CCUS White Paper

Table of Contents

Our experience. Your growth.

As we experience the unprecedented challenge of climate change, the urgency for a secure, affordable and sustainable energy transition has never been clearer. Global energy-related CO_2 emissions have reached a record 37.7 gigatons in 2023, underscoring the scale of the transformation needed to achieve net-zero emissions by 2050.

To achieve this ambitious target, a profound shift in the way we produce, transport, and consume energy is essential. It will require a broad spectrum of measures, from scaling up renewable energy sources such as solar and wind, to accelerating electrification, enhancing energy efficiency across sectors, and increasing reliance on hydrogen and low-emission fuels.

Equally vital is the development and deployment of Carbon Capture, Utilization, and Storage (CCUS) technologies, which play a critical role in addressing the emissions, especially from hard-to-electrify sectors.

Fossil fuels, expected to peak in the coming years will nonetheless remain a significant part of the energy mix of the next decades, according to international energy agencies.

At RINA, we recognize the magnitude of this challenge, as well as the need for strategic, coordinated action on a global scale. Each government must adopt a tailored approach to achieving net-zero emissions, taking into account unique economic characteristics, social circumstances and energy profiles.

With our operational presence in over 200 offices across 70 countries worldwide, RINA has developed deep insights into the complexities of the energy transition. In this white paper, we outline ten key priorities to accelerate the deployment of CCUS technologies, contributing to a cleaner, more secure, and sustainable energy future.

Andrea Bombardi
Global Market Development Executive Vice President, November 2024

The road to 2050: **reducing CO_2 emissions**

The population growth and global economic expansion, largely driven by emerging economies, raise significant questions regarding global energy demand and supply, carbon dioxide emissions, and climate change. Currently, global energy-related CO2 emissions have reached 37.7 gigatonnes (Gt CO2), and they must be reduced to net zero by 2050 to keep the global average temperature rise below 1.5°C. According to scientists, this target is crucial to ensuring a secure energy transition and avoiding severe consequences for global ecosystems and human well-being.

