Market Assessment for CCUS in MENA Region

A study for

CCE
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Preface

This report was released by the International Energy Forum in collaboration with Roland Berger and the King Fahd University of Petroleum and Minerals as lead knowledge partners in the framework of the Circular Carbon Economy Regional Collaboration and the Middle East Green Initiative.

1. List of abbreviations

Abbreviation	Description
°C	Degree Celsius
ACTL	Alberta Carbon Trunk Line
APAC	Asia-Pacific
BECCS	Bioenergy with Carbon Capture and Storage
bn	Billion
c.	Circa
CAGR	Compound Annual Growth Rate
Capex	Capital Expenditures
CCE	Circular Carbon Economy
CCERC	Circular Carbon Economy Regional Collaboration
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization and Storage
CIF	Carbon Capture and Storage Infrastructure Fund
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
DACS	Direct Air Capture and Storage
Dev.	Developed
DOGF	Depleted Oil and Gas Fields
e.g.	Exempli Gratia (For example)
EOR	Enhanced Oil Recovery
ETS	Emissions Trading System
EU	European Union
f	Forecasted
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GHG	Greenhouse Gases
Gt	Gigaton(s)
GVA	Gross Value Added
H_2O	Water
HBKA	Hamad Bin Khalifa University
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JV	Joint Venture
KAPSARC	King Abdullah Petroleum Studies and Research Center
KFUPM	King Fahd University of Petroleum and Minerals
Km	Kilometer(s)
LNG	Liquefied Natural Gas
MENA	Middle East and North Africa
Mt	Million Tons
Mtpa	Million Tons per Annum
N_2	Nitrogen
NDC	Nationally Determined Contribution
NGO	Nongovernmental Organization

NL	No Legacies
NPO	Nonprofit Organization
O&G	Oil & Gas
O_2	Oxygen
PPP	Public Private Partnership
PSA	Pressure Swing Adsorption
QCCSRC	Qatar Carbonates and Carbon Storage Research Centre
QEERI	Qatar Environment and Energy Research Institute
SA	Saline Aquifers
STEM	Science Technology Engineering and Mathematics
t	Ton(s)
TAM	Total Addressable Market
Transfo.	Transformation
UK	United Kingdom
UNFCCC	United Nations Framework Convention on Climate Change
USD	U.S. Dollar
Y	Year
WEA	Weighted Average
WL	With Legacies

2. Executive summary

2.1 Key findings

- **Governments around the world are setting ambitious climate targets**, and many are taking concrete steps to achieve them, with Carbon Capture, Utilization and Storage (CCUS) technologies being an important part. CCUS is gaining momentum worldwide and is now considered a key tool for mitigating climate change particularly in regions that are rich in oil and gas such as the Middle East and North Africa (MENA).
- **Several MENA countries have started investing in CCUS technology** due to its effectiveness in removing heavy emissions from hard-to-abate sectors. Ongoing and planned projects in Saudi Arabia, Qatar, the United Arab Emirates, and Kuwait are setting the basis for the development of a CCUS market in the MENA region.
- **The Americas lead the global CCUS market with a market share of 71% in 2022**. The Americas are projected to maintain their lead by 2025 with a market share of 66%. Meanwhile, Europe is expected to experience a significant increase in market share from 10% in 2022 to 18% in 2025. By contrast, the MENA region's market share is projected to decline from 8% in 2022 to 6% in 2025, mainly due to the high number of CCUS projects planned in Europe.
- **However, the MENA region has experienced accelerated growth in CCUS capacity** with an expected CAGR of c.19% between 2015 and 2030, in contrast to the 2% expected growth in emission levels during the same period. Despite this growth, it is estimated that only 1.5% of the potential market will be captured in 2030 with the current operational and planned CCUS capacity, indicating the potential for significant additional investments in CCUS projects in the region.
- **Technology readiness challenges remain across all stages of the CCUS value chain.** Infrastructure readiness is a multi-faceted challenge that requires a comprehensive approach to overcome. The implementation of CCUS requires infrastructure in place for each step of the value chain, including capture, transport, and storage. Another challenge associated with CCUS is the economic feasibility of the technology.
- **CCUS deployment costs are still too high for some industries or regions to deploy.** The total costs across all the steps of the value chain could reach up to USD c.370 per ton of CO_2. These high costs are due to multiple factors, such as technology complexity, high energy requirements, and the cost of building the necessary infrastructure.
- **However, the future expected cost of CCUS technologies is projected to decline** significantly due to technological advancements, economies of scale and standardization. In addition, the success of CCUS deployment depends on regulatory support and policies that incentivize the implementation of the technology.
- **Moreover, deployment of CCUS technologies has several benefits**, including opportunities for economic development based on enhanced carbon competitiveness and new market development. The deployment of CCUS can create new job opportunities in a range of sectors, helping to boost local economies and create new economic activities. The development of new markets for CCUS is a key opportunity for driving the deployment of carbon capture, transport, and storage technologies.

- **Despite these challenges, CCUS must play a critical role in mitigating climate change** in the MENA region and around the world. The MENA region can amplify opportunities in the field of CCUS if the potential is tapped through collaborative partnerships within the region. The importance of regional collaboration to bring CCUS projects to fruition at the required scale for cost reductions cannot be overstated.
- **The Circular Carbon Economy Regional Collaboration (CCERC)** helps to achieve that goal by making technical knowledge more accessible to countries, assists in developing the necessary human capital, supports the formulation of policy frameworks and facilitate investment opportunities in CCE technologies and projects.

2.2 Recommendations

Investments and plans, policies and regulations, research and development, as well as international collaboration are required to advance CCUS deployment. The following recommendations aim to create a conducive environment for the deployment of CCUS technologies, scale up their adoption, and reduce their overall cost which will be critical to achieve global carbon emission reduction targets and sustainable development goals.

Accelerate Investments and Plans: Governments and private industry should prioritize investments in CCUS technologies and projects. This includes funding for research and development, demonstration projects, and the deployment of commercial-scale CCUS facilities. Accelerated investment and deployment plans will help to scale up CCUS technologies and drive down costs, making it more economically viable for the industry to adopt these technologies.

Implement Policy and Regulatory Frameworks: Governments should create policies and regulations that encourage the deployment of CCUS technologies. This includes policies to incentivize investments in CCUS, regulatory frameworks to enable the deployment of CCUS, and standardization of frameworks across regions to facilitate international collaboration. The harmonization of policies and regulations will help to create a common playing field. Concretely, this might be done by reducing regulatory barriers, standardizing requirements, and creating a more efficient marketplace for CCUS.

Promote Research and Development: Research and development should focus on the further maturation of CCUS technologies. This includes innovations in carbon capture, storage, and utilization technologies, as well as the development of new business models that enable the deployment of CCUS technologies at scale. The private sector should work closely with academia and research institutions to identify new areas of innovation and to facilitate the commercialization of emerging technologies.

Aim for International Collaboration: Governments and industry should collaborate internationally to share best practices and knowledge in the deployment of CCUS technologies. This includes the sharing of information on research and development, the deployment of CCUS technologies, and the development of policies and regulations that encourage investment in CCUS technologies. International collaboration will help to accelerate the deployment of CCUS technologies globally and reduce the overall cost of deployment. For that reason, the Kingdom of Saudi Arabia launched the Circular Carbon Economy Regional Collaboration (CCERC) that aims to foster regional collaboration for the implementation of Circular Carbon Economy (CCE) technologies across four cooperation pillars: Technical knowledge building, human capability building, policymaking and joint investments. Section 9 provides a detailed outlook on the role of the CCERC in further deploying CCUS in the region across its cooperation pillars.

3. Introduction

3.1 Objectives of the report

The objective of this report is to provide a comprehensive overview and analysis of Carbon Capture, Utilization and Storage (CCUS) technology globally and in the MENA region, and its role in mitigating climate change. This will be achieved through (i) a global outlook on climate ambitions, (ii) an introduction to CCUS technologies and processes (iii) a valuation of potential contributions of CCUS to MENA ambitions, (iv) a global and MENA region CCUS market assessment, (v) a valuation of potential contribution of CCUS to MENA ambitions, (vi) an assessment of opportunities and challenges related to CCUS, and (vii) a definition of the role of the Circular Carbon Economy Regional Collaboration (CCERC) to create CCUS collaboration opportunities.

The report begins by assessing the global and regional climate ambitions and efforts in mitigating climate change. It continues with an overview of climate ambitions specifically related to CCUS globally and in the MENA region. Then, it provides a synopsis on the different capture technologies, transport, usage, and storage methods. In addition, the report provides an economic assessment of CCUS and discusses the cost and benefits associated with the technology. The report assesses the potential contribution of CCUS in reducing emissions and reaching MENA climate targets. This is achieved through analyzing the current and projected state of emissions in the MENA region and assessing the potential role of CCUS in reducing the projected emissions, with a focus on hard-to-abate sectors. Moreover, the report develops a global and regional market assessment of CCUS. The market assessment includes an overview of current and planned projects in CCUS with specific case studies of successful projects and best practices. It also includes an approximated estimation of the current and projected market size of the leading technologies in addition to a stakeholder landscape analysis across the CCUS value chain.

The objective of the report is to outline the different opportunities and challenges related to CCUS in addition to the role of the CCERC in creating collaboration opportunities.

Overall, the report aims to provide a comprehensive understanding of CCUS technology and its potential to support global and regional climate ambitions. By exploring the opportunities and challenges associated with CCUS deployment, it aims to serve as a valuable resource for policymakers, investors, and industry stakeholders interested in promoting sustainable development.

3.2 Overview of climate ambitions globally and in the MENA region

Climate change is one of the biggest challenges the world faces and governments around the globe are working to address this issue by setting ambitious climate targets. The Paris Agreement, signed in 2015, was a significant step in this direction, as it saw 195 countries pledging to limit global warming to well below 2 degrees Celsius above pre-industrial levels, and to pursue efforts to limit the temperature increase to 1.5 degrees Celsius. (United Nations Framework Convention on Climate Change, n.d.)

Since then, many countries have taken further steps to strengthen their climate ambitions. In the European Union for example, the European Green Deal is a comprehensive plan to make the region climate neutral by 2050. The plan includes measures such as increasing the share of renewable energy, improving energy efficiency, and promoting sustainable transport. The United States set a target of reducing greenhouse gas emissions by 50-52% below 2005 levels by 2030 and has also rejoined the Paris Agreement. (National Climate Task Force, n.d.) In Asia, China has pledged to achieve carbon neutrality by 2060. (International Energy Agency, 2021)

In the Middle East and North Africa (MENA) region, many countries are also taking steps to address climate change. Saudi Arabia, the largest economy in the region, has launched the Saudi Green Initiative with the aim to reduce carbon emissions and to protect the environment. The initiative includes plans to plant 10 billion trees and reduce carbon emissions by 278 Mtpa of CO_2e by 2030. (MGI, 2021)

Also, the United Arab Emirates has set a target of generating 50% of its energy from clean energy sources by 2050 and has launched the world's largest single-site solar energy project. (UAE Energy Strategy, 2050, 2022; Masdar, n.d.) Outside of the GCC, Egypt has set sectorial targets, aiming for increased efficiency and reduced emissions in the electricity, oil and gas and transport sectors. These targets correspond to 33% emission reduction from electricity generation, 7% from transport and 65% from oil and gas by 2030 compared to the business-as-usual scenario (2015). (United Nations Development Program, 2022)

Many countries in the region have set ambitious targets for reducing their emissions, particularly in the energy sector. Some countries have also set targets for increasing the share of renewable energy in their energy mix, with the aim of reducing their dependence on fossil fuels. As of 2021, 22 countries in the MENA region have submitted NDCs (National Determined Contributions) to the United Nations Framework Convention on Climate Change (UNFCCC) [1]. The targets vary significantly between countries, with some aiming to reduce emissions by a specific percentage (e.g., 15% reduction from business-as-usual levels), while others have set specific goals in terms of renewable energy deployment, energy efficiency improvements, or emissions intensity reductions.

In conclusion, there is a growing recognition of the need to address climate change in closer relation to energy security, energy access, and affordability. The MENA region and the holistic approach that Circular Carbon Economy solutions such as CCUS provide, play an ever more central role in the ambitious goals that governments around the world are setting to reach net-zero targets. The Circular Carbon Economy Regional Collaboration will continue to ensure that the MENA region realizes the potential of CCUS technologies and services within and between countries in the MENA region and beyond.

[1] Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, UAE, and Yemen.

4. Introduction to CCUS

4.1 Role of CCUS in mitigating climate change

CCUS is gathering momentum across the world and is considered as a key solution for climate change mitigation. A growing number of countries mentioned CCUS (or related technology applications) in their Nationally Determined Contributions. In addition, the European Union developed an overarching NDC which covers the implementation of CCUS across all its member countries. Therefore, the commitment of several large economies such as the European Union, the United States, Japan, China, India, the United Kingdom, and Saudi Arabia to CCUS can be noticed. The interest in this technology can be explained by the fact that it is one of the optimal solutions to reduce the emissions in hard-to-abate industries such as cement, iron, aviation, and steel, as well as the oil and gas sector. Therefore, large emitters and players in such industries are increasingly driven to develop this technology to achieve their climate targets.

The role of CCUS is particularly important in regions such as the Middle East and North Africa (MENA) where oil and gas industries' technological prowess is a significant enabler in the deployment of clean tech solutions, such as CCUS to reduce GHG emissions. Several countries in the MENA region have already begun to invest in CCUS technology due to its effectiveness in removing emissions from the oil and gas industry and related production processes.

All GHG emission reduction scenarios highlight the role of CCUS. In this context, the International Energy Forum has estimated in its Comparative Analysis of Energy Outlooks, that to achieve carbon neutrality by 2050, around 3.6 to 8.4 $GtCO_2$/y must be abated by 2050 according to IPCC IMP-1.5 and IRENA I.5-S projections (International Energy Forum, 2023).

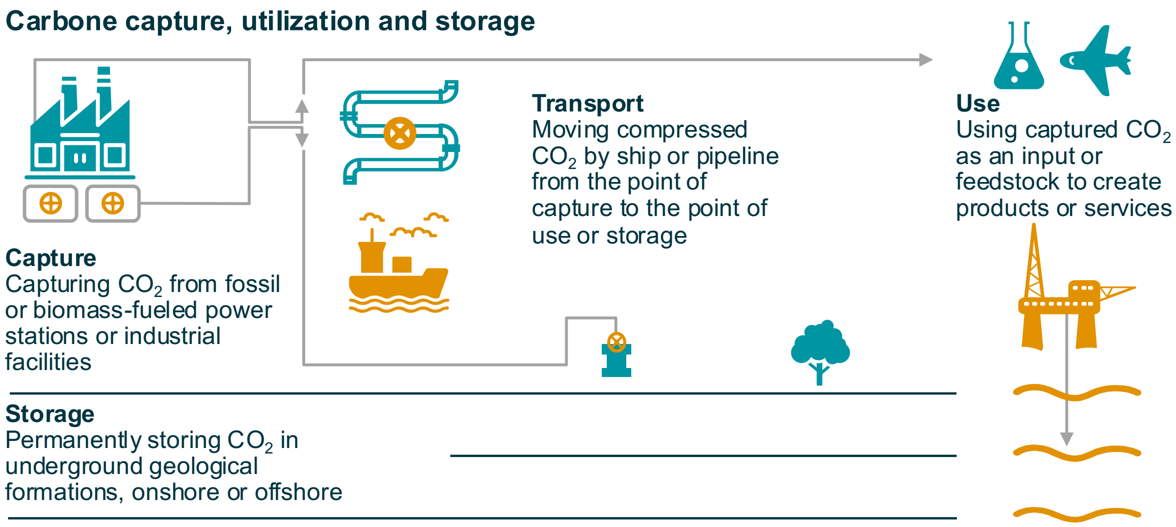
CCUS contributes to the mitigation of climate change through six levers:

- Remove emissions from existing energy generation processes
- Remove emissions from hard-to-abate sectors such as cement and steel production
- Remove and capture carbon directly from the atmosphere
- Facilitate the development of low-carbon production processes
- Facilitate the production of clean hydrogen, sustainable aviation fuels, other synthetic e-fuels and materials through carbon dioxide utilization
- Accelerate low carbon material production processes and accelerate transitions by increasing carbon utilization applications.

