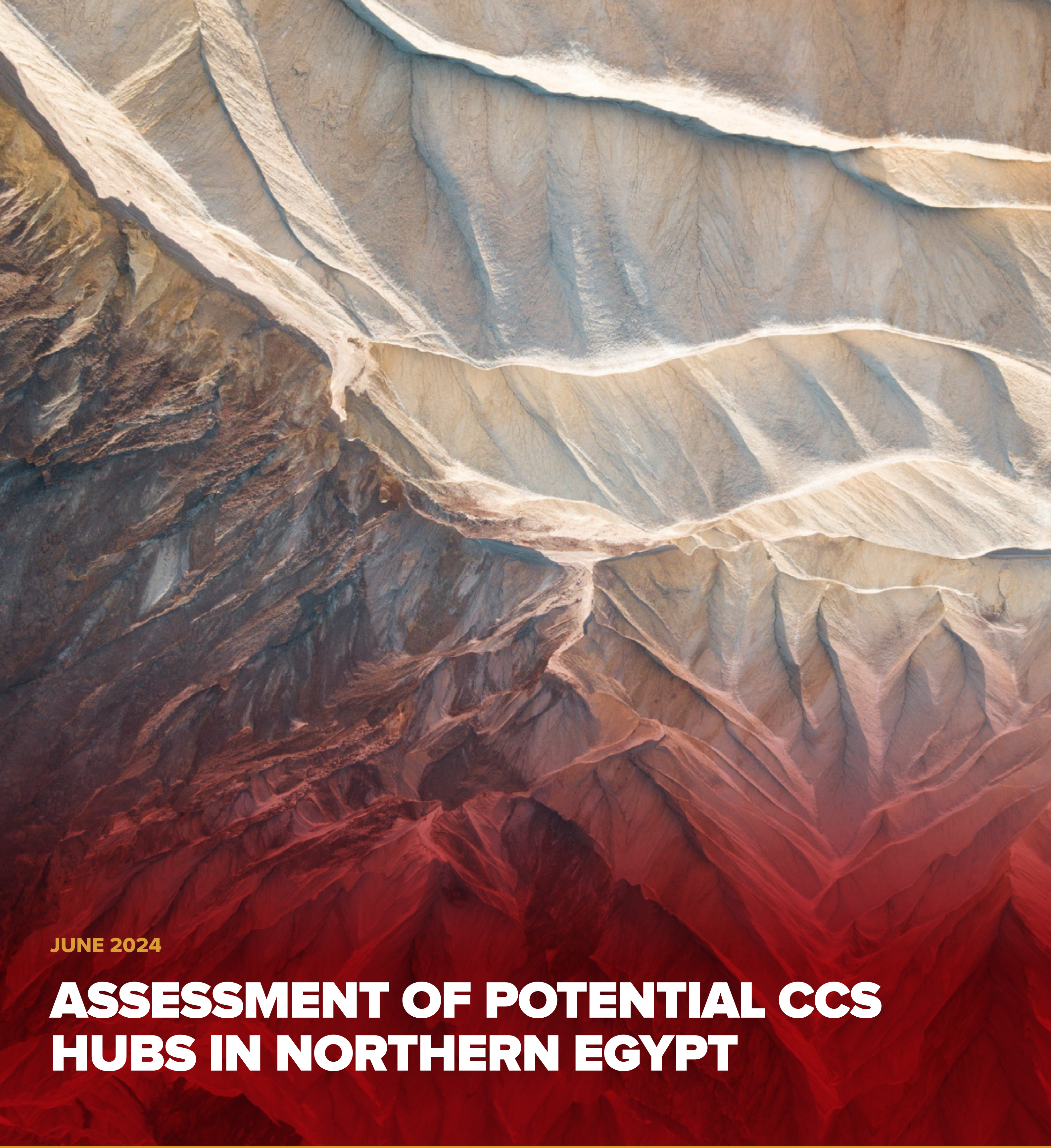

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ASSESSMENT OF POTENTIAL CCS HUBS IN NORTHERN EGYPT

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CONTENTS

1.0 AIM 4

2.0 KEY FINDINGS 5

3.0 REVIEW OF CCS POLICY IN EGYPT 6

4.0 REGULATION OF CCS ACTIVITIES IN EGYPT 17

5.0 CO_2 STORAGE RESOURCE ASSESSMENT 33

6.0 EGYPT CCS HUBS 40

7.0 ECONOMICS 85

8.0 REFERENCES 96

APPENDIX A: INTERNATIONAL CCS POLICY 105

- A.1 INTERNATIONAL CCS POLICY DEVELOPMENTS 105
- A.2 FISCAL AND COMMERCIAL MECHANISMS FOR CCS – AN INTERNATIONAL OVERVIEW 108

APPENDIX B: EGYPT EMISSIONS SOURCES 123

APPENDIX C: CARBON CAPTURE TECHNO-ECONOMIC ASSESSMENT METHODOLOGY 128

APPENDIX D: PIPELINE AND COMPRESSION COST ESTIMATE METHODOLOGY 132

APPENDIX E: STEAM METHANE REFORMER COST ESTIMATE METHODOLOGY 135

Acronyms

ADB	Asian Development Bank
abs	Absolute
AGRU	Acid Gas Recovery Unit
USD	United States Dollar
CAT	Climate Action Tracker
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon capture and storage
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
DAC	Direct Air Capture
DBNGP	Dampier Bunbury Natural Gas Pipeline
EBRD	European Bank for Reconstruction and Development
EEAA	Egyptian Environmental Affairs Agency
EIA	Environmental Impact Assessment
EIB	European Investment Bank
EGP	Egyptian pounds
ESG	Environment, Social and Governance
FEED	Front-end engineering and design
GCF	Green Climate Fund
GBP	Green Bond Principles; British pound sterling
GEF	Global Environment Facility
GEFF	Green Economy Financing Facility
GJ	Gigajoule
ICMA	International Capital Market Association
IFC	International Finance Corporation
ITMOs	Internationally Transferred Mitigation Outcomes
kg	Kilogram
kPa	Kilopascal
LNG	Liquefied natural gas
mol	Molar
MRV	Monitoring, Reporting and Verification
Mtpa	Million tonnes per annum
MW	Megawatt
NCCS	National Climate Change Strategy
NDC	Nationally Determined Contribution
NOK	Norwegian Kroner
OCGT	Open cycle gas turbine
PV	Present value
SAM	Social accounting matrix
tCO_2	Tonne of carbon dioxide
USD	US dollars
USDW	Underground sources of drinking water
WBG	World Bank Group
wt	Weight
vol	Volume

Disclaimer

1.0 AIM

The aim of this study is to explore the potential for Egypt to develop ambitious carbon capture and storage (CCS) hubs to reduce its industrial CO_2 emissions. We begin by evaluating the policy, legal and regulatory framework and identify where changes may be needed to enable the development of CCS hubs. We analyse the available geologic storage capacity in depleted oil and gas fields as well as saline aquifers to determine if sufficient storage is available to serve large-scale CCS hubs. Based on our understanding of storage, we then design both a grand-scale CCS hub as well as a series of local CCS hubs that can ramp up to capture the same tonnes of CO_2 per year as the large single hub system. The local hub approach is preferred for several reasons. Finally, we assess the economic implications for Egypt by investing in the staged series of local hubs, explore additional low-carbon product export opportunities, and identify possible sources of finance for the hubs.

2.0 KEY FINDINGS

2.1 Policy

1. Egypt's National Climate Change Strategy 2050 is a wide-ranging document covering a broad range of topics from sustainable economic growth to enhancing scientific research. While it has only one explicit reference to CCS, there are several directions, performance indicators, policies, and tools that could potentially support CCS projects in Egypt.
2. There have been several policy developments at the national and sub-national level around the world that support CCS projects. A regional overview of policy regimes from key jurisdictions is included to provide context on potential adaptation to the Egyptian context. While these policy regimes are in varying stages of implementation, some are more mature than others.
3. There are several examples of incentives that have enabled technical demonstrations and trials, and commercial developments for CCS projects. Some examples of various incentivisation schemes are also included. Jurisdictions have employed a combination of tax credits, bonds, grants, and loans to spur innovation and to deploy capital to CCS. In addition, taxes have also been used by governments to motivate industry and to align policy and regulatory frameworks to meet the goals of the Paris Climate Agreement and the Glasgow Climate Pact.
4. Several cap-and-trade systems function globally. An overview of these systems from the European Union, California, Quebec, Washington state, and Tokyo are included. While Tokyo's and Quebec's cap-and-trade systems do not have specific CCS protocols, they are covered as supplementary information and because there are CCS projects in their national jurisdictions. It is worth noting that the European Union and California also did not have CCS protocols when their respective cap-and-trade systems were first initiated.

2.2 Legal and regulatory

1. The legal and regulatory assessment reveals a largely incomplete and uncertain legal and regulatory environment for CCS-specific activities in Egypt. The country has not developed CCS-specific laws or regulations that will directly govern CCS project activities and there are currently no national protocols or guidelines relating to the implementation and operation of CCS-related projects.
2. Absent a dedicated CCS-specific model, however, it is likely that elements of Egypt's existing environmental and resource regimes may be successfully amended or augmented, to incorporate CCS activities.
3. The recent August 2022 amendment to the Egyptian Investment Law No. 72 of 2017 has now brought CCS projects under the scope of the single approval system. Under the amendment, CCS projects which satisfy two or more of the listed conditions will be considered strategic or national projects and therefore able to avail themselves of an expedited approvals pathway. Where projects do not meet the requirements of the single approval system, however, a proponent will be required to use a more complex and currently less-certain means of permitting a project.
4. Uncertainties surrounding the characterisation of CO_2, most notably whether it is to be considered a waste or a resource, will likely determine the approach to be adopted under existing regulatory frameworks. Further consequential amendments to wider regulatory frameworks may also be necessary to address other aspects of the CCS project lifecycle and to address issues such as tenure, monitoring and closure.
5. Aspects of the CCS project lifecycle remain largely unaddressed by Egypt's current legal and regulatory regime, and it is likely that further intervention will be required in order to fully regulate a project. The closure of a CCS project, CO_2 permanence and liability issues may all require further legislation to ensure effective management.

6. The roles and responsibilities of Egypt's various regulators will require further scrutiny and clarification. Presently several regulators may bear responsibility for regulating aspects of the CCS process, in line with the ambiguity surrounding the nature of the regulatory regime.

2.3 Storage assessment

1. Depleted oil and gas fields are distributed across northeast Egypt in both on- and offshore sedimentary basins, and offer opportunities for the permanent subsurface storage of CO_2. Available storage resources in fields, however, only range from <2.5 $MtCO_2$ to ~202 $MtCO_2$.
2. The largest available storage resources onshore are in near-depleted fields of the following concessions:
   - Obaiyed and Khalda Development Leases (65 and 42 $MtCO_2$, respectively) – Western Desert
   - Abu Madi Development Lease (56 $MtCO_2$) – Nile Delta
3. The largest available storage resources offshore (nearshore) are near-depleted fields of the following concessions:
   - Abu Qir Development Lease (72 $MtCO_2$) – just offshore the western Nile Delta, near Alexandria
   - Nooros Field (48 $MtCO_2$) – just offshore in the central Nile Delta
4. These CO_2 storage resources in near-depleted fields are significantly smaller than the storage resources estimated to be available in saline formations.
5. Storage resource estimates for saline formations in northeast Egypt are orders of magnitude larger than estimates for depleted fields (gigatonne-scale versus megatonne-scale, respectively). Saline formations with the largest storage resource potential are:
   - Kharita Formation (488 $GtCO_2$) – present across northeastern Egypt
   - Sidi Formation (58 $GtCO_2$) Abu Madi Formation (39 $GtCO_2$), Kafr Formation (14 $GtCO_2$), and Qawasim Formation (11 $GtCO_2$) – all present in the Nile Delta region
   - Matulla Formation (14 $GtCO_2$), Nubia Formation (9 $GtCO_2$), Kareem Formation (8 $GtCO_2$), and Rudeis Formation (3 $GtCO_2$) – all present in the Gulf of Suez
6. Because depleted fields are well-characterised with subsurface data and existing facilitates that can potentially be re-purposed, they may provide the fastest path to commercialisation of Egypt's CO_2 storage resources. As Egypt's CCS market grows, however, large-scale point-source projects or CCS networks will likely need to utilise the larger storage resources available in saline formations.

2.4 Hubs Study

1. Egypt has the potential to host large-scale commercial CCS projects offering an opportunity for mitigating CO_2 emissions from several industries and supporting the creation of new low-emissions industries that use natural gas as a feedstock, including blue hydrogen production
2. Egypt potentially has large-scale onshore storage that could support CCS. Reviews of the saline aquifer storage for Egypt indicate highly prospective onshore geological storage for CO_2, with a capacity to store several thousand million tonnes. Onshore storage could offer benefits by avoiding costly pipelines (both on and offshore) and offshore injection infrastructure (platforms).
3. The cost of capturing CO_2 can vary source to source, primarily based on the total gas flow and the CO_2 partial pressure. Near-pure CO_2 gas streams, such as reservoir CO_2 from natural gas processing facilities, where no additional work or energy is required to separate the CO_2, inherent sources, are often captured first. Sources that require capture infrastructure to recover the CO_2 typically follow, with selection based on recovering from sources with the lowest costs to capture first and then increasing costs to capture to a point where it is deemed uneconomic or there is no further storage available. The cost of compression, transport and storage of CO_2 depends on the pipe route selected (i.e., length of the onshore and offshore pipeline), the mass of CO_2 transported and stored per year (i.e. capacity and utilisation of infrastructure and energy required for compression), the cost of energy and the cost of capital.
4. Two CCS hub models were considered for Egypt. The first model is a pipeline transport CCS hub model with storage in saline formations in north Egypt via the existing depleted Abu Madi field, and a pipeline CCS hub, aggregating CO_2 from several emissions source clusters using hub compression.

The second CCS hub model considers the large-scale potential saline formation storage throughout Egypt. Storage is considered local to the CCS hub compression, reducing the pipeline infrastructure required as much as practically possible.

5. The pipeline CCS hub starts to the south of Cairo in Beni Suef moving north while gathering CO_2 from nearby industrial CO_2 emitters. CO_2 from industrial compression hubs in Helwan, Ain Sokhna and Suez are aggregated together as the main trunkline traverses east of Cairo before continuing north gathering further CO_2 from compression hubs from North Cairo, Shabab, Mansoura and lastly Damietta before reaching the storage location. This results in a CO_2 flow capacity of 99.9 Mtpa for the pipeline CCS hub. The local CCS hubs approach considers eight separate CCS hubs in Egypt based on the same sources included in the pipeline CCS hub with CO_2 flow capacities from 1.8 Mtpa to 36.0 Mtpa.

6. The cost of the pipeline CCS hub was USD 85/tCO_2. Costs could be further reduced if the cost of injection and monitoring was less than USD 10/tCO_2 or the cost of electricity for compression was less than USD 84/MWh, or the cost of capital was lower than 7.6% (e.g., through concessional finance provided by government). However, in all stages larger scale delivers economies of scale that reduce the unit cost for both large- and small-scale emitters. The high cost of capture is partially offset by the low costs for transport at the flow capacity considered, even accounting for a main trunkline of 450 km in length. Given the large scale and complexity of this CCS hub it would be unlikely that it would be constructed during a single project, and staged design would need to be considered. Staged design would likely consider low-cost emission sources or low-cost hubs acting as anchors to develop initial infrastructure with more expensive emission sources or hubs added through later stages of development. Appropriate master planning for hub design is necessary to provide the most cost-effective strategy for capture and storage of CO_2 sources.

7. The cost of blue hydrogen production via steam methane reformation with CCS at Damietta was estimated to be slightly more than USD 2.25/kg of hydrogen. The blue hydrogen plant was scaled to produce 82,000 tonnes per year of blue hydrogen. The cost of blue hydrogen production at Damietta would be considerably higher if it were not part of a CCS hub with a total CO_2 capacity of a few million tonnes per annum to leverage economies of scale which significantly reduce the unit cost of CO_2 transport and storage.

8. The cost of blue hydrogen production could be reduced through a lower cost of capital, and/or a lower cost of electricity or natural gas and/or a lower cost of CO_2 injection as previously described. Conversely, higher gas costs could increase clean hydrogen production costs. For example, if gas cost was USD 9/GJ instead of USD 5.01/GJ assumed in this study, the cost of blue hydrogen production would increase to approximately USD 3/kg. New technology such as the Allam-Fetvedt cycle integrated power and hydrogen production cycle could promise even lower hydrogen production costs.

9. The costs of the local CCS hubs ranged from USD 53/tCO_2 to USD 150/tCO_2. The overall cost of all local CCS hubs was USD 72/tCO_2 highlighting benefits that this approach offers when compared to the pipeline CCS hub through fewer pipelines required and lower compression costs. Costs could be reduced through a lower cost of capital, and/or a lower cost of electricity and/or a lower cost of CO_2 injection as previously described.

10. The duration for execution of large-scale and complex CCS projects is comparable to large scale projects in the oil and gas and mining sector. Typical CCS projects can take upwards of a decade to complete. If projects are staged this can result in decades of development. If the design of the cheapest cost per tonne CO_2 stored local CCS hub were to commence immediately with subsequent local hubs implemented every three years, the typical duration for CCS project construction, all local CCS hubs would be operational by 2048. Many factors could extend or delay project development putting pressure on industry meeting internal and government set decarbonization targets. The current increase in global CCS projects and forecast growth could put a constraint on materials and labor globally increasing costs and delay projects. The key message here is that if CCS is to be considered for managing CO_2 emissions in Egypt, then development should commence as soon as possible. Regulators and policy makers must take these timelines into account and develop regulations and policy that incentivises investment in complex, and less complex, CCS projects to support net-zero strategies.

2.5 Economics

1. The proposed hubs can contribute present value USD 48 billion (USD 30 billion direct and USD 18 billion indirect) in value added to the Egyptian economy – as much as 1.2% of current GDP on an annual basis.
2. The CCS hubs would create an average of 41,000 jobs per year with a peak of around 55,000 jobs per year.
3. The CCS hubs would significantly bolster Egypt's climate change commitments – ultimately contributing up to 100 MtCO_2 reductions per year – reducing Egypt's emissions an additional 25% from its stated goals in its NDC and climate strategy – and putting Egypt much closer to a CO_2 pathway fully compatible with the long-term Paris Agreement goals.
4. The CCS hub infrastructure can also help develop blue hydrogen in addition to Egypt's ambitious plans for green hydrogen, set to begin coming online around 2030.
5. Low-carbon cement exports to the EU and elsewhere may be an opportunity for Egypt by capturing and storing CO_2 in cement production.
6. UNFCCC non-market mechanisms like the Green Climate Fund (GCF) and market mechanisms through Article 6 of the Paris Agreement may offer an opportunity for partial funding and finance of CCS hubs in Egypt.
7. Traditional development financing through the World Bank, the European Investment Bank, and the European Bank for Reconstruction and Development (EBRD) are other avenues to finance CCS hubs, in addition to domestic finance options like the Sovereign Green Bonds.

3.0 REVIEW OF CCS POLICY IN EGYPT

In May 2022, Egypt launched its National Climate Change Strategy 2050, or NCCS 2050 (Arab Republic of Egypt and Ministry of Environment, 2022). The strategy was released in advance of Egypt hosting COP27 in November 2022. The document is wide-ranging and covers a broad range of topics from sustainable economic growth to enhancing scientific research (Bilal Hussein and Africa News, 2022; Mohammed Abu Zaid and Arab News, 2022; Samar Samir and Egypt Today, 2022).

While there is only one explicit reference to CCS in the NCCS 250 document, there are several directions, performance indicators, policies, and tools that could potentially support CCS projects in Egypt. They are summarised for convenience in Table 1.

The strategy's goals, objectives, and the associated supporting information are elaborated in section 5.1 below.

Table 1: NCCS 2050 initiatives that could potentially support CCS.

CATEGORY	INITIATIVE
Goal 1	Achieving sustainable economic growth and low-emission development in various sectors.
Objective 1.b	Reducing emissions associated with the use of fossil fuels.
Direction 1.b.5	Explore the possibilities of using carbon capture, utilisation, and storage technologies.
Policy/tool 1.8	Encouraging civil society institutions to calculate carbon emissions for various activities and allocating appropriate support to reduce these emissions.
Goal 3	Enhancing climate change action governance.
Objective 3.d	Enhancing institutional, procedural, and legal arrangements such as monitoring, reporting and verification (MRV) system.
Direction 3.d.3	Developing several institutional structures in the future, such as establishing an emission inventory system centrally in Egypt or a regulatory body for carbon markets if it is decided to establish them in Egypt.
Policy/tool 3.6	Enacting laws and regulations to address climate change.
Goal 4	Enhancing climate financing infrastructure.
Objective 4.b	Promoting innovative financing mechanisms prioritizing adaptation actions, e.g., green bonds.
Objective 4.d	Compliance with multilateral development banks (MDB) guidelines for climate finance.
Policy/tool 4.1	The National Council for Climate Change (NCCC) to coordinate with the banking sector, regarding the study of increasing facilitations to climate change projects.
Policy/tool 4.2	The NCCC to identify priority adaptation and mitigation programs for inclusion in the Green Bond Plan.
Policy/tool 4.3	The NCCC to study the requirements of the guidelines for MDBs, making a clear plan with a time-limit to comply with them, and directing each ministry to the most appropriate funding bodies.

The initiatives in the NCCS document are organised under different categories. At a high level, there are objectives that need to be met to achieve the goals. There are also performance indicators, directions, policies, and tools that support the implementation of the overall strategy. The initiatives that support CCS either explicitly or could potentially support CCS projects are highlighted in the relevant sections below.

[1] The 27th Conference of the Parties or the 2022 United Nations Climate Change Conference.

3.1 NCCS 2050 Goals and Objectives

The document covers five goals and 22 objectives, all of which are underpinned by performance indicators, policies, and tools to enable their implementation. The goals and their associated objectives are organised in Table 2 (Arab Republic of Egypt and Ministry of Environment, 2022).

Table 2: NCCS 2050 - Goals and Objectives (Those relevant to CCS hubs are shaded).

GOALS		OBJECTIVES	
1	Achieving sustainable economic growth and low-emission development in various sectors.	1.a	Energy transition by increasing the share of all renewable and alternative energy sources in the energy mix.
		1.b	Reducing emissions associated with the use of fossil fuels.
		1.d	Adopt sustainable consumption and production trends for the reduction of greenhouse gas emissions from other non-energy activities.
2	Enhancing adaptive capacity and resilience to climate change and alleviating the associated negative impacts.	2.a	Protect citizens from the negative health impacts of climate change.
		2.b	Minimise loss and damage to country assets and ecosystems by preserving them from the impacts of climate change.
		2.c	Preserving the country's resources from the impacts of climate change.
		2.d	Resilient infrastructure and services in the face of climate change impacts.
		2.e	Implementation of disaster risk reduction concepts.
		2.f	Preserving and expanding green spaces.
		2.g	Strengthening women's response considerations to help them adapt to climate change.
3	Enhancing climate change action governance.	3.a	Defining the roles and responsibilities of the different stakeholders to achieve the strategic goals.
		3.b	Improving the rank of Egypt in the international profile of climate change actions to attract further investments and climate finance opportunities.
		3.c	Sectoral policy reform to capture the required climate change mitigation and adaptation interventions.
		3.d	Enhancing institutional, procedural, and legal arrangements such as monitoring, reporting and verification (MRV) system.
4	Enhancing climate financing infrastructure.	4.a	Promoting local green banking and green credit lines.
		4.b	Promoting innovative financing mechanisms prioritising adaptation actions, e.g., green bonds.
		4.c	Private sector engagement in climate finance and promotion of green jobs.
		4.d	Compliance with multilateral development banks (MDB) guidelines for climate finance.
		4.e	Building on success of the current climate finance programs.
5	Enhancing scientific research, technology transfer, knowledge management, and awareness to combat climate change.	5.a	Strengthening the role of scientific research and technology transfer in climate change mitigation and adaptation.
		5.b	Facilitating the dissemination of climate-relevant information and knowledge management among government institutions and citizens.
		5.c	Raising awareness on climate change among different stakeholders (high-level policy/decision makers, citizens, and students).

3.2 NCCS 2050 Directions

Each listed objective has associated directions that contribute to achieving each objective. Of all the objectives and their associated directions, there is only one direction that makes explicit reference to CCS.

This direction pertains to objective 1.b and relates to exploring the possibilities of using CCS technologies. A listing of directions that could potentially offer support to CCS projects or to reduce GHG emissions are listed in Table 3.

Table 3: NCCS 2050 directions that could support CCS projects/reducing GHG emissions.

OBJECTIVE		DIRECTION	
1.b	Reducing emissions associated with the use of fossil fuels.	5	Explore the possibilities of using carbon capture, utilisation, and storage technologies.
1.d	Adopt sustainable consumption and production trends for reduction of greenhouse gas emissions from other non-energy activities.	3	Safe and proper disposal of solid waste in suitable landfills and collection of gases resulting from those landfills.
3.d	Enhancing institutional, procedural, and legal arrangements such as monitoring, reporting and verification (MRV) system.	3	Developing several institutional structures in the future, such as establishing an emission inventory system centrally in Egypt or a regulatory body for carbon markets if it is decided to establish them in Egypt.

3.3 NCCS 2050 Performance Indicators

The NCCS' goals and objectives have associated performance indicators which help the Ministry of Environment to determine Egypt's progress towards achieving the goals. The performance indicators are further divided into general and sector-specific categories where applicable.

The general performance indicators are shown in Figure 1, adapted directly from the NCCS 2050 document (Arab Republic of Egypt and Ministry of Environment, 2022). The sector-specific performance indicators for goals 1 and 2 are elaborated in Table 5.