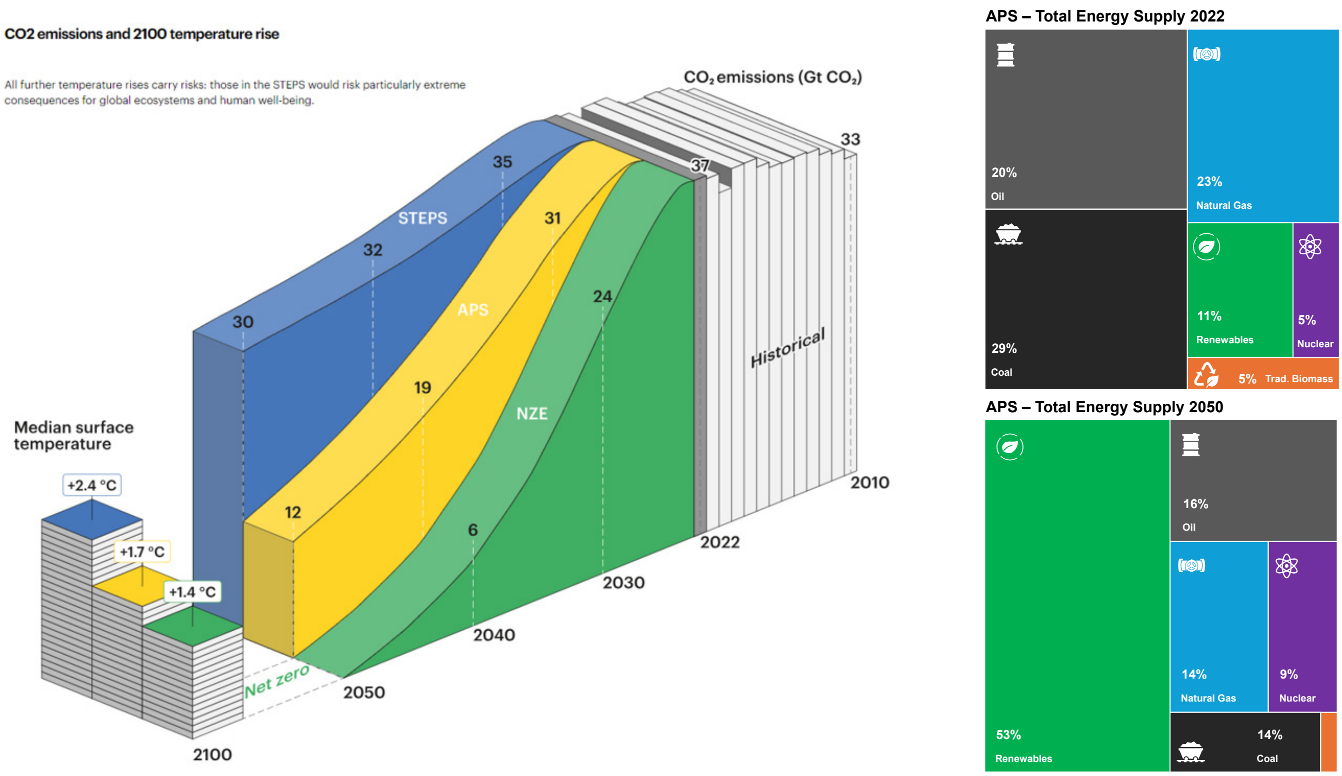

Figure 1. CO2 emissions and 2100 temperature rise based on IEA 2023 (left). Breakdown of total final energy consumption by energy carrier over 2020-2050 under the IEA Announced Pledges scenario, 2024 (right).

The International Energy Agency (IEA) has projected future world energy supply trends up to 2050 under different scenarios and assumptions. These include the Stated Policies Scenario (STEPS), which reflects the current policy and industrial landscape; the Announced Pledges Scenario (APS), which assumes that all global climate commitments are fully met on time; and the Net Zero Emissions by 2050 (NZE50) scenario, which translates the goal of limiting global warming to 1.5°C into a concrete roadmap for the global energy sector. These scenarios represent, respectively, conservative, ambitious yet achievable, and ideal conditions. The IEA also outlines the energy mix across these scenarios. Despite the expected peak of fossil fuel use within this decade, coal, oil, and natural gas remain significant in the energy mix of 2050, accounting for roughly 58%, 34%, and 14% of world energy supply, respectively.

In the APS, which represents an optimistic but attainable scenario, the corresponding emissions are projected to decline to 12 Gt CO2 by 2050, down from the current 37.7 Gt. Managing CO2 emissions will be critical in the coming years and cannot be overlooked.

The CCUS **Value Chain**

The acronym CCUS stands for Carbon Capture, Utilization, and Storage. The carbon capture refers to technologies that capture CO2 at the emission source from combustion product streams before it can reach the atmosphere (e.g., in industrial processes, power plants, refineries) or directly from the air to remove historical emissions from the atmosphere. Once separated, CO2 is conditioned, compressed, and transported either for permanent storage in geological formations (CCS) or for use as a raw material in the production of new products (CCU).