4.2 CCUS technology types and processes

Engineered CCUS technology solutions consist of the capture, transport, use and storage of CO_2 from industrial processes or energy generation. Each stage of the process has its own technical features that are illustrated in Figure 1.

Figure 1: Technology overview of carbon capture, utilization, and storage



Source: Medium (2021), Global CCS Institute (2021), IEA (2021), Roland Berger

This section describes the most used capture technologies available in the market, and gives an overview of the different transport, usage, and storage methods.

The first step of the process is to capture carbon emissions. This can be done directly from the atmosphere through direct air capture technologies and nature-based solutions (e.g., trees and mangroves) or from point source emitters. In this report, the focus is on point-source capturing technologies. CCUS can be implemented on multiple emissions point sources such as power stations (fossil or biomass-fuel), industrial sites, or other large emitters facilities. After the carbon emissions are captured, the next step is typically a separation step that utilizes multiple types of technologies to separate CO_2 from other gases. These separation technologies can include absorption, membrane separation, cryogenic distillation, and others. The choice of separation technology will depend on factors such as the concentration of CO_2 in the feed gas, the purity requirements of the captured CO_2, as well as the cost and energy requirements of the separation process.

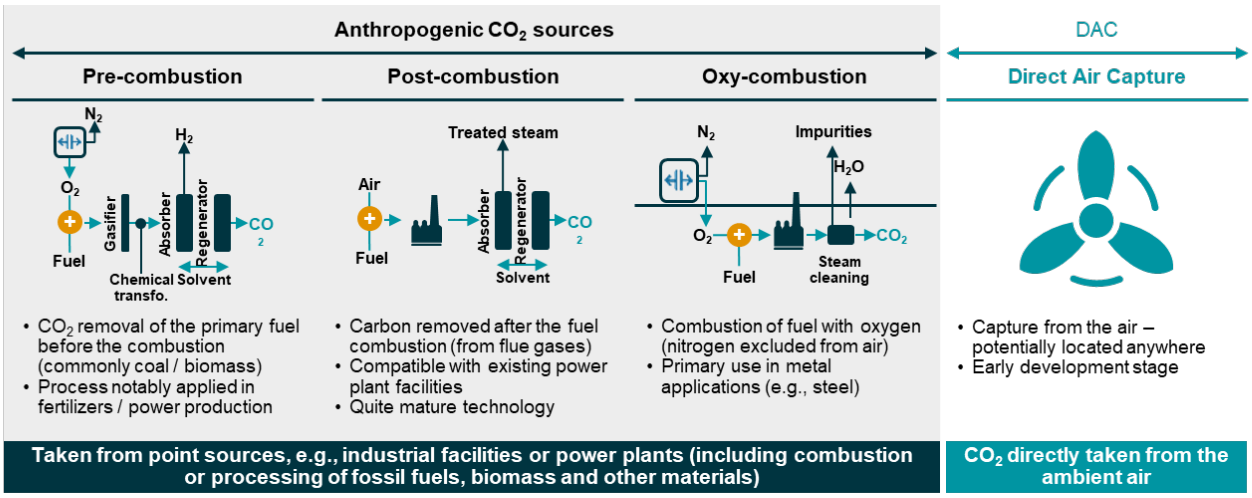
In this report, the focus is on the three primary carbon capture processes used in industrial processes: Post-combustion, pre-combustion, and oxy-combustion. The reason for focusing on these three primary capture technologies is that they are currently the most widely used and commercially available methods for capturing CO_2 from industrial sources.

Additionally, these technologies have been extensively researched and tested, and are currently in use in several large-scale CCUS projects around the world. However, it is important to note that other carbon capture and separation technologies are also being developed and may play a role in future CCUS projects. Such technologies include Bioenergy with Carbon Capture and Storage (BECCS), and Chemical Looping Combustion.

- **Pre-combustion capture:** Consists of capturing CO_2 before it is produced in combustion processes. This technology is commonly used in the production of coal and biomass. In this process, the fossil fuel, is converted into a gas (such as syngas). The CO_2 is then separated from the gas before it is combusted, allowing its capture and subsequent storage or utilization.

- **Post-combustion capture:** Consists of capturing CO_2 after it has been produced during combustion processes. The most common method of post-combustion capture is to use solvents, such as amines, to absorb CO_2 from flue gas. Once the CO_2 has been absorbed, it is separated from the solvent and compressed for transport and storage.
- **Oxy-combustion capture:** Consists of burning fossil fuels in an oxygen-rich environment, which produces a flue gas that is mostly CO_2 and water vapor. The water vapor is removed using condensation, leaving behind a stream of almost pure CO_2, which can be compressed for transport and storage.

Figure 2: Explanation of pre-, post- and oxy-combustion



Focus of the report

Source: Global CCS Institute (2021), Roland Berger

As of today, post-combustion capture is the most mature CCUS technology and is the common method used in existing power plants. As the CO_2 is separated from the exhaust of a combustion process, post-combustion capture can be built into existing large-emitters facilities, known as retrofitting, without significant modifications to the original plant. Pre-combustion capture technologies are also developed at a commercial level and used by industrial facilities but are much more difficult to implement for power plants. In fact, the process of gasifying the fuel and separating the CO_2 can only be built into new facilities. Retro-fitting an existing facility to implement this technology would be prohibitively costly. Finally, oxy-combustion capture is a promising technology that would allow capturing up to 100% of the CO_2 from the point source. However, the capital cost, energy consumption, and operational challenges to achieve oxygen separation are still too significant to consider oxy-combustion as a viable technology at a large-scale level.

The second step of the process is CO_2 transportation. After being captured, compressed CO_2 is transported through pipelines, ships, trucks, or by rail from the point of capture to the point of use or storage. The choice of transportation method depends on multiple factors such as the distance between the capture site and the storage site, the amount of CO_2 to be transported, and the cost and efficiency of each method. Most commonly, transportation of CO_2 is done through pipelines or ships. Most importantly, transportation must be done safely and efficiently to avoid any leaks or accidents that could result in the release of CO_2 into the atmosphere. To ensure safe transportation, the modes of transport typically used are designed to meet strict safety standards and are monitored for leaks or other issues.

The third and final step of the process is one of two options. The CO_2 is either utilized in different industrial applications or is stored underground.

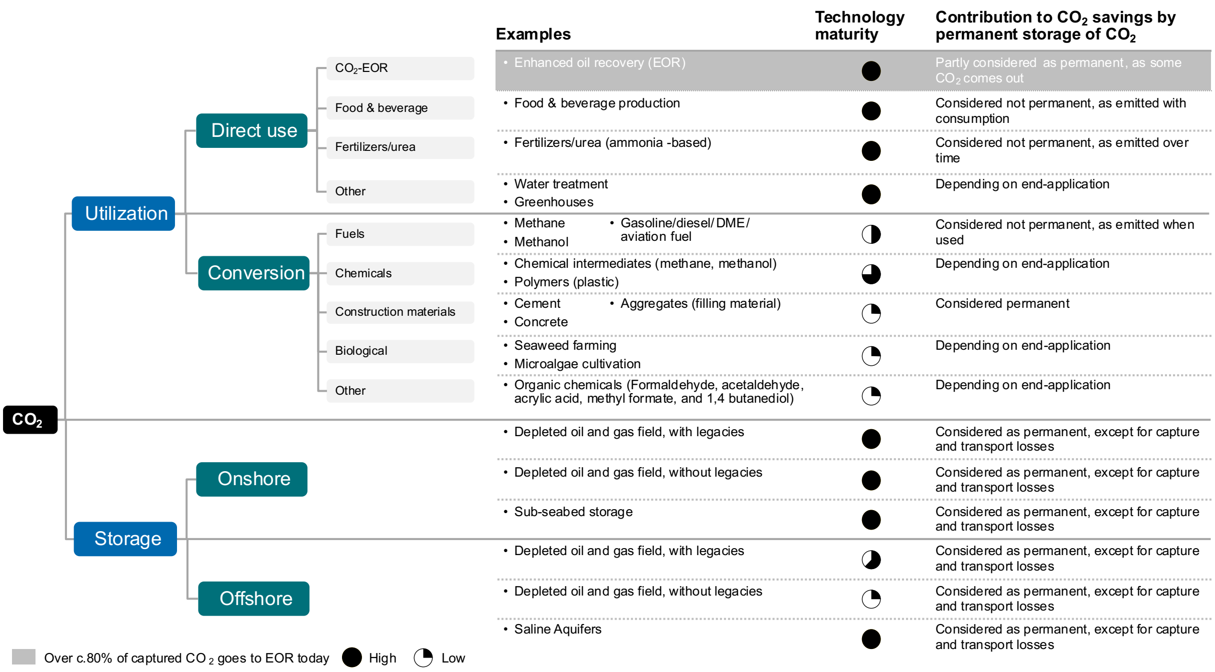
According to the IEA, the majority of CO_2 captured is stored and not utilized, suggesting that by 2030, 95% of captured CO_2 will be stored in geological formations. However, where CO_2 is to be utilized, it can be directly used without chemical alterations or converted through multiple biological or chemical process as summarized below:

- **Direct use:** CO_2 is not chemically altered. This is currently the most common usage of CO_2, particularly for Enhanced Oil Recovery (EOR) purposes. C.80% of the captured CO_2 today goes to EOR. (Global CCS Institute, 2022) This use is particularly interesting for countries dependent on the oil and gas sector. Among other direct applications, CO_2 can be used in other industrial processes such as food & beverages production or agricultural applications.
- **Conversion:** CO_2 is altered through multiple chemical and biological processes. This usage is relevant to produce synthetic fuels (e-fuels), obtained by combining CO_2 with low-carbon energy. Other fields of application are the conversion of the captured CO_2 to produce chemicals (e.g., polymers, methanol), and building materials (e.g., aggregates, cement, concrete).

Moreover, CO_2 can be stored in underground rock formations in a process called geological storage. This method involves injecting CO_2 into specific types of rock formations, where it can be stored permanently. There are two main types of geological storage, onshore and offshore. Onshore storage can be done by injecting CO_2 into deep saline aquifers, which are rock formations containing water with high salt content. On the other hand, it can also be injected into depleted oil and gas reservoirs, which are underground rock formations that have already been exploited and are no longer producing hydrocarbons. Offshore storage is like onshore storage, but it involves injecting CO_2 beneath the ocean floor. This can be done using sub-seabed storage, where CO_2 is injected into formations beneath the ocean floor. The pressure of the water in such depths prevents the CO_2 from resurfacing. The choice of storage method depends on factors such as the location, storage capacity, and specific requirements of the application. Permitting and other constraints in densely populated areas mean that offshore storage often provides more viable options as is the case in Northwest Europe.

Figure 3 summarizes the technology advancement of each type of implementation as well as its contribution to reducing CO_2 emissions. As highlighted, direct uses are the most mature technologies while storage is the most efficient due to permanent capture.

Figure 3: Overview of CCUS technology advancements

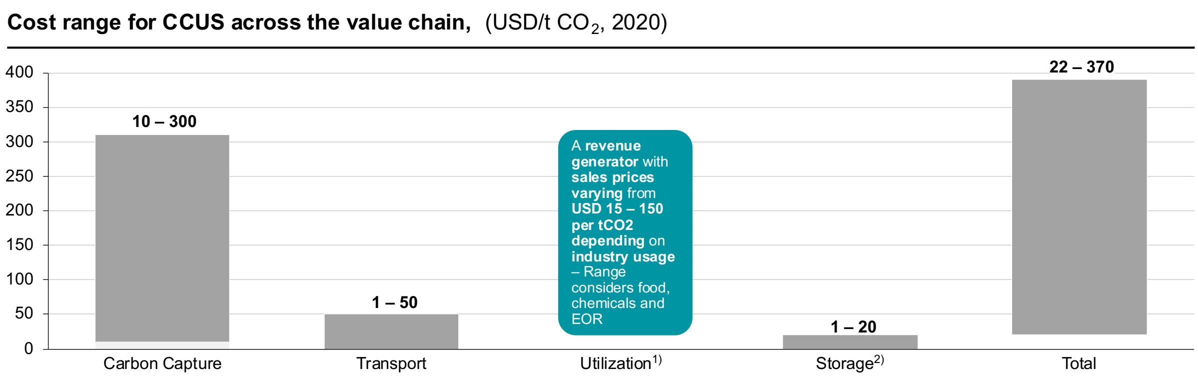


Source: Global CCS Institute (2021), Roland Berger

4.3 CCUS cost assessment

This section aims to assess the economic feasibility of CCUS technology. In recent years, there has been increasing attention and investment in CCUS technology as a potential solution to combat climate change. However, the economic viability of CCUS remains a critical factor in its widespread adoption. By examining the costs associated with each step of the CCUS process, (including carbon capture, transport, and storage), and by identifying the main cost drivers, this section provides insights into the economic feasibility of CCUS. Utilization on the other hand, is considered as a revenue generator for CCUS projects. Additionally, the section highlights the importance of placing a value on greenhouse gas emissions, or carbon price discovery mechanisms and their role in making CCUS economically viable.

Figure 4: Overview of costs of CCUS



1) CO_2 emissions that are captured and used, are considered emitted in EU (ETS) and NL CO_2 taxation policies, and CO_2 levies will apply regardless of usage; 2) Generally, includes costs related to MMV (Measurement & monitoring) during the storage lifetime and close down of the reservoir when the storage if full)

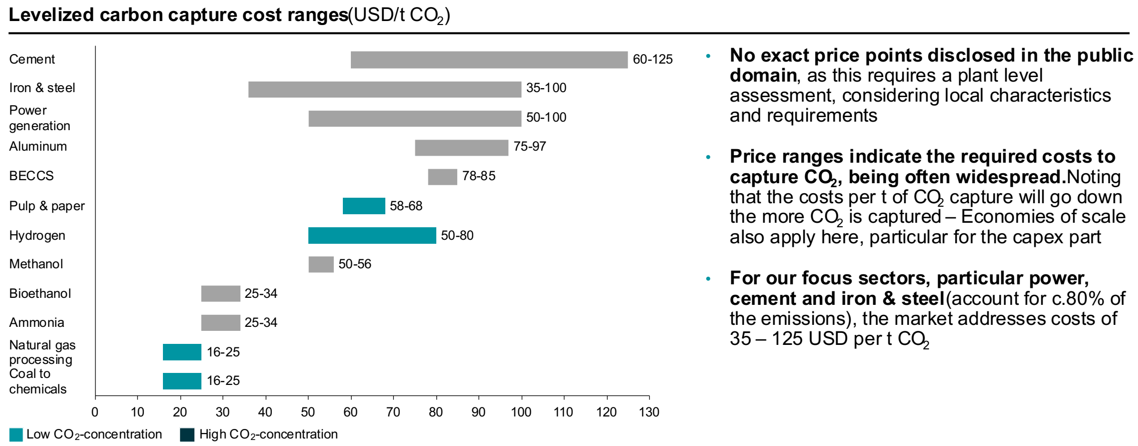
Source: IEAGHG, Global CCS Institute, expert interviews, Roland Berger

Carbon capture

The cost of carbon capture is a crucial factor in determining the economic feasibility of CCUS technology as it accounts for c.75% of the total cost. The range varies significantly from USD 10 to 300 per ton of CO_2, depending on many cost drivers.