Figure 1: NCCS 2050 General Performance Indicators.

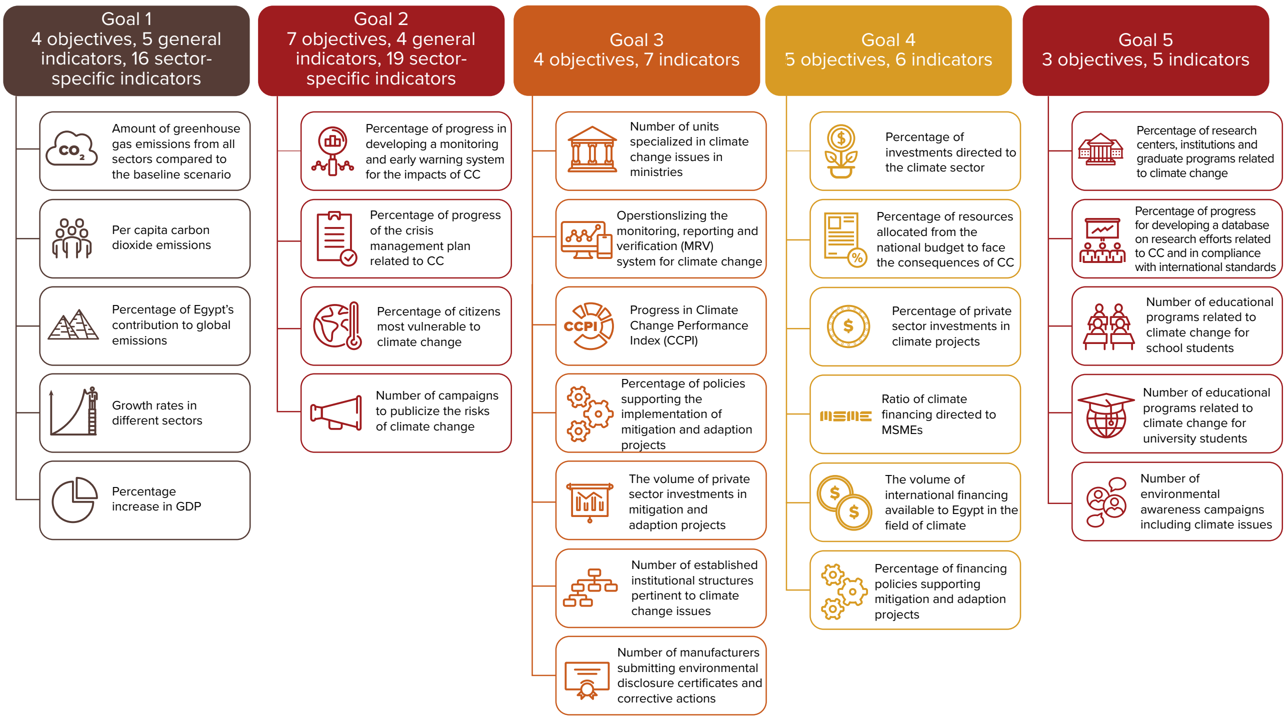


Table 4: NCCS 2050 sector-specific performance indicators for Goal 1.

PERFORMANCE INDICATORS FOR GOAL 1		TREND
1	Percentage of contribution of new and renewable energy to the total electricity production.	Increase
2	Percentage of the contribution of new and renewable energy from the production of electric and thermal energy in the industrial sector.	Increase
3	Percentage of contribution of biofuels in the transportation sector.	Increase
4	Number of cars converted to work with natural gas.	Increase
5	Number of car conversion centres to work with natural gas.	Increase
6	The amount of energy consumption per sector compared to the baseline scenario.	Reduction
7	Lengths of metro/electric train networks.	Increase
8	Percentage of electric buses out of the total public transport buses.	Increase
9	Percentage increase in the number of mass transit users.	Increase
10	Quantity of goods transported using the railway network.	Increase
11	Quantities of waste disposed of in landfills.	Reduced
12	Quantities of waste that are recycled.	Increase
13	Ratio of raising the efficiency of power plants.	Increase
14	Electricity transmission line efficiency ratio.	Increase
15	Percentage of reduction in energy consumption in the tourism sector	Reduction
16	Number of facilities that have obtained international certificates for energy management.	Increase

Table 5: NCCS 2050 sector-specific performance indicators for Goal 2.

PERFORMANCE INDICATORS FOR GOAL 2		TREND
1	Percentage of health sector teams trained on health risks posed by climate change impacts.	Increase
2	Number of hospital beds available for each citizen.	Increase
3	Percentage of the development of infrastructure in health facilities.	Increase
4	Number of educational seminars on climate change and its impact on health.	Increase
5	Development rate in water networks.	Increase
6	Percentage of sewage stations coverage.	Increase
7	Amount of industrial and sewage water recycled.	Increase
8	Length of lined canals and channels.	Increase
9	The area of the agricultural lands.	Increase
10	The amount of water consumed per feddan of agricultural land.	Reduced
11	Amount of collected water from flash floods.	Increase
12	Length of road networks equipped for climate change.	Increase
13	Percentage of personnel whose efficiency has been raised in the field of climate change.	Increase
14	Number of infrastructure development projects related to education, digital transformation, and distance education technologies.	Increase
15	Number of opinion surveys to assess the percentage of women's satisfaction with the technology used in initiatives related to climate change.	Increase
16	Number of research collecting and using gender-disaggregated data.	Increase
17	Percentage of policies that consider the active participation of women in setting financing criteria and allocating resources for climate change initiatives.	Increase
18	Percentage of national policies and action plans that include women-specific aspects.	Increase
19	Percentage of women's access to financing, credit and training opportunities in projects related to mitigation and adaptation to climate change.	Increase

3.4 NCCS 2050 Policies and Tools

Each NCCS Goal also has associated policies and tools, all of which are proposed. They are listed in Table 6, Table 7, Table 8, Table 9 and Table 10. It is unclear if any of them have been implemented or are being implemented.

No policy or tool makes an explicit reference to CCS technologies. Policies/tools shaded in the tables below may offer support to CCS projects but the NCCS 2050 document lacks specifics to offer more clarity at this time.

Table 6: NCCS 2050 policies and tools for Goal 1.

POLICIES AND TOOLS FOR GOAL 1	
1	Developing additional incentive policies to expand the use of electric cars and expanding the establishment of charging stations for electric car batteries, with the expansion of the production of such batteries locally.
2	Providing facilitations to the private sector in establishing a power plant for self-use within the space, if they are high-efficiency co-generation plants or renewable energy plants.
3	Expanding the use of natural gas in the petrochemical industry to maximise its value and to provide facilitations for the use of solar thermal energy as an alternative in the industrial sector.
4	Adopting and activating the local and global green building codes.
5	Developing incentive policies to encourage the use of biofuels in the transport sector.
6	Reassessing all studies and plans for improving energy efficiency in the industrial sector and operationalising what will be approved of them.
7	The National Council for Climate Change (NCCC) to study various ways to encourage the local manufacture of renewable energy equipment (focusing on solar thermal energy and photovoltaic cells) in all parts of the value chain.
8	Encouraging civil society institutions to calculate carbon emissions for various activities and allocating appropriate support to reduce these emissions.
9	Enabling smart applications and systems in various sectors such as the energy sector by supporting, financing, and incubating emerging companies to provide smart solutions in those sectors that would rationalise the use of electricity, increase its efficiency, and increase its productivity.
10	Studying the possibility of adopting green procurement standards.

Table 7: NCCS 2050 policies and tools for Goal 2.

POLICIES AND TOOLS FOR GOAL 2	
1	Activating the project of creating and using interactive maps to study the expected impacts of climate change on regions and new projects and hence various sectors and updating interactive maps every five years as part of climate change adaptation measures, according to new data and methodologies.
2	The Ministry of Health and Population will study the expected health impacts because of climate change, and then develop and adopt a plan to address these impacts effectively.
3	Study different solutions to adapt to sea level rise and protect coasts and coastal cities such as construction and architectural interventions, including traditional and non-conventional engineering protection works
4	The Ministry of Planning giving priority to projects that raise the efficiency of infrastructure, especially old ones, and increasing the coverage of services such as sewage treatment plants for the most vulnerable areas.
5	Building on the policies related to the water resources development and management strategy 2050 issued by the Ministry of Environmental Resources and Irrigation to prepare an action plan with a timetable to maximise the treatment and recycling of wastewater, industrial and agricultural.
6	Developing programs and policies to support the development of rural communities to enhance their resilience to the impacts of climate change, especially land use change, plant and animal production, and the impact of migration to urban areas.

7	Disseminating climate change strategies like the Giza governorate strategy in a more comprehensive manner at the governorate level with the aim of localising climate change issues during the regional planning and project implementation processes.
8	Using the climate risk insurance tool as one of the financial mechanisms that increase the ability of societies to overcome the risks of climate change.
9	Establishing a mechanism for coordination with civil society to implement pilot projects, and coordination between NGOs to benefit from experiences and applied models for dissemination in society.
10	Exploiting the use of artificial intelligence to provide solutions to challenges facing farmers such as climate change, pest outbreaks and the spread of weeds that reduce yields.
11	Coordinating with the Remote Sensing Authority to benefit from its applications in climate change studies.
12	Creating policies that ensure the effective participation of women in setting financing standards and allocating resources for climate change initiatives.
13	Developing policies that encourage a systematic analysis of gender equality, based on the collection and use of data disaggregated by gender, the development of gender-sensitive standards and indicators, and opinion surveys to assess the level of women's satisfaction in different governorates with the technology used in climate change initiatives.
14	Ensure participation and consultation of women in climate change initiatives by integrating women-specific aspects of national policies and action plans.

Table 8: NCCS 2050 policies and tools for Goal 3.

POLICIES AND TOOLS FOR GOAL 3	
1	Issuing of a prime ministerial decision to form a committee within each of the ministries relevant to climate change to be responsible for managing this file considering the guidelines of the NCCC.
2	Providing training and raising the technical capabilities of employees in ministries, especially regarding concepts and calculations related to climate change.
3	Each governorate to determine the training needs required for members of the risk management department, and the CCCD prepares the required plan to implement such trainings.
4	Issuing a clear mandate from the NCCC for each of the relevant ministries clarifying all roles and responsibilities, including coordination with the governorates.
5	Preparing forms and templates for annual reports and biennial reports that are required to be filled out by the relevant ministries to summarise the progress of technical and financial work related to mitigation and adaptation projects.
6	Enacting laws and regulations to address climate change.

Table 9: NCCS 2050 policies and tools for Goal 4.

POLICIES AND TOOLS FOR GOAL 4	
1	The NCCC to coordinate with the banking sector, regarding the study of increasing facilitations to climate change projects.
2	The NCCC to identify priority adaptation and mitigation programs for inclusion in the Green Bond Plan.
3	The NCCC to study the requirements of the guidelines for MDBs, making a clear plan with a time-limit to comply with them, and directing each ministry to the most appropriate funding bodies.
4	Building on Law No. 152 of 2020 regarding the development of MSMEs, especially with the most affected groups, such as women in the poorest areas.

Table 10: NCCS 2050 policies and tools for Goal 5.

POLICIES AND TOOLS FOR GOAL 5	
1	Ministry of Education to put climate change issues and raising awareness of its effects as an essential part of school education programs.
2	Ministry of Higher Education and Scientific Research to include the field of climate change in university studies and postgraduate programs.
3	Encouraging the establishment of more research institutes and centres specialised in climate change issues, whether at the sectoral level or from multidisciplinary research groups.
4	The NCCS to develop a system that regulates communication between research centres and ministries to share research results until they are converted into projects ready for implementation.
5	The Ministry of Environment, in cooperation with the Ministry of Social Solidarity, prepares awareness materials for all ages about climate change, and uses all means of communication to ensure that information reaches all citizens.

3.5 Sustainable Development Strategy 2030

Egypt also has a sustainable development protocol alternatively called Egypt Vision 2030 or Sustainable Development Strategy (SDS) 2030 (Arab Republic of Egypt, 2016). Components of the SDS 2030 are meant to integrate into the NCCS 2050. For example, Goals 3 and 5 of the SDS 2030 feed into the NCCS 2050 Goal 1.

An illustration adapted directly from the NCCS 2050 that shows these correlations is shown in Figure 1.

The previous section focused on the policy environment that could potentially support the development and deployment of CCS in Egypt. Similarly, countries around the world have employed various policy mechanisms to incentivise deployment within their jurisdictions. A review of these policy mechanisms has been provided in Appendix A to this report.

In Egypt, a conducive regulatory framework that addresses the issues that arise within the CCS project lifecycle will prove imperative for CCS project deployment. Thus, the following section will focus on the legal and regulatory framework in Egypt that would facilitate CCS projects within its jurisdiction.

Figure 2: Relationships between Egypt's SDS 2030 and NCCS 2050.

4.0 REGULATION OF CCS ACTIVITIES IN EGYPT

4.1 Overview and scope

Egypt has not enacted a CCS-specific legal and regulatory regime. Previous assessments of the country's regulatory framework for the technology revealed that it has very few existing laws and regulations that would support the regulation of a CCS project throughout the project lifecycle. Recently however, Egypt amended its Investment Law to facilitate the attainment of a single approval for the development, operation and management of a CCS project.

The following sections offer a detailed review and assessment of Egypt's legal and regulatory system, as it would currently apply to CCS activities. The principal aim of this analysis is to determine the extent to which it may already support the regulation of a CCS project and to subsequently identify gaps and barriers that presently exist within the country's current legal framework.

A further aspect of this review has focused upon the identification of legislation and specific laws that could potentially be adapted, to support the deployment of CCS projects in Egypt. In some instances, recommendations have been made for the development of new legislation, that will be required to address discrete aspects of the CCS project lifecycle.

4.2 Role of law and regulation

The development of law and regulation remains a critical component of governments' policy response to CCS deployment. Technical studies, completed in several jurisdictions over the past decade, have highlighted the absence, or the perceived unsuitability of existing law and regulation, as a substantial barrier to the technology's more widespread or commercial deployment.

Legal and regulatory regimes play a critical role in supporting policy commitments to the technology and in many instances, they formalise and underpin national climate strategies and international pledges towards both emissions reductions and CCS deployment. Several jurisdictions with significant policy commitments towards more widespread CCS deployment, as part of their national climate policies or Nationally Determined Contributions (NDCs), have also sought to enhance their legal and regulatory response to the technology.

A strong focus upon law and regulation has also played an important role in removing direct prohibitions and/or more discrete impediments to the technology, found in international agreements and national or regional legislation. The CCS-specific amendments to the 1996 London Protocol, made in 2006 and 2009, are just one example of the role law and regulation has played in enabling the technology's deployment.

4.3 Emergence of CCS-specific legal and regulatory regimes

Challenges posed by aspects of the CCS project lifecycle, as well as the novel application of familiar technical concepts to a climate mitigation objective, has led to policymakers and regulators undertaking further reviews and assessments of their legal and regulatory regimes to determine their capacity to effectively regulate CCS projects. Over the past two decades, this activity has resulted in the emergence of several CCS-specific legal and regulatory regimes in jurisdictions globally.

Legal and regulatory frameworks, of varying extent and detail, may now be found at the national and sub-national level throughout North America, Europe and the Asia Pacific regions. In addition, international and regional bodies have also developed legislation aimed at removing discrete barriers to the technology and providing incentives, which may enable more widespread deployment. In many instances, the emergence of CCS-specific regimes and dedicated legislation has had a strongly positive impact upon project development and affords an important foundation for more widespread commercial deployment.

The CCS-specific models, adopted across the various jurisdictions to date, have largely followed a similar approach to regulate the entirety or aspects of the CCS process. In all but one instance, one of two pathways has been chosen, with policymakers and regulators deciding to either enhance existing regulatory frameworks with CCS-specific provisions, or to enact a dedicated legal framework aimed at regulating CCS activities.

A further option has been the development of project-specific legislation that regulates the operations of a single project; an example of which may be found in the Barrow Island Act that regulates Western Australia's Gorgon CO_2 injection project. While these regimes vary in their complexity, they also share many commonalities in the manner in which they address the novel challenges of the CCS process.

4.4 Legal and regulatory assessment framework

To assess Egypt's existing capacity to regulate CCS activities for the purposes of this study, the Global CCS Institute and its project partner, Baker McKenzie, have built upon the assessment model that was previously developed and deployed as part of its CCS Legal and Regulatory Indicator review (Global CCS Institute, 2018).

The assessment model utilised in this assessment seeks to determine how comprehensive an individual jurisdiction's legal and regulatory framework is for regulating a CCS project throughout the CCS project lifecycle. The assessment focuses upon several key criteria, which comprise issues that are likely critical to the regulation of a CCS project through its planning and operational stages and beyond into the post-closure phase. The five core assessment criteria consider the:

1. Administrative process for applying for and obtaining regulatory approval for CCS projects;
2. Legal framework for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring;
3. Siting of projects and Environmental Impact Assessment (EIA) processes;
4. Stakeholder and public consultation;
5. Liability - closure, monitoring and accidental releases of stored CO_2.

In addition to these five core conditions, the project team considered a broader set of secondary sub-criteria as part of the assessment. The sub-criteria were aimed at exploring Egypt's policy, legal and regulatory environment and the country's approach to these core themes in greater detail.

The final stage in this analysis focused upon those aspects of Egypt's existing legal and regulatory regime that may be adapted to support the deployment of CCS projects. The review also considered areas where further legislative intervention would likely be required to enable CCS projects to be deployed. The experiences of other jurisdictions around the world, in particular the approach taken to the regulation of CCS activities throughout the project lifecycle, was considered when determining further actions to be taken in Egypt.

4.5 Review of local CCS policy, regulation, and law in Egypt

The following section examines the results of the project team's analysis, for each of the key assessment criteria. The analysis of these five core criteria identifies and reviews several local regulatory and policy instruments that are relevant to the development, implementation, and operation of CCS projects. The existing legislation and regulations that have been identified are relevant to both on- and offshore CCS activities.

4.5.1 Administrative process for applying for and obtaining regulatory approval for CCS projects

Egypt's civil law legal system effectively permits an activity unless it is otherwise prohibited within legislation or considered to be in breach of public order or morality. Examination of existing legal and regulatory approvals and pathways is therefore critical for project proponents. Egyptian legislation that is applicable to CCS projects may be divided into three principal categories:

1. General legislation (such as the Companies Law, Environmental Law, etc.)
2. Activity-specific legislation (such as the Electricity Law, Gas Markets Law, Waste Management Law, Concessions Law, etc.); and
3. Laws linked to specific geographical locations (such as Sinai Development Law and the Special Economic Zones Law).

For project proponents seeking to develop a project under the auspices of these various regimes, it will be important to determine and subsequently obtain all relevant approvals and authorisations for the project. A critical first step in this process will be determining the government departments and agencies with responsibility for approving the relevant elements of the project process.

4.5.1.1 Relevant government departments and agencies

The Egyptian Environmental Affairs Agency (EEAA) and the Waste Management Agency (WMA) are likely to be the most critical entities for the deployment of CCS projects in Egypt. Both the EEAA and WMA are subordinate to the Egyptian Ministry of Environment.

The EEAA administers the air, water and land pollution provisions of the Environmental Law and is responsible for regulating both onshore and offshore activities. The Environmental Law requires an environmental approval prior to the development of a project or the development of any expansion of a project. The environmental approval is determined on the basis of an Environmental Impact Assessment (EIA) report, which is to be submitted by the applicant to the EEAA.

The WMA was created for the purpose of providing a framework for the management of all major categories of waste. Among the agency's functions is the requirement to review draft bills related to waste management and to approve research and development and projects necessary for the improvement of the waste management system.

Where CO_2 falls within the definition of waste, such as industrial waste under the Waste Management Law, the project proponent will be required to obtain a licence from the WMA. In that case, the CCS project would be subject to the provisions of the Waste Management Law regulating transport, dumping and leakage (which are not currently drafted in a way that accounts for CO_2). Consequent to recent amendments to Egypt's Investment Law, there is also an accelerated process applicable if a CCS project is eligible for single approval, a separate pathway established for strategic projects under Egypt's Investment Law.

Other agencies and their governing legislation have a mandate that is linked to specific geographical locations. The location of a CCS project may, therefore, trigger the application of such laws and the jurisdiction of such agencies. Specific examples include, but are not limited to, the Sinai Development Law and the Special Economic Zones Law. Additionally, if a project is in proximity to military facilities, military approval is required and, if obtained, can trigger a requirement to fund the relocation of military facilities.

Furthermore, for offshore projects, there is an agency that regulates all Egyptian shorelines. It is likely that the Egyptian navy would also be involved in any offshore project.

4.5.1.2 Approvals pathways for CCS projects

4.5.1.2.1 Single Approval System

An August 2022 amendment to the Egyptian Investment Law No. 72 of 2017 (the Investment Law), has created a pathway for CCS projects to be included under the scope of the single approval system, where they meet the specified criteria.

Under the amended Investment Law, a single approval may be granted by the Cabinet of Ministers to companies incorporated to develop national or strategic projects. The single approval encompasses the development, operation and management of the project including building permits, the allocation of necessary real estate and may also include one or more of the incentives specified under the Investment Law.

The amendments enable CCS projects, which satisfy two or more of the following conditions, to be considered strategic or national projects:

1. Contribute to the increase of exports by exporting 50% or more of their products on a yearly basis, within three years from the commencement of operation;
2. Rely on foreign financing transferred via an Egyptian bank, in accordance with the Investment Law and its executive regulations and the conditions set forth by the Central Bank of Egypt;
3. Aim to decrease imports, support industrial localisation and increase the usage of local components (i.e., raw materials and inputs) in their production whereby they would constitute at least 50% of their products. Such ratio shall be calculated by deducting the value of imported components from the product's cost;
4. Be established in one of the prioritised development zones mentioned in Cabinet of Ministers decree No. 7 of 2020;
5. Contribute to bringing and localising modern technology in Egypt, supporting innovation, and encouraging development and scientific research, at the discretion of the competent Minister for Communications and Information Technology, the

competent Minister for Industry, or the competent Minister for Scientific Research Affairs, as the case may be;

6. Aim to secure strategic commodities and limit their importation;
7. Be considered a domestic labor-intensive project in accordance with the executive regulations of the Investment Law;
8. Contribute to limiting environmental impact, reducing emissions, and improving climate, at the discretion of the competent Minister of the Environment.

4.5.1.2.2 Multiple approval pathway

Where the CCS project in question does not satisfy at least two of the conditions identified above, it will likely need to obtain several, wider approvals set out in Egyptian law.

In Egypt, some approvals can be deemed to be approved if no response is received from the regulator within the stipulated timeframe. For other permits, this is not the case and there may be no statutory timeframe for a determination by the regulator. Some approvals in Egypt are sought directly from the relevant authority, others must be sought via an intermediary approving authority first.

An environmental approval would likely be necessary and is made through an Environmental Impact Assessment (EIA). The EEAA divides projects into categories/lists (Category A, Category B and Category C) and the approval process differs for each category. Category C projects, for example, will require applicants to undertake a public consultation process.

The EEAA is to respond to an EIA application within 60 days, however, in general an absence of response is a deemed to be an approval. The 60-day deadline may be extended, in instances where the EEAA asks questions, or requests further clarification from the applicant.

Depending on the nature of the CCS project proposed, further approvals may also be required. Additional approvals may include:

- Construction approval
- Ministry of Agriculture approval in respect of laying pipes or other utilities in agricultural land; a
- Other non-environmental approvals.

The requirement for a construction approval will depend on whether the proposed works to be constructed are permitted under any concession or licensing process and if so, a separate construction approval is unlikely to be required. The CCS project may also require a WMA licence, should CO_2 be classified as waste as defined under the Waste Management Law.

For the transportation aspect of the CCS process, approvals from the relevant authorities may be required for the installation of any pipelines, or the use of any existing pipelines. In the case of vehicular transportation and noting that CO_2 is not currently classified as a hazardous material under Egyptian law, transport via vehicles would be permissible.

4.5.1.3 National protocols and guidelines

Egypt's National Climate Change Strategy (NCCS) 2050 identifies five main goals and 22 objectives, each containing a number of directions that will contribute to achieving the objectives. One direction identified to achieve the objective of "reducing emissions associated with the use of fossil fuels" is to "explore the possibilities of using carbon capture, utilisation and storage technologies".

To date, however, guidelines and policies have not been issued with respect to CCS activities. The recent August 2022 amendment to the Investment Law, afforded the first, formal mention of CCS projects under Egyptian law.

There have been examples of the Environmental Law being amended to introduce new climate-related laws. By way of analogy, the government amended the Environmental Law and its executive regulations in order to regulate the environmental impact of coal production and usage and the production, use and storage of charcoal. Between 2016 and 2021, a series of ministerial decrees were published which (i) set out standards and controls for the import/export, transportation, storage and trading of coal, and (ii) the creation of committees within the EEAA responsible for the regulation and monitoring of the environmental impact of coal-related activities.