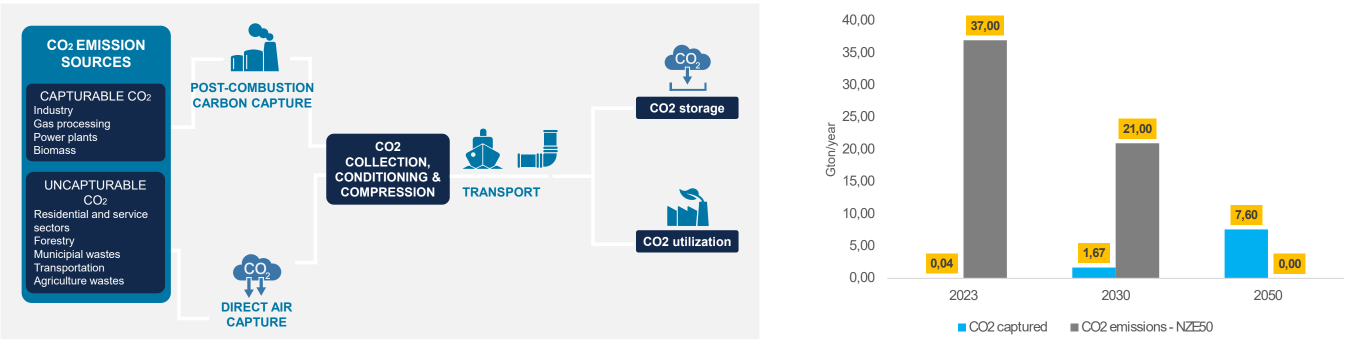

Figure 2. CCUS Value Chain (left). CO2 Emissions and Capacity of Current and Future Large-Scale CO2 Capture Projects according to NZE, 2020-2050 (right)

CO2 capture is not a new technology, with origins dating back nearly a century, particularly in the natural gas industry. Similarly, CO2 transport and storage in geological formations have a well-established history. However, the large-scale deployment of the CCUS value chain in the context of decarbonizing energy and industry poses new challenges. To meet net-zero targets, this upscaling requires substantial investment and careful coordination among all stakeholders.

The scale of this challenge is enormous. Global CO2 emissions currently reached about 38 gigatons (Gt) annually, yet only about 40 million tons (Mt) of CO2 are captured per year. According to the IEA, this capacity must increase drastically to reach about 1 Gt per year by 2030 and about 6 Gt per year by 2050 in the Net Zero Emissions (NZE) scenario. This would require not only the proliferation of CO2 capture facilities but also the development of extensive transport infrastructure, including new pipelines and repurposed ones. Shipping will also play a key role, offering flexibility for transporting CO2 over long distances and moderate volumes.

Geological storage is expected to remain the primary destination for captured CO2 due to its vast capacity, which far exceeds what is necessary to meet net-zero goals. Global storage capacity is estimated between 8,000 and 55,000 Gt, with major reserves in regions like North America, Russia, and Africa. Significant potential is also identified in Australia. While CO2 utilization offers promise, particularly in the creation of synthetic fuels, many of these technologies remain in early development and are not yet commercially scalable. By 2050, around 95% of captured CO2 is expected to be stored in permanent geological sites, with the remaining 5% used for synthetic fuel production, according to IEA.

CCUS in the **O&G industry**

In 2022, Oil & Gas (O&G) operations contribute approximately 15% of global energy-related emissions, amounting to 5.1 billion tons of CO2-equivalent. To tackle climate crisis, it is essential to transition away from the current fossil fuel-based energy system, with the O&G industry needing to make the most significant changes. Unfortunately, the business portfolios of O&G companies are still heavily reliant on fossil fuels, and investments in new explorations continue. In recent years, most of O&G majors announced GHG-reduction plans, albeit with significant differences in terms of strategy, and targets. An encouraging trend is that O&G companies have intensified their investments in clean technologies. These investments span a range of technologies, including wind, solar PV, hydrogen, CCUS, and bioenergy. However, overall spending levels remain quite low, particularly in comparison with other sectors. In 2022, the O&G industry accounted for just about 1.2% of global clean energy investments. Nevertheless, CCUS stands out as a particularly promising option for the O&G industry to pursue its decarbonization strategies.