One important cost driver is the technical maturity of the technology. Newer technologies may have higher capital costs due to the need for additional research and development but may also have lower operating costs due to increased efficiency. Currently, the post-combustion capture and pre-combustion capture are considered as mature technologies compared to oxy-combustion. Another cost driver is the scale of the capture project, as larger projects may benefit from economies of scale which results in lower costs per ton of CO_2 captured. The type of industrial process being targeted for capture is also a cost driver. The capture cost can drastically decrease for applications with high concentrations of CO_2 (95-100%) and can increase for applications that contain other impurities or contaminants as an output of their industrial processes. This is mainly since applications with higher CO_2 concentrations are more amenable to capture than others. Additionally, the energy source used to power the capture technology can have a significant impact on costs. For example, using renewable energy sources to power capture technologies can result in lower operating costs, while using fossil fuels can result in higher costs due to fuel consumption and emissions. A carbon capture cost assessment has been conducted considering different point sources as presented in Figure 5.

Figure 5: Levelized carbon costs

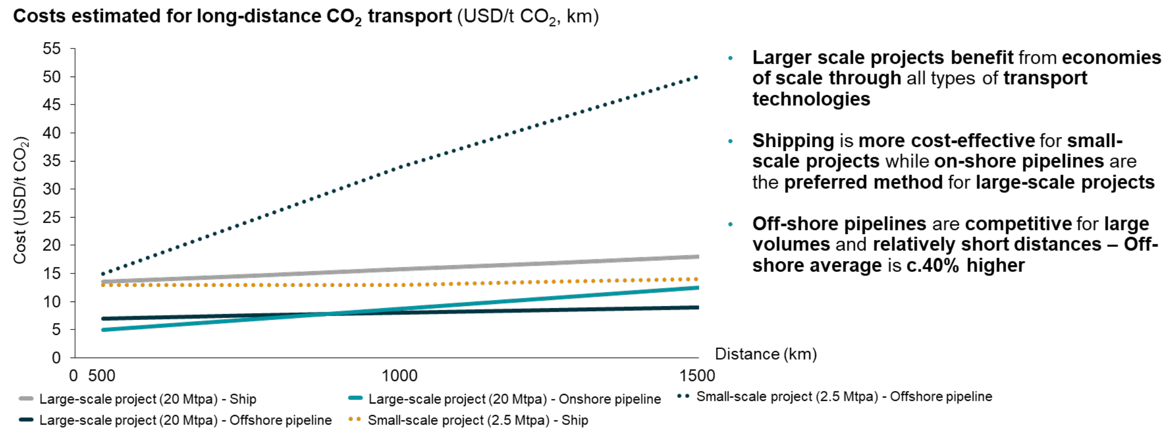


Source: IEA, CCS Institute, Roland Berger

Transport

The cost of CO_2 transport is another important factor in determining the economic feasibility of CCUS technology. The costs associated with CO_2 transport can vary from USD c.1 to 50 per ton of CO_2, depending on many cost drivers. One significant cost driver is the distance between the capture site and the storage site, as longer distances may require additional infrastructure and result in higher costs. The effect of the cost has been assessed for large-scale and small-scale projects in Figure 6. The capacity and utilization of the transport infrastructure are also important cost drivers. For example, underutilized pipelines or ships may result in higher costs per ton of CO_2 transported. The type of transport technology used is also a cost driver, with pipelines generally considered as the most cost-effective method for transporting large volumes of CO_2 and on shorter distances, while ships become competitive at longer distances. Finally, the regulatory environment can also be a cost driver, as regulations governing CO_2 transport may result in additional costs for compliance depending on the region.

Figure 6: Costs estimation for CO_2 transport

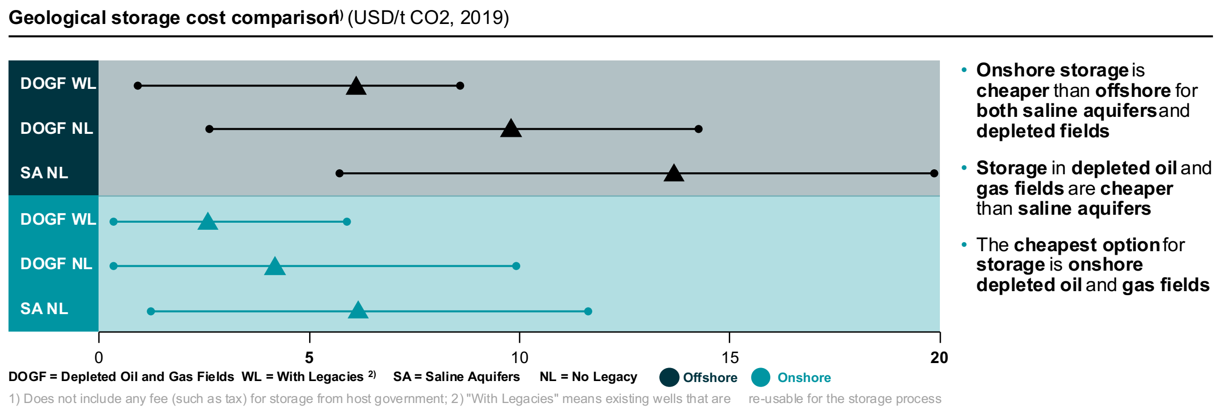


Source: Zero emissions platform (2011), BEIS (2020), Global CCS Institute

Storage

The cost of CO_2 storage is another critical factor in determining the economic feasibility of CCUS technology. The costs associated with CO_2 storage can vary from USD c.1 to 20 per ton of CO_2, depending on many cost drivers. One significant cost driver is the type of storage site used as assessed in Figure 7. Geologic storage, in saline formations or depleted oil and gas fields, is generally considered the most viable option for long-term CO_2 storage. The costs vary based on factors such as site characteristics and infrastructure availability. Another cost driver is the injection rate of CO_2. Higher injection rates result in higher capital and operational costs. The duration of storage and the extent of monitoring and verification required are also cost drivers, as longer storage durations and more extensive monitoring programs may result in additional costs. The depth and quality of the storage site are also important factors, as deeper and higher quality sites may require more extensive site characterization and result in higher costs. Finally, regulatory requirements can be a significant cost driver, with regulations governing CO_2 storage potentially resulting in additional costs for compliance.

Figure 7: Storage costs of CCUS



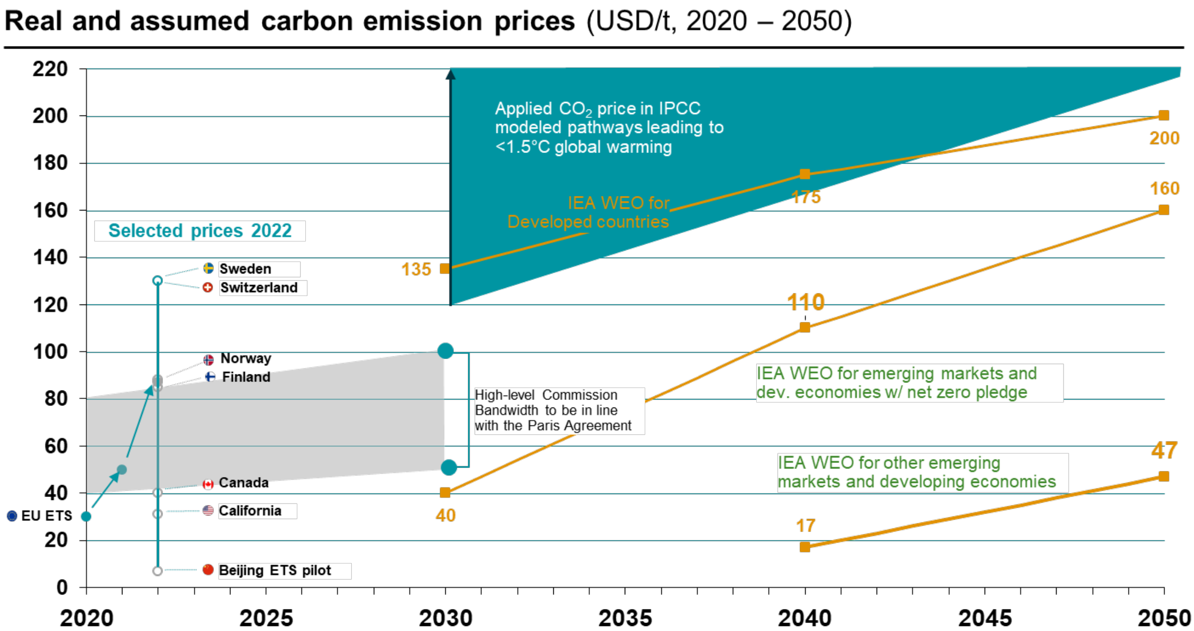
Source: Zero emissions platform (2019), Global CCS Institute

Overall, the current cost of CCUS technologies is relatively high, making it difficult for industries to justify the investment required to implement these technologies. The total cost across all steps of the value chain could reach up to USD c.370 per ton of CO_2. The high cost is driven by multiple factors such as the complexity of the technology, the high energy requirements, and the cost of building the necessary infrastructure. However, the future expected cost of CCUS technologies is projected to decline significantly due to several factors, including technological advancements, economies of scale, and increased competition. For instance, the IEA estimates that by 2030 the cost of CCUS technologies could fall to 20-50 USD per ton of CO_2, and to USD 10-35 per ton of CO_2 by 2050. These projections assume that there will be significant investment in CCUS technologies, including research and development, demonstration projects, and government incentives.

Another factor that might influence the future expected cost of CCUS technologies is the deployment of carbon price discovery mechanisms, which could potentially drive down the overall cost of the technology. However, the effectiveness of placing a price on carbon through emission trading systems, fiscal and or trade policies depends on their design and implementation modes. Their application remains the exception rather than the rule in most developed OECD economies and non-OECD emerging economies.

Carbon price discovery mechanisms and fiscal policies may include carbon taxes and emissions trading schemes, which aim to put a price on greenhouse gas emissions to incentivize industries to reduce their emissions. The revenue generated from carbon pricing policies could also be used to finance CCUS technologies and research and development in the sector. Figure 8 gives an overview of carbon emission price discovery in selected OECD economies and carbon price trends assumptions used by the IEA and IPCC in scenarios for OECD and non-OECD economies.

Figure 8: Overview of carbon emission price discovery in selected OECD economies and IEA IPCC scenario assumptions



Source: High-Level Commission (2017), IEA World Energy Outlook (2022), IPCC SR15 (2022), World Bank (2023), Roland Berger

Carbon price discovery mechanisms, fiscal, and trade policies, when applied in accordance with well-established market rules and principles and with due consideration for their social economic impact, can help to make CCUS and related technologies more economically feasible. Enhanced dialogue on evolving carbon markets in producer and consumer countries can help create a more broadly shared level playing field for industries that are implementing carbon abatement technologies to improve their carbon competitiveness on domestic and/or global markets.

5. Potential of CCUS to contribute to emission reduction in the MENA region

5.1 Methodology and assumptions

To assess the potential contribution of CCUS technologies in reducing greenhouse gas emissions in the MENA region, a comprehensive methodology was employed. The methodology includes the estimation of two main parameters: (i) emission levels of energy generation and hard-to-abate sectors and (ii) capacity of operational and planned CCUS projects in the region.

Emission levels of energy generation and hard-to-abate sectors

The first step included a historical and projected emission estimation of energy generation and hard-to-abate sectors covering the years 2015 till 2030. Hard-to-abate sectors comprise industries that are challenging to decarbonize, such as cement, steel, and chemicals which account for a significant share of global and MENA emissions. In addition, the energy generation sector is considered as being such an industry for the analysis, since it is one of the largest contributors to emissions worldwide and in the MENA region. This enables a more comprehensive understanding of the potential of CCUS technologies to reduce emissions in the region. Additionally, many ongoing and planned CCUS projects are specifically aimed at energy generation in the region, highlighting the importance of including this sector in the analysis.

To estimate and project the emission levels of these sectors, historical data and projected growth in population and GDP were considered. Notably, the analysis was conducted under the assumption that the emission reduction targets announced by some MENA countries may not materialize. This approach allows us to determine the potential market for CCUS technologies in the region in terms of million tons per annum (Mtpa). The countries considered as part of this assessment are Algeria, Bahrain, Comoros, Djibouti, Egypt, Iraq, Jordan, Kuwait, Lebanon, Mauritania, Morocco, Oman, Qatar, Saudi Arabia, Somalia, Sudan, South Sudan, Syria, Tunisia, and the UAE. Due to limited public data availability for Palestine and Yemen, especially in regard to the countries' emission level, the two countries are not included in the calculation. Moreover, it is worth noting that the potential capture market represents an opportunity for the implementation of other technologies and is not just limited to engineered CCUS solutions. International sources and databases such as Euromonitor and the International Energy Agency have been utilized to interpolate the results and verify emission projections.

Capacity of operational and planned CCUS projects

The subsequent phase involved the identification of operational and planned CCUS projects in MENA countries to assess total capture capacity. This data is an aggregated result of international CCUS sources and databases such as the Global CCUS Institute, International Energy Forum, and the International Energy Agency. In addition, experts in the field of CCUS deployment and development in the MENA region were interviewed to verify the generated results. By calculating the total capture capacity of CCUS projects, an estimation of the present and projected capture market for CCUS technology in the region has been determined.

Finally, by comparing the estimated emission levels with the expected capture capacity, the impact of CCUS to reduce emissions in hard-to-abate sectors across the MENA region can be determined.

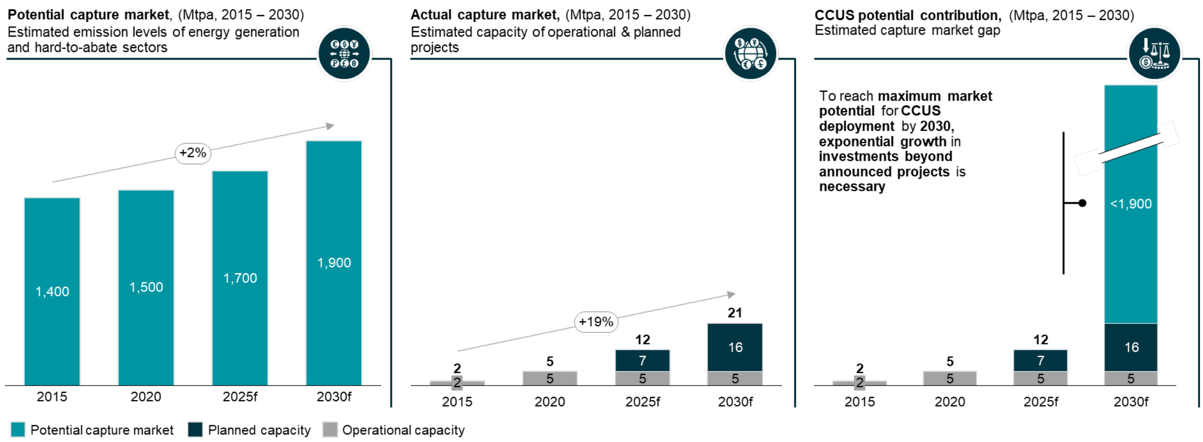
The gap between these two figures reveals the potential for further CCUS implementation. The results of this analysis are presented in section 6.2.

