makes sense.

iii. Renewable integration potential: Nigeria’s strong solar resource and growing interest in renewables could supply electricity for electrified capture/regeneration or DAC in medium term, but large-scale renewables and storage must be deployed to reach cost parity and reliability. Pilot CCUS projects should evaluate hybrid energy systems (gas + renewables + storage) to reduce emissions and grid dependence.

3.3 Potential Contribution of CCUS to Accelerating Nigeria’s 2060 Net-Zero Goal

Carbon Capture, Utilization, and Storage (CCUS) can significantly accelerate Nigeria's 2060 net-zero goal by addressing emissions from hard-to-abate sectors and supporting its Energy Transition Plan (ETP) and other climate commitments. CCUS is a crucial technology for decarbonizing the oil and gas, power, and industrial sectors, which are major sources of Nigeria's greenhouse gas (GHG) emissions.

Nigeria's commitment to achieving net-zero emissions by 2060 is enshrined in its Climate Change Act of 2021 and is a central pillar of its Energy Transition Plan (ETP) and Long-Term Low-Emission Development Strategy (LT-LEDS). While these policies prioritize renewable energy and energy efficiency, they explicitly recognize the role of CCUS, particularly for sectors where emissions are difficult to eliminate.

i. Nigeria's ETP: The ETP, a data-backed roadmap, outlines strategies for decarbonizing key sectors like Power, Oil and Gas, Transport, and Industry. It identifies CCUS as a critical measure for the industrial sector, proposing its application in cement production, for instance, through Bioenergy with Carbon Capture and Storage (BECCS). It also highlights the use of CCUS to reduce emissions from natural gas, which is considered a "transition fuel" in Nigeria's energy mix.

ii. Decarbonization of Key Industries: Industries like cement, steel, and chemicals are particularly emissions-intensive. CCUS offers a viable pathway to capture and store CO2 from these stationary sources, enabling them to continue operating while drastically reducing their carbon footprint. Without CCUS, achieving net-zero in these sectors would be incredibly challenging.

iii. Gas Flaring Reduction: Nigeria has a long-standing issue with gas flaring in its oil and gas operations. While the ETP aims to end routine flaring, CCUS provides a method to capture and utilize the associated CO2. For instance, the captured CO2 can be used for Enhanced Oil Recovery (EOR), which both increases oil production and permanently stores the CO2 underground.

3.4 Development of a Policy and Regulatory Framework for CCUS in Nigeria

3.4.1 Existing Legislative and Regulatory Enablers

Nigeria has a well-established history of strategic policy development for climate and environmental issues, laying a foundational groundwork for a future CCUS framework. Key legislative milestones include the establishment of the National Environmental Standards and Regulations Enforcement Agency (NESREA) in 2007, the National Policy on Climate Change in 2012, and, most recently, the Climate Change Act of 2021. These acts demonstrate the government's commitment to addressing greenhouse gas emissions and integrating climate action into national planning.

From a technical and operational perspective, the Petroleum Industry Act (PIA) of 2021 provides a crucial starting point. It requires petroleum license holders to incorporate environmental plans to mitigate adverse impacts, and the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) has explicitly noted that a lessee may, with the Commission's consent, provide carbon capture and storage services within a lease area. Similarly, the Nigerian Midstream and Downstream Petroleum Regulatory Authority (NMDPRA) has midstream and downstream environmental regulations that require licensees to monitor, estimate, and report GHG volumes, and to submit a decarbonization strategy. This existing legal and institutional framework, built upon the nation's mature oil and gas sector, is an important enabler, providing an initial legal basis and a trusted regulatory body to oversee a nascent CCUS industry. This prior experience with subsurface resource management is a key strength that should be leveraged

3.4.2 Regulatory Gaps for a Full-Scale Value Chain

Despite these existing enablers, the Nigerian regulatory landscape contains critical gaps that must be addressed to unlock full-scale, private sector-led CCUS investment. The current frameworks, being extensions of the oil and gas regime, are not designed to manage the unique challenges of permanent CO_2 storage, particularly in underexplored saline aquifers that hold the majority of the nation's storage potential.

Table 3.1: A Gap Analysis: Existing Nigerian Policies vs. Comprehensive CCUS Framework Requirements

Regulatory Area	Existing Nigerian Policy/Regulator	Identified Gap	International Best Practice
Pore Space Ownership	NUPRC allows CCUS services in lease areas via PIA	Unclear legal basis for ownership of pore space outside of hydrocarbon leases	US: Pore space ownership varies by state, but is legally defined. UK/EU: Government typically assumes ownership of pore space.