4.5.1.4 Legal Issues for consideration

Administrative process for applying for and obtaining regulatory approval for CCS projects

	Regulator	Operator
Regulatory roles and responsibilities of government departments and agencies	• Regulatory clarification is required as to the roles and responsibilities of respective government agencies for all stages of a CCS project. • At a minimum, discussions relating to the feasibility of CCS projects in Egypt should involve the Ministry of Environment.	• Project proponents will need to obtain all necessary approvals from the applicable government departments and agencies.
Approval process for CCS projects	• In the event a CCS project is deemed to be ineligible to qualify for single approval under the latest Investment Law, the standard approvals under various legislation applicable to activities similar to CCS projects may apply. • However, regulatory clarity is needed in relation to the exact approvals required, relevant application processes and conditions uniquely applicable to CCS projects.	• As with any project, a proponent must assess: • the exact number of approvals required to construct, operate and close a CCS project • the risk of obtaining the approval, • the length of time that obtaining an approval or all necessary approvals can take and • obtaining satisfactory conditions of approval • the availability of recourse against the action or inaction of the relevant administrative authority before the administrative courts.
Project operator and regulator roles at each CCS project stage	• A regulatory framework allocating distinctive roles for the project operator and the regulator at each stage of the CCS project lifecycle is required.	
Royalty or other financial payments / requirements	• Clarity required as to any applicable fees and other financial requirements, such as bonds, which may be payable.	
National protocols and guidelines	• Notwithstanding the development of a single approval pathway, further protocols and guidelines are required to clarify the application of existing laws and regulations for CCS projects.	• Although detailed policies in respect of CCS are absent, operators are not precluded from proceeding with a CCS project in Egypt.

4.5.2 Legal framework for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring

Egypt does not currently possess a detailed CCS-specific legal and regulatory regime of the type developed in other jurisdictions around the world. Existing Egyptian law, however, may be adapted to accommodate CCS projects through the adoption of regulations and decrees by the relevant ministries and/or authorities in addition to the introduction of a series of amendments to existing laws where relevant. The regulation of CCS projects under Egyptian law is highly unlikely to be fully integrated. The level of integration will likely depend on the classification of CO_2 (as waste or as a resource) that will be adopted.

In general, the amendment of legislation is a process that can take an average of six months. The proposed amendments are first drafted by the relevant ministry. The final draft is then presented to the Cabinet of Ministers to obtain the approval of all other ministries prior to being presented before Parliament. The proposed amendments are then reviewed and debated in Parliament. Once agreement is reached in respect of the final draft, the Parliament would pass the amendments. The document would then be sent to the President of Egypt for ratification. Please note that this process may be accelerated if the matter is of high priority and/or is of national or strategic importance.

The following sections consider Egypt's current approach to several key aspects of the CCS process and project lifecycle.

4.5.2.1 Classification of CO_2

Egyptian legislation does not currently expressly define or classify CO_2. In the absence of specific legislation, there is potential for CO_2 to be classified either as either a resource or as waste.

There is no single definition of a resource under Egyptian law. Each type of resource (i.e., petroleum resources, water resources, etc.) is regulated and defined separately under the primary law which regulates it. The common aspect between the different definitions is that the substance in question may be commonly found in nature.

In the case of waste, Waste Management Law No. 202 of 2020 regulates the collection, storage, sorting, transportation, treatment, valuation, recycling, reuse, and disposal of waste through environmentally safe means.

Under the Waste Management Law, waste is defined as "damaged material, or things or moveables that are given up by its possessor whether capable of recycling or must be disposed of". There is no specific reference to CO_2 in the Waste Management Law, however:

- Industrial Waste is broadly defined to mean "waste resulting from industrial, crafts and similar activities that do not contain Hazardous Waste".
- Hazardous Wastes are defined as "material having hazardous elements hazardous to human health or having an adverse impact on the environment such as mineral, toxic, inflammable, explosive or poisonous materials".

While there is potential for CO_2 to be classified as a resource, the definition of industrial waste and its related legal framework is sufficiently broad to potentially capture CO_2.

It will be important to formally determine how CO_2 is to be classified, in order to clarify the applicable regulatory framework and associated approvals required. In other jurisdictions, the lack of a classification may pose issues for the environmental assessment and approval process unless CO_2 is exempted or explicitly carved out. However, it is uncertain if this would be the case in Egypt.

4.5.2.2 Ownership and access regime for subsurface CO_2 storage

It is anticipated that land comprising sub-surface aquifers, as well as the surface of the land, would be owned by the state. This is likely to be the case for the pilot projects currently under consideration.

Under existing legislation, in all cases, rights of the surface and sub-surface of the land in question will be contractually agreed between the parties, i.e., the landowner and the project proponent, whether the land is state- or privately-owned. The manner in which access may be obtained to land and the subsurface to conduct CO_2 storage would also be determined by whether CO_2 is classified as a waste or resource.

For example, if CO_2 is classified as a resource and a model analogous to that which applies to oil and gas projects is adopted, the project proponent will likely enter into a concession-like agreement with the government which will provide access to the land which is determined to be suitable for CO_2 storage based on the studies and assessments which would be completed beforehand.

If CO_2 is classified as waste, under the waste management framework the WMA is required by law to make land available for waste management and storage. Accordingly, if CO_2 is categorised as waste under the Waste Management Law, per the executive regulations of such law, the project proponent may be potentially aided by the WMA in obtaining rights to land for the purpose of CO_2 storage. This may help accelerate the process of obtaining the required land.

If the land in question is privately owned, access to such land will be subject to negotiation and agreement between the landowner and the project proponent. The most likely scenario in such a context is that the government will seek to acquire the land from its private owner in exchange for appropriate and fair compensation which it will then make available to the project proponent for use. Such an arrangement is the more likely approach to be adopted for privately-owned land as it would facilitate access, control and monitoring over the land by the competent authorities.

4.5.2.3 Design standards for CCS projects

Egypt does not currently have specific design standard requirements for CCS projects. However, it is likely that existing international CCS design standards will be taken into consideration when reviewing the designs which will be included in the EIA.

Subject to those standards, standard health and safety requirements for the protection of personnel (Article 43 of the Environmental Law), safety requirements regarding transportation and storage and, general building regulations would be applicable to CCS operations.

4.5.2.4 Leakage of CO_2

The risks and potential impacts posed by CO_2 leakage, as well as the means of mitigating and remediating any associated damages, is an important regulatory consideration. Under Egyptian law, an EIA addresses the environmental impacts of a project, which may include leakage. The issue of leakage is also potentially addressed in the study to be submitted to the WMA should a waste management licence be required pursuant to the Waste Management Law (if applicable).

Under the current statutory regimes, there are no leakage provisions in place to deal with liability arising from CCS projects. During operations, an operator will be required to self-monitor its activities. In the case of leakage, it is likely that it could be potentially regulated by the EEAA.

It is anticipated that any liability for CO_2 leakage would follow a model analogous to that set out under the Environmental Law regarding pollution from oil. In accordance with these provisions, liability for leakage will likely be on the owner(s) of the structure from which the leak occurred (i.e., pipeline, truck, ship, storage area etc.) or on the person(s) responsible for that leakage. Responsibility for and/or ownership of the structure can be established by agreements and documentation.

In the absence of specific liability provisions, the general liability regime under Egyptian law will likely apply. Under these provisions, parties may determine the quantum of damages in advance, either in the contract or in a subsequent agreement. Damages fixed by agreement are not due, if the debtor establishes that the creditor has not suffered any loss. A judge may also reduce the amount of damages in certain circumstances. In the absence of contractual provisions, a judge will determine the magnitude of damages on a case-by-case basis.

4.5.2.5 Transportation of CO_2

Egyptian law does not currently include CCS-specific provisions to manage the transportation of CO_2. Similarly, there are no existing laws that specifically deal with the trans-boundary movement of CO_2 with respect to CCS projects. Where CO_2 is characterised as waste under the Waste Management Law, however, its provisions explicitly regulating the import and export of waste and the transportation of waste across Egyptian land and waterways, will likely apply to transportation.

There is also potential for CO_2 to be added to the list of substances that are set out under Article 4 of the executive regulations of Law No 48 of 1982. The law, which concerns the protection of the river Nile and waterways (to include freshwater bodies, non-fresh water and underground water), regulates the types of pollutants which may not be transported through waterways.

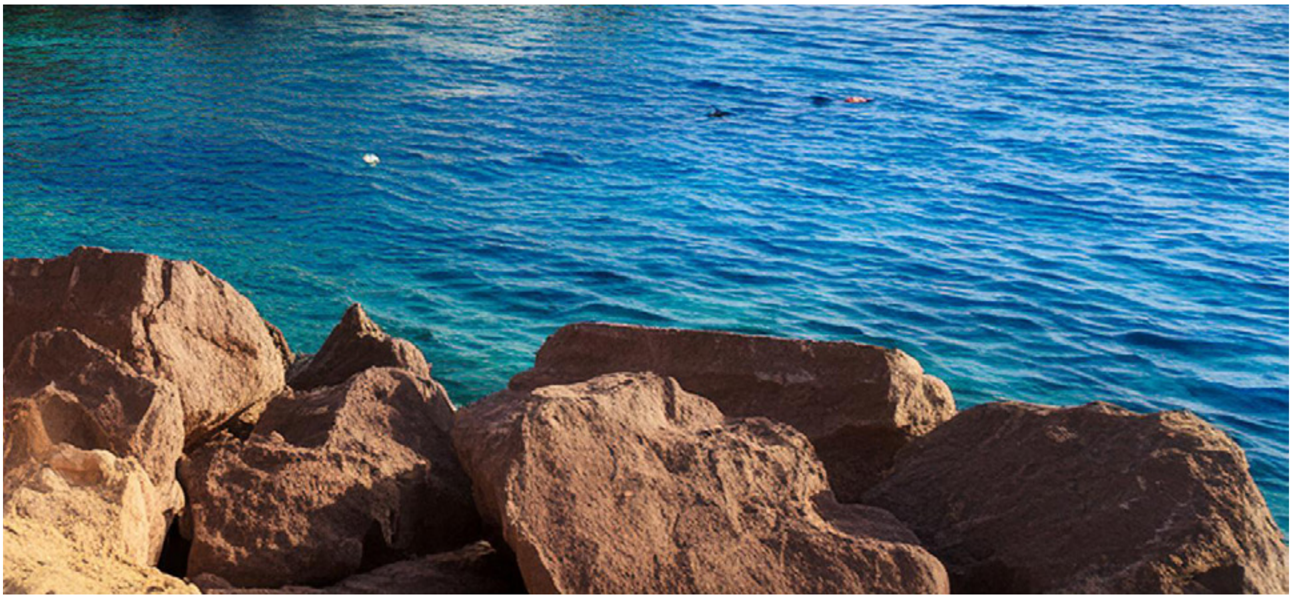
In instances where pipelines are to be used for the transport of CO_2 and the land through which the pipelines would pass is privately owned, it may be established by law or by agreement of the relevant parties that the landowner allow access to the land for the purposes of laying pipelines. These activities may be undertaken in exchange for appropriate, fair consideration in accordance with Article 805 of the Egyptian Civil Code.

4.5.2.6 Monitoring and verification requirements

Egyptian law does not currently include provisions governing the verification of injected and stored levels of CO_2. Provisions found in the nation's existing environmental legislation, however, may apply to aspects of CCS operations.

The Environmental Law No. 4 of 1994 subjects parties responsible for a project to self-monitoring obligations. According to Law No. 4, an environmental impact assessment study in respect of a project will be submitted to the relevant authority prior to the commencement of the project (or any expansions). The relevant authority submits the EIA to the EEAA. The manager of the project is required to maintain an environmental impact register reflecting the impact of the project on the environment. The form of such register and the obligations, and information to be recorded therein, are detailed under the executive regulations of Law No. 4.

In accordance with Article 22 of the Environmental Law, if the EEAA determines that one or more of the following has occurred, the EEAA must notify the relevant authority



responsible for monitoring the activities of the entity in question and request that the relevant authority require the matter to be corrected:

- Project proponent has not created an environmental register as required by law;
- Project proponent has not regularly updated the register with the relevant information;
- Information recorded on the register is not regarded as true or accurate; or
- Project has not complied with the relevant standards, or any other violation of applicable environmental laws, regulations and controls has occurred.

If the project proponent does not do so within 60 days from notification by the relevant administrative authority, the EEAA may, following the authority's notification:

- Permit an additional grace period to the project proponent to correct the violation, otherwise the EEAA may carry out works itself at the project's expense; or
- Suspend the violating activity until the effects of the violation are removed and without prejudice to the wages of the affected employees.

In the event of a matter regarded as posing a serious environmental danger or harm, the source of the matter must be immediately stopped.

4.5.2.7 Storage of CO_2

The existing legal and regulatory regime does not include provisions regulating either storage activities or CO_2 storage sites. Once again, however, existing regulatory regimes may be applicable, should clarification be afforded by the relevant regulator.

The Waste Management Law, which includes provisions regarding the burial of waste underground and provides certain regulation depending on the type of waste, is one example where CCS activities could be regulated.

4.5.2.8 Closure of a storage site

While Egyptian law does not currently include provisions governing the closure of the CO_2 storage sites, there is potential to amend existing regulatory frameworks to bring this activity within their scope. One example is the Waste Management Law which, subject to clarification of its application, has the potential to apply to CCS activities.

An example which demonstrates a closure regime in a different context may be found in the executive regulations of the Mines and Quarries Law. Under articles 33 and 34, general requirements and a framework for handling the closure of depleted oil wells are provided.

However, further legislation will likely be required to address CCS operations specifically. Provisions to regulate the means of closing a storage, closure period obligations and post-closure protocols - including in respect of liability during the post-closure period – will all be necessary.

4.5.2.9 Legal issues for consideration

Legal framework for all aspects of a CCS project, including siting, design, capture, transport, storage, closure and monitoring

	Regulator	Operator
Integrated approach	• Adopt an integrated approach to regulating CCS projects, to provide clarity and accountability and mitigate risks to the project proponent across all elements of the CCS project lifecycle.	

Classification of CO_2	• CO_2 to be formally classified and exempted or expressly carved out to assist in:
	  • Determining the applicable regulatory framework and associated approvals required.
	  • Preventing an inadvertent barrier to the feasibility of CCS projects in Egypt and issues for the environmental assessment and approval process
	  • the deployment of the utilisation component of CCS.
	• The potential for sequestered CO_2 to receive the benefit of a carbon credit for retirement or trade domestically and/or potentially internationally.	

Ownership regime for sub-surface storage	• Consider a legal regime that clearly defines ownership or access rights in relation to stored CO_2 and the allocation/ management of CO_2.	
Design standards for CCS projects	• Clarify the regulatory requirements necessary for project design elements. • Determine the status of CO_2 (as a waste or resource) and consequently whether additional project design requirements may apply under waste management laws.	
Trans-boundary movement of CO_2	• Develop a framework establishing the regulatory requirements necessary for the transboundary movement of CO_2 during the capture, transportation and storage of CO_2. • Provide clarity as to the status of CO_2 (as a waste or resource), to determine whether waste management laws regulating the import and export of waste and the transportation of waste across Egyptian land and waterways will apply to CCS activities.	
Surface access and reclamation	• Regulatory clarity is required to resolve uncertainty in respect of surface access and reclamation activities and the relevant approvals that must be obtained to facilitate land access for the purposes of CCS projects.	
Leakage	• An express legislative framework addressing the issue of liability for CO_2 leakage is required particularly to address concerns of uncertainty between parties and the general public.	• A project proponent is responsible for any leakage of CO_2 during the operational phase of a project. • Project proponents may determine the allocation of post-closure liability for leakage through agreements and other documentation. • In all cases, any exclusion of liability for gross negligence and/or fraud will be void.

Transportation	• Clarification of the classification of CO_2 is required to assist proponents in identifying the regime that will apply to the transport of CO_2 • Regulatory clarity on the minimum design standards and requirements for CO_2 pipelines is also necessary.	• Enter into agreements or comply with laws establishing a process for private landowners to permit access to land where a CCS project involves laying pipelines on private land. • Consider design standards and requirements analogous to the design standards and requirements applicable to gas pipelines established by the Gas Regulatory Authority. However, these standards are not publicly available.
Monitoring and verification requirements	• Although existing monitoring requirements can be applied to CCS projects, supplementing the existing regime with agreed national protocols and guidelines for CCS projects is beneficial. • Establishing a verification regime for injected and stored volumes of CO_2 may be beneficial in the context of assuring the integrity of Egypt's emissions reductions targets or proposed mechanisms incentivising emissions reductions.	
Storage and siting	• Regulatory clarity is required to resolve uncertainty in relation to the requirements for investigation, assessment and selection of suitable sites for storage.	
Closure	• Matters of closure, closure period obligations and post-closure protocols including in respect of liability during the post-closure period require clarification within future laws and regulations.	

4.5.3 Siting of projects and Environmental Impact Assessment (EIA) processes

As described in section 5.1, the government retains the discretion to determine whether a proposed CCS activity warrants further environmental assessment, due to its potential environmental impact. Furthermore, the government retains ultimate discretion in respect of whether to approve activities under the single approval framework or via the various other approvals that would be required.

The requirement to obtain an EIA approval prior to the development of a project, or the development of any expansion of a project, is a critical aspect of Egypt's Environmental Law. Any CCS projects involving siting and/or storage would be subject to provisions of Environmental Law No. 4 of 1994, and therefore require an EIA.

In instances where a concession regime was to be followed for CCS projects, the practice in Egypt is for these agreements to include a clause granting the government the discretion to prevent any operation on any well that it might reasonably expect would result in loss or damage to the well or the oil or gas field.

If CO_2 is categorised as waste, the siting of a CO_2 storage project will be subject to a further study for the purposes of obtaining a licence from the WMA. Any activities related to the subsurface storage of CO_2, which will require the construction of structures to undertake them, will also likely require a building permit, unless the project is granted an approval under the single approval system.

In the offshore, depending upon a project's location, there may be a requirement to engage additional agencies (such as the Egyptian navy) in the regulation of offshore operations. Subject to the question of the classification of CO_2 in Egypt, another analogy under Egyptian law is the regulation of offshore oil reserves. For example, Article 52 of the Environmental Law includes requirements on entities undertaking exploration, extraction and exploitation of offshore oil reserves to dispose of polluting substances using the most technologically advanced and safe methods which do not result in damage to the marine environment. This framework may be relevant to exploration, injection and storage activities in offshore waters.

4.5.3.1 Legal Issues for consideration

Siting of projects and Environmental Impact Assessment (EIA) processes

	Regulator	Operator
EIA capture/ transport laws	• Provide clarity with respect to third-party access rights to pipeline systems.	
EIA siting and storage laws	• Clarify the type of approvals that CCS project operators must obtain, under laws relating to environmental impact, construction and offshore projects. • Provide clarity as to the classification of CO_2 as a waste or resource, in order to ascertain the necessity of obtaining relevant permits under waste management laws. • Further regulatory clarification is also needed for the site selection of CCS projects and options in respect of site selection.	• Egypt's latest Investment Law envisages the allocation of real estate as part of the process of obtaining a single approval for strategic CCS projects.
Project proponent responsibilities	• Address the uncertainty relating to the extent of legal requirements a project proponent would need to meet. • Characterisation of CO_2 as a waste or resource is needed to clarify the operator's responsibilities. • Providing clarity as to whether the Egyptian government would accept the transfer of liability for CO_2 during the post-closure stage is likely to act as a key incentive for project proponents to undertake CCS projects.	• The project proponent bears responsibility for all aspects of a CCS project.
Government discretion	• Resolve the uncertainty regarding the extent of environmental assessment the Government may require in respect of CCS activities.	
Mitigation and risk management	• Although existing requirements can be applied to CCS projects, further regulatory clarity and agreed national protocols and guidelines for CCS projects, that supplement the existing regime, may be beneficial.	
Technology information and technology development	• The EEAA to clarify any explicit requirements for technical and scientific information that must be submitted with an EIA for a CCS project.	

4.5.4 Stakeholder and public consultation

Egyptian environmental law includes a general requirement to hold public hearing sessions, to enable stakeholders and the public to discuss their opinions of the environmental impact of the project, prior to issuance of an environmental approval.

4.5.4.1 Public engagement requirements

The consultation of the public and other concerned entities, within the EIA planning and implementation phases, is mandatory for all Category C projects (as defined under the Guidelines of Principles and Procedures for Environmental Impact Assessment through the public published by the EEAA in 2009). While CCS is not specifically included under any of the current project categories lists, it may be assumed that CCS projects are likely to be characterised as Category C projects.

The consultation process provides concerned parties with the opportunity to indicate their opinion in relation to measures to minimise potential negative environmental and social impacts. It also provides an opportunity to strengthen social acceptance of the project and to inform the concerned parties of the proposed measures for environmental impacts to be minimised to levels that are low as reasonably practical.

If CCS projects are categorised as Category C projects, consultation would be undertaken twice during the EIA process: the first in the phase of identifying the scope of the project EIA, and the second following the preparation of the draft EIA.

4.5.4.2 Dispute resolution

The default recourse for affected individuals, agencies or organisations in the event of a dispute, is for the dispute to be resolved pursuant to Egyptian law before Egyptian courts. Further, more specific frameworks may also be available, including arbitration, as is the case in oil and gas projects.

In addition, and particularly in the case of projects involving foreign proponents, parties may have a contractually agreed dispute resolution mechanism or treaty-based dispute resolution mechanism (such as the International Centre for Settlement of Investment Disputes (ICSID)).

In certain circumstances, special dispute resolution mechanisms under Egyptian law may be available. An example of one such mechanism would be the Investment Dispute Resolution Committee.

4.5.4.3 Legal issues for consideration

Stakeholder and public consultation

	Regulator	Operator
Public engagement	• Determining under which category CCS projects would be classified under the general environmental framework. To include clarification of the extent to which public consultation is required for a CCS project to be determined under the Investment Law. • Clarity from the government as to the availability of up-to-date public consultation guidelines accessible to the public is also necessary.	
Notification requirements	• Clarity is required from the EEAA as to notification requirements to stakeholders and the general public.	
Dispute resolution mechanisms		• Contractual provisions are needed in respect of CCS projects to address dispute resolution mechanisms including choice of law and choice of forum.

4.5.5 Liability - closure, monitoring and accidental releases of stored CO_2

While there are existing provisions within Egyptian law that would likely apply to liabilities borne during the operational phase of CCS operations, there are currently no provisions or processes in place for project proponents to follow upon completion of a CCS project. In the absence of a specific closure regime, the general rule under Egyptian law provides that the person whose action or inaction caused the damage would be liable (assuming there is no transfer of liability).

A closure regime to deal with the closure of storage sites and potentially the transfer of long-term liability, including dealing with post-closure liabilities that might arise or have arisen during the operation of the CCS project, will need to be developed. As part of this, a risk assessment framework to deal with closure issues would also have to be considered.

It is suggested that the development of any future liability regime will also need to consider long-term climate-related liabilities which arise from CCS projects.

4.5.5.1 Legal Issues for consideration

Liability - closure, monitoring and accidental releases of stored CO_2

	Regulator	Operator
Closure of CCS project	• Regulatory clarity is needed to address the uncertainty arising from the lack of regulatory processes for project proponents to follow on completion of a CCS project. • Future regulatory efforts to focus upon establishing a closure regime to deal with the closure of sites and potentially the transfer of long-term liability, including provisions relating to post-closure liabilities that might arise or have arisen during the operation of the CCS project. This extends to the need for clarification on storage liability including in respect of long-term liability.	
Risk assessment framework	• Clarify the leakage risk assessment criteria and provide certainty in relation to monitoring, measurement and verification processes for CCS projects arising on closure.	
Localised effect liability	• Clarify the issue of post-closure liability is required to resolve uncertainties arising from the lack of existing provisions in this regard.	• As the question of post-closure liability is not addressed in law, operators will be subject to the general liability regime under Egyptian law.
Climate change related liabilities	• In the event climate related liabilities are recognised in law, regulatory clarity is needed regarding measures to deal with long-term leakages and in particular any long-term climate related liabilities which arise from CCS projects.	

4.6 Developing Egypt's legal and regulatory regime to support CCS deployment

Egypt may consider adapting or strengthening its existing legal and regulatory regimes or decide to introduce dedicated CCS-specific legislation to support project deployment. It is the view of the project team, however, that it is more likely that Egypt will amend and/or augment existing laws , rather than establish a completely new CCS-specific regime.

The preceding section of this report examined the ability of the current framework to govern the development, operation and closure of projects, and considered the potential application of existing laws and regulations to CCS projects. The following section examines those areas where further legislative intervention would likely be required. Existing regulatory pathways may be successfully adapted to regulate a CCS project throughout the project lifecycle, however, there remain outstanding issues where there is currently insufficient coverage in existing regimes, which will require further legislative intervention to support project deployment.

The experiences of other jurisdictions around the world, in particular the approach taken to the regulation of CCS activities throughout the project lifecycle, were considered by the project team when determining further actions that may be necessary in Egypt.

The key issues have been summarised in accordance with the following key elements of the CCS project lifecycle:

- the identity of proponents, including eligibility criteria;
- licensing and/or approvals;
- tenure;
- monitoring (both pre- and post-closure);
- closure plan and conditions of closure;
- liability related to the operation and closure of relevant sites; and
- permanence of storage.

[2] Several jurisdictions around the world have chosen to adopt this approach to the regulation of CCS. Examples include the Australian state of South Australia, which has amended its Petroleum and Geothermal Energy Act of 2000 to incorporate a permitting regime for injection activities and storage of regulated substances, which includes CO_2. Another example is the province of British Columbia in Canada, which made amendments to its Petroleum and Natural Gas Act and the Oil and Gas Activities Act to incorporate CCS within the province's existing regime governing underground natural gas storage and acid gas disposal.

The following table sets out both the legislation that could be adopted or is required to be developed to allow CCS projects to be deployed. It also highlights any outstanding legal issues, where further legislative intervention will likely be required.