It is essential to note that there are some limitations to this methodology. First, it assumes that there are no technological or economic barriers for the deployment of CCUS projects in the region, which may not be the case. Second, it projects the emission levels of hard-to-abate sectors, which may vary depending on upcoming targets, policies, and climate actions. Third, it does not consider the potential for demand-side measures, such as energy efficiency and renewable energy to reduce emissions in the defined sectors. Despite these limitations, the methodology provides a useful starting point for understanding the potential contribution of CCUS to emission reduction in the MENA region. It highlights the need for significant investment in CCUS projects to capture the maximum potential market and reduce emissions from hard-to-abate sectors.

5.2 CCUS contribution to emission reduction in the MENA region

Based on the potential market and the capture market projections, the expected contribution of CCUS to emission reduction of hard-to-abate sectors in the MENA region is identified. The results of our analysis demonstrate that there is a significant gap between the two parameters. The gap represents the potential for further CCUS deployment in the region, as represented in light blue in Figure 9. The results show that 1.5% of the potential market will be captured by 2030 with the operational and planned capacity, indicating the potential for significant investment in CCUS projects in the region.

Figure 9: Analysis of CCUS potential



Source: EDGAR, PRIMAP, Euromonitor, IMF, World Economic Outlook, IEA CCUS database, desk research, Roland Berger, expert interviews

Despite the accelerated growth of CCUS capacity by c.19% CAGR as compared to c.2% for emission levels between 2015 – 2030, the expected capture capacity of 21 Mtpa from CCUS is not enough to cover the whole potential by far. The MENA region has vast potential for CCUS deployment, given its abundant sources of CO_2 emissions from the oil and gas sector, and the need to decarbonize hard-to-abate sectors. By investing in CCUS, MENA countries can not only reduce their emissions but also create new opportunities for economic growth and job creation based on the enhanced carbon competitiveness of the hydrocarbon industries and hard to abate sectors.

Moreover, the disparity has profound implications for the attainment of global climate ambitions. If the region fails to achieve its potential in CCUS deployment, this could significantly slow down progress towards global climate targets, as the hard-to-abate sectors would continue to generate emissions. Additionally, failure to invest adequately in CCUS technologies may hinder our ability to achieve neutrality, potentially exacerbate existing climate risks and challenges, such as the impact of climate change on public health, agriculture, and water security. As such, accelerating investments in CCUS is crucial to reduce emissions, mitigate climate risks and contribute to the attainment of global climate objectives, particularly in the MENA region.

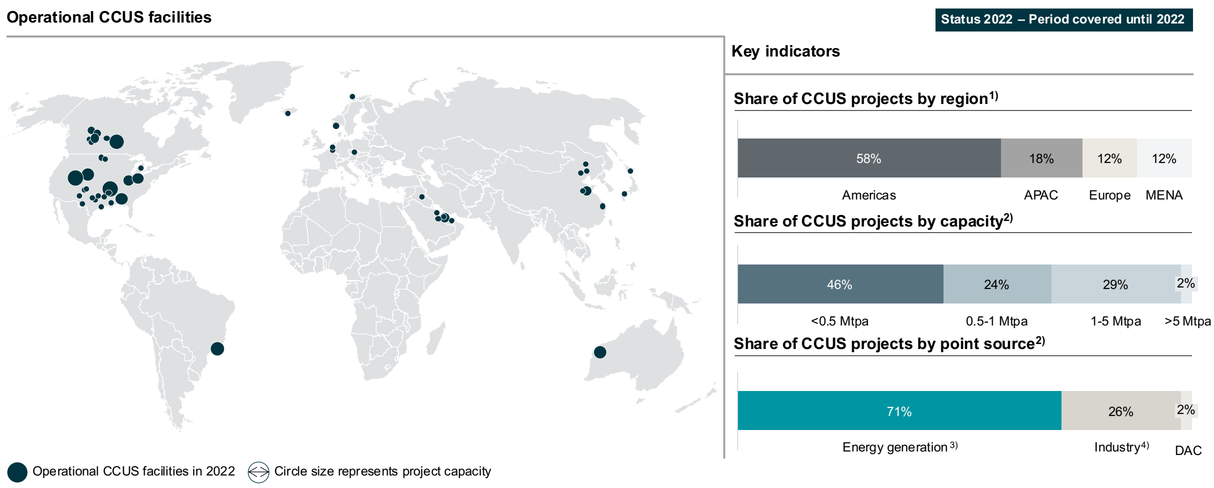
6. Market assessment of CCUS globally

In this market assessment, the analysis is based on the IEA CCUS database published in March 2023. The database is a compilation of publicly announced projects only and might be subject to constraints. This is due to a lack of announced information such as project capture capacity. However, the database is a fair representation and close approximation to the market dynamics of CCUS globally given the currently available information. It is important to note that some assumptions have been considered as indicated in footnotes (see Figure 10).

6.1 Overview of current CCUS projects

In this section, a summary of current global CCUS projects will be presented, followed by an examination of leading countries in this field. Afterwards, the report will delve into the details of individual CCUS projects. An overview of CCUS facilities and projects in operation is given in Figure 10.

Figure 10: Overview of global operational CCUS projects



1) Projects include individual facilities with CCUS operations and transport & storage hubs with shared infrastructure;
2) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources;
3) Energy generation includes carbon capture from oil and gas, natural gas, biofuels, power and heat, hydrogen and ammonia, and other fuel transformation facilities including refineries, coal-to-gas, coal-to-liquids, and gas-to-liquids processes;
4) Industry includes carbon capture from cement, steel and iron, chemicals, and other industrial facilities including aluminum smelters, pulp and paper mills

Source: IEA CCUS database, Roland Berger

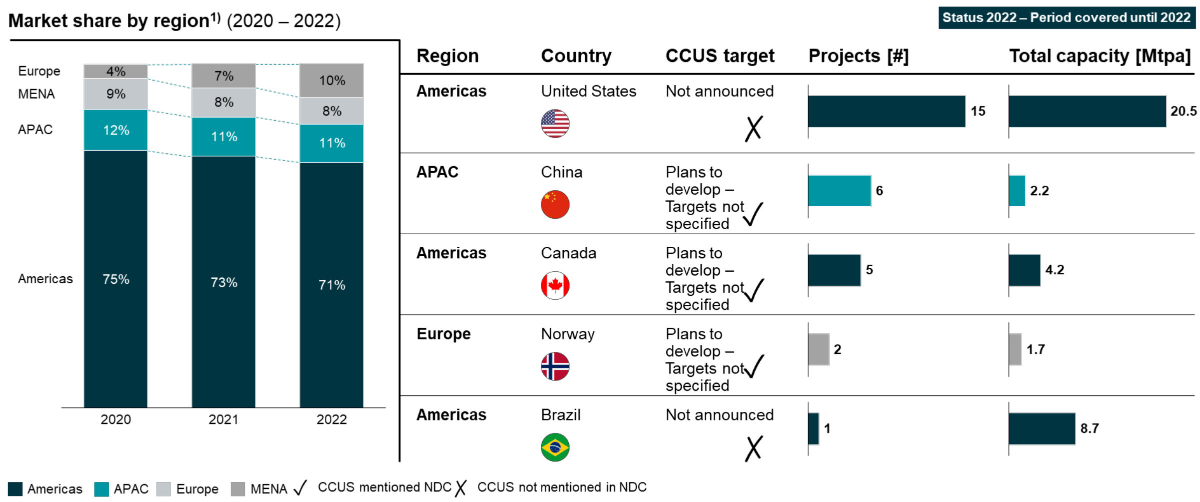
Currently, there are c.40 CCUS projects in operation globally (including MENA region) with a total capture capacity of c.50 Mtpa. This includes individual facilities with CCUS operations and transport & storage hubs with shared infrastructure. The analysis indicates that the Americas are leading in the field of CCUS with the highest share of projects, followed by the APAC region, with Europe and the MENA region following. The leading position of Americas is mainly due to projects in the United States and Canada. The key enabler is the combined joint efforts of their governments and industries. The Americas and APAC region have more favorable policies and regulations and a greater willingness to invest in carbon management technologies than other regions. These factors have helped to drive investments in CCUS projects there.

In terms of capacity, smaller-scale projects (<0.5 Mtpa) account for almost half of the projects. Furthermore, there is a balanced distribution among mid-sized projects (0.5-1 Mtpa) and large-scale projects (1-5 Mtpa). This is primarily because pilot projects are the most common means of testing and refining CCUS technology before its full-scale deployment. The number of very large-scale (>5 Mtpa) projects is relatively low, as these projects primarily concentrate on developing infrastructure, which are not accounted for in the capacity divide as this report aims to capture the operational capability of CCUS technology.

When considering point sources of the operational CCUS projects, energy generation projects dominate, while the presence of industry is comparatively limited. The natural gas processing, oil and gas as well as power and heat industry are major contributors to emissions, companies in these industries are investing in innovative solutions, such as CCUS to reduce their emissions.

Direct air capture (DAC) technology is in a very early stage which is reflected by the share of CCUS projects. Figure 11 displays the market share per region and the 5 leading countries, both in terms of the number of projects and the total project capacity installed.

Figure 11: CCUS market share and top 5 countries in CCUS deployment



1) Market share is based on Technavio analysis – It is calculated based on estimated value and volume of carbon capture and storage activities across the whole value chain, an in-depth overview of the approach is provided in the Global Carbon Capture and Storage Market 2021-2025 report

Source: IEA, Technavio, desk research, Roland Berger

In terms of market share, Americas is the leading region. This is mainly driven by the United States and Canada. In 2022, 45% of global CCUS investments was deployed in the United States, which is equivalent to about USD 2.8 bn. APAC investments surged to USD 1.2 bn in 2022. (Ghilotti, 2023) However, a notable increase is observed in market share for Europe between 2020 and 2022.

Looking at the top 5 countries, the United States has 15 projects in operation with a total capacity of 20.5 Mtpa. China is the main driving force for the APAC region with six projects in operation accounting for a total capacity of 2.2 Mtpa.

Canada has five operational projects with a combined capacity of 4.2 Mtpa. In Europe, Norway is leading in terms of CCUS projects with two projects accounting for a total capacity of 1.7 Mtpa. Brazil stands out with a highly impactful EOR project which has a capacity of 8.7 Mtpa.

Moreover, a ranking of top 10 CCUS projects has been developed based on capture capacity, which is presented in Figure 12.

Figure 12: Top 10 largest operational CCUS projects by capacity (2022)

#	Project name[1)]	Country	Operational year	Carbon point source	Use type	Capacity [Mtpa]
1	Petrobras Santos Basin pre-salt oilfield CCS	Brazil	2013	Energy generation – Natural gas processing	EOR	8.7
2	Century plant - (TX)	United States	2010	Energy generation – Natural gas processing	EOR	4.3
3	Gorgon CCS	Australia	2019	Energy generation – Natural gas processing	Dedicated storage	4.0
4	Labarge Shute Creek Gas Processing Plant 2010 expansion (WY)	United States	2010	Energy generation – Natural gas processing	EOR	3.5
5	Labarge Shute Creek Gas Processing Plant original (WY)	United States	1986	Energy generation – Natural gas processing	EOR	3.5
6	Great Plains Synfuel Plant (ND) Weyburn-Midale (SK)	United States	2000	Energy generation – Other fuel transformation	EOR	3.0
7	Qatar LNG	Qatar	2019	Energy generation – Natural gas processing	Dedicated storage	2.1
8	NWR CO2 Recovery Unit (Sturgeon Refinery) (ACTL) (ALB)	Canada	2020	Energy generation – Other fuel transformation	EOR	1.3
9	Quest (ALB)	Canada	2015	Energy generation – Other fuel transformation	Dedicated storage	1.2
10	Boundary Dam CCS (SASK)	Canada	2014	Energy generation – Power and heat	EOR	1.0

A case study is provided in Appendix A

1) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources

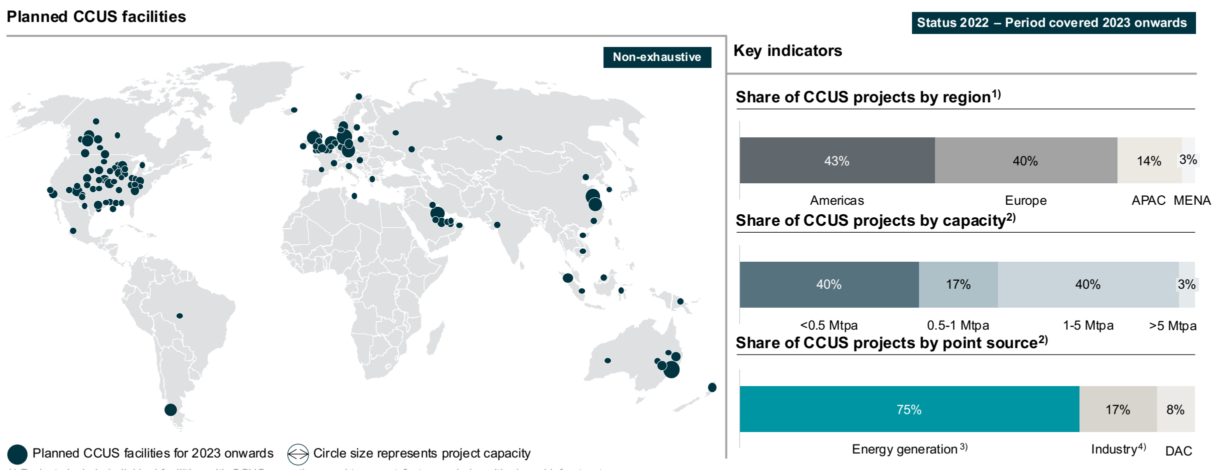
Source: IEA, desk research, Roland Berger

As expected, due to the large market share, 80% of the top 10 largest CCUS projects are situated in the Americas region, with four of them located in the United States. All the top 10 projects have a capacity in the range of 1-5 Mtpa and are therefore labeled as large-scale projects. In terms of utilization, 70% of the projects are focused on Enhanced Oil Recovery (EOR). Notably, the Qatar LNG (Ras Laffan) CCS project is present among the top 10. This marks an achievement for the region, given the early development stage of CCUS compared to other regions globally.

6.2 Overview of future CCUS projects

Due to the significant potential of CCUS, there are numerous projects in the planning or construction phase. In this section, the focus lies on the development of CCUS projects in 2023 and onwards. Figure 13 features a non-exhaustive map that displays the locations of planned projects. Additionally, it provides further information on the division by region, capacity, and point of source of these projects at individual project level.