Permitting	NUPRC and NMDPRA regulations provide a starting point	No dedicated "one-stop-shop" or streamlined permitting process for CCUS projects	US: EPA's Class VI permitting is a long, stringent process but is well-defined. UK/EU: Centralized permitting and cluster-sequencing simplify approval
Long-Term Liability	No specific provisions for long-term liability transfer or management	Legal liability for stored CO_2 and site stewardship after closure are undefined	US: Legal pathway for transfer of long-term liability to a state or federal entity. Australia: Long-term liability transfer to the government after a monitoring period.
Financial Incentives	No specific financial incentives for CCUS	Lack of market-based or fiscal incentives to de-risk investment and accelerate deployment	US: Section 45Q tax credits and "direct pay" mechanisms. EU: Emissions Trading System (ETS) and Innovation Fund.
Technical Standards	No specific standards for MMV or site assessment	No standardized procedures for geological site assessment, monitoring, reporting, and verification (MMV)	International Standards Organization (ISO) standards (ISO/TC 265) are widely adopted as a baseline. US EPA requires detailed MMV plans for Class VI wells.

3.4.3 International Lessons: A Case Study Comparative Analysis

1. North American (USA) Model: Incentivizing Investment and Regulatory Clarity

The United States has emerged as a leader in CCUS deployment, primarily driven by a robust and predictable system of financial incentives. The cornerstone of this system is the *Section 45Q tax credit*, a performance-based mechanism that provides a credit per tonne of CO_2 captured and securely stored. The Inflation Reduction Act (IRA) of 2022 significantly enhanced this incentive, increasing the credit value to $85 per tonne for industrial and power facilities and introducing "direct pay" provisions *(U.S. Department of Energy, 2023)*.. This direct pay mechanism allows entities to receive the full credit value in cash, eliminating the need for complex tax equity structures and significantly de-risking projects for investors. The central lesson for Nigeria is that a predictable, long-term financial incentive is a powerful catalyst for private investment, even in the absence of a fully mature carbon market.

The US regulatory framework for geological storage is governed by the Environmental Protection Agency (EPA) through its Class VI well permits. This process is comprehensive and stringent, requiring detailed site characterization, a robust monitoring, reporting, and verification (MMV) plan, and a demonstration of financial assurance to cover long-term liability. While this process can be lengthy, often taking up to 24 months for a complete application, its clarity provides a high degree of certainty for developers and investors. This framework's focus on clear, technically-sound requirements is a crucial model for Nigeria, though the long timelines highlight the need for a streamlined approach to permitting, perhaps by designating a single regulatory agency to serve as a "one-stop-shop" to coordinate all approvals.

2. European (EU & UK) Model: Strategic Hubs and Carbon Pricing

The European approach to CCUS is defined by a combination of market-based mechanisms and strategic, top-down government intervention. The EU's Emissions Trading System (ETS) is a primary policy tool, which creates a price for carbon that incentivizes emissions reductions across key sectors. The Net-Zero Industry Act further solidifies this approach by designating CCUS as a "strategic net-zero technology" and establishing a framework to simplify regulatory procedures and attract investment. *(European Commission, 2024)*

The United Kingdom provides a particularly relevant blueprint for Nigeria through its Cluster Sequencing program. The UK government proactively identified and is funding the development of CCUS hubs in major industrial clusters to minimize risk and achieve economies of scale. This includes significant government funding for shared transport and storage infrastructure, such as the £21.7 billion committed to the HyNet and East Coast clusters*(UK DESNZ, 2024).* This model is highly applicable to Nigeria's Niger Delta, where multiple emitters and high-potential storage sites are co-located. The lesson for Nigeria is that waiting for a carbon market to develop is not a prerequisite for action. A government-led, hub-based strategy can provide the initial momentum and financial certainty needed to de-risk projects and accelerate deployment.

3. Emerging Market Models (Australia & Brazil): Agile and Responsive Frameworks

The experiences of Australia and Brazil offer pragmatic lessons for developing economies. *Australia's Otway International Test Centre* serves as a prime example of how pilot projects can precede and inform the evolution of a comprehensive regulatory framework. The project was initiated and operated under existing environmental regulations while providing a real-world testing ground for geological storage and monitoring technologies. The lessons learned from this project directly contributed to the development of new, tailored legislation for the industry. This "learning-by-doing" approach demonstrates that a perfect regulatory framework is not required to begin; instead, a pragmatic approach can accelerate progress by building regulatory capacity and confidence on the ground.