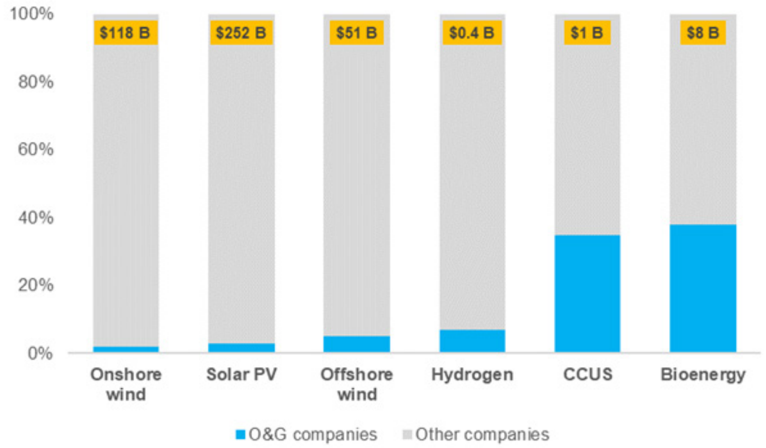

Figure 3. Average annual investment in clean energy technologies made by O&G companies and other companies, 2019-2022, IEA 2024

CCUS technologies can play an important role in helping hard-to-abate sectors to decarbonize but must be used wisely. CO2 capture cannot be adopted by O&G companies to justify further investments in new exploration and extraction projects. Instead, CCUS should be part of a broader strategy to transition to cleaner energy sources and reduce overall emissions of the O&G industry. To assess the relevance of CCUS for the O&G industry, RINA selected a sample composed by 20 among the largest O&G companies worldwide, based on market cap and geographical distribution. All selected companies have already announced the relevance of CCUS, highlighting their ambition and willingness to invest in this technology.

Notably, 70% of the sampled companies have CCUS projects in operation. These projects are already commissioned and running. Currently, there are 20 projects in operation worldwide. 25% of the sample has CCUS projects under construction, having reached final investment decision. To date, 8 projects belong to this category. Finally, 80% of the selected players have planned CCUS projects, which are at concept, feasibility study or FEED stage. As of 2024, there are 141 planned projects worldwide.

In terms of geographical distribution of the identified CCUS project's location, the US leads in the number of CCUS projects, followed by the UK, with notable efforts in the Netherlands and Canada. The concentration of projects is higher in developed countries due to better access to technology and funding. O&G companies are heavily investing in European CCUS projects, which are structured in regional industrial clusters near multiple emitters.

Decalogue of **priorities**

The next decade is crucial for the development and deployment of Carbon Capture, Utilization, and Storage (CCUS) technologies to meet global climate objectives. Governments, industries, research and financial institutions must work together to create a sustainable and viable market for CCUS. A mix of policy, regulatory, financial and technological measures is essential to overcome current barriers and accelerate the uptake of these technologies. RINA, with its decades of experience in energy and industry sectors, has identified ten priorities to support the scale-up of CCUS and drive decarbonization across industries.

1. Driving investment through a Comprehensive Policy Portfolio

Securing the estimated USD 160 billion in investment required for CCUS by 2030 is a major challenge. A key barrier to investment is the absence of a commercial driver for CO2 capture, particularly in regions without a clear price on carbon emissions. Effective policies are essential to attract investment in CCUS, as the initial capital costs and risks often deter private sector involvement. Governments must establish frameworks that integrate CCUS into national energy strategies, providing clear signals to investors. Carbon pricing mechanisms, tax incentives, and operational subsidies can reduce financial risks, while public-private partnerships will help develop shared infrastructure.

The creation of a favorable regulatory environment is also critical to encourage private investment, particularly in sectors with high emissions, such as power generation, steel, and cement. Over time, as the market for CCUS technologies matures, these policies should shift towards market-driven solutions that reduce dependency on direct subsidies, ensuring long-term sustainability.

2. Reducing Costs and Scaling Up CCUS

Cost reduction across the CCUS value chain is necessary to make the technology economically viable. Currently, the capture phase accounts for the largest portion of overall costs, up to 75%, particularly in sectors with lower CO2 concentrations. Governments and industry must invest in research and development to improve the efficiency of existing capture technologies while exploring innovative solutions.

Economies of scale can also be achieved by developing shared CO2 transport and storage networks, distributing infrastructure costs across multiple emitters. Collaboration among stakeholders will be key to achieving these cost reductions and enabling large-scale deployment of CCUS projects.