Figure 13: Overview of global planned CCUS projects



1) Projects include individual facilities with CCUS operations and transport & storage hubs with shared infrastructure;
2) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources;
3) Energy generation includes carbon capture from oil and gas, natural gas, biofuels, power and heat, hydrogen and ammonia, and other fuel transformation facilities including refineries, coal-to-gas, coal-to-liquids, and gas-to-liquids processes;
4) Industry includes carbon capture from cement, steel and iron, chemicals, and other industrial facilities including aluminum smelters, pulp and paper mills

Source: IEA CCUS database, Roland Berger

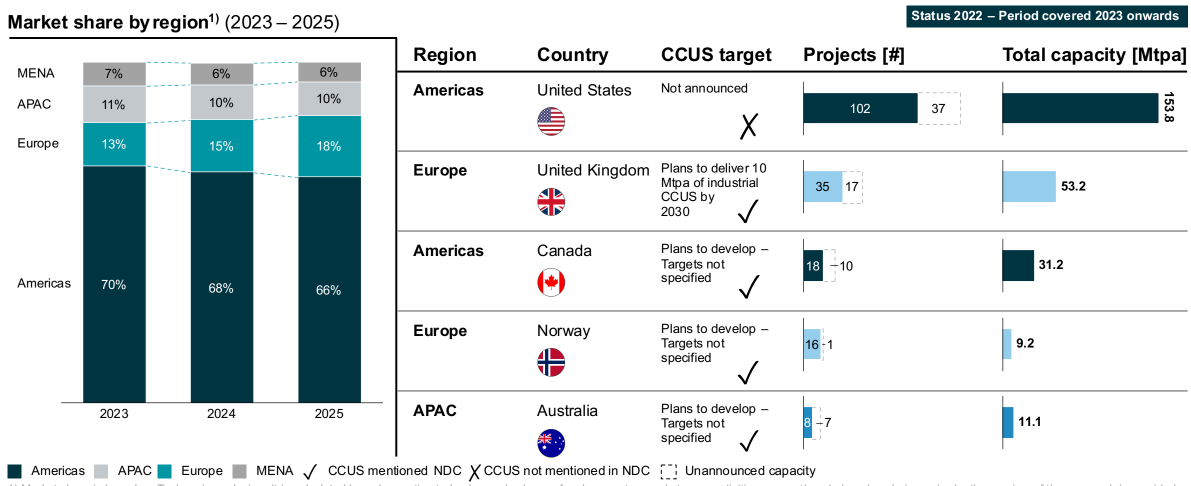
According to the planned CCUS projects, the Americas region will continue to have a strong presence in the market at a share of 43%. A significant increase in projects located in Europe is observed, this goes back to the strong governmental support and regulatory incentives such as provided by government support mechanisms, the EU Emissions Trading System, and carbon taxation that Sweden and Norway apply to incentivize CCUS adoption among others.

In terms of capacity, there will be a shift towards larger projects, with a decrease in the proportion of small-scale (<0.5 Mtpa) projects and a significant increase in both large-scale (1–5 Mtpa) and very large-scale (>5 Mtpa) projects. The reason for this shift in project capacity is maturation of technologies, larger investment size and supportive regulation.

The point source share of planned CCUS projects is about equal to the projects currently in operation. However, an increase in Direct Air Capture and Storage (DACS) projects is observed. This expected uptake can be attributed to government regulations and advancements in technology. Governments implement regulations and incentives to encourage the use of Bioenergy with CCS, while advancements in Bioenergy with CCS (BECCS) technology will make it easier and more cost-effective to produce them on a larger scale.

An assessment of the top 5 countries based on planned CCUS projects is presented in Figure 14.

Figure 14: CCUS market share and top 5 countries in planned CCUS deployment



1) Market share is based on Technavio analysis – It is calculated based on estimated value and volume of carbon capture and storage activities across the whole value chain, an in-depth overview of the approach is provided in the Global Carbon Capture and Storage Market 2021-2025 report

Source: IEA, Technavio, desk research, Roland Berger

The market share outlook for the period 2023 – 2025 shows a notable increase in market size for Europe, largely due to initiatives taken by Norway, the United Kingdom, and the Netherlands driven amongst others by the CCS Infrastructure Fund (CIF) and the Sustainable Energy Production and Climate Transition Incentive Scheme (SDE++). The CIF entails an investment of approximately USD 1.2 bn in CCUS in the UK. The SDE++ subsidizes market stakeholders including non-profit organizations that generate renewable energy or reduce CO_2 emissions on a large scale in the Netherlands. The SDE++ grant budget (around 9 billion in 2023 down from 13 billion in 2022) and greater investor confidence in the reliable functioning of the EU ETS played a major role in enabling the Port of Rotterdam CO_2 Transport Hub and Offshore Storage project (Porthos) project to move forward towards implementation. Porthos that is earmarked as a Project of Common European Interest (PCEI) will store around 37 Mton CO_2, approximately 2.5 Mton CO_2 per year for 15 years after public and private partners have taken a final investment decision. The APAC's and MENA's market share in CCUS is expected to remain about equal over this period, resulting in a declining market share for the Americas region.

Looking at planned CCUS projects, the United States maintains its leading position in both number of projects and overall capacity with 139 projects planned with a total capacity of 153.8 Mtpa. Out of these projects, the capacity for 37 of them has not yet been announced. Second in line is the United Kingdom with a total capacity of 53.2 Mtpa divided over 35 projects. The capacity of 17 additional projects has not been announced yet. Canada has 28 projects planned of which 18 have an announced capacity totaling 31.2 Mtpa.

Norway is the second European country present in the top 5 with 17 projects and a total announced capacity of 9.2 Mtpa. Finally, Australia appears in the top 5 which helps to keep the market share of the APAC region steady for the period between 2023 and 2025.

Moreover, a ranking of the top 10 planned CCUS projects has been developed based on their capture capacity capabilities, which is presented in Figure 15.

Figure 15: Top 10 largest planned CCUS projects by capacity (until 2032)

#	Project name[1)]	Country	Operational year	Carbon point source	Use type	Capacity [Mtpa]
1	**Ascension Clean Energy (ACE) complex (LA)**		2027	Energy generation – Hydrogen/ammonia	Dedicated storage	12.0
2	**Oil Sands CCUS Pathways to Net Zero (ALB) (14 facilities)**		2030	Energy generation – Other fuel transformation	Not specified	12.0
3	**Integrated clean ammonia production, Port of Corpus Christi (TX) phase 2**		t.b.d.	Energy generation – Hydrogen/ammonia	Not specified	10.0
4	**Illinois Clean Fuels Project (IL)**		2026	Energy generation – Biofuels	Dedicated storage	9.7
5	**Hynet Northwest phase 2**		2030	Energy generation – Hydrogen/ammonia	Dedicated storage	8.1
6	**Prairie State Generating Station Carbon Capture (IL)**		2025	Energy generation – Power and heat	Dedicated storage	7.2
7	**ExxonMobil Baytown petrochemical site (TX)**		2028	Energy generation – Other fuel transformation	Dedicated storage	7.0
8	**RWE Eemshaven power plant**		2030	Energy generation – Power and heat	Dedicated storage	7.0
9	**RWE Amer power plant**		2032	Energy generation – Power and heat	Not specified	5.5
10	**NextDecade Rio Grande LNG (TX)**		2025	Energy generation – Natural gas processing	Not specified	5.0

1) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources

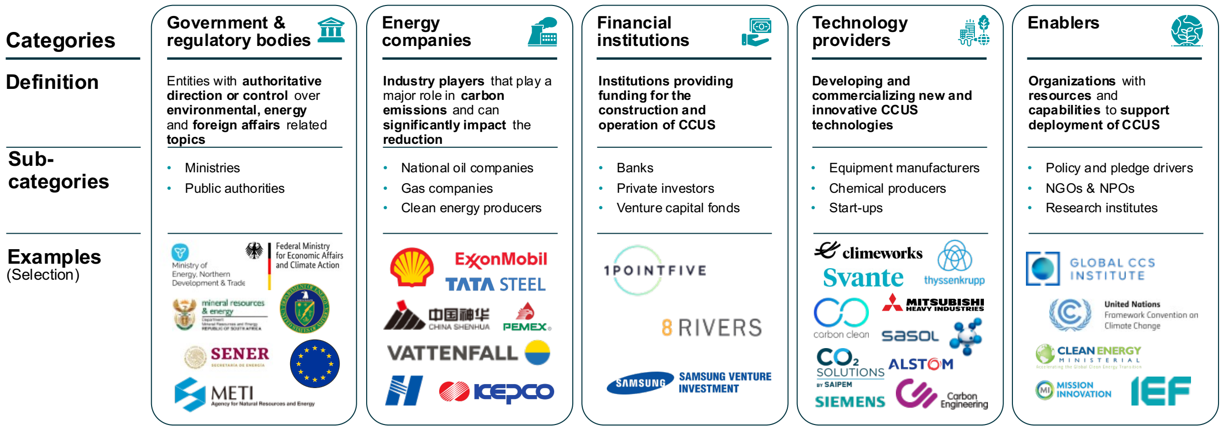
Source: IEA, desk research, Roland Berger

70% of the largest projects in the top 10 are located in the Americas with only 1 being in Canada and the remaining 6 in the United States. Three of the top 10 largest projects are located in Europe. This confirms Europe's growth in market share for the near future. Notable is the fact that all planned projects or projects under construction have energy generation as carbon point source.

6.3 Global CCUS stakeholder landscape

This section provides an overview of global stakeholders in CCUS, followed by a description of four different business models for integrated CCUS projects. To begin with, an assessment of five overarching stakeholder types has been developed as presented in Figure 16.

Figure 16: Categories of global stakeholders – Including examples



Source: Desk research, Roland Berger

Government & regulatory bodies

National governments play a critical role in supporting the development and deployment of CCUS technologies. They provide funding, regulatory frameworks, and policy incentives to encourage the uptake of CCUS. As overarching body, national governments also work together on international initiatives to promote the development of CCUS as a solution for climate change.

Industry players

Industry players, especially those in the hydrocarbon and hard to abate sectors, have a significant stake in the development of CCUS. They account for a large portion of global carbon emissions and share an interest in finding ways to reduce their carbon footprint with consumers and other stakeholders. Industry players can be active over the whole CCUS value chain, starting from implementing carbon capturing technologies for those that operate power plants or industrial facilities that produce large amounts of CO_2 emissions. Oil and gas companies with experience in pipeline construction and operation are well-suited to transport captured CO_2 through their existing pipeline networks. Industry players can gain competitive edge in globally evolving transitions by leveraging their expertise in drilling, well operations, and reservoir management as well as refining and petrochemical processes to develop and operate carbon storage projects. Examples of key players are Shell, KEPCO, Pemex, Vattenfall, Chevron, EQUINOR, and ExxonMobil.

Financial institutions

Investments from financial institutions are essential for the development and deployment of CCUS projects. These institutions can provide funding for the construction and operation of carbon capture, utilization, and storage infrastructure, as well as for research and development initiatives aimed at improving the efficiency and cost-effectiveness of CCUS technology. There are multiple financing options and each stage in the value chain has its own financing characteristics. The technology providers behind carbon capture technologies and equipment commonly acquire funding through venture capital and private investors. This especially applies to start-ups. Transportation infrastructure and project finance commonly acquire funding from larger financial institutions or national investment funds. Examples of key players are 1PointFive, 8Rivers and Samsung Venture Investment.

Technology providers

Development and commercialization of new and innovative CCUS innovations is ensured by technology providers. These companies play an important role in driving innovation and reducing the costs of CCUS. Technology providers are active in the technology behind the capturing of carbon, the transportation and storage and utilization of captured CO_2. This group consists of technology companies active in equipment manufacturing, chemical manufacturing, or pipeline manufacturing. Their innovations and expertise are critical for driving progress in the CCUS industry. According to a report by Research and Markets, as of 2021, the main markets for CCUS technology are the United States and Europe, where several companies offer capture technology solutions. Unexpectedly, there is no clear market leader, but the market share is divided among several companies. Other countries, such as China, Japan, and South Korea, are also investing heavily in CCUS technology and have multiple companies offering capture technology solutions. Examples of key players are Climeworks, Mitsubishi Heavy Industries, Svante, CO_2 solutions by SAIPEM, Carbon Engineering, Siemens, Alstom, and Sasol.

Enablers

Enablers are organizations or institutions that advance policies and funding in support of carbon management solutions such as CCUS. Intergovernmental organizations play a critical role in reducing both market and non-market hurdles to de-risk trade and investment in the deployment of these technologies.

Enablers can also provide training and education programs to help with the development of necessary skills and knowledge to implement and operate CCUS technology effectively. Knowledge is gained from research institutes which play an important role in the further development and deployment of CCUS. Key players are the International Energy Forum, Clean Energy Ministerial CCUS initiative, the Global CCS Institute, and the United Nations Framework Convention on Climate Change (UNFCCC).

An assessment of each stakeholder type has been developed to understand their positioning across the CCUS value chain. A summary of the results is provided in Figure 17.

Figure 27: Global key players

	Carbon capture	Transport	Utilization and storage
Description	• Provide **carbon capture solutions** and **services** for **industrial processes** and **power generation** • Different types of **players** active such as **equipment manufacturers**, **chemical producers** and **start-ups**	• Facilitate **transportation** of **captured CO_2** from **capture site** to **storage** or **utility site** • Different types of **transport** possible, by **pipeline**, **ship**, **truck** or **train**	• Utilize **captured carbon** as **feedstock** for **chemical** and **industrial processes** or use it for **Enhanced Oil Recovery** (EOR) • Store **captured carbon** in **depleted** O&G **reservoirs** of **O&G companies** or in **purchased CO_2 storage** (purchased by governments to reach climate goals)
Role	• **Largest share** of **Total Addressable Market** (TAM) • **Requires partners** in **transport**, **utilization** or **storage** to **implement CCUS projects**	• **Smaller share** of **TAM** • Requires **intensive capital investments** if **infrastructure not readily available**	• **Lowest share** of **TAM** • **Storage** is the **most adopted method** • **IEA** estimates **95%** of **captured CO_2** will be **stored** and **only 5% utilized**
Key stakeholders	ALSTOM, SIEMENS, MITSUBISHI HEAVY INDUSTRIES, carbon clean, GE, climeworks	KINDER MORGAN, nationalgrid, NIPPON GASES, MAERSK TANKERS, GASSCO, LarvikShipping	Schlumberger, pondtech, CARBON CURE, HALLIBURTON, Denbury
Active across the whole value chain	Shell, nrg, Peabody ENERGY, sse, AIR PRODUCTS, PEMEX, ADM, sasol, RioTinto, ENGIE, thyssenkrupp, Southern Company, TATA STEEL, VATTENFALL, ExxonMobil, KEPCO, 中国神华 CHINA SHENHUA, enhance, VEOLIA		

Active across the whole value chain

Source: Expert interviews, desk research, Roland Berger

Partnership models

There are two types of partnership models for CCUS project implementation. The first consists of an integrated model in which one entity is responsible and operates across the entire value chain. The second is a segmented model in which contractual agreements are developed across different players in the value chain.

Integrated model

An integrated model could be one of two types, a single entity owner or public-private partnership.

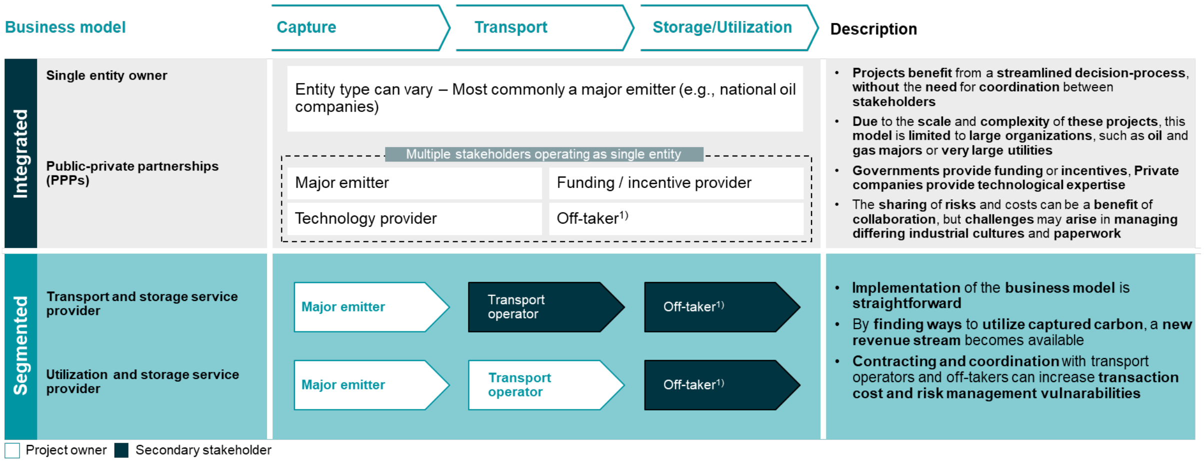
- **Single entity owner**
  The single entity owner represents one entity that is responsible for developing and implementing carbon capture, transport, utilization, and storage from end-to-end. One advantage of this model is the existence of one single point of control, which streamlines the process significantly. However, due to the demanding technical and economic requirements, only a limited number of entities are capable of independently developing CCUS. The primary players in this field are O&G and utility companies.
- **Public private partnerships**
  The public-private partnership option involves the government and private companies working together to develop the project. The government usually provides funding or incentives and regulatory support to enable the project implementation. Private companies provide technical expertise in CO_2 capture, transport, utilization, and storage. The costs and risks of the project are shared, as well as any revenues generated from the sale of CO_2 or products created from CO_2 utilization.