Issue	Legislation that could be adopted or required to be developed to allow CCS projects to be deployed	Outstanding legal issues
Proponents	Natural, legal, public and private persons are capable of becoming proponents of a CCS project, provided they satisfy the eligibility requirements. We understand in Egypt a broad range of persons may apply to become a proponent. However, natural persons would not benefit from the single approval system for CCS projects proposed under Egypt's Investment Law.	There is a need to clarify eligibility requirements for project proponents. The Investment Law clarifies the eligibility of strategic CCS projects for the single approval framework, but further explanation is required in relation to the eligibility of proponents to undertake such projects. If CO_2 is formally characterised as waste and a CCS project be governed by the Waste Management Law, certain qualifications must be met by the project proponent. Details of such requirements are not publicly available. To provide clarity over whether these qualifications need to be met, formal clarification of CO_2's classification as a waste or resource, would be beneficial. Additionally, certain laws require relevant project companies to take specific legal forms. For instance, the Electricity Law requires project companies subject to it to be joint stock companies. Consideration of these additional obligations under various laws would be required of operators.
Licensing/ approvals	Proponents are subject to licensing and/or approval requirements via: 1. the requirement for a proponent to obtain legal documents (such a licences and permits) to carry out greenhouse gas injection, storage and/or utilisation activities 2. the designation of certain licence areas / permitted sites; or 3. a combination of 1 and 2 (as in several jurisdictions). The Egyptian Government has introduced amendments to the Investment Law related to the eligibility of certain projects for the single approval regime. The amendments expressly facilitate the process of obtaining approval for certain strategic CCS projects, provided certain conditions are met, as discussed in the preceding sections.	Where a CCS project does not meet the criteria for a strategic project under the Investment Law, there may need to be a centralised licencing or permit scheme that identifies and directs a person to the existing applicable licence / permits required to be held upon meeting relevant requirements. It is possible to obtain from Government an indicative list of the approvals necessary for other types of large-scale projects. It would likely assist CCS project proponents, which are not included within the Investment Law pathway, to have the benefit of a similar list.
Tenure	In other international jurisdictions, express tenure regimes for CCS activities have been developed. These include: • exploration permits including for certain volume areas • identification of onshore and offshore zones for the carrying out of CCS projects • a CCS-related permit, lease, licence or other approval for transport, injection and storage; and • limiting the sites on which CO_2 may be stored. There may be scope for existing resources legislation, which provides for exploration rights, to be adopted for CCS projects, namely, the exploration of land for the purposes of determining land suitable for CO_2 storage. In such a case, exploration rights would likely be granted under a concession agreement. The process of carbon capture, of itself, will likely be subject to a separate agreement. In respect of offshore activities, Egypt's Environmental Law includes requirements for entities undertaking exploration, extraction and exploitation of offshore oil reserves, to dispose of polluting substances using the most technologically advanced and safe methods which do not result in damage to the marine environment. This framework has the potential to be adapted to exploration, injection and storage activities in offshore waters which is likely to be set out under an agreement similar to a concession agreement.	Where a CCS project is not eligible for the single approval process, there remains a number of uncertainties regarding the onshore and offshore areas within which CCS projects may be undertaken, the approvals required to enable the activities and the ownership/property rights necessary for a proponent to carry out CCS activities. It would assist if the rights of a proponent, in respect of CCS activities in offshore areas, were stipulated (e.g. rights over "blocks" within below sea geological formations as in the Australian example. The designation of onshore storage areas may also simplify the approvals required to carry out CCS projects within those areas. However, if CCS projects were to follow the model used for oil and gas projects, an agreement similar to a concession agreement will likely be agreed between the project proponent and the Government. In such a case, the standard timeframe for completion of this process (i.e., agreeing and executing the concession agreement) may take between 8 to 12 months and this timeframe may vary on a case-by-case basis.

Monitoring	**Pre-closure** The existing Egyptian Environmental Law is applicable to monitoring activities for CCS activities. As in other jurisdictions, operators of a CCS project / site are required to conduct monitoring activities. In Egypt, the level of monitoring is self-determined by the operator. There is scope for this regime to be supplemented by any specific requirements of the EEAA or further policies or guidelines. **Post-closure** In other jurisdictions, there are specific requirements for an operator to continue its monitoring, reporting and corrective responsibilities until the responsibility of the storage site is transferred to a competent authority. For example, operators of a CCS project / site are required to provide suggestions to the government body regarding approaches to be taken by the government body in relation to monitoring post-closure. In Egypt, monitoring post closure would continue pursuant to the pre-closure regime. There is uncertainty as to the extent to which monitoring continues in respect of a site and the requirements for closure of a site.	**Pre-closure** It is recommended that the onus be placed on the operator to propose a monitoring plan.[3] **Post-closure** There is a need for a closure regime to deal with the closure of sites including monitoring and liability in respect of closure and long-term storage.
Liability	If CO_2 is classified as a resource and a framework analogous to that adopted in the oil and gas sector is applied to CCS projects, liability would likely be regulated under an agreement similar to a concession agreement. Under this agreement, which would be entered into with the Government, liability for any damage would be the responsibility of the project proponent. Separately, if CO_2 is classified as waste, the framework regulating liability for pollution has the potential to be expanded to encompass pollution caused by CO_2. For example, the Environmental Law in respect of pollution from oil may be capable of being adapted for CO_2 leakage. If this were to occur, it would provide a framework for allocation of responsibility in the event of leakage. Liability for leakage would likely be the owner(s) of the structure from which the leak occurred (i.e. the pipeline, truck, ship, storage area) or the persons responsible for it or having possession of it. In the absence of the amendment of one of the above regimes or the introduction of a new framework, existing laws on liability would apply. Government, liability for any damage would be the responsibility of the project proponent. Separately, if CO_2 is classified as waste, the framework regulating liability for pollution has the potential to be expanded to encompass pollution caused by CO_2. For example, the Environmental Law in respect of pollution from oil may be capable of being adapted for CO_2 leakage. If this were to occur, it would provide a framework for allocation of responsibility in the event of leakage. Liability for leakage would likely be the owner(s) of the structure from which the leak occurred (i.e. the pipeline, truck, ship, storage area) or the persons responsible for it or having possession of it. In the absence of the amendment of one of the above regimes or the introduction of a new framework, existing laws on liability would apply.	If the Environmental Law in respect of pollution of oil were to be adapted for CO_2 leakage, it would need to address the complexity of CCS projects which may have multiple owners and operators. It would also need to address the need for an integrated framework for CCS activities, particularly in relation to liability and closure. There is a further outstanding legal issue as to whether liability for long term storage would be transferred to the Government. And if so, the extent of powers of the Government in a serious event such as a reversal of abatement.

[3] Other jurisdictions with advanced regulatory frameworks for conducting CCS operations, such as the US and Australia, have established baseline requirements for conducting monitoring activities relating to injected CO_2. The monitoring plan required to be submitted by an operator under such frameworks typically incorporates information that would comply with such requirements. It is unclear at this stage whether the Egyptian government will develop regulation around a pre-closure monitoring plan. The recommendation that the onus is placed on the operator to propose a monitoring plan takes into consideration the absence of specific requirements for injected CO_2 in Egypt and aligns with practice under existing environmental legislation that allows operators to self-determine the level of monitoring for activities similar to CCS.

Closure	**Condition of Closure** Conditions of closure deal with providing evidence to the state body responsible that the site, once closed, will not pose a risk to the environment and human health. Approval from relevant state bodies is required prior to closing of CCS projects / sites and such approval may be obtained based on a closure protocol which would be submitted to the relevant authority for review. In Egypt, there is uncertainty as to which governmental authorities would be involved in the closure of a CCS site for instance - the EEAA or the WMA. The executive regulations of the Mines and Quarries Law, in which articles 33 and 34 provide general requirements and framework for handling the closure of oil wells, may be illustrative. This framework has the potential to be amended or adopted for the closure of CCS sites. **Closure Plan** To close a CCS project / site in other jurisdictions, an operator is required to provide a closure-plan that deals with certain issues including, but not limited to; the remediation of the storage formation, plan or proposal for long-term monitoring (see section on post-closure monitoring above), and have that plan approved as a condition of closure.	There is uncertainty as to the relevant government authorities involved in issuing any approvals or requirements in respect of closure. Even if an existing regime such as the framework for closure of oil fields were to be adopted, it would not afford an integrated regime for CCS activities. **Closure Plan** We recommend the provision of a compliant closure plan to be a condition of closure.
Storage Permanence	In some jurisdictions (such as the Australian Commonwealth and Victoria in Australia), storage permanence is a condition of granting a licence for a CCS project / site.	While CCS projects are not prohibited and are therefore permissible in Egypt, there is no regulatory framework or requirements in respect of permanence.

5.0 CO_2 STORAGE RESOURCE ASSESSMENT

Sedimentary basins in Egypt offer geologic storage options for CO_2 in both hydrocarbon fields and saline formations. Methods for estimated CO_2 storage resources for each of these storage options are unique and are presented in turn.

5.1 Hydrocarbon Field Storage Methodology

CO_2 storage resource estimates for Egyptian hydrocarbon fields were made using the approach published by the United States Geological Survey (Brennan et al., 2010). This method is based upon the assumption that some portion of the reservoir pore volume originally occupied by hydrocarbons produced from that reservoir can be replaced with injected CO_2. This quantity is defined as the Known Recovery Replacement storage resource (KRR_{RES}) and is calculated using Equation 1:

Equation 1

$$KRR_{RES} = (KR_{RES} \times B_{SE}) \times pCO_2$$

where,

KRR_{RES} = the known recovery replacement storage resource (mass, $MtCO_2$)

KR_{RES} = the known recovery production volumes corrected to reservoir conditions – see Equation 2 (volume, barrels of oil equivalent, boe)

B_{SE} = the storage efficiency of buoyant CO_2 (fraction)

pCO_2 = the density of CO_2 at reservoir conditions (mass per unit volume, kg/m^3)

The known recovery production volume of hydrocarbons at reservoir conditions, KR_{RES}, is defined by Equation 2:

Equation 2

$$KR_{RES} = [((KR_{OIL} + KR_{NGL}) \times FVF_{OIL}) + (KR_{GAS} \times FVF_{GAS})]$$

where,

KR_{OIL} = the known recovery of oil (volume, barrels of oil equivalent, boe)

KR_{NGL} = the known recovery of natural gas liquids (volume, barrels of oil equivalent, boe)

FVF_{OIL} = the formation volume factor for oil and natural gas liquids (fraction)

KR_{GAS} = the known recovery of gas (volume, barrels of oil equivalent, boe)

FVF_{GAS} = the formation volume factor for gas (fraction)

Buoyant trapping storage efficiency, B_{SE}, is governed by the irreducible water fraction (S_{wirr} or S_{wc}, saturation of connate water) and the mobility of CO_2 relative to the in-situ fluids in a physical closure (Blondes et al., 2013). Although irreducible water fractions can leave 60-80 % (i.e., 1-S_{wirr}) of reservoir pore space available for CO_2 storage, sweep efficiency will be less than 100 %, so CO_2 mobility reduces the 1-S_{wirr} value down to B_{SE} values of approximately 20, 30, or 40 % (minimum, most likely, maximum, respectively) (Blondes et al., 2013).

5.1.1 Resource Calculation Assumptions and Approximations

For simplicity, a deterministic approach using a B_{SE} value of 30 % was used to estimate the storage resources in Egpyt's depleted hydrocarbon fields. Recovered resource volumes for Egypt's hydrocarbon fields were taken from the hydrocarbon reserves database compiled by Global Data (https://www.globaldata.com/).

Formation Volume Factors (FVFs) account for fluid volume changes between reservoir and surface conditions. FVFs are unique to each fluid in each field and are not often published with identifiable field data. When available, published FVFs were used for resource calculations. When FVF_{oil} was unavailable, an average of

1.40 RB/STB (Reservoir Barrels/Stock Tank Barrels) was used. When FVF_{gas} was unavailable, it was estimated based on the temperature and pressure conditions of the gas field and an assumption of the field's gas gravity and composition (0.55 and pure CH_4, respectively).

In many cases, reservoir data – including depth, temperature, and pressure – were unavailable. In these cases, depth was estimated from the total depth (TD) of a well in the field. This depth was then used to estimate pressure from regional trends or by calculating a hydrostatic pressure (assuming a water gradient of 1.44 psi/m). An average geothermal gradient of 33 °C/km was used to calculate reservoir temperature when temperature data was unavailable.

Saline formations are subsurface sedimentary rock layers saturated with brine with a high concentration of total dissolved solids (TDS). In the United States, for example, underground sources of drinking water (USDW) are those subsurface water resources containing less than 10,000 mg/L of TDS (US EPA, 2010). Those formations with TDS exceeding 10,000 mg/L can be targets for CO_2 storage. TDS data for Egyptian formations were unavailable for this report and it is assumed the formations assessed herein could be potential targets for CO_2 storage.

5.2 Saline Formation Storage Methodology

The United States Department of Energy, National Energy Technology Laboratory (US DOE NETL) has developed a CO_2 storage resource calculator, called CO_2-SCREEN, intended to be used as a high-level screening tool to predict the storable mass of CO_2 in saline formations (Sanguinito et al., 2022). The Python-based tool utilises Monte Carlo simulations to perform probabilistic resource estimates for saline formations, shale zones, and residual oil zones (ROZ) and is available for download from the US DOE NETL Energy Data Exchange website (EDX) here: *https://edx.netl.doe.gov/dataset/CO2-screen*.

Version 4.1 of CO_2-SCREEN was used to estimate the CO_2 storage resource in the major saline formations of northeast Egypt. The following data and assumptions were used when determining the physical parameters for the saline formations:

- Area – estimated from distribution of well penetrations in the Global Data database
- Gross Thickness – averaged from well data in the Global Data database
- Porosity – averaged from well data in the Global Data database
- Pressure – estimated from the reservoir depth (using a hydrostatic gradient of 0.44 psi/ft when pressure data in wells was unavailable)
- Temperature – estimated from the reservoir depth (using a geothermal gradient of 33 °C/km when temperature data was unavailable)

Storage efficiency factors developed by the International Energy Agency Greenhouse Gas R&D Programme (IEA GHG, 2009) were used for resource estimation. Default IEA efficiency factors for the relevant formation lithology and depositional environment were selected (see Table 12 in section 5.3.2). Default net-to-total area, net-to-gross thickness, and effective-to-total porosity were used as well.

5.3 Storage Resource Assessment Results

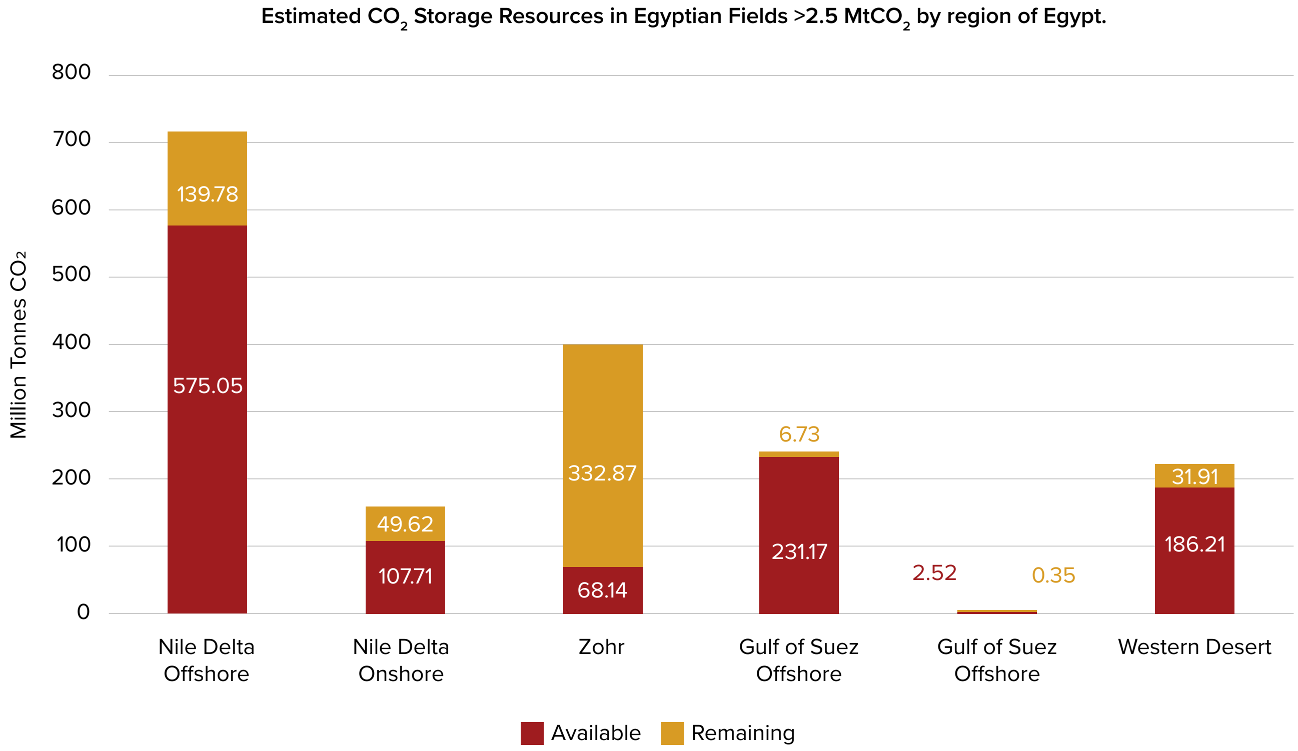
5.3.1 Hydrocarbon Fields

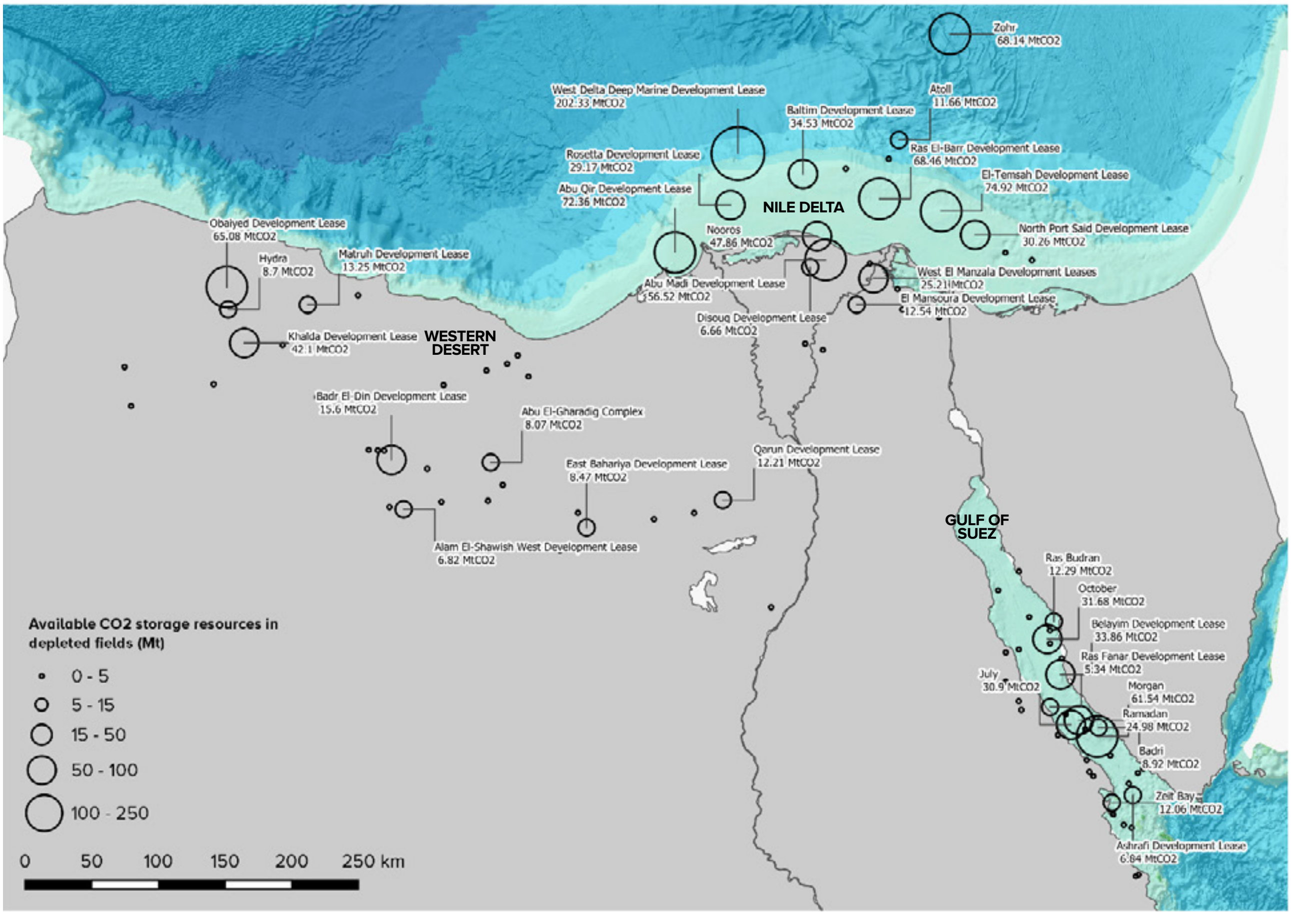
Storage resource calculations were performed on 74 fields or development leases (in these cases reported reserves were attributed to the concession area rather than individual fields) across five regions (Figure 3):

- the Nile Delta (on- and offshore)
- the Gulf of Suez (on- and offshore)
- Western Desert

The Zohr Field is shown separately due to its anomalous size and distance from the coast. Produced reserves compiled by Global Data were used to calculate KRR_{RES}. These Known Recovery Replacement resources are reported in Figure 3 as "**available**" resources and resources associated with yet-to-be-produced reserves are reported as "**remaining**" resources. Remaining resources are not available for CO_2 storage until those remaining reserves in a field have been produced. The sum of the available and remaining resources in a field is reported as the **total** CO_2 storage resource in Figure 3.

Figure 3: Upper panel: Estimated CO_2 storage resources in Egyptian hydrocarbon fields by region. Only fields greater than 2.5 $MtCO_2$ were included in this figure. Lower panel: Map of estimated CO_2 storage resources in Egyptian hydrocarbon fields. The values shown are the estimate available resources ($MtCO_2$).





Individual oil and gas fields or development leases contain estimated total CO_2 storage resources ranging from less than 2.5 $MtCO_2$ to 401 $MtCO_2$ (Table 11). The maximum available CO_2 storage resource among Egypt's depleted fields is 202 $MtCO_2$ (West Delta Deep Marine Development Lease). Onshore, the largest available storage resources are in the Obaiyed and Khalda Development Leases of the Western Desert (65 and 42 $MtCO_2$, respectively) and in the Abu Madi Development Lease of the Nile Delta (56 $MtCO_2$). In shallow water, just offshore of the western Nile Delta, the Abu Qir Development Lease, near Alexandria, has the largest available storage resource (72 $MtCO_2$), while just offshore the central Nile Delta, the Nooros Field has the largest available storage resource (48 $MtCO_2$). The latter still has a significant reserves remaining and unlikely to be used in the short term.

Table 11: Estimated CO_2 storage resources for Egyptian oil and gas fields exceeding 2.5 Mt of available CO_2 storage resources.

Field	Status	Water Depth	Region	Available ($MtCO_2$)	Remaining ($MtCO_2$)	Total ($MtCO_2$)
West Delta Deep Marine Development Lease	Producing	Deepwater	Nile Delta Offshore	**202.33**	**19.51**	**221.84**
El-Temsah Development Lease	Producing	Shallow Water	Nile Delta Offshore	**74.92**	**2.08**	**77.00**
Abu Qir Development Lease	Producing	Shallow Water	Nile Delta Offshore	**72.36**	**28.95**	**101.31**
Ras El-Barr Development Lease	Producing	Shallow Water	Nile Delta Offshore	**68.46**	**2.20**	**70.66**
Zohr	Producing	Deepwater	Zohr	**68.14**	**332.87**	**401.01**
Obaiyed Development Lease	Producing	Onshore	Western Desert	**65.08**	**4.32**	**69.40**
El Morgan	Producing	Shallow Water	Gulf of Suez Offshore	**61.54**	**2.21**	**63.75**
Abu Madi Development Lease	Producing	Onshore	Nile Delta Onshore	**56.52**	**0.56**	**57.08**
Nooros	Producing	Shallow Water	Nile Delta Offshore	**47.86**	**45.24**	**93.10**
Khalda Development Lease	Producing	Onshore	Western Desert	**42.10**	**1.50**	**43.60**
Baltim Development Lease	Producing	Shallow Water	Nile Delta Offshore	**34.53**	**11.58**	**46.11**
Belayim Development Lease	Producing	Shallow Water	Gulf of Suez Offshore	**33.86**	**3.05**	**36.91**
October	Producing	Shallow Water	Gulf of Suez Offshore	**31.68**	**0.42**	**32.10**
July	Producing	Shallow Water	Gulf of Suez Offshore	**30.90**	**0.05**	**30.95**
North Port Said Development Lease	Producing	Shallow Water	Nile Delta Offshore	**30.26**	**1.19**	**31.45**
Rosetta Development Lease	Abandoned	Shallow Water	Nile Delta Offshore	**29.17**	**0.00**	**29.17**
West El Manzala Development Leases	Producing	Onshore	Nile Delta Onshore	**25.21**	**23.99**	**49.20**
Ramadan	Producing	Shallow Water	Gulf of Suez Offshore	**24.98**	**0.04**	**25.02**
Badr El-Din Development Lease	Producing	Onshore	Western Desert	**15.60**	**3.00**	**18.60**
Matruh Development Lease	Producing	Onshore	Western Desert	**13.25**	**0.28**	**13.53**
El Mansoura Development Lease	Producing	Onshore	Nile Delta Onshore	**12.54**	**1.57**	**14.11**
Ras Budran	Producing	Shallow Water	Gulf of Suez Offshore	**12.29**	**0.05**	**12.34**

Field	Status	Water Depth	Region	Available ($MtCO_2$)	Remaining ($MtCO_2$)	Total ($MtCO_2$)
Qarun Development Lease	Producing	Onshore	Western Desert	12.21	1.74	13.95
Zeit Bay	Producing	Shallow Water	Gulf of Suez Offshore	12.06	0.02	12.08
Atoll	Producing	Deepwater	Nile Delta Offshore	11.66	29.02	40.68
Badri	Producing	Shallow Water	Gulf of Suez Offshore	8.92	0.10	9.02
Hydra	Producing	Onshore	Western Desert	8.70	1.68	10.38
East Bahariya Development Lease	Producing	Onshore	Western Desert	8.47	3.41	11.88
Abu El-Gharadig Complex	Producing	Onshore	Western Desert	8.07	12.07	20.14
Ashrafi Development Lease	Producing	Shallow Water	Gulf of Suez Offshore	6.84	0.17	7.01
Alam El-Shawish West Development Lease	Producing	Onshore	Western Desert	6.82	2.05	8.87
Disouq Development Lease	Producing	Onshore	Nile Delta Onshore	6.66	3.36	10.02
Ras Fanar Development Lease	Producing	Shallow Water	Gulf of Suez Offshore	5.34	0.56	5.90
Qantara Development Lease	Producing	Onshore	Nile Delta Onshore	3.62	16.83	20.45
Thekah Complex	Abandoned	Shallow Water	Nile Delta Offshore	3.50	0.00	3.50
East Ras Qattara Development Lease	Producing	Onshore	Western Desert	3.24	1.82	5.06
West El-Qantara Development Lease	Producing	Onshore	Nile Delta Onshore	3.15	3.31	6.46
Al-Zaafarana	Producing	Shallow Water	Gulf of Suez Offshore	2.76	0.07	2.83
Ras Qattara Development Lease	Producing	Onshore	Western Desert	2.68	0.05	2.73
West Esh El-Mallaha Development Lease	Producing	Onshore	Gulf of Suez Onshore	2.52	0.35	2.87
			SUM	1170.80	561.27	1732.07

Still in shallow water, but some distance offshore, the West Delta Deep Marine Development Lease, the El-Temsah Development Lease, and the Ras El-Barr Development Lease feature the largest available storage resources at 202 $MtCO_2$, 75 $MtCO_2$, and 69 $MtCO_2$, respectively. The largest total storage resource among Egypt's depleted fields is in the Zohr Field (401 total $MtCO_2$). However, because the field is in the early phases of production, it will not be available in the near term. Therefore, it was not considered further.