Brazil's recent legal developments provide a more recent parallel. The enactment of Federal Law No. 14,993/2024 designates the National Agency of Petroleum, Gas and Biofuels (ANP) as the primary regulator for CCUS, leveraging an existing, trusted institution with a deep understanding of subsurface operations. This approach to utilizing a petroleum-focused regulator is a direct parallel to Nigeria's NUPRC and demonstrates a practical method for accelerating the development of a legal framework by building upon existing expertise and infrastructure. These emerging market models confirm that a proactive, phased approach that leverages existing institutional strengths is a highly effective strategy.

3.4.4 Recommendations: A Tailored CCUS Framework for Nigeria

Based on the analysis of Nigeria's unique context and the lessons from international case studies, a pragmatic and phased approach to developing a comprehensive CCUS framework is recommended. This strategy is designed to mitigate risk, accelerate deployment, and build investor confidence.

I. A Phased Approach to Policy Development and Implementation

A successful framework for Nigeria should be implemented in three distinct phases:

i. **Phase 1 (Immediate - 1-3 years):** Foundational Actions and Pilot Projects. The priority must be to establish the core legal pillars that address investor uncertainty. This involves enacting a "Nigerian CCUS Enabling Act" to clarify the legal basis for CO_2 storage, define long-term liability, and establish national ownership of subsurface pore space. Simultaneously, a single, designated regulatory body such as NUPRC should be mandated to create a "CCUS One-Stop-Shop" to streamline the permitting process for initial pilot projects, drawing inspiration from Brazil's model. This phase should culminate in the launch of a government-led consortium to develop the first CCUS hub in the high-potential Niger Delta region, capitalizing on the co-location of emitters and storage sites identified in the Atlas.

ii. **Phase 2 (Near-Term - 3-7 years):** Scaling Up and Hub Development. Building on the lessons from Phase 1, the government should expand the

"Enabling Act" into a more comprehensive, full-value-chain "Nigerian CCUS Act." This Act would codify technical standards, MMV requirements, and financial provisions. . Concurrently, planning and characterization should begin for a second hub, likely in the Lagos area, to broaden the geographic scope of the industry. The Nigerian Geological Survey Agency (NGSA) should be formally empowered and funded to conduct pre-competitive data acquisition and characterization of other basins, such as the Benue and Bida Basins, de-risking these areas for future private sector investment.

iii. **Phase 3 (Long-Term - 7+ years):** Market Maturation and Commercialization. Once a robust regulatory and infrastructural foundation is in place, the government can evaluate and potentially implement a market-based incentive, such as a national carbon pricing mechanism or a CCUS tax credit, to stimulate wider market participation and commercialization, similar to the US model.

II. ***Legal and Regulatory Pillars of the Framework***

The proposed framework must be built on clear legal and regulatory pillars to succeed. A comprehensive CCUS Act should:

i. **Define Clear Roles for Regulatory Bodies:** The Act must formalize the roles of NUPRC (subsurface storage), NMDPRA (capture and transport), and NGSA (geological data) to prevent jurisdictional overlap and accelerate project approval. A binding Memorandum of Understanding (MOU) between these agencies would be a critical first step.

ii. **Establish a Clear Legal Basis for Pore Space Ownership:** The Act must unequivocally declare that subsurface pore space is a national resource to be managed by a designated entity. This addresses a major ambiguity and provides legal certainty for project developers.

iii. **Implement a Tiered Liability Model:** The framework must define a clear pathway for the transfer of long-term liability from the operator to a government-designated entity after a period of successful injection and monitoring. This is a crucial element for attracting private finance, as no company will assume perpetual risk for an asset.

III. Designing a Commercial and Financial Model

The commercial model for CCUS in Nigeria should align with a hub-based approach to reduce initial capital expenditure.

i. **Public-Private Partnerships:** The government should provide targeted, upfront funding for the development of shared transport and storage infrastructure, mirroring the UK's approach. This reduces the financial burden on individual emitters and encourages them to participate.

ii. **CCUS Hubs:** The framework must prioritize the development of open-access hubs in the Niger Delta and other key regions. This model allows multiple emitters, including smaller ones, to share the high capital costs of infrastructure, achieving economies of scale that would otherwise be unattainable.