3. Accelerating Innovation through R&D&I

Innovation in CCUS technology is fundamental to scaling up deployment and reducing costs. Investment in Research, Development, and Innovation (R&D&I) should focus on all stages of the CCUS value chain—capture, transport, utilization, and storage. Significant progress is needed to improve the efficiency of CO2 capture in energy-intensive industries such as steel, cement, and chemicals, where existing technologies are often cost-prohibitive. R&D should optimize mature technologies such as chemical absorption, while exploring innovative methods like advanced separation materials and energy-efficient processes.

Additionally, the further development and scale up of new technologies, such as Direct Air Capture (DAC), and synthetic fuels production could play a key role. Governments must foster collaborations between research institutions, industries, and international bodies to advance these innovations, while ensuring that the necessary funding and resources are in place to transition promising technologies from pilot stages to full-scale deployment.

4. Building Scalable CO2 Transport and Storage Infrastructure

CCUS infrastructure, particularly CO2 transport and storage systems, is a critical enabler for the widespread deployment of the technology, ensuring the integration of all the stages of the value chain.

The construction of transport networks—primarily pipelines—requires significant upfront investment, time and careful planning, given the uncertainties surrounding future demand and project scalability. Early-stage CCUS projects often operate on a smaller scale, which limits the feasibility of constructing extensive transport infrastructure. However, to support future growth, scalable and adaptable networks must be developed. Shared infrastructure models, offer a cost-effective solution to these challenges. On the long-term CO2 storage side, careful management to ensure safety and environmental compliance is needed. Government support, through both direct funding and streamlined regulatory processes, will be essential to reduce the financial risk of these large-scale infrastructure projects and accelerate their development.

5. Developing CO2 Shipping and Terminal Infrastructure

The rise of CCUS projects is creating new opportunities for the maritime sector, as major CO2 emitters are often located far from storage and utilization sites. Maritime transport emerges as the ideal solution for connecting capture facilities with offshore storage reservoirs, particularly over long distances. As demand for carbon dioxide shipping grows, investment in specialized vessels and terminal facilities becomes essential to support the large-scale movement of liquefied CO2 (LCO2). Currently, the global LCO2 fleet is limited, with only a few vessels in operation and a modest number of new builds expected to come online by 2026.

To meet future demand, significant capital must be directed towards expanding this fleet and developing state-of-the-art terminals equipped for the loading, unloading, and temporary storage of LCO2. These terminals must be strategically located and integrated into existing port infrastructures to streamline logistics and reduce costs. Public-private partnerships, along with targeted regulatory frameworks, will be key to fostering investment and ensuring the rapid development of this critical infrastructure.

6. Securing Safe and Permanent CO2 Storage Solutions

The final step in the CCUS value chain—CO2 storage—ensures the long-term removal of CO2 from the atmosphere. Geological storage in deep saline formations or depleted oil and gas fields is the most viable large-scale option. Global CO2 storage resources are considered to be well in excess of likely future requirements. In many regions, however, extensive geological surveys and modeling are required to assess the capacity and integrity of these sites.

Public trust is also critical to the success of CO2 storage, and transparent communication about the safety and reliability of these systems is essential. In the early stages of CCUS deployment, government funding and regulatory frameworks will be vital to mitigate the financial risks of storage projects. Over time, as storage technologies improve and confidence in their long-term reliability grows, private sector investment in storage will become more feasible.

7. Advancing Viable CO2 Reuse Pathways

Creating viable pathways for CO2 reuse is critical to unlocking the full potential of CCUS technologies, particularly in the production of synthetic fuels. These fuels, synthesized from captured CO2 and renewable hydrogen, offer a promising route to decarbonizing hard-to-abate sectors like aviation, shipping, and heavy industry, where electrification is not a feasible solution.

For synthetic fuels to become a commercially viable option, significant advancements are needed in both cost reduction and scalability. Current processes remain energy-intensive and costly, requiring innovation in CO2 conversion technologies and more efficient production methods. Public and private investment in research and development will be essential to address these challenges, as will the creation of market incentives to drive demand for low-carbon synthetic fuels. In parallel, efforts to reduce the cost of renewable hydrogen and to scale up production facilities will play a key role in making CO2-based synthetic fuels a competitive alternative to fossil fuels.