In the Gulf of Suez, most storage resources are offshore. The largest available storage resources in this region are in the El Morgan Field (62 $MtCO_2$), followed by the Belayim Development Lease (34 $MtCO_2$), October (32 $MtCO_2$) and July (31 $MtCO_2$) Fields.

5.3.2 Saline Formations

Additional work is required to determine the suitability of Egypt's saline formations for CO_2 storage. Results in table 12, assume the formations are suitable for CO_2 storage (i.e., feature high concentrations of total dissolved solids).

The Kharita Formation has the largest saline formation CO_2 storage resource in northeast Egypt at roughly 488 $GtCO_2$ (Table 12). The significant resource estimate is driven by its thickness – averaging nearly 400 m gross thickness – and its aerial extent. The Kharita Formation is penetrated by wells across northeastern Egypt, from the Western Desert through to the Gulf of Suez. Well penetrations confirm the extent of the Kharita Formation and provide the area for volumetric calculations.

Table 12: Estimated CO_2 storage resources for saline formations in northeast Egypt. Resources were calculated using the US DOE NETL CO_2-SCREEN tool and are shown in gigatonnes (Gt) of CO_2.

Formation	Depositional Envt.	Lithology	p10 ($GtCO_2$)	p50 ($GtCO_2$)	p90 ($GtCO_2$)
Kharita	Shallow Marine	Clastic	119.0	488.0	1433.0
Sidi	Slope Basin	Mixed (Marl/SS)	14.2	57.6	175.4
Abu Madi	Fluvial	Clastic	10.3	38.8	119.0
Kafr	Slope Basin	Clastic	2.8	13.8	57.5
Matulla	Shallow Marine	Clastic	3.4	13.7	42.3
Safa	Shallow Marine	Clastic	2.9	12.8	43.7
Qawasim	Shallow Marine	Clastic	2.4	10.6	37.0
Alam	Shallow Marine	Dolomite	2.4	9.5	29.3
Nubia	Fluvial	Clastic	2.3	9.0	28.0
Kareem	Shallow Marine	Mixed (Marl/SS)	2.0	8.2	24.7
Rudeis	Shallow Marine	Limestone	0.6	2.5	8.4
El Wastani	Shallow Marine	Clastic	0.2	1.0	3.9
Tineh	Slope Basin	Clastic	0.1	0.5	1.4
		SUM	**163**	**666**	**2004**

In the Nile Delta region, the Sidi Formation offers the highest saline formation storage resource at approximately 58 $GtCO_2$. The Sidi Formation's storage resources are driven largely by its significant gross thickness – approximately 450 m. Storage in the Sidi Formation, however, may be challenging and expensive in areas where it exceeds more than 3000 m in depth. Also significant in the Nile Delta region are the Abu Madi (39 $GtCO_2$), marine (slope basin) Kafr (14 $GtCO_2$), and shallow marine Qawasim Formations (11 $GtCO_2$) – all of which stratigraphically overlay the Sidi Formation.

In the Gulf of Suez region, the Matulla Formation is a significant saline storage resource at 14 $GtCO_2$. Additionally, the Nubia Formation (9 $GtCO_2$) and Kareem and Rudeis formations (8 and 3 $GtCO_2$, respectively) are additional saline formation storage options in the Gulf of Suez.

And in the Western Desert region, the Safa and Alam formations (13 and 10 $GtCO_2$, respectively) are significant potential saline storage formations.

5.4 CO_2 Storage Resource Assessment Summary

Oil and gas fields are distributed across northeast Egypt in both on- and offshore sedimentary basins, and offer opportunities for the permanent subsurface storage of CO_2. Available storage resources in depleted fields, however, only range from <2.5 $MtCO_2$ to ~202 $MtCO_2$.

The largest available storage resources onshore are in near-depleted fields of the following concessions:

- Obaiyed and Khalda Development Leases (65 and 42 $MtCO_2$, respectively) – Western Desert
- Abu Madi Development Lease (56 $MtCO_2$) – Nile Delta

The largest available storage resources offshore (nearshore) are fields of the following concessions:

- Abu Qir Development Lease (72 $MtCO_2$) – just offshore of the western Nile Delta, near Alexandria
- Nooros Field (48 $MtCO_2$) – just offshore in the central Nile Delta

These CO_2 storage resources in depleted fields are significantly smaller than the storage resources estimated to be available in saline formations.

Storage resource estimates for saline formations in northeast Egypt are orders of magnitude larger than estimates for depleted fields (gigatonne-scale versus megatonne-scale, respectively). Saline formations with the largest storage resource potential are:

- Kharita Formation (488 $GtCO_2$) – present across northeastern Egypt
- Sidi Formation (58 $GtCO_2$) Abu Madi Formation (39 $GtCO_2$), Kafr Formation (14 $GtCO_2$), and Qawasim Formation (11 $GtCO_2$) – all present in the Nile Delta region
- Matulla Formation (14 $GtCO_2$), Nubia Formation (9 $GtCO_2$), Kareem Formation (8 $GtCO_2$), and Rudeis Formation (3 $GtCO_2$) – all present in the Gulf of Suez

Because depleted fields are well-characterised with subsurface data, they may provide the fastest path to commercialisation of Egypt's CO_2 storage resources. As Egypt's CCS market grows, however, large-scale point-source projects or CCS networks will likely need to utilize the larger storage resources available in saline formations.

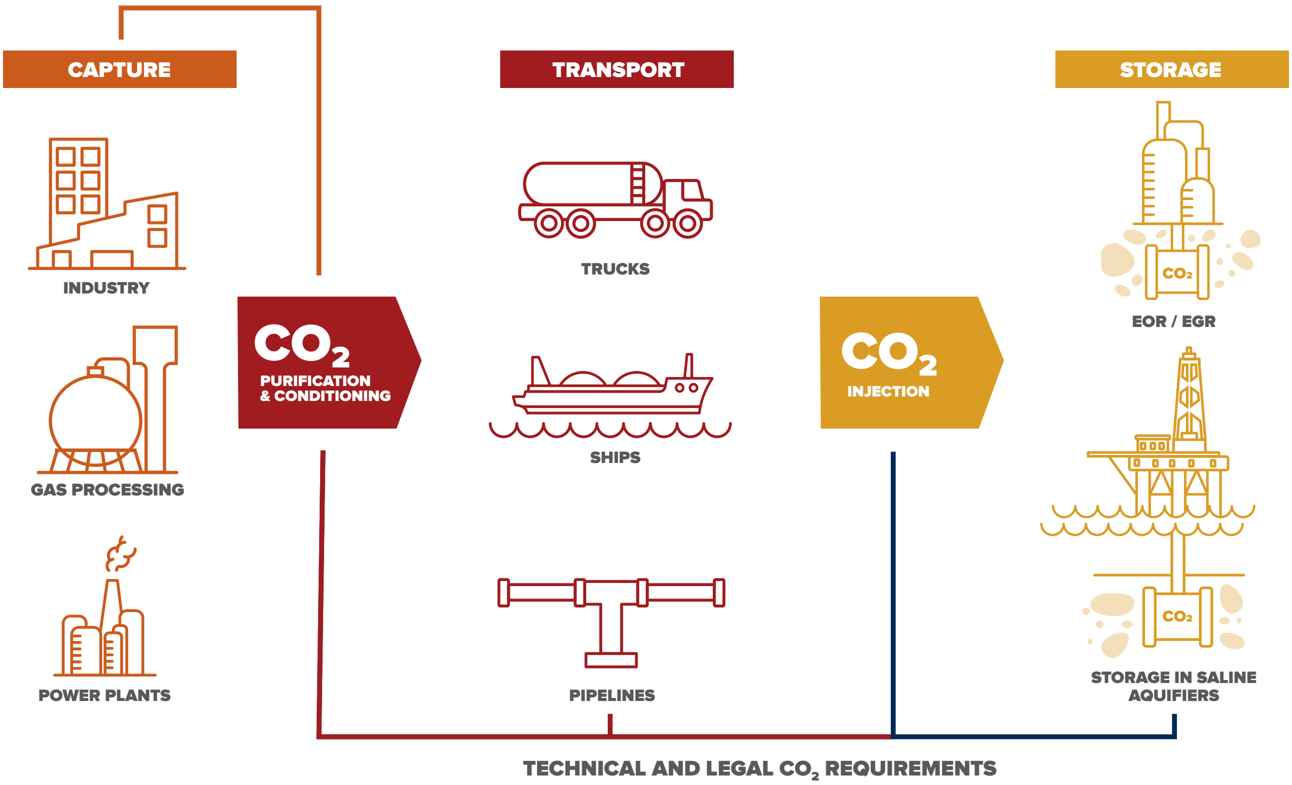
6.0 EGYPT CCS HUBS

6.1 Typical CCS hub design

A CCS value chain typically consists of the following elements:

- CO_2 capture at the emission source – purifying CO_2 from a gas stream up to over 95% purity by volume;
- CO_2 dehydration and compression/liquefaction, depending on the transport method;
- CO_2 transport by pipeline, ship, rail or truck;
- CO_2 injection, and monitoring and verification of stored CO_2.

Figure 4: CCS value chain concept diagram.



The cost of each CCS component varies from project to project, primarily due to differences in the size and location of the CCS facility and the characteristics of the CO_2 source. Technology is a vital consideration in CCS, but it is not the only factor. A range of other factors feed into costs across the CCS value chain that will be explored in this section.

One avenue for looking at reducing and sharing the costs for CCS is the use of a CCS hub model. A CCS hub model consists of bringing together multiple sources of CO_2 to a single location (the hub) for compression before flowing to a shared transmission pipeline to the storage site.

(GCCSI, 2021b) highlighted the key advantages of a hub model including:

- Reduced per-tonne compression costs through economies of scale at the compression hub;
- Flexibility in compression train operation across multiple sites, including better turndown to enable lower CO_2 flows when necessary – for example, when one or more upstream facilities are offline;
- Using cheaper low-pressure gas-phase lines to transport CO_2 flows when necessary – for example, when one or more upstream facilities are offline;
- Using cheaper low-pressure gas-phase lines to transport CO_2 from each source facility to the hub results in lower cost piping overall.

6.2 Egypt hub design

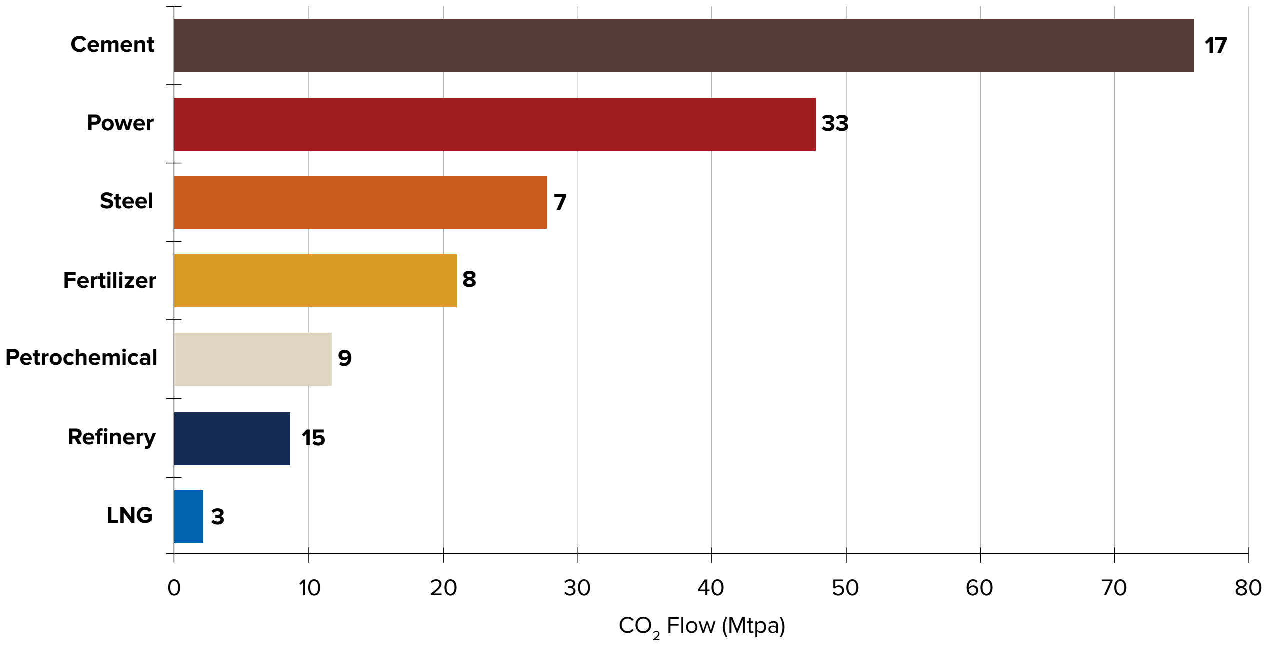
6.2.1 Egypt emissions sources

The GCCSI identified a number of CO_2 emitters in Egypt that could be considered for CCS covering a wide range of industries.

The total potential CO_2 that could be considered for CCS was estimated at approximately 180 Mtpa CO_2. The main industries that could benefit from CCS include hard-to-abate sectors, including cement and steel production. Egypt also has a strong fertilizer industry, relying on the production of ammonia. Ammonia production is quite conducive to CCS for reasons that will be detailed in the subsequent sections.

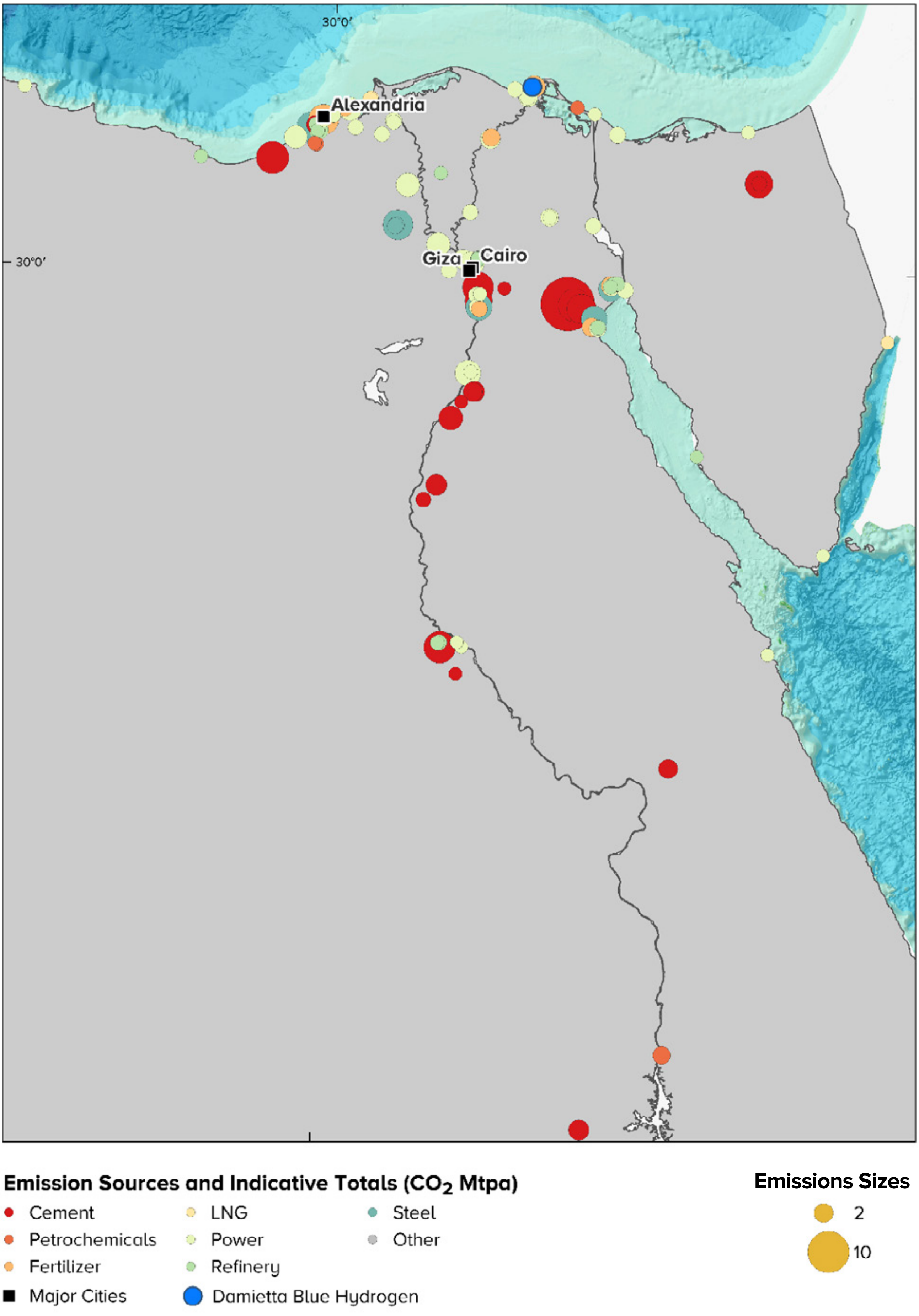
Besides the scale and type of industry, the location of the CO_2 sources to other sources is also important. As described in the previous section, Typical CCS Hub Design, multiple sources in the same location offer the opportunity for hub compression assisting in taking advantages of economies of scale to reduce transport costs.

Figure 5: Egypt CO_2 emissions by industry (sources: see Appendix B).



Numbers represent the number of facilities per industry identified

Figure 6: Egypt industrial emissions source locations.



As the map indicates, there are multiple clusters of large-scale industrial emitters throughout Egypt in areas surrounding the cities of Suez, Helwan, Beni Suef, Damietta and Alexandria as examples. Clusters of emitters like this provide good starting points for any proposed CCS hub.

The full list of identified Egypt industrial emitters and details can be found in Appendix B. For the purpose of the analysis in this study, it is assumed that the estimated emissions are constant until 2050 (and beyond) unless projects have been identified that may influence those emissions.

6.2.2 Capture costs

CO_2 capture in the power generation and industrial sectors usually accounts for the majority of the cost in the full CCS chain. CO_2 sources that require reduced effort, and therefore lower cost, to capture are more likely to be considered for CCS as a means of decarbonization. Other factors that can contribute to whether a source is likely to be considered for CCS include the remote location of the source, and therefore complexity and cost for pipeline transport, or the ability to leverage other sources of renewable energy to displace the fossil fuel-based energy demand.

The technology exists to capture CO_2 from all sources, however all at varying costs and complexities. A key factor in CO_2 capture cost is the properties of the source gas.

Table 13: CO_2 characteristics in typical industrial flue gas streams (GCCSI, 2021b).

Industry	Point Source	CO_2 concentration (wet)	Gas stream pressure (kPa)	CO_2 partial pressure (wet) (kPa)	Inherent CO_2 capture****
Power	Natural gas combined cycle (NGCC) power plant	3.8 – 4.5 vol%	Atmospheric***	3.8 – 4.6	No
	Coal fired-power plant	12 – 14 vol%	Atmospheric***	12.2 – 14.2	No
	Biomass / waste-fired power plant	10 – 12 vol%	Atmospheric***	10.1 – 12.2	No
Power / Industrial Heat	Natural gas-fired power and/or heat plant (Open Cycle)	4 – 8 vol%	Atmospheric***	4.1 – 8.1	No
Petroleum Refining / Petrochemicals	Fluid catalytic cracking	10-14 vol%	Atmospheric***	10.1 - 14.2	No
	Process heater	8-10 vol%	Atmospheric***	8.1 - 10.1	No
	Ethylene production steam cracking	7-12 vol%	Atmospheric***	7.1 - 12.2	No
	Steam methane reforming hydrogen production	15 – 16 vol%	2000 – 3000	300 – 480	No
	Ethylene oxide production	>90 vol%	Atmospheric***	> 92	Yes
Cement	Kiln flue gas	~18 vol%	Atmospheric***	~ 18	No
	Pre-calciner	20 -30 vol%	Atmospheric***	20 - 30	No
Pulp and paper	Lime kiln	~16 vol%	Atmospheric***	~ 16	No
Iron & Steel	COREX smelting reduction process	32-35 vol%	Atmospheric***	32 - 35	No
	Hot Stove	24 – 28 vol%	Atmospheric***	24 - 28	No
	Lime calcining	7 – 8 vol%	Atmospheric***	7.1 – 8.1	No
	Sinter plant	3.7 – 4.2 vol%	Atmospheric***	3.7 – 4.2	No
Aluminum	Aluminium smelter	0.8 – 1.1 vol%	Atmospheric***	0.8 – 1.1	No
Fertilizer	Coal gasification syngas	25 – 42 vol%	3000 – 6000	750 - 2500	Yes*
	Natural gas reforming syngas	15-40 vol%	2000 – 3000	300 - 1200	Yes*
Natural gas processing / LNG	Natural gas processing / LNG	Various to 60 vol%	900 – 8200+	Varies, up to 5000	Yes, acid gas removal
Bioethanol	Ethanol fermentation	>85 vol%	Atmospheric***	> 85	**

* CO_2 from syngas stream is captured for downstream urea production

** Only dehydration and compression required

*** Standard atmospheric pressure is 101.3 kPa, which is close to the average air pressure at sea level. However, atmospheric pressure does vary by location and altitude

**** Inherent CO_2 capture means no additional work or energy is required to separate the CO_2

The partial pressure is a key property influencing the cost of capture. In a mixture of gases, each gas contributes to the total pressure of the mixture independently. This contribution is the partial pressure. In an ideal gas, the partial pressure of a gas in a mixture is equal to the volume fraction of that gas in that mixture, multiplied by the total pressure.

The partial pressure of CO_2 reflects the relative ease with which CO_2 can be captured from a gas mixture. Higher partial pressures are easier and cheaper to capture than lower pressures because less external energy is required to increase the CO_2's partial pressure to that in the final captured CO_2 stream. Higher CO_2 partial pressures are observed when the fraction of CO_2 is higher, the overall gas pressure is higher, or both.

There are several post combustion capture technologies available that could be suited to capturing CO_2 from the CO_2 sources identified in Egypt. For the purpose of simplifying the study a 30 wt% monoethanolamine (MEA) solvent technology is used to estimate the costs for CO_2 capture. MEA solvent technology is widely used as the reference technology for capturing CO_2 from flue gases with a wide range of CO_2 partial pressures (IEAGHG 2019; Rochelle 2009; Bains, Psarras & Wilcox 2017).

The GCCSI undertook process modelling of a 30 wt% MEA solvent technology CO_2 capture plant to quantify expected overall costs of CO_2 capture across a range of partial pressures and scales. Capture cost was estimated as the combination of capital and operating cost for the plant expressed in US Dollars per tonne of CO_2 captured. This is a form of levelised cost for CO_2 capture and is a consistent basis for comparison between capture plants operating at different scales across different applications. Detailed methodology for the capture cost estimation can be found in Appendix C. The capture costs exclude upstream gas treatment, which is facility and industry specific, and downstream local compression, which is subject to the transport conditions required.

6.2.3 CO_2 storage

While capture costs are significant when assessing the emissions sources to be considered for a CCS hub, the location of a suitable storage site for large scale CCS hub must also be considered. It is often an iterative process during initial screening, identifying potential CO_2 sources with available nearby storage. While CCS hubs offer the opportunity for reducing the transportation of CO_2, economies of scale only go so far. Beyond this, it is distance to potential storage sites and the resulting cost of transport and storage.