IV. Ensuring Public Confidence and Social License to Operate

For any CCUS project to succeed, it must have a social license to operate. The framework must mandate and provide a clear structure for stakeholder engagement.

i. **Frameworks for Stakeholder Engagement:** The policy must require transparent public consultation and engagement throughout the project lifecycle, similar to the public comment periods for Class VI permits in the US. This builds public trust and addresses concerns early on.

ii. **Integrating Public Safety and Environmental Monitoring:** The framework should mandate the adoption of globally recognized standards, such as those from the International Standards Organization (ISO/TC 265), for the monitoring, measuring, and verification (MMV) of stored CO_2. A robust MMV plan provides a crucial layer of security and transparency, demonstrating the long-term safety of geological storage to the public.

3.5 Key Challenges and Barriers to CCUS Deployment in Nigeria

3.5.1 Regulatory, legal & institutional barriers

1. ***No CCS-specific regulatory framework yet for full commercial projects.***
The Atlas notes existing laws (Petroleum Industry Act, NMDPRA regulations, NESREA) can support pilots, but Nigeria lacks a coherent CCS permitting, MMV (monitoring–measurement–verification), liability transfer and post-closure regime for large-scale storage. That gap raises investor and community uncertainty.
2. ***Fragmented institutional responsibilities.***
Multiple agencies have relevant mandates (NUPRC for subsurface/pore space in hydrocarbon fields; NMDPRA, NESREA, NGSA, NIMASA and Ministry of Transport for transport/ports/permits). Clear allocation of roles and a "single window" permitting route are required to avoid costly delays.
3. ***Long-term liability & asset transfer unresolved.***
International practice assumes operator liability then handover to state or a stewardship body after demonstration of safe containment. Nigeria needs explicit, bankable rules on when and how liability transfers occur and what financial security (bonds, insurance) is required. The Atlas highlights this as a core regulatory need.

3.5.2 Transport & logistics barriers (pipelines, rail, ship, inland waterways)

1. ***Pipeline network condition & repurposing limits.***
Nigeria has legacy gas/oil pipelines concentrated in the Niger Delta, but many assets require rehabilitation (pigging, cleaning, corrosion assessment) before CO_2 service. Repurposing oil/gas pipelines is not always possible due to pressure/ materials and may require booster stations or new materials to handle supercritical CO_2 adding cost. The Atlas flags the need for detailed pipeline asset condition surveys.

2. Security & vandalism risk in Niger Delta

Recurrent pipeline vandalism, illegal refining and community attacks are material risks (recent emergency declarations and incidents attest to this). Security issues increase OPEX (guarding, repairs), insurance costs and project timelines and may make onshore pipelines politically sensitive.

3. Geography of emitters vs storage: long inland transport for some industries. Cement plants and other industrial emitters in central Nigeria are hundreds of kilometers from the Niger Delta storage fairways. For these emitters, pipeline transport may be uneconomic; rail, ship or river transport are options but have smaller economies of scale and higher per-tonne costs. The Atlas analyses hub-and-spoke approaches and alternative transport (rail/river/ship) for such cases.

4. Lack of shared trunk infrastructure & hub business models.

Large-scale CCS relies on shared trunk pipelines/hubs to lower unit costs. Nigeria needs coordinated planning and financing to build trunk lines; otherwise first movers will bear very large CAPEX and stranded-asset risk. The Atlas recommends hub planning and phased trunk development.

3.5.3 Economic & financing barriers (CAPEX, OPEX, incentives)

1. High upfront CAPEX and uncertain revenue streams.

Capture plus compression, transport and storage require large capital outlays. Nigeria's higher cost of capital (relative to OECD) and limited domestic green finance increase levelized costs. The Atlas and recent climate-finance analyses note that concessional finance, guarantees, and tax instruments are needed to attract private capital.

2. Weak or nascent carbon pricing / credit markets.

Absent robust domestic carbon pricing or long-term carbon offtake guarantees, CCUS projects must depend on EOR revenues, bilateral grants, or voluntary credit markets none of which reliably monetize CO_2 removal at scale today. The Atlas highlights need for market mechanisms and references Nigeria's plans for carbon market activation.

3. EOR economics are location- and oil-price dependent.

EOR can monetize captured CO_2 via incremental oil recovery, improving payback for capture projects. But EOR value depends on reservoir characteristics, oil price, and logistics; EOR revenue may not be sufficient alone to make capture bankable across all sites—especially when long-distance transport is required.

4. Hydrogen / Blue-Hydrogen Market Uncertainty.

Blue hydrogen can provide a revenue stream but requires high capture rates and cheap, reliable gas feedstock and energy; export markets (or domestic offtakers) must pay sufficiently to cover capture costs. Reports stress uncertainty around blue H_2 costs and market development timelines.