8. Facilitating the Development of CCUS Hubs and a Global CO2 Market

The development of CCUS hubs—industrial clusters that share CO2 transport and storage infrastructure—is a critical strategy for scaling up CCUS deployment. These hubs enable multiple emitters to pool resources, lowering individual costs, spreading risk, and achieving economies of scale. However, their success depends on detailed planning and early collaboration among stakeholders, including governments, industries, and storage site operators.

Equally important is the creation of a global regulatory framework that allows CO2 to be traded and transported across borders as a commodity. Without harmonized international regulations, the rollout of large-scale CCUS projects will face significant obstacles. Governments must play a leading role in identifying industrial clusters, aligning them with suitable storage locations, and creating business models that promote collaboration. At the same time, they must work to establish global regulations that facilitate the free movement of CO2.

9. Creating a Robust and Adaptable Regulatory Framework

A clear and comprehensive regulatory framework is essential to the success of CCUS, providing legal certainty for investors and ensuring that projects meet high safety and environmental standards. Regulations must cover every aspect of the value chain—from CO2 capture and transport to storage and long-term liability. For capture, regulations should set performance standards, monitor emissions, and integrate CCUS into broader climate policy mechanisms like carbon pricing.

CO2 transport, particularly through pipelines, requires strict safety protocols and land-use planning to mitigate risks. Storage sites must be rigorously evaluated and monitored to ensure that CO2 remains securely contained over time. One of the most complex regulatory issues is the long-term liability for stored CO2, which may need to be shared between the private sector and governments to encourage investment while ensuring public safety.

10. Enhancing Public Awareness and Engagement

Public acceptance is a critical factor in the successful deployment of CCUS technologies. Many people remain unfamiliar with the concept of CO2 storage and may have concerns about its safety and long-term environmental impact. Effective communication strategies are needed to educate the public on the role of CCUS in mitigating emissions, particularly in industries like cement and steel, where other decarbonization options are limited.

Transparent regulatory frameworks and ongoing community engagement are essential to build trust and address misconceptions about the risks of CO2 storage. Governments and industry stakeholders must work together to promote awareness of CCUS as a safe and necessary tool for achieving net-zero emissions, emphasizing that it complements, rather than competes with, renewable energy solutions.

References

- IEA_NetZeroby2050-ARoadmapfortheGlobalEnergySector, 2021
- IEA_WorldEnergyOutlook2024
- IEA_WorldEnergyOutlook2023
- IEA_NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach, 2023 Update
- IEA_NetZeroby2050-ARoadmapfortheGlobalEnergySector, 2024
- https://edgar.jrc.ec.europa.eu/report_2022
- https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage
- GHG EMISSIONS OF ALL WORLD COUNTRIES, European Commission JRC SCIENCE FOR POLICY REPORT, 2023
- https://ourworldindata.org/grapher/population-long-run-with-projections?country=CHN~BRA~NGA~IDN~USA~JPN~IND~OWID_WRL
- https://co2re.co/FacilityData
- https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019
- https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf
- https://iea.blob.core.windows.net/assets/2f65984e-73ee-40ba-a4d5-bb2e2c94cecb/EmissionsfromOilandGasOperationinNetZeroTransitions.pdf
- https://www.iea.org/data-and-statistics/data-product/ccus-projects-database
- https://iea.blob.core.windows.net/assets/41800202-d427-44fa-8544-12e3d6e023b4/TheOilandGasIndustryinNetZeroTransitions.pdf
- https://iea.blob.core.windows.net/assets/2f65984e-73ee-40ba-a4d5-bb2e2c94cecb/EmissionsfromOilandGasOperationinNetZeroTransitions.pdf
- https://www.ren21.net/wp-content/uploads/2019/05/GSR2023_GlobalOverview_Full_Report_with_endnotes_web.pdf
- https://www.iea.org/data-and-statistics/data-product/ccus-projects-database