Segmented model

The segmented model also includes two options, transport and storage service providers or utilization and storage.

- **Transport and storage model**
  The transport and storage service providers option involves companies providing CO_2 transport and storage services to industrial facilities or power plants that need to reduce their carbon emissions. These companies can charge customers for the transport and storage of CO_2, either through a fee-per-ton or a fixed-price contract. The project may be financed by investors through equity or debt financing.
- **Utilization and storage model**
  The utilization and storage option involves companies capturing CO_2 emissions and using them as feedstock to produce chemicals or building materials. Any excess CO_2 that is not used can be stored underground, and the products created from CO_2 utilization can be sold to customers, providing a new revenue stream. This project can also be financed by investors through equity or debt financing.

Figure 18: Business models for integrated and segmented projects



1) Mainly O&G players for EOR

Source: Expert interviews, desk research, Roland Berger

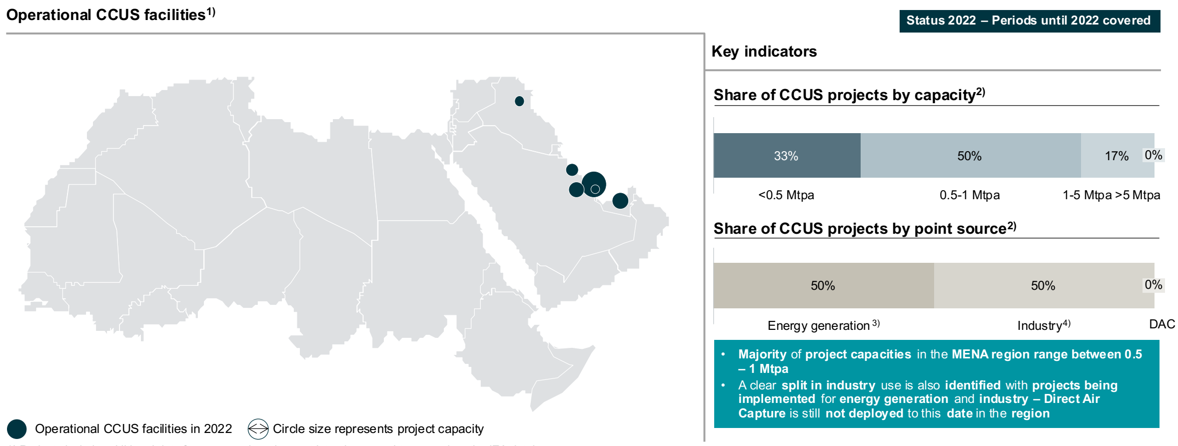
7. Market assessment of CCUS in the MENA region

The MENA market assessment is subjected to similar constraints of the IEA CCUS database mentioned in Section 6 (Market assessment of CCUS globally). However, additional research and expert interviews have been conducted to provide a holistic overview of MENA projects and capture additional efforts.

7.1 Overview of current CCUS projects

An assessment of projects divided by capacity and point source for the MENA region has been developed, as presented in Figure 19.

Figure 19: Overview operational CCUS projects in MENA



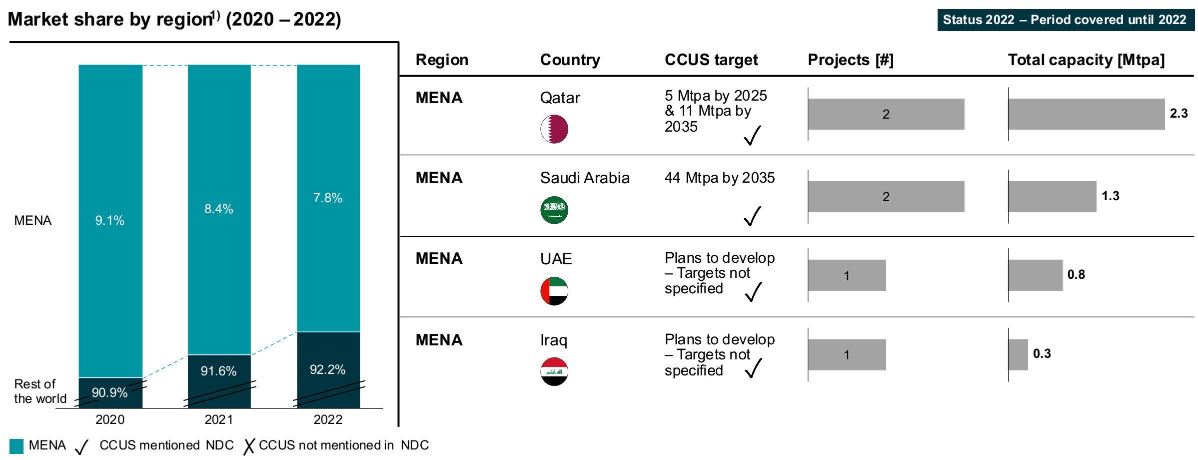
1) Projects include additional data from research and expert interviews used to expand on the IEA database;
2) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources;
3) Energy generation includes carbon capture from oil and gas, natural gas, biofuels, power and heat, hydrogen and ammonia, and other fuel transformation facilities including refineries, coal-to-gas, coal-to-liquids, and gas-to-liquids processes;
4) Industry includes carbon capture from cement, steel and iron, chemicals, and other industrial facilities including aluminum smelters, pulp and paper mills

Source: IEA CCUS database, Roland Berger

The capacity of CCUS projects in MENA region are mainly small-size (<0.5 Mtpa) and mid-scale (0.5-1 Mtpa) projects due to the early stages of CCUS technologies. As the MENA region has a strong presence in the oil and gas sector, a substantial portion of CCUS initiatives is observed in the energy generation and industrial sector.

Figure 20 shows the five leading countries in terms of both the number of projects and total project capacity.

Figure 20: CCUS market share and top countries in CCUS deployment in MENA



1) Market share is based on Technavio analysis – It is calculated based on estimated value and volume of carbon capture and storage activities across the whole value chain, an in-depth overview of the approach is provided in the Global Carbon Capture and Storage Market 2021-2025 report

Source: IEA, Technavio, desk research, Roland Berger

The six CCUS projects that are currently operational in the MENA region are located in Qatar, Saudi Arabia, the United Arab Emirates and Iraq. In the MENA region, the Middle East is leader in terms of CCUS projects, this has mainly to do with investment in CCUS by governments and major emitters in this region. Qatar has two CCUS projects in operations with a total capacity of 2.3 Mtpa, followed by Saudi Arabia with a total capacity of 1.3 Mtpa divided over two projects. The United Arab Emirates and Iraq both have one project with a capacity of 0.8 Mtpa and 0.3 Mtpa, respectively. The market share analysis shows a slight decrease over the period 2020-2022 for the MENA region which is caused by increasing activities of Europe in the field.

Figure 21 presents the individual projects situated in the MENA region. It provides a ranking based on the capacity of the CCUS projects. A case study featuring the three projects with the largest capacity can be found in Appendix B.

Figure 21: Top six largest operational CCUS projects by capacity in MENA

#	Project name	Country	Operational year	Carbon point source	Use type	Capacity [Mtpa]
1	Ras Laffan Qatar CCS Project Phase 1		2019	Energy generation – Natural gas processing	Dedicated storage	2.1
2	Uthmaniyah CO_2-EOR Demonstration Project		2015	Industry – Iron and steel	EOR	0.8
3	Al Reyadah CO_2-EOR Project Phase 1		2016	Energy generation – Natural gas processing	EOR	0.8
4	SABIC Carbon Capture & Utilisation Project		2015	Industry – Chemicals	Chemicals	0.5
5	Peshkabir Gas Capture and Injection Project		2020	Energy generation – Natural gas processing	EOR	0.3
6	Qatar Fuel Additives Company Methanol Project		2015	Industry – Methanol	Feedstock to boost methanol	0.2

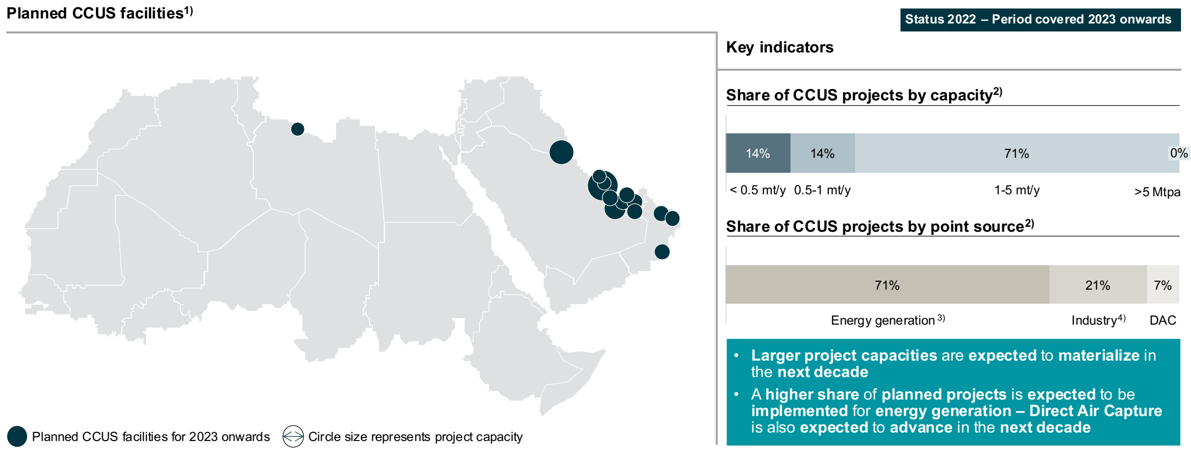
A case study is provided in the Appendix

Source: IEA, desk research, Roland Berger

7.2 Overview of future CCUS projects and plans

Figure 22 shows the geographical distribution of planned CCUS projects in the region. It also shows the division by capacity and point source for planned CCUS projects in the MENA region.

Figure 22: Overview of planned CCUS projects in MENA



1) Projects include additional data from research and expert interviews used to expand on the IEA database;
2) Projects include individual facilities solely dedicated to CCUS operations (excluding transport & storage hubs), aiming to capture the operational capabilities of CCUS technology and target specific emission sources;
3) Energy generation includes carbon capture from oil and gas, natural gas, biofuels, power and heat, hydrogen and ammonia, and other fuel transformation facilities including refineries, coal-to-gas, coal-to-liquids, and gas-to-liquids processes;
4) Industry includes carbon capture from cement, steel and iron, chemicals, and other industrial facilities including aluminum smelters, pulp and paper mills

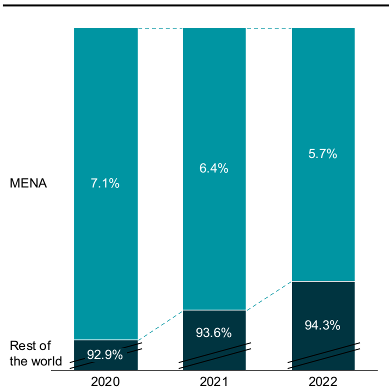
Source: IEA CCUS database, Roland Berger

The analysis comprises 15 planned CCUS projects in the MENA region. A significant shift in capacity of CCUS projects compared between projects currently in operation and planned projects can be observed. This is due to the maturation of CCUS technologies and results in an increase of large-scale projects. 71% of the planned CCUS projects in the MENA region are large-scale (1–5 Mtpa) projects, compared to c.17% of the projects in operation. Moreover, the point source remains stable because of the dominance of the oil and gas sector in the MENA region. These sectors are major emitters, and they are expected to address their emissions by adopting CCUS solutions.

Figure 23: CCUS market share and top 5 countries in planned CCUS deployment in MENA

Market share by region[1] (2023 – 2025)

Status 2022 – Period covered 2023 onwards



Region	Country	CCUS target	Projects [#]	Total capacity [Mtpa]
MENA	UAE	Plans to develop – Targets not specified ✓	3, 3	6.2
MENA	Oman	Not announced ✗	2, 1	0.0
MENA	Bahrain	Plans to develop – Targets not specified ✓	1, 1	0.5
MENA	Saudi Arabia[2]	44 Mtpa by 2035 ✓	1	9.0
MENA	Qatar	5 Mtpa by 2025 & 11 Mtpa by 2035 ✓	1	5.0

MENA ✓ CCUS mentioned NDC ✗ CCUS not mentioned in NDC ⬚ Unannounced capacity

1) Market share is based on Technavio analysis – It is calculated based on estimated value and volume of carbon capture and storage activities across the whole value chain, an in-depth overview of the approach is provided in the Global Carbon Capture and Storage Market 2021-2025 report; 2) This is a hub which includes multiple projects

Source: IEA, Technavio, desk research, Roland Berger

On country level, Figure 23 shows an increase of six planned CCUS projects for the United Arab Emirates, of which three projects have a total capacity of 6.2 Mtpa, and the remaining three projects have an unannounced capacity. Additionally, Oman plans three projects of which two are small scale and one project has an unannounced capacity. Bahrain has two projects planned of which one has a capacity of 0.5 Mtpa. Saudi Arabia plans one project, the Jubail CCS hub. This is a hub with a total capacity of 9.0 Mtpa and can be found in Figure 24.