Egypt potentially has large-scale onshore storage that could support CCS. Reviews of the saline aquifer storage for Egypt indicate highly prospective onshore geological storage for CO_2, with a capacity to store several thousand million tonnes. Onshore storage could offer benefits by avoiding costly pipelines (both on and offshore) and offshore injection infrastructure (platforms).

6.2.4 Egypt hub emissions sources

For this study, the following methodology was considered in the selection of CO_2 sources for the CCS hub.

- Inherent CO_2 were considered highly suitable sources to act as anchor facilities;
- Larger-scale low carbon capture costs, such as those for cement and steel, offer opportunities to take advantage of economies of scale for transport and were also considered as anchor facilities;
- Smaller-scale CO_2 sources would be considered if they were within a facility with low cost and large-scale sources of CO_2 for transport to form a hub;
- Smaller-scale CO_2 sources would be considered if they were adjacent to a main trunkline route limiting the piping infrastructure costs solely absorbed by the facility operator;
- For other small-scale CO_2 sources an alternative means of decarbonization, such as pre-combustion carbon capture through the generation of blue hydrogen or direct air capture (DAC), could be considered.

Using the above methodology and accounting for the prospective storage location for CO_2 injection, the CO_2 sources considered for the Egypt Hub are given in Table 14.

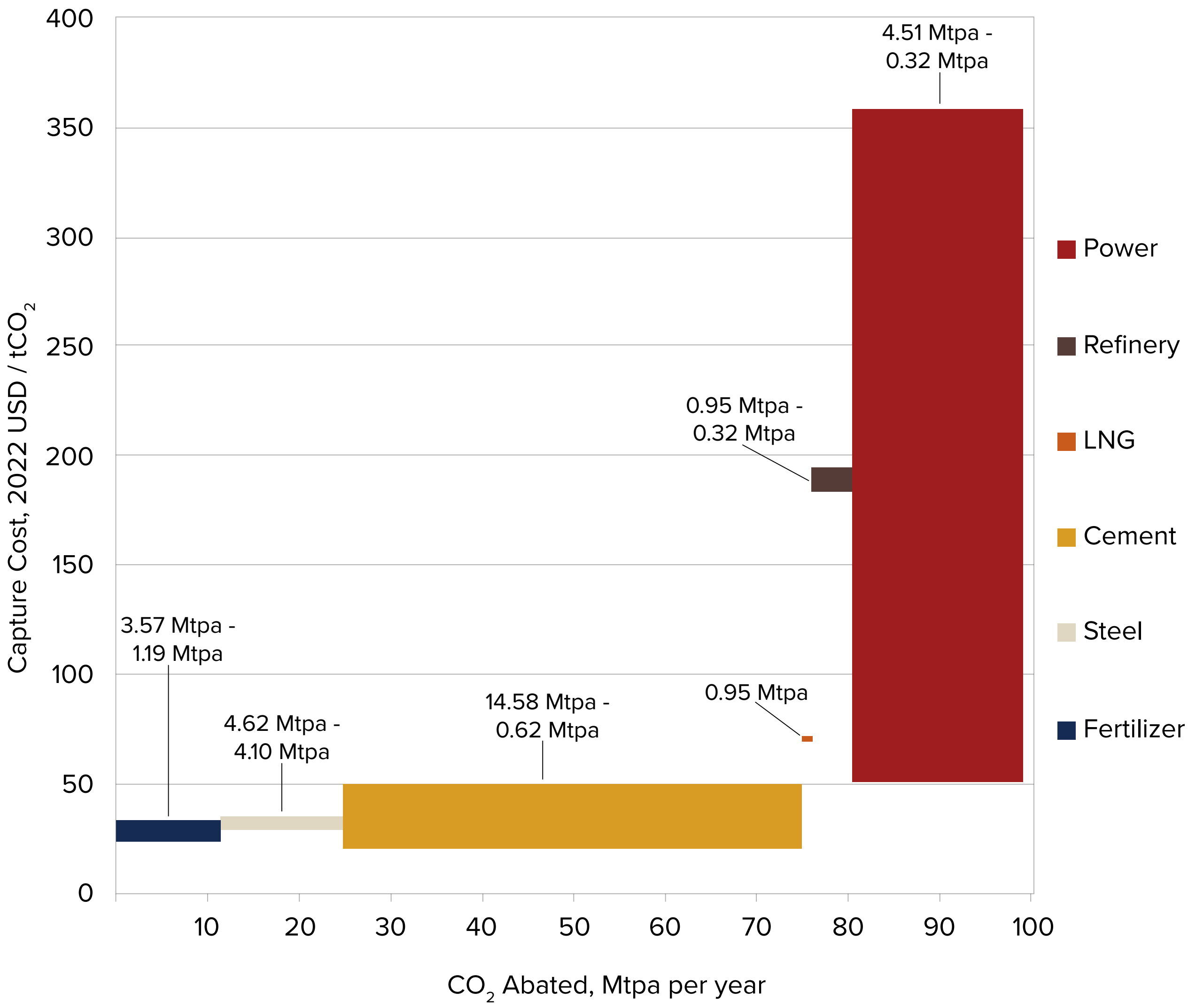
Specific CO_2 concentrations and pressures were not publicly available for the industrial emissions sources. For the purpose of this CCS hub design, the CO_2 pressure and concentration for each source were assumed based on either input from OGCI or typical values for the industry or equipment from (GCCSI, 2021b).

Table 14: Egypt industrial CO_2 sources for the proposed CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
Mostorod I	Refinery	0.51	7.9
El Suez I	Refinery	0.62	7.9
Mostorod II	Refinery	0.95	15.2
El Suez II	Refinery	0.75	11.8
Soukhna	Refinery	0.61	7.9
Suez I	Refinery	0.63	7.9
Suez II	Refinery	0.32	7.9
MISR Fertilizer Production Company Damietta Complex	Fertilizer	3.57	117.9
Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	2.44	117.9
El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	1.82	117.5
Helwan Fertilizers Company El Tabbin Complex	Fertilizer	1.19	117.9
El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	2.38	117.9
Damietta	LNG	0.95	1,945.3
Arabian Cement Company SAE	Cement	6.88	20.6
Helwan Cement Co SAE	Cement	4.97	20.6
Suez Cement Company SAE (2)	Cement	5.78	20.6
Egyptian Tourah Portland Cement Co SAE	Cement	6.36	20.6
Lafarge Cement Co Egypt SAE	Cement	14.58	20.6
Misr Beni Suef Cement Co SAE	Cement	3.85	20.6
Misr Cement Company SAE	Cement	2.75	20.6
Royal El Minya Cement	Cement	0.62	20.6
South Valley Cement Co SAE	Cement	2.06	20.6
Wadi El Nile Cement Co	Cement	2.48	20.6
Egyptian Iron & Steel Company Cairo plant	Steel	4.62	13.1
Ezz Flat Steel Ain Sokhna plant	Steel	4.60	19.2
Suez Steel Solb Misr Attaka plant	Steel	4.10	19.2
Abu Sultan	Power	0.98	4.2
Ataka	Power	1.48	4.2
Cairo South	Power	1.17	4.2
Cairo West	Power	2.23	4.2
Damietta West	Power	0.82	4.2
El-Tebeen	Power	1.15	4.2
Kuriemat 2	Power	4.51	4.2
Kuriemat Solar/Thermal	Power	0.20	4.2
New Gas Damietta	Power	0.82	4.2
New Gas Shabab	Power	1.64	4.2
Shabab	Power	0.16	4.2
Suez Gulf	Power	1.12	4.2
Talkha	Power	2.39	4.2
Wadi Hof	Power	0.16	4.2
Total		**99.22**	

Figure 7 shows the cost of capture by industry for the sources included in the pipeline CCS hub (see Section 6.2.8).

Figure 7: Egypt CO_2 source scale and capture costs. Callouts above each industry show the CO_2 flow ranges for that industry.



For a typical CCS hub inherent CO_2 sources are the simplest and lowest cost sources for CO_2 recovery and are therefore most suited for initially starting a CCS hub. Beyond this it comes down to capture cost and scale of the CO_2 source as this will help support economies of scale with transport costs and relative distance of the source of CO_2 to the CO_2 storage site. Staged design of the pipeline CCS hub is beyond the scope of work of this study, the pipeline CCS hub is intended to demonstrate the overall cost of transport to compare to local CCS hub concept (Section 6.2.9).

6.2.5 Blue Hydrogen

Blue hydrogen could contribute significantly to Egypt's decarbonization strategy and economy with available gas and storage in Egypt and access to existing port infrastructure through the following:

- Blue hydrogen could help establish Egypt as a credible future supplier of large quantities of low emissions hydrogen for export and supply blue hydrogen for production of ammonia or urea which is also in high demand;
- In the short term, blue hydrogen can be used to spike natural gas supply, up to pipeline design constraints (typically 5-15% by volume) to deliver some useful emission abatement in remote facilities (such as gas-fired power generation) where post-combustion carbon capture is deemed too costly;
- In the medium term, existing power generation infrastructure could be replaced by new generators that use blue hydrogen to deliver a net-zero aligned power grid;
- Blue hydrogen could supply a future freight fleet powered by hydrogen fuel cells;
- Blue hydrogen could supply a future mine haul truck/excavator fleet which is powered by hydrogen fuel cells.

Therefore, for the purpose of this study, a blue hydrogen facility will be designed to produce 100,000 normal cubic metres per hour, or 82,000 tonnes per year, of clean hydrogen. The blue hydrogen facility will be located in Damietta, where existing gas processing facilities and port infrastructure are located. This provides the necessary starting point for the development of infrastructure supporting the use of blue hydrogen in Egypt or for export.

6.2.6 Direct air capture

Direct air capture (DAC) technologies remove CO_2 directly from the atmosphere. The CO_2 can be permanently stored (achieving negative emissions or carbon removal) or it can be used, for example the production of synthetic fuels if combined with hydrogen.

DAC can play a unique role among technological options in meeting net zero. DAC functions as a backstop technology that caps the overall price of CO_2 as long as that price would otherwise exceed the cost of DAC. For sources of CO_2 that are either extremely costly to abate through direct means DAC could provide an avenue for abatement. Currently DAC is yet to be demonstrated at large scale and reported and projected costs vary significantly from USD 100/tCO_2 to USD 1,000/tCO_2.

For this study DAC has been excluded, however as the technology matures and costs lower it could offer an opportunity for supporting decarbonization in Egypt in the future.

6.2.7 CCS Hub Design

The focus was to explore the potential for large-scale decarbonization of facilities in Egypt. To make any measurable impact to emissions reduction in Egypt, the hub must be at a scale at or greater than the largest global scale CCS projects perceived at the time of this study. Given the large-scale saline formations available for storage in Egypt identified in Section 5.4, Egypt is in a prime position to consider onshore storage as described previously. Onshore storage offers benefits by eliminating costly off-shore pipeline costs as well as costs for offshore platforms.

For this study two CCS hub approaches have been studied given the potential for onshore injection across Egypt.

- The first investigates a large-scale CCS hub with pipeline transport to storage in saline formations in north Egypt via the existing depleted field Abu Madi, the pipeline CCS hub;
- The second investigates local CCS hubs, where multiple sources in a given location store their CO_2 a short distance (ie, local) from their aggregation and compression location in saline aquifers. As many CO_2 sources operate above suitable saline aquifer storage this removes the need for a large proportion of any transport piping required. With a reduced pipeline length, the pipeline pressure drop will also reduce (for the same pipeline diameter), leading to reduced compression costs.

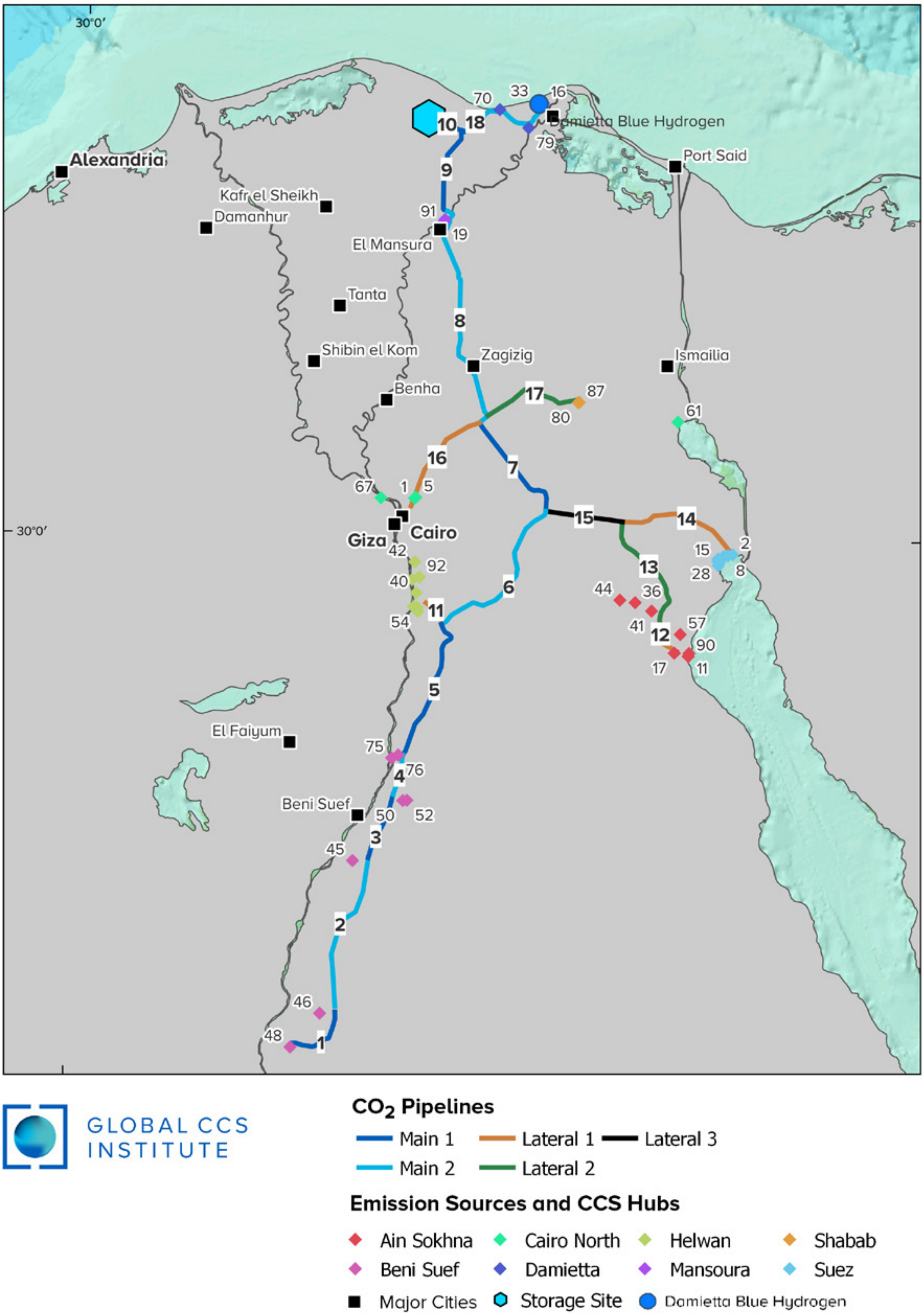
6.2.8 Pipeline CCS hub

6.2.8.1 Main trunkline route

Figure 8 shows the proposed routes for the main trunklines for each stage of development of the CCS hub. For this study a new pipeline is proposed. Limited information on existing piping routes (known to have pipeline easements) were available to consider for CO_2 pipeline routes. The new trunklines follow roads, which may make for fewer risks around land and construction. This also offers the least risk to cultural heritage sites.

The pipeline route is central to aggregating CO_2 from a series of sources to the south, east and north of Cairo before reaching the storage injection location. The main trunkline serves the purpose of gathering CO_2 from several individual large CO_2 emitters and a series of CO_2 emitter clusters, or hubs.

Figure 8: Main trunkline route for the proposed Egypt CCS hub.

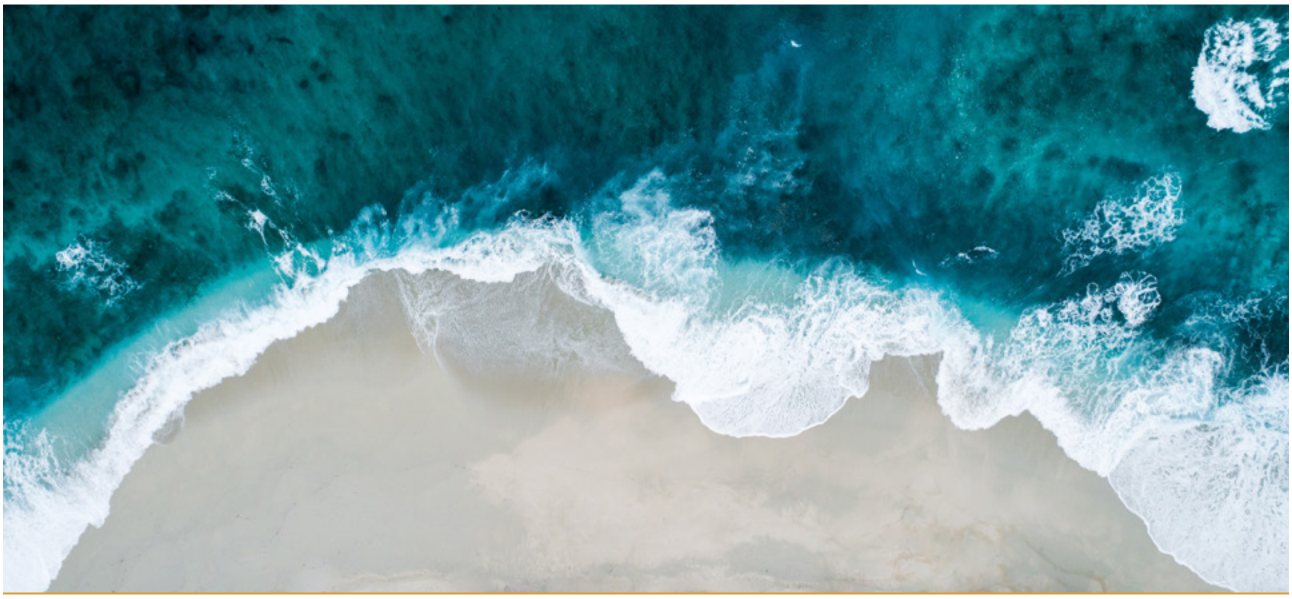


The pipelines are broken into segments to assist with CCS hub design. While Alexandria has a relatively large cluster of CO_2 emitters, any resulting hub and transport would be independent to the overall pipeline CCS hub considered here. Alexandria could also consider storage to the west in the Western Desert. Therefore, it was excluded from the proposed pipeline CCS hub, although it would have many similarities to Damietta.

Table 15 defines the segments for both main trunklines and lateral pipelines supporting the aggregation of CO_2 from each of the hubs.

Table 15: Pipeline segments for the Egypt CCS hub development.

Type	Segment	Description	Length (km)
Main Trunkline	1	Royal El Minya Cement to Misr Cemen Company SAE Injection Point	32
	2	Misr Cement Company SAE to South Valley Cement Co SAE Injection Point	60
	3	Misr Cement Company SAE to South Valley Cement Co SAE Injection Point	30
	4	South Valley Cement Co SAE to Kueiemat Injection Point	15
	5	Kuriemat to Halwan Hub Injection Point	55
	6	Halwan Hub Injection Point to Suez Hubs Injection Point	65
	7	NE Cairo Injection Point to Shabab and North Cairo Hub Injection	52
	8	NE Cairo Injection Point to Mansoura Injection Point	82
	9	Mansoura Injection Point to Damietta Hub Injection Point	42
	10	Damietta Hub Injection Point to Storage Location	18
Lateral Pipelines	11	Halwan Hub Injection Point to Halwan Hub Main Trunkline Injection Point	15
	12	Ain Sokhna Coastal Industrial Hub to Ain Sokhna Cement Hub Injection Point	15
	13	Ain Sokhna Cement Hub to Suez Hub Aggregation Point	46
	14	Suez Hub To Ain Sokhna Hubs Aggregation Point	47
	15	Suez and Ain Sokhna Hubs to Hub Injection Point with Main Trunkline	30
	16	Cairo North Hub to North Cairo Main Trunkline Injection Point	33
	17	Shabab Power Hub to North Cairo Main Trunkline Injection Point	44
	18	Damietta Hub to Damietta Hub Main Trunkline Injection Point	35



6.2.8.2 Reuse of existing piping infrastructure for CO_2 transport

The pipeline CCS hub for Egypt considers new pipelines for the transport of CO_2. An alternative to using new pipelines is to repurpose existing pipelines (typically gas transmission pipelines) for CO_2 transport. Existing gas pipeline data was pursued for Egypt for the purpose of assessing potential for repurposing, however information was limited.

Repurposing of existing gas pipelines may seem attractive, and if it possible can potentially reduce the cost of CO_2 transport by removing the need to install new pipelines in part of full. However, the following factors need to be considered when looking at repurposing existing gas pipelines (DNV GL, 2019).

6.2.8.2.1 Design pressure of the re-used pipeline

Typical natural gas transmission pipelines are designed to operate between 40-85 bar. The CO_2 critical pressure is 73.8 bar, therefore typical natural gas transmission pressure range falls over the transition from gas to liquid phase. CO_2 transport is typically undertaken at a safe margin either side of the critical pressure. Dense phase transport is a margin above the critical pressure (typically >85 bar and towards 200 bar) and gas phase transport below the critical pressure (<45 bar) to avoid two phase flow. For natural gas pipelines with pressure ratings at or above 100 bar, dense phase transport of CO_2 using existing gas pipelines may be feasible; if the pipeline is rated for lower pressures, this limits CO_2 transport to gas phase transport. Gas phase transport is typically not cost-effective for long distances based on need for additional and very costly gas booster compression that would be required. The total mass flow of CO_2 may also be limited as the density of CO_2 as a gas is considerably smaller than the density of dense, supercritical of liquid CO_2. Typically, a pipeline is sized to meet the flow requirements, however when re-purposing an existing pipeline it will constrain the amount of CO_2 that can be transported.

6.2.8.2.2 General age and condition

If repurposing existing infrastructure it would need to be assessed in order to understand the extent it had been maintained and modifications that may be required to use of for CO_2 transport. Maintenance history, inspection results, etc which should be available, may not be, and this may be an additional challenge for re-purposing an existing pipeline.

Depending on the age of the pipeline it may require large scale life-extension efforts to be viable for long term sustained CO_2 transport. Typical CCS projects are designed for 20-30 years of operation and beyond.

6.2.8.2.3 Zoning issues

The properties of CO_2 differ to natural gas. While natural gas is flammable and CO_2 is not, CO_2 is denser than air and can create a hazard at a significant distance from any leak location. The zoning around existing pipelines would need to be redefined to reflect requirements for CO_2 pipelines.

6.2.8.3 Basis of design

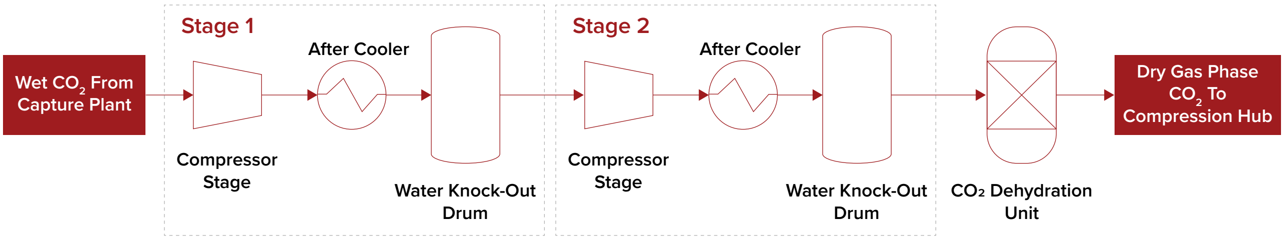
6.2.8.3.1 Compression and transport design

The following assumptions have been considered for the Egypt CCS pipeline transport hub design.

6.2.8.3.2 Pipeline and compression selection and conditions:

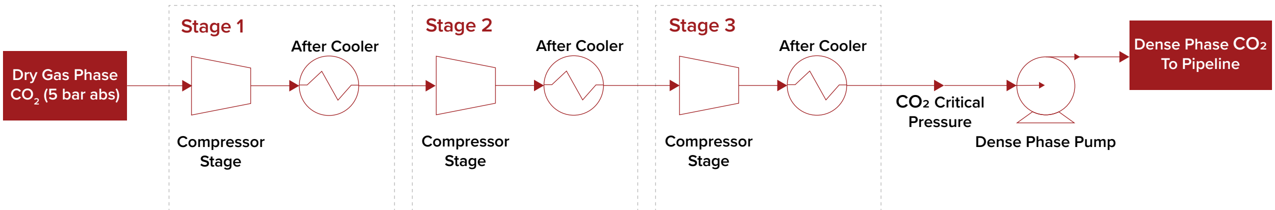
- Each CO_2 source for each hub cluster is assumed to require 5 km of piping to reach the CO_2 compression hub. For some CO_2 sources the distance may be less following more rigorous design, however for this level of design this is sufficient.
- CO_2 from each hub cluster source (LNG facility, industrial plant etc) is compressed modestly on-site at each capture facility and remains in the gas phase followed by CO_2 dehydration. Two-stage compression is employed, sufficient to deliver CO_2 to the CO_2 compression hub at 5 bar abs (4 bar gauge)

Figure 9: Gas-phase two-stage compression and dehydration located at each Burrup Peninsula CO_2 source plant.