3.5.4 Energy and Operational Barriers

1. High energy intensity of capture + unreliable power supply.

Post-combustion capture and compression require substantial thermal and electrical energy. Nigeria's grid has chronic under-generation, reliability issues and high backup fuel costs; on-site dedicated power (gas cogeneration) or waste-heat integration is often needed to keep OPEX reasonable. The Atlas and energy sector reports underline the imperative of co-locating capture with reliable heat/electricity sources.

2. Competition for gas & fuel resources.

Blue hydrogen and capture plants require large gas volumes and/or electricity. Nigeria's domestic gas allocation, LNG commitments and gas-to-power needs could create competition, affecting feedstock prices for CCUS projects unless supply is contracted.

3. Water requirements for some storage / DAC / basalt mineralization options.

Unconventional storage (e.g., basalt mineralization) or some DAC processes can have large water footprints; water availability and regulatory oversight are important constraints in some basins. The Atlas notes water-resource regulatory interfaces for certain storage options.

3.5.5 Social, Land & Security Barriers

1. ***Community Consent & local mistrust in Oil Belts.***

Niger Delta communities have long experience of environmental damage and conflicts around oil infrastructure; CCUS projects will need robust community engagement, benefit sharing and grievance mechanisms to avoid opposition. The Atlas and regional studies call out the social licence to operate as critical.

2. ***Land Access & Rights-of-way for Pipelines.***

Securing long, continuous rights-of-way is complex in Nigeria (land tenure, compensation, local politics) and can delay pipeline development. This increases permitting time and cost.

3. ***Safety Perception and Public Acceptance.***

CO_2 transport and injection raise safety questions for the public (e.g., perceived leakage risks). Transparent MMV, emergency planning and communication campaigns are required to build acceptance.

4. Recommendations and Conclusion

Carbon Capture, Utilization, and Storage (CCUS) holds significant promise for accelerating Nigeria's pathway to net-zero emissions by 2060, particularly in hard-to-abate sectors such as cement, steel, refining, and natural gas processing. Nigeria's vast geological potential, with an estimated 10,700 Gt of prospective CO_2 storage capacity primarily in the Niger Delta, provides a strong technical foundation. Coupled with mature oil and gas infrastructure and opportunities for CO_2-Enhanced Oil Recovery (EOR), the country is strategically positioned to leverage CCUS both for emissions reduction and revenue generation. However, widespread deployment faces major hurdles including high CAPEX/OPEX, weak regulatory clarity, limited transport infrastructure, and a lack of market-based incentives. Compared to leading jurisdictions like the US, EU, and UK, Nigeria lags in establishing a coherent CCUS framework, dedicated financial mechanisms, and standardized monitoring and verification protocols. Without urgent interventions, Nigeria risks missing the opportunity to integrate CCUS into its energy transition and industrial decarbonization strategy

Key Recommendations:

1. Policy and Regulation:

i. Enact a dedicated Nigerian CCUS Enabling Act to clarify pore space ownership, long-term liability, and liability transfer mechanisms.

ii. Establish a one-stop permitting body under NUPRC to streamline approvals, reduce bureaucracy, and build investor confidence.

iii. Introduce fiscal incentives such as tax credits, carbon pricing mechanisms, or production incentives for blue hydrogen and CCUS-enabled industries.

2. Infrastructure Development:

i. Prioritize the creation of open-access CCUS hubs in the Niger Delta and Lagos industrial corridors, enabling shared pipelines and storage to lower unit costs.

ii. Invest in the rehabilitation and repurposing of existing oil and gas pipelines where feasible, while developing new trunk lines with enhanced security measures.

3. Technology Adoption and Innovation:

i. Focus near-term efforts on low-cost capture opportunities (gas processing, refineries, cement) integrated with EOR.

ii. Support pilot projects in blue hydrogen and modular capture systems to build technical capacity.

iii. Encourage R&D collaborations to adapt CCUS technologies to Nigeria's unique energy and grid realities, with a long-term view toward DAC as renewables expand.

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About IAP

Integrated Africa Power (IAP) is a multi-unit enterprise specialized in energy and infrastructure development on the African continent. We seek to solve Africa’s energy deficits, through integrated systems solutions, resource pooling and cross-border cooperation. Our approach is based on our philosophies of tailored suitability, cost-effectiveness, sustainability and energy-development linkages.

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