Figure 24: Top 7 largest planned CCUS projects by capacity in MENA

#	Project name	Country	Comissioning	Carbon point source	Use type	Capacity [Mtpa]
1	Jubail CCS Hub[1]	Saudi Arabia	2027	Not specified	Not specified	9.0
2	Ras Laffan Qatar CCS Project Phase 2	Qatar	2025	Energy generation – Natural gas processing	EOR	5.0
3	Al-Zour CCS Project	Kuwait	2025	Energy generation – Oil	EOR	2.5
4	Shah Adnoc CCUS Project	UAE	2025	Energy generation – Gas	EOR	2.3
5	Al Reyadah CO2-EOR Project Phase 2	UAE	2025	Industry – Iron and steel	EOR	2.0
6	Habshan & Bab Adnoc CCUS Project	UAE	2025	Energy generation – Gas	EOR	1.9
7	Bahrain CCUS Pilot Project	Bahrain	2025	Energy generation – Oil	EOR	0.5

A case study is provided in Appendix B

1) The hub will include multiple projects

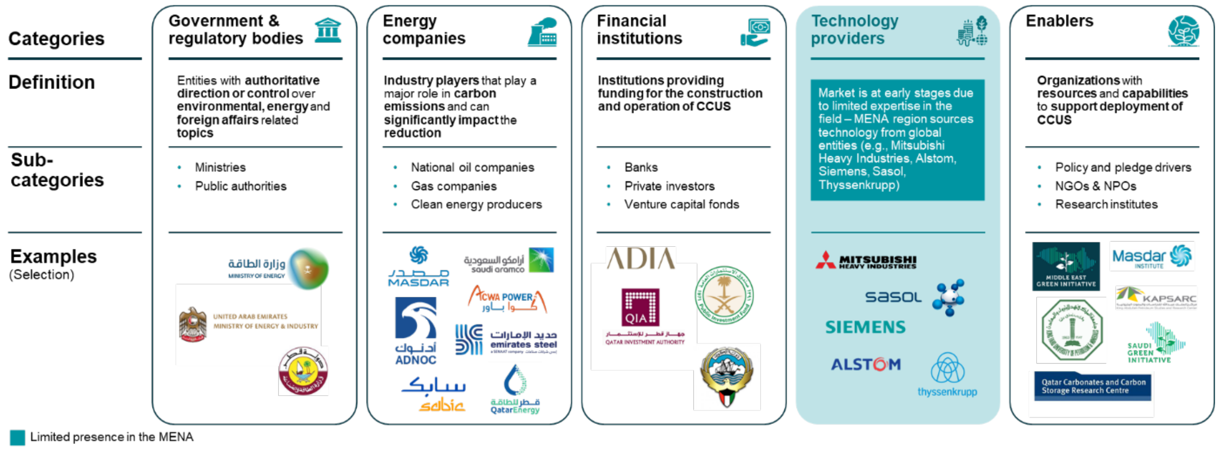
Source: IEA, desk research, Roland Berger

By 2027, the Jubail CCS hub will be operational in Saudi Arabia which is able to extract and store 9.0 Mtpa. Moreover, case studies for the Project Phase 2 of Ras Laffan Qatar CCS, Kuwait CCs project and Shah Adnoc CCUS are available in Appendix B.

7.3 MENA CCUS stakeholder landscape

This section provides an overview of MENA stakeholders for CCUS, followed by an overview of the commonly adopted business models of CCUS. The stakeholder landscape in MENA region has similarities with the global stakeholder landscape. Though, there are some differences which are highlighted below. As a beginning, an assessment of five overarching stakeholder types has been developed as presented in Figure 25.

Figure 25: Categories of MENA stakeholders



Source: Desk research, Roland Berger

Government & regulatory bodies

National governments in this region increasingly recognize the importance of CCUS for reducing carbon emissions and mitigating climate change. Several countries in this region, such as Saudi Arabia, the United Arab Emirates, and Qatar, have announced plans to develop CCUS infrastructure and are investing heavily in this area. Ministries and authorities play a crucial role as regulatory bodies in the development and deployment of CCUS. Examples of regulatory bodies that put great effort in CCUS are the Abu Dhabi Department of Energy, Qatar General Electricity and Water Corporation, and the Saudi Arabian Ministry of Energy.

Industry players

The hydrocarbon and other hard to abate sectors in the MENA region account for a large portion of regional carbon emissions and share an interest in finding ways to reduce their carbon footprint with consumers, including off takers and other stakeholders on international markets. National companies play a major role in reducing carbon emissions within this region and have a significant stake in the development and deployment of CCUS technologies. Many of these companies are investing in CCUS to reduce their carbon footprint and meet emission reduction targets. Examples of key players are Saudi Aramco, ADNOC and QatarEnergy.

Financial institutions

Financial institutions play an important role in the development and deployment of CCUS projects in the MENA region. Most of the investments are expected to come from national investment funds like the Public Investment Fund, Abu Dhabi Investment Authority, Kuwait Investment Authority, or Qatar Investment Authority. Besides national investment funds, national oil companies such as Saudi Aramco, ADNOC, and Qatargas invest in CCUS development and deployment.

Technology providers

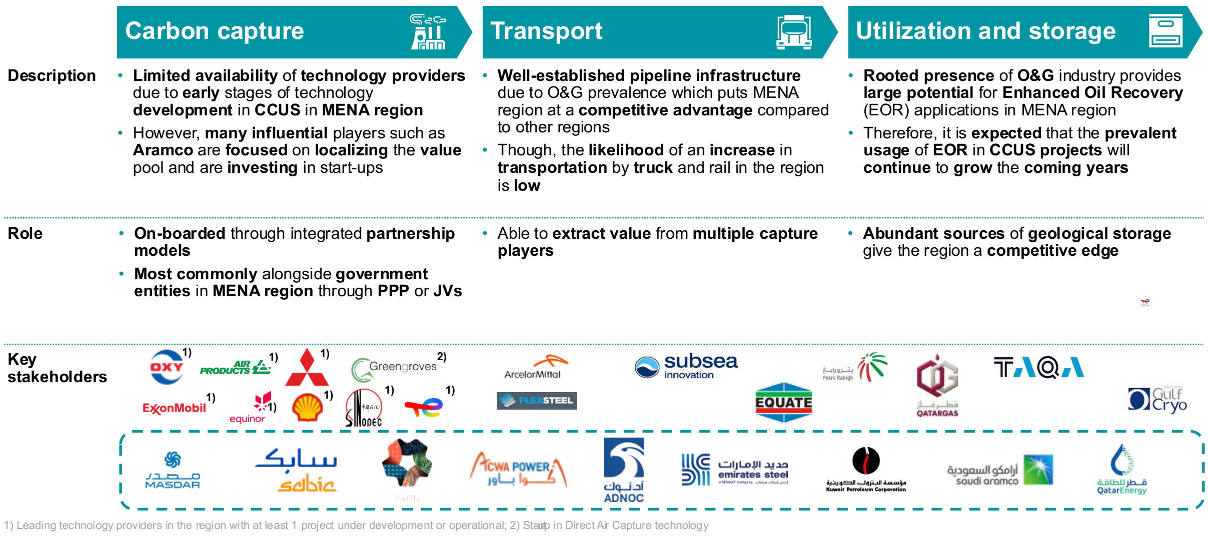
The MENA region has expertise in development and commercialization of new and innovative CCUS technologies but also leverages partnerships with industry partners and technology providers. Therefore, MENA region sources technology mainly from global entities like GE, Mitsubishi Heavy Industries, Siemens, Alstom, and Sasol. There are also a few start-ups in the region. An example is Green Groves, a start-up in Bahrain which produces artificial trees that capture and filter CO_2 or UAE-based Oxygenate that pursues bamboo based nature-based CCUS and renewable energy solutions.

Enablers

Finally, enablers in the MENA region are research and development institutions or national initiatives that promote efforts for the deployment of CCUS technologies. Their role is to advocate for measures that facilitate the implementation of CCUS and ensure that these technologies are widely adopted. Enablers are of great essence since they provide expertise by doing research and help to develop CCUS technologies. Examples of key players in this category are the Middle East Green Initiative, Masdar Institute, King Fahd University of Petroleum and Minerals, King Abdullah Petroleum Studies and Research Center, as well as Qatar Carbonates and Carbon Storage Research Centre and King Abdullah University of Science and Technology.

An assessment of each stakeholder type in the region has been developed to understand their positioning across the CCUS value chain. A summary of the results is provided in Figure 26.

Figure 36: MENA key players



Source: Expert interviews, desk research, Roland Berger

Partnership model

Due to the early stage in technological CCUS development within the MENA region, a preference for different partnership models is observed to develop and deploy CCUS on large scale. Therefore, the majority of CCUS business models in the MENA region are performed through segmented partnership models or through Public Private Partnerships (PPP)s as indicated in section 6.3.

The main advantage of these models is minimizing risk due to the involvement of multiple partners and experts across the value chain. One key disadvantage is the coordination effort between the stakeholders and the risk of one partner stepping out.

8. CCUS challenges and opportunities

8.1 Challenges for the effective implementation of CCUS

There are several challenges associated with CCUS that must be addressed to ensure its effectiveness and viability as a tool for mitigating carbon emissions. In this section, the report will discuss the challenges related to CCUS including economic viability, infrastructure readiness, and the regulatory landscape.

- **Economic feasibility**

  One of the significant challenges associated with CCUS is the economic feasibility of the technology. The cost of CCUS deployment can be high, making it challenging for some industries or regions to employ it as a mitigation strategy for fighting climate change.

  One of the primary cost drivers of CCUS is the capture technology. The development and deployment of carbon capture technology can be costly, particularly for retrofitting existing industrial processes or power plants. The cost of carbon capture technology depends on the type of technology used, the scale of the project, and the specific requirements of the capture process.

  Transportation and storage of CO_2 are additional drivers for the cost of CCUS projects. Transporting CO_2 over long distances requires pipelines or other forms of transportation, which can be expensive to construct and maintain. The cost of storage depends on the geological characteristics of the storage site and the monitoring requirements to ensure the safe and secure storage of CO_2.

  Overcoming the economic challenges associated with CCUS requires a range of solutions. Financing mechanisms, research and development, policies and regulatory support, as well as knowledge sharing are key aspects for overcoming this challenge. Policies such as carbon pricing or emissions trading schemes can provide a clear economic signal for the deployment of CCUS projects.

- **Infrastructure readiness**

  The infrastructure readiness challenge associated with CCUS is multi-faceted and requires an integrative approach to overcome. To implement CCUS effectively, it is necessary to have infrastructure in place for each step of the value chain including capture, transport, and storage.

  Developing and deploying the necessary infrastructure for CCUS can be challenging, particularly in developing countries where infrastructure may still be limited. In these regions, investment in infrastructure development is crucial for the adoption of CCUS. This includes building of new pipelines, transportation systems, constructing storage facilities in suitable geological formations, retrofitting power plants as well as industrial processes with carbon capture equipment.

  Another critical aspect of infrastructure readiness is the availability of suitable storage sites. Identifying and developing suitable storage sites is a critical challenge associated with CCUS. Suitable storage sites must be able to safely store CO_2 over long periods, without leakage or environmental impacts. This requires detailed geological assessments to determine the suitability of storage sites and monitoring reporting and verification to ensure the safe and secure storage of CO_2.

- **Regulatory landscape**

  The success of CCUS depends on regulatory support and policies that incentivize the implementation of the technology. The lack of supportive policies and regulations can be a barrier to the adoption of CCUS. Policies that promote investment in research and development, provide financial incentives for the implementation of CCUS, and set emissions reduction targets will encourage the implementation of CCUS.

  The main challenge related to the creation of a clear regulatory framework is the establishment of cohesive and complementary industry standards to allow CCUS to scale faster. Other ideas would be effective implementation of emission reduction targets through market incentives such as carbon price discovery mechanisms and government support measures such as contracts for difference or tax allowances.

  The implementation of CCUS policies requires global cooperation and coordination to ensure that the technology is implemented effectively and efficiently. This requires international agreements and dialogue and cooperation between governments, industries, and other stakeholders.

  In addition to the lack of a clear consistent and compatible regulatory frameworks, there are also challenges associated with the permitting process for CCUS projects. The current permitting process can be lengthy and complex, requiring approvals from multiple agencies and stakeholders. This can lead to delays and increased costs for CCUS projects.

  Legal and regulatory challenges are a significant barrier to the deployment of CCUS and require a range of solutions to be overcome. Establishing clear and consistent regulatory frameworks, developing international standards, collaboration among stakeholders, education and outreach efforts are all critical steps to overcome the challenges associated with CCUS.

8.2 Opportunities for the implementation of CCUS

CCUS presents a range of opportunities to achieve climate and sustainable development goals including, the creation of jobs, enhancing international competitiveness and other economic benefits. These opportunities can be seen across a range of sectors, including energy generation, industrial processes, technology advancement and transportation. In this section, the opportunities related to CCUS will be discussed. This includes environmental, economic, and new market development opportunities.

- **Environmental opportunities**

  CCUS has promising applications in the decarbonization of hard-to-abate sectors. Specifically, energy generation and industrial processes are two of the major sectors in which CCUS presents an opportunity for emission reduction.

  Energy generation: CCUS can be applied to energy generation processes, helping to reduce emissions from the electricity sector. This can play a significant role in reducing the carbon footprint of electricity generation, which is a major contributor to global greenhouse gas emissions. CCUS can help to abate GHG emissions from existing energy production and infrastructure to ensure energy security and market stability in support of reliable energy system transformations. By retrofitting existing power plants with CCUS technologies, they can continue to operate while reducing their emissions.

  Industrial processes: CCUS can be applied to a range of industrial processes, such as cement and steel production which are responsible for a significant proportion of global greenhouse gas emissions. By capturing and storing carbon dioxide emissions from these sectors, CCUS can help to decarbonize the industries and can contribute to the global efforts to address climate change. Decarbonization of industrial processes can also help industries to achieve carbon-neutral status, as the captured carbon dioxide can be utilized for enhanced oil recovery (EOR), materials, e-fuels or for other purposes.

- **Economic development**

  The deployment of CCUS requires a wide range of skills and expertise, from engineering and construction to monitoring and maintenance. This can create new job opportunities in a range of sectors, helping to boost local economies and create new economic activities. The development and deployment of CCUS technologies can also create new revenue streams for companies involved, helping to drive innovation and investment in this area.

  Specifically in the MENA region, CCUS has a promising future. Being already a leading energy exporting region, CCUS could allow MENA to boost its exports with decarbonized energy, delivering a double benefit of supporting the economy while supporting climate targets. Current projections estimate that new market opportunities in hydrogen export and CO_2 storage services could add USD c.15.5 bn to 44 bn in gross value added (GVA) to the GCC in 2050. Job opportunities would also be significant with estimated c.87,000 to 245,000 direct and indirect new jobs by 2050 (AFRY & GaffneyCline, 2022).

- **New markets development**

  The development of new markets for CCUS technologies is a key opportunity for driving the deployment of carbon capture, transport, utilization, and storage technologies. As countries and companies strive to reduce their greenhouse gas emissions and meet their climate targets, there is an increasing demand for CCUS technologies that can help to achieve these goals.

  One of the key markets for CCUS technologies is in the oil and gas industry. CCUS can be utilized for enhanced oil recovery (EOR). This is a process that involves injecting carbon dioxide into oil reservoirs to increase the amount of oil that can be extracted. Carbon dioxide can also be utilized for other purposes, such as producing chemicals or fuels. These markets can provide a new source of revenue for CCUS projects and help to drive investment in the development and deployment of CCUS technologies.

Another potential market for CCUS technologies is in the production of clean hydrogen. Hydrogen is a versatile energy carrier that can be used in a range of applications, including transportation, heating, and electricity generation. However, the production of hydrogen can be carbon-intensive, as it is often produced from fossil fuels. CCUS can be used to capture the carbon dioxide emissions from hydrogen production, creating clean or carbon-neutral hydrogen that can be used to support the transition.

There is also a growing market for carbon offsets which can be used by companies to compensate for their greenhouse gas emissions. CCUS projects can generate carbon offsets by capturing and storing carbon dioxide emissions while enhancing economic viability by providing a new source of revenue for these projects at the same time. As more companies seek to reduce their carbon footprint, the demand for carbon offsets will increase, creating a new market for CCUS technologies including nature based CCUS solutions.

The development of new markets for CCUS technologies presents significant opportunities for driving the deployment of these technologies and supporting the transition to a low-carbon economy and achieve climate and sustainable development targets.

9. Role and collaboration opportunities of CCERC in CCUS

9.1 Technical knowledge building

Academia, research centers and big oil & gas companies play a significant role in the creation of technical knowledge for CCUS in the Middle East. Academia and research centers provide necessary expertise and resources to develop new CCUS technologies and test them in real-world conditions. They work on developing new materials, technologies, and processes that can improve the efficiency and effectiveness of CCUS. Academic and research centers with advanced CCUS technological knowledge offer technical support and training to those that are in earlier stages of development. With CCERC this is done both regionally within the countries but also internationally within the MENA region.