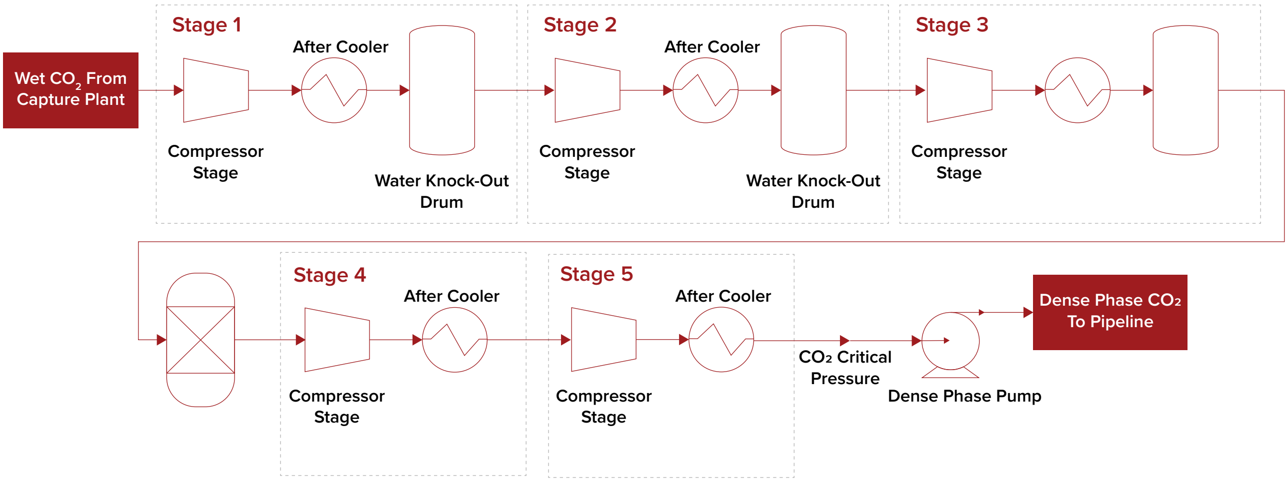
- The CCS compression hub has three-stage gas compression compressing the aggregated dry CO_2 from 5 bar abs up to the CO_2 critical pressure (approximately 73.8 bar abs). Above the critical pressure CO_2 is in the dense phase and behaves like a liquid and can be pumped. A dense phase pump provides the necessary compression above the critical pressure to ensure CO_2 can be transported to the storage location at the required injection pressure.

Figure 10: Three-stage compression and pumping arrangement at main compression hub.



- CO_2 from plants not located adjacent to other CO_2 sources (within 10 km) is transported in the dense phase. The CO_2 from each plant is compressed by five-stage compression and dense phase pumping with dehydration providing the necessary compression to ensure CO_2 can be transported in the dense phase to the main trunkline for transport to the storage location.

Figure 11: Five-stage compression, dehydration and dense phase pumping.



- For main trunk lines, the pipeline is sized for the overall CO_2 flow expected up to the maximum standard nominal pipe size of 600 mm. For the purpose of this study, booster pumps have been considered at pipeline segment junctures to limit parallel pipelines. If a pipeline pressure drop exceeds design limits within a segment, then parallel pipelines are considered. More rigorous design and analysis will optimise the use of booster pumps and pipelines further, however for the purpose of this study this approach is suitable;
- Dense-phase CO_2 lines sized for 2 m/s CO_2 velocity (Peletiri, Rahmanian and Mujtaba, 2018);
- Gas-phase CO_2 lines sized for 20 m/s CO_2 velocity (Sinnot and Towler, 2009, p. 259);
- Steel schedule 160 piping was selected for dense/supercritical phase CO_2. With a maximum allowable working pressure of 253 bar (Atlas Steels, 2010), this pipe has thicker walls than conventional schedule 40 piping and is suitable for the pressures seen in CO_2 transport;
- Steel schedule 40 piping was selected for gas phase CO_2;
- Dense/supercritical phase operations must stay between two limits:
  - Pressure must be well above the critical pressure to avoid two-phase behaviour which can introduce mechanical stress and risk to piping integrity. In this work that minimum pressure has been selected as 100 bar abs;
  - Pressure must remain below the safe operating pressure for the pipeline. This has been taken as 10% below the 253 bar abs maximum allowable working pressure, or 227.7 bar abs.

6.2.8.3.3 Key assumptions and data:

- Compression station elevation is 10 m above sea level;
- The endpoint of trunk line is 10 m above sea level (onshore injection);
- Destination pressure target is 100 bar abs (ENI S.p.A, 2018, p. 10);
- Discharge temperature of CO_2 at the compression hub is 50°C;
- Soil temperature is 25°C (for CO_2 cooling in buried onshore line);
- 20% was added to route length to account for fittings losses when calculating pressure drop;
- The pressure ratio of each stage of compression is assumed to be the same;
- CO_2 is cooled to 50°C after each stage of compression. This is reasonable given the high ambient temperatures in Egypt. Conventional cooling towers, air-cooling or seawater cooling could be used depending on the location of the CO_2 emitter;
- Maximum power consumption for a compression train (all stages / pumps) is 40 MW electric. For cases requiring more power than this, multiple trains were used to keep individual power consumption below 40 MW (Mccollum and Ogden, 2006).

6.2.8.3.4 Capital costs:

The methods for estimating the capital and operating costs for the compression, pipelines and SMR for blue hydrogen production for the CCS hub design are given in Appendix D and E. All costs given are in US dollars (USD), unless otherwise stated.

Existing storage costs were pursued for Egypt, however information was limited. (Smith et al., 2021) provides a range of costs for storage in several onshore reservoirs of varying characteristics in the US. The following table provides a summary of these costs for a range of CO_2 flows.

Table 16: US storage cost range (2019 USD/tCO_2) under base monitoring assumptions (Smith et al., 2021).

Total flow of CO_2 (Mtpa)	Low	Mean	High
1	$9.74	$16.47	$23.20
3.2	$5.25	$8.00	$10.75
6	$4.36	$6.73	$9.09
15	$4.05	$6.24	$8.44

The cost of storage decreases with increasing scale of storage, demonstrating economies of scale for storage costs.

For the purpose of this study we have assumed a cost per tonne for storage and monitoring of $10 accounting for both scale, high storage cost estimates (conservative basis) and the higher cost of construction in Egypt versus the US observed through Richardson location factors. It should be noted that the storage costs are dependent on the monitoring and verification protocol adopted by the government/regulatory body and will also differ slightly for Egypt.

6.2.8.4 CCS hub design results

6.2.8.4.1 Pipeline and compression design

The engineering process simulator Aspen HYSYS was used to calculate the pressure drop along the pipelines. The following results outline the pipeline design for each stage of CCS hub design.

Figure 12: Pipeline segments for the main trunklines and lateral pipelines for the Egypt pipeline CCS hub. Figure 12 is identical to Figure 8.

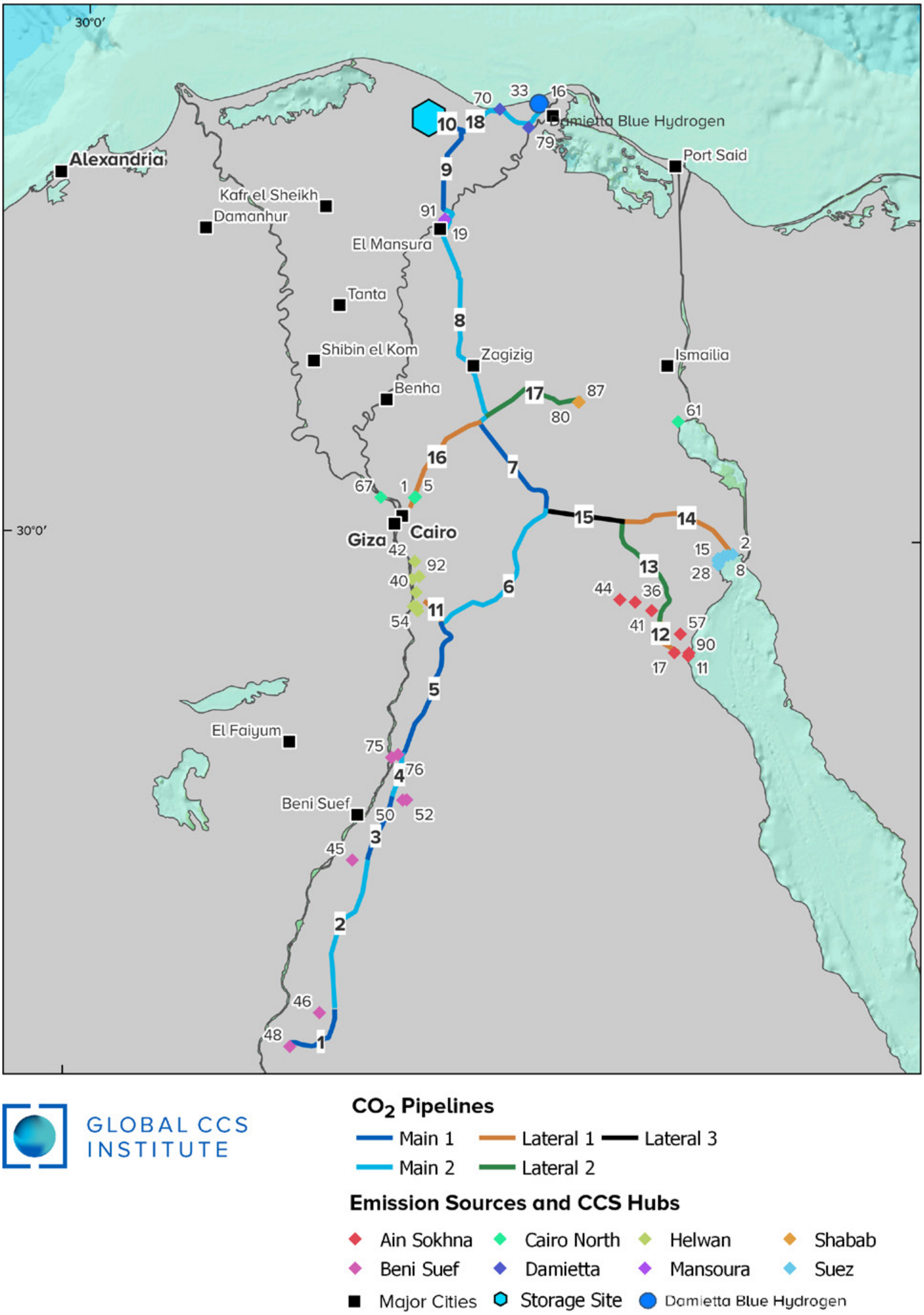


Table 17: Pressures and flows for main trunkline segments given in Figure 12.

Main Trunkline Segment	Length (km)	Onshore/ Offshore	Total CO_2 Flow (Mtpa)	Number of Parallel Pipelines	Nominal Line Diameter (mm)	Inlet Pressure (Bar abs)	Outlet Pressure (Bar abs)	Booster Compression in Trunkline Segment?
1	32	Onshore	0.62	1	150	220.4	164.2	No
2	60	Onshore	3.37	1	350	164.2	100	No
3	30	Onshore	7.22	1	450	221.5	188.7	Yes
4	15	Onshore	11.76	1	600	188.7	178.5	No
5	55	Onshore	16.47	1	600	178.5	100	No
6	65	Onshore	36.10	2	600	202.8	100	Yes
7	52	Onshore	82.37	4	600	206.5	100	Yes
8	82	Onshore	88.84	5	600	223.3	100	Yes
9	42	Onshore	93.06	5	600	198.9	133.9	No
10	18	Onshore	99.94	5	600	133.9	100	No

Table 18: Pressures and flows for lateral pipeline segments given in Figure 12.

Main Trunkline Lateral Segment	Length (km)	Onshore/ Offshore	Total CO_2 Flow (Mtpa)	Number of Parallel Pipelines	Nominal Line Diameter (mm)	Inlet Pressure (Bar abs)	Outlet Pressure (Bar abs)	Booster Compression in Trunkline Segment?
11	15	Onshore	19.63	1	600	139.6	100	No
12	15	Onshore	8.77	1	600	224.3	218.4	No
13	46	Onshore	36.01	2	600	218.4	139.8	No
14	47	Onshore	10.27	1	600	168.1	139.8	No
15	30	Onshore	46.27	3	600	139.8	100	No
16	33	Onshore	4.67	1	400	139.5	100	No
17	44	Onshore	1.80	1	250	158.5	100	No
18	35	Onshore	6.88	1	600	144.1	133.9	No

6.2.8.4.2 Injection design well count

The final injection and infrastructure requirements can only be confirmed through detailed engineering design during the Front End Engineering Design stage of development.

The potential well count for the pipeline CCS hub assuming 35 MMscfd, or 1,920 tpd, per well is given in Table 19 based on (Ringrose and Meckel, 2019).

The well count of 150 injection wells is significant. However, these wells will be distributed across northern Egypt targeting multiple saline formations. In addition to the 150 injection wells, it is standard practice to have contingency and monitoring wells. These have not been considered in this study.

Table 19: Potential well count for the development of the Egypt pipeline CCS hub.

	Total flow of CO_2 (Mtpa)	Number of Wells (based on 35 MMscfd per well)
Egypt Pipeline CCS Hub	99.94	150

6.2.8.4.3 CCS hub costs

The following tables define the costs for the infrastructure the main trunkline, lateral pipeline and hub and local compression system design.

Table 20: Main trunkline costs.

Trunkline Segment	Length (km)	Onshore/ Offshore	Segment CO_2 Flow (Mtpa)	Number Parallel Pipelines	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
1	32	Onshore	0.62	1	150	23.0	2.0	0.9	2.9	4.7
2	60	Onshore	3.37	1	350	141.1	12.1	5.6	17.7	5.3
3	30	Onshore	7.22	1	450	106.8	9.1	4.3	13.4	1.9
4	15	Onshore	11.76	1	600	87.3	7.5	3.5	11.0	0.9
5	55	Onshore	16.47	1	600	320.2	27.4	12.8	40.2	2.4
6	65	Onshore	36.10	2	600	756.9	64.7	30.3	95.0	2.6
7	52	Onshore	82.37	4	600	1211.1	103.5	48.4	152.0	1.8
8	82	Onshore	88.84	5	600	2387.2	204.1	95.5	299.6	3.4
9	42	Onshore	93.06	5	600	1222.7	104.5	48.9	153.4	1.6
10	18	Onshore	99.94	5	600	524.0	44.8	21.0	65.8	0.7

Table 21: Lateral pipeline costs.

Trunkline Segment	Length (km)	Onshore/ Offshore	Segment CO_2 Flow (Mtpa)	Number Parallel Pipelines	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
11	15	Onshore	19.63	1	600	87.3	7.5	3.5	11.0	0.6
12	15	Onshore	8.77	1	600	87.3	7.5	3.5	11.0	1.2
13	46	Onshore	36.01	2	600	535.7	45.8	21.4	67.2	1.9
14	47	Onshore	10.27	1	600	273.7	23.4	10.9	34.3	3.3
15	30	Onshore	46.27	3	600	524.0	44.8	21.0	65.8	1.4
16	33	Onshore	4.67	1	400	96.6	8.3	3.9	12.1	2.6
17	44	Onshore	1.80	1	250	67.2	5.7	2.7	8.4	4.7
18	35	Onshore	6.88	1	600	203.8	17.4	8.2	25.6	3.7

Table 22: Local dense phase pipelines for upstream plants.

Upstream Plant Source	Industry	Length (km)	CO_2 Flow (Mtpa)	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Misr Cement Company SAE	Cement	5	2.75	300	11.04	0.94	0.44	1.39	0.5
Misr Beni Suef Cement Co SAE	Cement	5	3.85	350	12.93	1.11	0.52	1.62	0.4
South Valley Cement Co SAE	Cement	5	2.06	300	11.04	0.94	0.44	1.39	0.7
Wadi El Nile Cement Co	Cement	5	2.48	300	11.04	0.94	0.44	1.39	0.6
Kuriemat Solar/Thermal	Power	5	0.20	100	2.42	0.21	0.10	0.30	1.6
Kuriemat 2	Power	5	4.51	400	15.97	1.37	0.64	2.00	0.4
Lafarge Cement Co Egypt SAE	Cement	10	14.58	600	62.25	5.32	2.49	7.81	0.5
Suez Cement Company SAE (2)	Cement	10	5.78	450	38.60	3.30	1.54	4.84	0.8
Arabian Cement Company SAE	Cement	10	6.88	450	38.60	3.30	1.54	4.84	0.7
Talkha	Power	5	2.39	300	11.04	0.94	0.44	1.39	0.6
El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	5	1.82	250	8.47	0.72	0.34	1.06	0.6

Table 23: Local gas phase pipelines for upstream plants.

Upstream Plant Source	Industry	Length (km)	CO_2 Flow (Mtpa)	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD /tCO_2
Helwan Fertilizers Company El Tabbin Complex	Fertilizer	5	1.19	600	15.91	1.36	0.64	2.00	1.7
El-Tebeen	Power	5	1.15	600	15.91	1.36	0.64	2.00	1.7
Egyptian Iron & Steel Company Cairo plant	Steel	5	4.62	900	24.89	2.13	1.00	3.12	0.7
Helwan Cement Co SAE	Cement	5	4.97	900	24.89	2.13	1.00	3.12	0.6
Cairo South	Power	5	1.17	600	15.91	1.36	0.64	2.00	1.7
Wadi Hof	Power	5	0.16	400	9.31	0.80	0.37	1.17	7.1
Egyptian Tourah Portland Cement Co SAE	Cement	5	6.36	900	24.89	2.13	1.00	3.12	0.5
Suez Gulf	Power	5	1.12	600	15.91	1.36	0.64	2.00	1.8
Soukhna	Refinery	5	0.61	600	15.91	1.36	0.64	2.00	3.3
Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	5	2.44	900	24.89	2.13	1.00	3.12	1.3
Ezz Flat Steel Ain Sokhna plant	Steel	5	4.60	900	24.89	2.13	1.00	3.12	0.7
Ataka	Power	5	1.48	600	15.91	1.36	0.64	2.00	1.4
El Suez I	Refinery	5	0.62	450	10.95	0.94	0.44	1.37	2.2
El Suez II	Refinery	5	0.75	600	15.91	1.36	0.64	2.00	2.7
Suez I	Refinery	5	0.63	600	15.91	1.36	0.64	2.00	3.2
Suez II	Refinery	5	0.32	450	10.95	0.94	0.44	1.37	4.3
El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	5	2.38	800	21.27	1.82	0.85	2.67	1.1
Suez Steel Solb Misr Attaka plant	Steel	5	4.10	900	24.89	2.13	1.00	3.12	0.8
Mostorod I	Refinery	5	0.51	450	10.95	0.94	0.44	1.37	2.7
Mostorod II	Refinery	5	0.95	600	15.91	1.36	0.64	2.00	2.1
Cairo West	Power	5	2.23	800	21.27	1.82	0.85	2.67	1.2
Abu Sultan	Power	5	0.98	600	15.91	1.36	0.64	2.00	2.0
Shabab	Power	5	0.16	400	9.31	0.80	0.37	1.17	7.1
New Gas Shabab	Power	5	1.64	800	21.27	1.82	0.85	2.67	1.6
MISR Fertilizer Production Company Damietta Complex	Fertilizer	5	3.57	900	24.89	2.13	1.00	3.12	0.9
Damietta	LNG	5	0.95	600	15.91	1.36	0.64	2.00	2.1
New Gas Damietta	Power	5	0.82	600	15.91	1.36	0.64	2.00	2.4
Damietta West	Power	5	0.82	600	15.91	1.36	0.64	2.00	2.4
(New) Blue Hydrogen	Hydrogen	5	0.72	600	15.91	1.36	0.64	2.00	2.8

Table 24: Hub compression costs.

Compression Location	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD /tCO_2
Misr Cement Company SAE to South Valley Cement Co SAE Injection Point	Dense phase pump	1	20	53	5	14.5	2.1	21.2	2.9
Halwan Hub Injection Point to Suez Hubs Injection Point	Dense phase pump	1	24	64	5	17.6	2.6	25.6	0.7
Suez Hub Injection Point to Shabab and North Cairo Hub Injection	Dense phase pump	2	49	131	11	35.7	5.2	52.1	0.6
North Cairo Injection Point to Mansoura Injection Point	Dense phase pump	2	57	154	13	42.0	6.1	61.3	0.7
Mansoura Injection Point to Damietta Hub Injection Point	Dense phase pump	2	45	120	10	32.9	4.8	48.1	0.5

Table 25: Main trunkline booster compression costs.

Compression Location	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD /tCO_2
Halwan Hub Injection Point to Halwan Hub Injection Point	3 stage + pump, dense phase	5	172	346	30	126.0	13.8	169.4	8.6
Ain Sokhna Coastal Industrial Hub to Ain Sokhna Cement Hub Injection Point	3 stage + pump, dense phase	3	103	221	19	75.8	8.8	103.5	11.8
Suez Hub To Ain Sokhna Hubs Aggregation Point	3 stage + pump, dense phase	3	96	210	18	70.6	8.4	97.0	9.4
Cairo North Hub to NE Cairo Injection Point	3 stage + pump, dense phase	2	41	106	9	30.0	4.2	43.2	9.3
Shabab Power Hub to NE Cairo Injection Point	3 stage + pump, dense phase	1	17	49	4	12.1	1.9	18.2	10.1
Damietta Hub to Damietta Hub Injection Point	3 stage + pump, dense phase	2	61	131	11	44.7	5.2	61.1	8.9

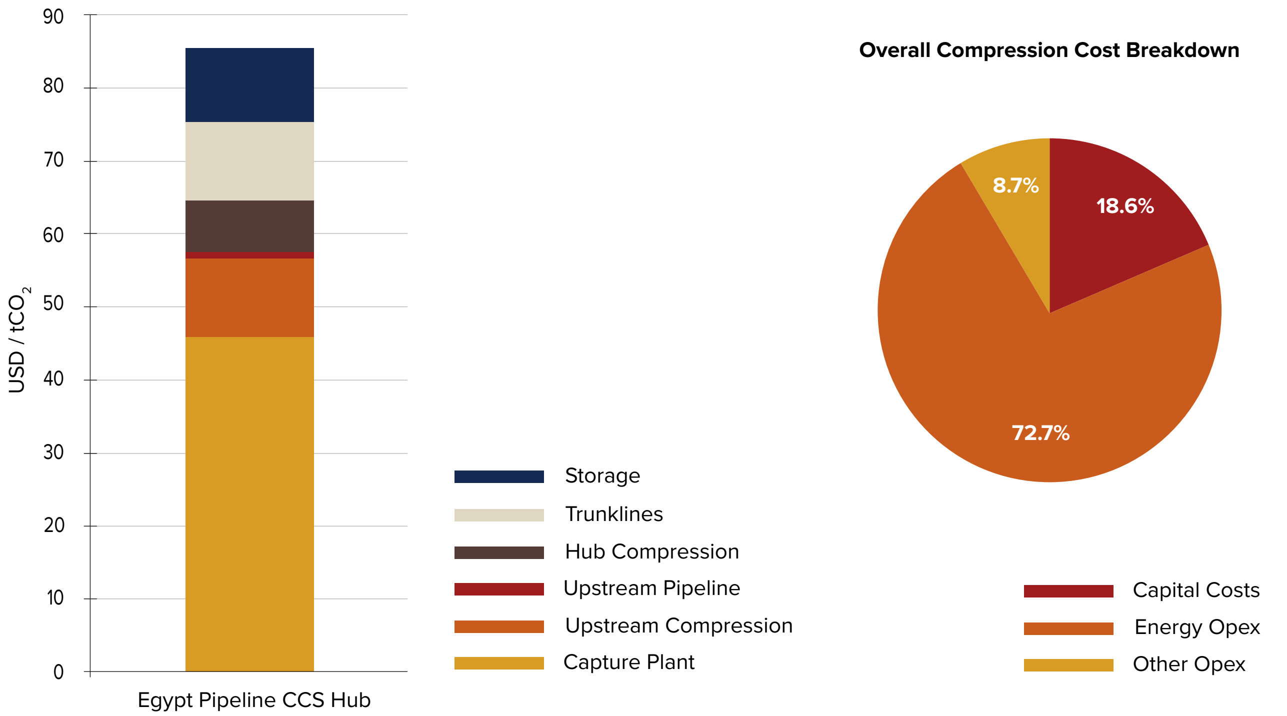
Table 26: Compression costs for upstream plants.