Big oil & gas companies in the Middle East have significant experience and resources in developing and implementing CCUS technologies, and they share this knowledge with other countries that are in earlier stages of CCUS development. This can take many forms, such as sharing technical expertise, technical support, or collaborating on joint projects. CCERC makes this technical knowledge more accessible to countries that are in earlier stages of CCUS adoption.

9.2 Human capability building

The development of CCUS technology requires a skilled workforce with expertise in areas such as engineering, geology, and environmental and data sciences (STEM). This is where human capability building comes in, which is essential for ensuring the successful deployment of CCUS technology in the MENA region.

There are several institutions in the MENA region that are actively involved in CCUS research and development. Qatar is home to the Qatar Environment and Energy Research Institute (QEERI), which is part of Hamad Bin Khalifa University (HBKU). QEERI focuses on the industrial utilization of CO_2 for value-added materials and commodities. QEERI's Energy Center mandate is to support the competitiveness and sustainability of Qatar's energy sector through the development and deployment of technological solutions. This includes developing and improving carbon capture technologies and innovation in the uses of CO_2 through new technologies to make it more attractive in the long term. QEERI's CCUS project is developing processes and technologies to be able to convert CO_2 into value-added products aimed at reducing the carbon footprint.

Moreover, Qatar Carbonates and Carbon Storage Research Centre (QCCSRC) at Imperial College London, offers a range of research programs and training courses related to CCUS. Examples of the courses offered by QCCSRC are Fundamentals of CO_2 Capture and Storage, Modelling and Simulation of CO_2 storage, Advanced Methods for CO_2 Storage and Monitoring and Industrial Applications of CO_2 Capture and Utilization. These courses help to build human capital for the energy, the environmental, and engineering sectors. Additionally, they offer insights for students and researchers interested in CCUS technology.

Saudi Arabia's King Abdullah Petroleum Studies and Research Center (KAPSARC), King Fahd University of Petroleum and Minerals (KFUPM), King Abdullah University of Science (KAUST), as well as other institutions such as the Masdar Institute of Science and Technology in Abu Dhabi offer research and training programs related to CCUS.

By investing in education and training programs, the MENA region can develop a workforce that is skilled in the latest technologies and practices, which can help to attract foreign investment and spur economic growth. Furthermore, a well-trained workforce can help to build capacity for the future, ensuring that the region remains competitive and innovative in the global CCUS landscape.

In addition to the institutions mentioned above, there are other opportunities for collaboration in the field of human capability building for CCUS technology in the MENA region. For example, partnerships between academia and industry can help to bridge the gap between theory and practice and can provide valuable hands-on experience to students. Furthermore, international partnerships can help to bring in expertise and resources from other parts of the world, which can accelerate the development and deployment of CCUS technology in the MENA region. For example, in 2022, the Global Carbon Capture and Storage Institute has opened its first Middle East headquarters in Masdar City, Abu Dhabi. International cooperation initiatives can help to share knowledge and best practices, coordinate research and development efforts, and provide financial support to accelerate the deployment of this critical technology. By working together, countries can innovate and scale CCUS technologies faster and achieve better results than if they were working alone.

Human capability building is essential for the successful development and deployment of CCUS technology in the MENA region. By investing in education and training programs, the region can develop a skilled workforce that has sufficient, shared knowledge which is accessible because of CCERC, to develop and deploy CCUS technologies. Through CCERC, the MENA region has the potential to emerge as a prominent global player in the field of CCUS. This could pave the way for long-term innovation and sustainable development in the region.

9.3 Policy making

CCUS technology has the potential to significantly reduce carbon emissions, but its economic viability must be improved to accelerate global deployment at scale. To make CCUS more attractive governmental support mechanisms (including contracts for difference, tax incentives and a transparent and stable regulatory environment that may include carbon price discovery mechanisms such as the EU ETS provides or voluntary carbon markets) should be pursued in different settings. This will create an economic incentive to develop emission reduction methods such as CCUS and make carbon abatement more economically advantageous.

The carbon market provides a greenhouse gas emission price discovery mechanism that is already functioning in the European Union, the United Kingdom, and Australia though scope and operational aspects differ. Some initiatives have already emerged in the MENA region, such as Saudi Arabia's Regional Voluntary Carbon Market Company which will facilitate carbon credit auctions, and the United Arab Emirates' regulated carbon credit trading exchange and clearing house.

Moreover, Saudi Arabia’s GHG Crediting and Offsetting Mechanism (GCOM) is designed to incentivize and promote GHG reduction and removal efforts. Usually, such Mechanisms allow organizations or entities to earn credits from their emission reduction and/ or removal activities, and these credits can be sold or traded to other entities to offset their own emissions.

Through establishing a competitive carbon market or incentivizing market players through an offsetting and crediting Mechanism, CCUS technology can become a more economically viable solution to reducing carbon emissions in the MENA region. This would not only create a more sustainable future but also drive innovation and economic growth in the region.

Part of CCERC is sharing knowledge of frameworks and regulations related to CCUS among countries. To achieve this objective, a report has been created that outlines guiding principles for carbon policies. The main objective of the report is to offer a summary overview of the regulatory environment of CCUS, and its ability to contribute towards global and regional climate goals. By analyzing the prospects and obstacles connected with CCUS regulations, the report intends to be a valuable source of information for policymakers, investors, and industry stakeholders interested in promoting sustainable development.

Moreover, another report on this topic has been published under the title "CCUS Regulatory and Policy Landscape – A Global and MENA perspective". It can be found on the IEF and CCE Knowledge Hub websites.

9.4 Investment opportunities

CCUS is a capital-intensive technology, which means that it requires significant investment to be viable. To make CCUS projects financially viable, it is essential to choose the most profitable investment opportunities.

One of the most critical factors in selecting efficient investment opportunities for CCUS projects is the proximity of hubs to industrial clusters. Hubs that are located near industrial clusters can reduce transportation costs which makes projects financially more viable also for smaller market participants. These hubs can capture larger CO_2 volumes by aggregating streams from various emitters, which can also help to reduce costs.

Several potential hubs are being considered in the GCC region, taking into account their proximity to industrial clusters and transportation costs. On the eastern and western coasts of Saudi Arabia, the regions near Jubail and Yanbu have already been earmarked. CO_2 captured in these hubs can be transported to Rub'al-Khali or Red Sea Basin aquifers for storage.

On the United Arab Emirates coast, the regions near Dubai and Abu Dhabi are the most likely to develop hubs. CO_2 captured in these hubs could be transported to Rub'al-Khali or Oman Ophiolite for storage. In northern Qatar, the region near Ras Laffan is the most suitable to develop a hub. CO_2 captured in this hub could be transported to the Jubail hub or Rub'al-Khali for storage. The southern and eastern regions of Qatar also have important industrial clusters that are suitable to have a second hub.

In Northern Oman, it is also suitable to develop a hub. CO_2 captured in this hub can be transported to the Oman Ophiolite, which has a storage capacity of 8.2 CO_2 Gt. (AFRY & GaffneyCline, 2022) However, the storage efficiency of the Oman Ophiolite needs to be further assessed.

In Kuwait, the region near Shuaiba is the most suitable to develop a hub. The captured CO_2 can also be transported to Qatar. Finally, in northeastern Bahrain, the regions near Hidd, Sitra, and Askar are the most suitable to develop a hub. CO_2 captured in this hub can be transported to Jubail.

The GCC region has several potential hubs that can be developed with careful planning and investment, which will help to stimulate CCUS development and deployment within the MENA region. CCERC helps with the development of these hubs by allowing stakeholders to capitalize on the comparative advantages and accelerate CCUS deployment through the regional markets and resources they share.

10. Conclusion

Carbon capture, utilization, and storage (CCUS) is a critical technology to combat climate change, especially in regions where hydrocarbon power demand is a significant contributor to greenhouse gas emissions. Countries like the United States, China, India, the United Kingdom, and Saudi Arabia have already set ambitions for the use of CCUS in their Nationally Determined Contributions. CCUS technology is effective in removing heavy emissions from hard-to-abate industries such as cement and steel production.

The economic feasibility of CCUS remains a critical factor in its widespread adoption. The high cost of CCUS technologies can be attributed to various factors, including the complexity of the technology, the high energy requirements, and the cost of building the necessary infrastructure. The total costs across all the steps of the value chain could reach up to USD c.370 per ton of CO_2. Nonetheless, the future expected cost of CCUS technologies is projected to decline significantly due to several reasons, including technological advancements, economies of scale, and increased competition. Achieving these cost reductions requires a significant focus on research and development, demonstration projects, and government incentives. Moreover, carbon price discovery mechanisms can encourage the use of CCUS technologies since it incentivizes market players to reduce their emissions. Emissions trading schemes aim to incentivize industries to reduce their emissions by allocating a price on greenhouse emissions. The revenue they generate could also be used to finance CCUS technologies, especially research and development in the sector.

Currently, there are 53 CCUS projects in operation with a total capture capacity of c.103 Mtpa. The Americas are leading in the field of CCUS with the highest number of projects, followed by the APAC region, Europe and MENA region. The CCUS industry is expected to experience significant growth by 2030. The Americas region will continue to have a strong presence in the market, and Europe is projected to see a notable increase in market share from 10% in 2022 to 38% in 2030.

The MENA region, Qatar, Saudi Arabia, the United Arab Emirates, and Iraq have current operational CCUS projects. Those are the leading countries in terms of CCUS in the Middle East due to investment by governments and major emitters. The MENA region is projected to have a total of 13 operational CCUS projects by 2030, with most of them being planned in the oil and gas, chemicals, and power generation sector. In addition, there is an expected shift in capacity towards large-scale projects due to the maturation of CCUS technologies over the years. Furthermore, the MENA region has a significant potential for CCUS deployment to reduce emissions from hard-to-abate sectors.

The results of our analysis demonstrate that there is a significant gap between the potential market and actual capture market projections. The gap represents the potential for further CCUS deployment in the MENA region and beyond. The results showed that only 1.5% of the potential market will be captured by 2030 with the operational and planned capacity, indicating the possibility for significant investment in CCUS projects in the region. Therefore, to ensure CCUS projects will be deployed, the region must collaborate. This highlights the role of the CCE Regional Collaboration.

The CCERC ensures technical knowledge building within the MENA region and makes information more accessible to countries in earlier stages of CCUS adoption. Furthermore, human capital building is an important part of CCERC. The platform bridges the gap between theory and practice by fostering partnerships between academia and industry through providing training about CCUS. It also provides individuals with valuable hands-on experience. Moreover, as part of CCERC a policy report was set up which aims to be a useful resource for decision-makers, investors, and industry stakeholders. The main objective of the report was to offer a complete overview of the regulatory environment of CCUS. The policy report outlined guiding principles for carbon policies which can support countries to set up their own policy. Finally, it is important that the most efficient investment opportunities are chosen. CCERC brings all stakeholders together which makes it easier to collaborate and develop efficient CCUS hubs in the MENA region.

In conclusion, accelerating investments in CCUS is crucial for reducing emissions, mitigating climate risks, and contributing to the attainment of global climate objectives and sustainable development goals in the MENA region and globally. While there are current economic and technological challenges to the widespread adoption of CCUS, continued advancement in the sector is expected to further increase its adoption in the future.

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Appendix A

Century Gas Processing Plan

Project characteristics	Details
Country	United States (Texas)
CO_2 savings	4.3 Mtpa
Partnerships	Occidental Petroleum, Sandridge Energy
CCUS	-
Business type	Captured CO_2 is transported through a 160 km onshore pipeline into the Kinder Morgan Permian delivery system for EOR purposes
Planning	2010: Phase I operational 2012: Phase II operational
Capture type	Solvent-based physical absorption
Transport type	Onshore pipeline
Storage type	Storage & EOR

Gordon CCUS Project

Project characteristics	Details
Country	Australia
CO_2 savings	4.0 Mtpa
Partnerships	Chevron, ExxonMobiil, Shell, Osaka Gas, Tokyo Gas, JERA and the Australian government
CCUS	-
Business type	CO_2 is captured from offshore gas reservoirs and then injected into a giant sandstone formation beneath Barrow Island, in the Dupuy Formation, where it is permanently trapped
Planning	2019: Operational
Capture type	Amine solvent-based absorption
Transport type	Onshore pipeline
Storage type	Storage

Appendix B

Ras Laffan Qatar CCS Project

Project characteristics	Details
Country	Qatar
CO_2 savings	Phase 1: 2.1 Mtpa Phase 2: 5.0 Mtpa
Partnerships	Qatar Petroleum, ExxonMobil, TotalEnergies, Royal Dutch Shell and the Qatari government
CCUS	Phase I stores the carbon permanently. Phase II will include EOR purposes
Business type	Phase I captures carbon from a gas liquefaction plant at Ras Laffan. The CO_2 is than piped and re-injected into the Dunkhan oilfield for permanent geological storage
Planning	2015: Phase 1 operational 2025: Phase 2 operational with a capture capacity of 5.0 Mtpa and will include EOR
Capture type	Acid gas injection
Transport type	Onshore pipeline
Storage type	Storage & EOR

Uthmaniyah CO_2-EOR Demonstration Project

Project characteristics	Details
Country	Saudi Arabia
CO_2 savings	0.8 Mtpa
Partnerships	Saudi Aramco, Air products and the Saudi Arabian government
CCUS	7 to 9% of CO_2 is used for EOR and 40% is permanently sequestered
Business type	CO_2 is captured from the Hawiyah Natural Gas Liquids (NGL) plant and then transported for injection into the Uthmaniyah in the Ghawar oilfield, the largest oil field in the world
Planning	2015: Operational
Capture type	Amine solvent-based absorption
Transport type	Onshore pipeline
Storage type	Storage & EOR

Al Reyadah CO_2-EOR Project Phase 1

Project characteristics	Details
Country	United Arab Emirates
CO_2 savings	0.8 Mtpa
Partnerships	Mitsubishi Heavy industries, Masdar, Abu Dhabi National Oil Company (ADNOC) and the Abu Dhabi government
CCUS	90% of CO_2 is captured
Business type	Capture, compress, and dehydrates CO_2 from the Emirates Steel plant in Abu Dhabi. The CO_2 is then transported and injected into onshore oilfields for EOR purposes
Planning	2016: Operational 2030: Phase 2 will be operational with capacity of 5 Mt per year
Capture type	Amine solvent-based absorption
Transport type	Onshore pipeline
Storage type	EOR

Al-Zour CCS Project

Project characteristics	Details
Country	Kuwait
CO_2 savings	2.5 Mtpa
Partnerships	Kuwait Integrated Petroleum Industries Company (KIPIC) and Fluor Corporation
CCUS	-
Business type	Construction of a pipeline infrastructure to transport captured CO_2 from the Al-Zour refinery to the Umm Niqa formation (deep saline aquifer). CO_2 will then be used for EOR
Planning	2025: Operational
Capture type	Post-combustion capture technology that involves the use of an amine-based solvent
Transport type	Onshore pipeline
Storage type	Storage & EOR

Shah ADNOC CCUS Project

Project characteristics	Details
Country	Abu Dhabi
CO_2 savings	2.3 Mtpa
Partnerships	ADNOC, Occidental Petroleum and Abu Dhabi Future Energy Company (Madar)
CCUS	-
Business type	The plant processes sour gas and associated condensates, composed by over 10 % of CO_2. The CO_2 would be piped and stored in an onshore field in the Liwa Desert for EOR
Planning	2025: Operational 2030: 2nd phase with an expected increase of total CO_2 capture for EOR of 5.0 Mtpa
Capture type	Second and third generation capture technologies with a pre-combustion separation type
Transport type	Onshore pipeline
Storage type	Storage & EOR

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