Compression Location	Industry	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Royal El Minya Cement	Cement	5 stage + pump, dense phase	1	9.88	41.68	3.56	7.24	1.67	12.47	20.1
Misr Cement Company SAE	Cement	5 stage + pump, dense phase	2	40.90	115.26	9.85	29.97	4.61	44.43	16.1
Misr Beni Suef Cement Co SAE	Cement	5 stage + pump, dense phase	2	62.11	146.99	12.57	45.51	5.88	63.95	16.6
South Valley Cement Co SAE	Cement	5 stage + pump, dense phase	1	31.65	72.33	6.18	23.19	2.89	32.27	15.6
Wadi El Nile Cement Co	Cement	5 stage + pump, dense phase	1	38.06	79.54	6.80	27.89	3.18	37.87	15.3
Kuriemat Solar/Thermal	Power	5 stage + pump, dense phase	1	2.99	24.60	2.10	2.19	0.98	5.28	26.9
Kuriemat 2	Power	5 stage + pump, dense phase	2	68.38	149.29	12.76	50.10	5.97	68.84	15.3
Helwan Fertilizers Company El Tabbin Complex	Fertilizer	2 stage, gas phase	1	7.34	17.49	1.50	5.38	0.70	7.57	6.4
El-Tebeen	Power	2 stage, gas phase	1	7.04	17.10	1.46	5.16	0.68	7.30	6.4
Egyptian Iron & Steel Company Cairo plant	Steel	2 stage, gas phase	1	30.12	32.07	2.74	22.07	1.28	26.09	5.6
Helwan Cement Co SAE	Cement	2 stage, gas phase	1	33.00	33.77	2.89	24.18	1.35	28.41	5.7
Cairo South	Power	2 stage, gas phase	1	7.22	17.33	1.48	5.29	0.69	7.46	6.4
Wadi Hof	Power	2 stage, gas phase	1	0.92	7.10	0.61	0.68	0.28	1.57	9.6
Egyptian Tourah Portland Cement Co SAE	Cement	2 stage, gas phase	2	45.11	61.48	5.26	33.05	2.46	40.77	6.4
Suez Gulf	Power	2 stage, gas phase	1	6.84	16.85	1.44	5.01	0.67	7.13	6.4
Soukhna	Refinery	2 stage, gas phase	1	3.49	12.15	1.04	2.56	0.49	4.08	6.7
Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	2 stage, gas phase	1	14.25	21.65	1.85	10.44	0.87	13.16	5.4
Ezz Flat Steel Ain Sokhna plant	Steel	2 stage, gas phase	1	29.96	31.97	2.73	21.95	1.28	25.96	5.6
Lafarge Cement Co Egypt SAE	Cement	5 stage + pump, dense phase	6	235.48	499.93	42.74	172.53	20.00	235.27	16.1

Compression Location	Industry	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Suez Cement Company SAE (2)	Cement	5 stage + pump, dense phase	3	92.91	219.86	18.80	68.07	8.79	95.66	16.6
Arabian Cement Company SAE	Cement	5 stage + pump, dense phase	3	111.06	242.20	20.71	81.37	9.69	111.76	16.2
Ataka	Power	2 stage, gas phase	1	9.51	20.12	1.72	6.97	0.80	9.49	6.4
El Suez I	Refinery	2 stage, gas phase	1	4.17	15.13	1.29	3.05	0.61	4.95	8.0
El Suez II	Refinery	2 stage, gas phase	1	4.32	13.41	1.15	3.17	0.54	4.85	6.5
Suez I	Refinery	2 stage, gas phase	1	3.61	12.34	1.06	2.65	0.49	4.20	6.6
Suez II	Refinery	2 stage, gas phase	1	1.83	9.48	0.81	1.34	0.38	2.53	8.0
El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	2 stage, gas phase	1	14.46	22.55	1.93	10.60	0.90	13.43	5.6
Suez Steel Solb Misr Attaka plant	Steel	2 stage, gas phase	1	26.03	29.57	2.53	19.07	1.18	22.78	5.6
Mostorod I	Refinery	2 stage, gas phase	1	3.08	12.24	1.05	2.26	0.49	3.79	7.5
Mostorod II	Refinery	2 stage, gas phase	1	5.66	15.29	1.31	4.15	0.61	6.07	6.4
Cairo West	Power	2 stage, gas phase	1	13.41	21.68	1.85	9.83	0.87	12.55	5.6
Abu Sultan	Power	2 stage, gas phase	1	5.89	15.60	1.33	4.31	0.62	6.27	6.4
Shabab	Power	2 stage, gas phase	1	0.92	7.10	0.61	0.68	0.28	1.57	9.6
New Gas Shabab	Power	2 stage, gas phase	1	9.50	18.30	1.56	6.96	0.73	9.26	5.6
Talkha	Power	5 stage + pump, dense phase	1	37.30	79.39	6.79	27.33	3.18	37.29	15.6
El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	5 stage + pump, dense phase	1	28.44	69.16	5.91	20.84	2.77	29.52	16.2
MISR Fertilizer Production Company Damietta Complex	Fertilizer	2 stage, gas phase	1	22.04	27.03	2.31	16.15	1.08	19.54	5.5
Damietta	LNG	2 stage, gas phase	1	5.70	15.34	1.31	4.17	0.61	6.10	6.4
New Gas Damietta	Power	2 stage, gas phase	1	4.80	14.09	1.20	3.51	0.56	5.28	6.4
Damietta West	Power	2 stage, gas phase	1	4.80	14.09	1.20	3.51	0.56	5.28	6.4
(New) Blue Hydrogen	Hydrogen	2 stage, gas phase	1	4.16	13.17	1.13	3.05	0.53	4.70	6.5

Combining the capture costs, pipeline, compression and storage costs the overall levelised cost for each element of the value chain for the pipeline CCS hub is given in Figure 13.

Figure 13: Levelised costs per tonne of CO_2 for each component in the CCS value chain for the Egypt pipeline CCS hub.



The cost of capture is a dominant cost of the overall value chain. Beyond this, compression costs are considerable, largely dominated by energy costs. This means that any factors that could result in the cost of energy either going up or down can have a considerable impact to the overall cost to the CCS value chain.

The hydrogen plant designed in this study is sized to produce 100,000 Nm^3/h of hydrogen, or 82,000 tonnes per year (at 95% availability). Table 27 provides the breakdown of costs associated with the production of blue hydrogen.

6.2.8.4.4 Blue hydrogen

As defined previously, blue hydrogen can provide a significant opportunity to support decarbonization in Egypt.

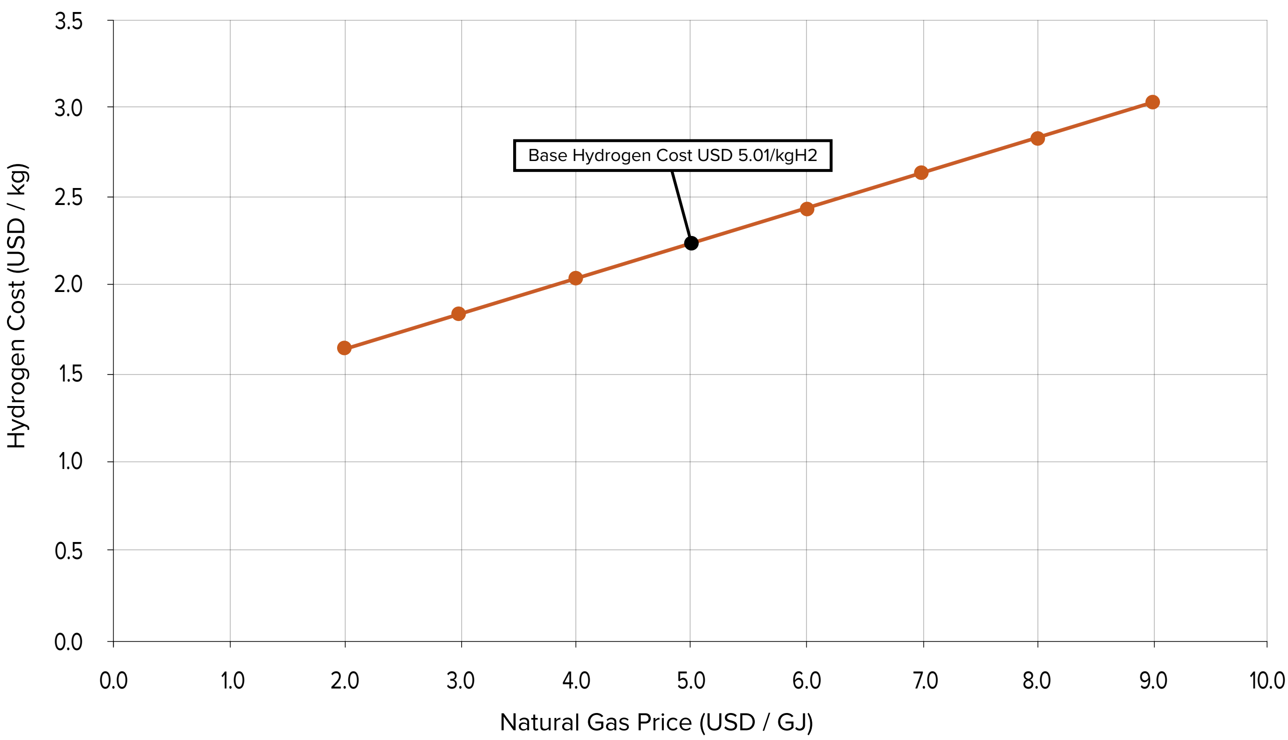
Table 27: Summary of blue hydrogen plant costs.

Cost item	USDM/year
Annualised capital cost	37.38
Utilities / variable opex (excluding natural gas)	7.26
Natural gas cost (@USD6.79/GJ)	74.26
Fixed operations & maintenance opex	17.49
CO_2 transport and storage costs	32.55
Total	**168.95**

This means the cost of decarbonised hydrogen is USD2.25/kg or on an energy basis USD15.87/GJ (@142 MJ/kg HHV)

A substantial fraction of hydrogen costs are from purchases of natural gas, as a feedstock and as a fuel for the reformer. In Table 27 the natural gas price was USD5.01 per GJ. If we consider a natural gas price range of USD2-9/GJ the resulting range of hydrogen prices spans USD1.66/kg to USD3.02/kg scaling linearly with the natural gas price.

Figure 14: Hydrogen cost sensitivity to natural gas price.



6.2.9 Local CCS hub design

6.2.9.1 Local CCS hub locations

Local CCS hubs in Egypt offer a number of benefits, such as removing the need for a large proportion of any transport piping required. With a reduced pipeline length, the pipeline pressure drop will also reduce (for the same pipeline diameter), leading to a decrease in compression costs.

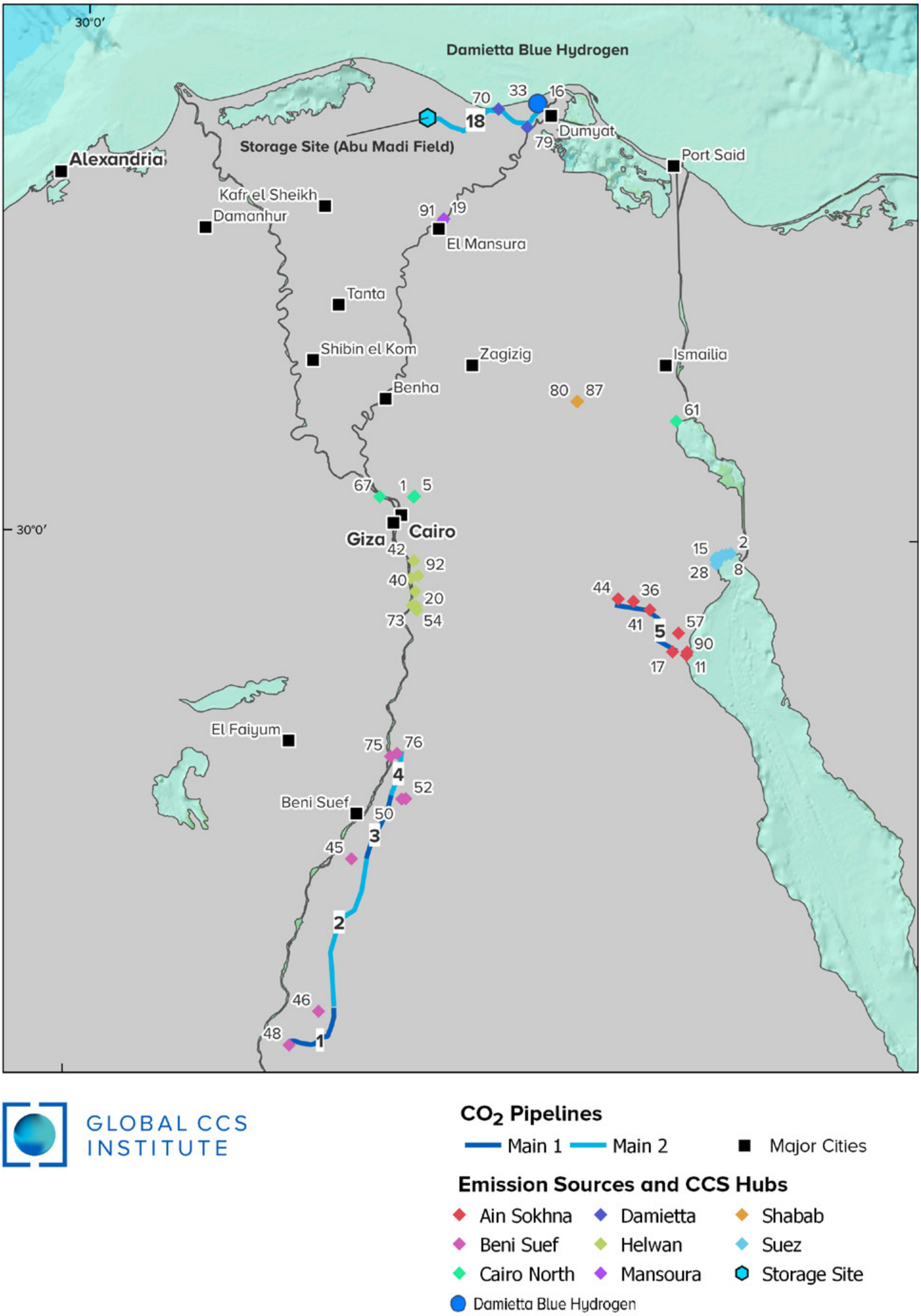
Besides the benefit to overall costs of transport for proposed hubs in Egypt, this approach offers increased flexibility for increasing scale for proposed hubs either for existing CO_2 emitters or future industrial growth. It also allows for simpler staged design for multiple hubs as hubs are independent. While a level of master planning would be required to manage the resources required for infrastructure build-out (materials and labor), independent hubs mean that the design and construction of hubs can move forward, be delayed or be constructed at the same time with limited impact, assuming all hubs are developed to a masterplan.

For large-scale integrated pipeline hubs, such as that designed previously for Egypt, staged design must be master planned, and all stages are typically dependent on each other. Any delay can impact all stages, bringing stages forward requires further planning to manage dependencies and any future industrial growth not identified may result in further elaborate changes to design or the need for separate infrastructure for transport and storage, potentially at a higher cost.

Local hubs in Egypt focus on hubs identified in the pipeline CCS hub. Figure 15 gives the proposed local CCS hubs. Alexandria could also be considered for a local hub. However, the terrain for Alexandria for capturing CO_2 from local facilities is complex, with facilities located adjacent to densely populated areas and lakes. This terrain could be addressed through more rigorous design, but would be beyond the time available to provide a suitable design for this study. It would be recommended that further analysis be completed in the future to assess the design and costs for an Alexandria CCS hub to allow comparison with the local hubs explored in this study.

Pipelines from the compression hub to the storage location are not shown as the true location will be subject to site appraisal and field development that is beyond the scope of this study.

Figure 15: Locations for the proposed local Egypt CCS hubs



The following table outlines the CO_2 sources included in each of the respective local CCS hubs.

Table 28: Egypt industrial CO_2 sources for the Beni Suef Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
Misr Beni Suef Cement Co SAE	Cement	3.85	20.6
Misr Cement Company SAE	Cement	2.75	20.6
Royal El Minya Cement	Cement	0.62	20.6
South Valley Cement Co SAE	Cement	2.06	20.6
Wadi El Nile Cement Co	Cement	2.48	20.6
Kuriemat 2	Power	4.51	4.2
Kuriemat Solar/Thermal	Power	0.20	4.2
Total		**16.47**	

Table 29: Egypt industrial CO_2 sources for the Helwan Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
Helwan Fertilizers Company El Tabbin Complex	Fertilizer	1.19	117.9
Helwan Cement Co SAE	Cement	4.97	20.6
Egyptian Tourah Portland Cement Co SAE	Cement	6.36	20.6
Egyptian Iron & Steel Company Cairo plant	Steel	4.62	13.1
Cairo South	Power	1.17	4.2
El-Tebeen	Power	1.15	4.2
Wadi Hof	Power	0.16	4.2
Total		**19.62**	

Table 30: Egypt industrial CO_2 sources for the Ain Sokhna Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
Soukhna	Refinery	0.61	7.9
Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	2.44	117.9
Arabian Cement Company SAE	Cement	6.88	20.6
Suez Cement Company SAE (2)	Cement	5.78	20.6
Lafarge Cement Co Egypt SAE	Cement	14.58	20.6
Ezz Flat Steel Ain Sokhna plant	Steel	4.60	19.2
Suez Gulf	Power	1.12	4.2
Total		**36.01**	

Table 31: Egypt industrial CO_2 sources for the Suez Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
El Suez I	Refinery	0.62	7.9
El Suez II	Refinery	0.75	11.8
Suez I	Refinery	0.63	7.9
Suez II	Refinery	0.32	7.9
El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	2.38	117.9
Suez Steel Solb Misr Attaka plant	Steel	4.10	19.2
Ataka	Power	1.48	4.2
Total		**10.28**	

Table 32: Egypt industrial CO_2 sources for the Cairo North Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
Mostorod I	Refinery	0.51	7.9
Mostorod II	Refinery	0.95	15.2
Abu Sultan	Power	0.98	4.2
Cairo West	Power	2.23	4.2
Total		**4.67**	

Table 33: Egypt industrial CO_2 sources for the Shabab Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
New Gas Shabab	Power	1.64	4.2
Shabab	Power	0.16	4.2
Total		**1.80**	

Table 34: Egypt industrial CO_2 sources for the Mansoura Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	1.82	117.5
Talkha	Power	2.39	4.2
Total		**4.21**	

Table 35: Egypt industrial CO_2 sources for the Damietta Local CCS Hub.

Facility	Industry	CO_2 Flow (Mtpa)	CO_2 Partial Pressure (kpa)
MISR Fertilizer Production Company Damietta Complex	Fertilizer	3.57	117.9
Damietta	LNG	0.95	1945.3
Damietta West	Power	0.82	4.2
New Gas Damietta	Power	0.82	4.2
(New) Blue Hydrogen	Power	0.72	22.8
Total		**6.88**	

6.2.9.2 Basis of design

6.2.9.2.1 Compression and transport design

All assumptions for the Egypt pipeline hub design remain for the Egypt local CCS hub designs. On top of those assumptions already outlined, the following additional assumptions were applied.

6.2.9.2.2 Pipeline and compression selection and conditions:

- For pipelines from hub compression it is assumed to require 20 km of piping to reach the storage location. For the purpose of this study, 20 km provides a reasonable radius from the hub location to identify a suitable injection point given it is unknown at this stage without site appraisal and field development.

6.2.9.3 Local CCS hub design results

6.2.9.3.1 Pipeline and compression design

The engineering process simulator Aspen HYSYS was used to calculate the pressure drop along the pipelines. The following results outline the pipeline design for each stage of CCS hub design.

Figure 16: Egypt local CCS hubs. Pipeline segments are shown for the pipelines leading to Hub compression or final aggregation point.

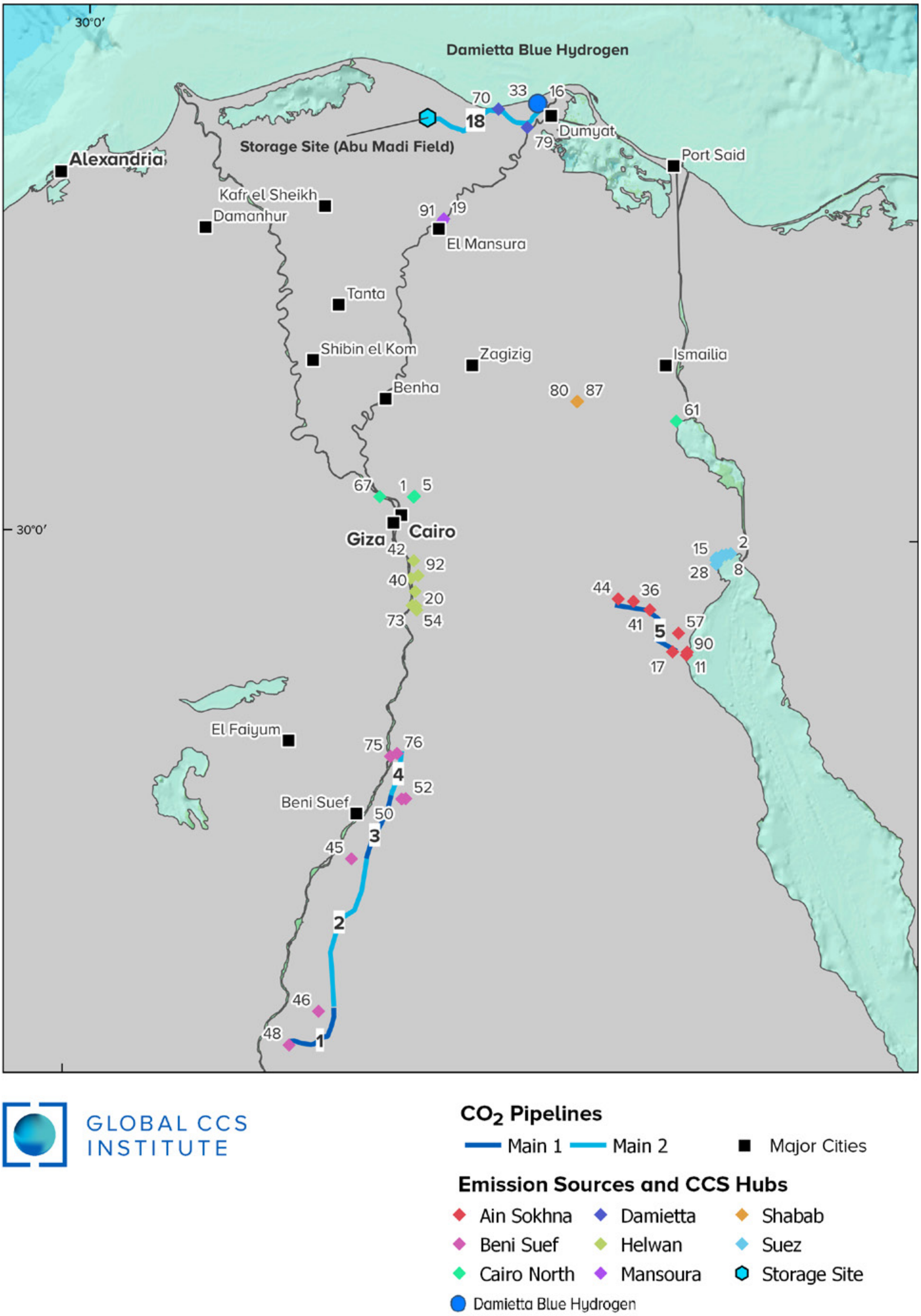


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Table 36: Pressures and flows for main pipelines segments for Egypt local CCS hubs given in Figure 16.

Local Hub	Trunkline Segment	Length (km)	Onshore/ Offshore	Segment CO_2 Flow (Mtpa)	Number of Parallel Pipelines	Nominal Line Diameter (mm)	Inlet Pressure (Bar abs)	Outlet Pressure (Bar abs)	Booster Compression in Trunkline Segment?
Beni Suef	1	32	Onshore	0.6	1	250	186.3	181.9	No
Beni Suef	2	60	Onshore	3.4	1	450	181.9	166.2	No
Beni Suef	3	35	Onshore	7.2	1	450	166.2	131.6	No
Beni Suef	4	10	Onshore	4.7	1	400	133.8	131.6	No
Beni Suef	Hub to storage[4]	20	Onshore	16.5	1	650	131.6	100.0	No
Helwan Hub	Hub to storage	20	Onshore	19.6	1	600	145.6	100.0	No
Ain Sokhna	5	15	Onshore	8.8	1	600	149.9	142.8	No
Ain Sokhna	Hub to storage	20	Onshore	36.0	2	600	142.8	100.0	No
Suez	Hub to storage	20	Onshore	10.3	1	600	113.8	100.0	No
North Cairo	Hub to storage	20	Onshore	4.7	1	400	121.7	100.0	No
Shabab	Hub to storage	20	Onshore	1.8	1	250	125.5	100.0	No
Mansoura	Hub to storage	20	Onshore	4.2	1	400	117.8	100.0	No
Damietta	6	53	Onshore	6.9	1	450	118.1	100.0	No

[4] 'Hub to storage' is an assumed pipeline length (of 20km) from hub compression or an overall aggregation point for CO_2 sources (if source CO_2 is already in dense phase) to a prospective local onshore storage location.

6.2.9.3.2 Injection design

The potential well count for the pipeline CCS hub assuming 35 MMscfd, or 1,920 tpd, per well is given in Table 37 based on (Ringrose and Meckel, 2019). In addition to the injection wells, it is standard practice to have contingency and monitoring wells. These have not been considered in this study.

Table 37: Potential well count for each local Egypt CCS hub.

Local Hub	Total flow of CO_2 (Mtpa)	Number of Wells (based on 35 MMscfd per well)
Beni Suef Hub	4.54	25
Helwan Hub	28.19	30
Ain Sokhna Hub	38.76	54
Suez Hub	10.89	16
Cairo North Hub	4.67	7
Shabab Power Hub	1.80	3
Mansoura Local Hub	4.21	7
Damietta Hub	6.88	11

6.2.9.3.3 CCS hub costs

The following tables define the costs for the infrastructure the main pipelines and hub and local compression system design for the local CCS hubs.

Table 38: Main pipeline costs for local CCS hubs.

Local Hub	Trunkline Segment	Length (km)	Onshore/ Offshore	Segment CO_2 Flow (Mtpa)	Number of Parallel Pipelines	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Beni Suef	1	32	Onshore	0.6	1	250	48.8	4.2	2.0	6.1	9.9
Beni Suef	2	60	Onshore	3.4	1	450	213.5	18.3	8.5	26.8	8.0
Beni Suef	3	35	Onshore	7.2	1	450	124.5	10.6	5.0	15.6	2.2
Beni Suef	4	10	Onshore	4.7	1	400	29.3	2.5	1.2	3.7	0.8
Beni Suef	5	20	Onshore	16.5	1	650	29.7	2.5	1.2	3.7	0.2
Helwan	6	20	Onshore	19.6	1	600	116.4	10.0	4.7	14.6	0.7
Ain Sokhna	7	15	Onshore	8.8	1	600	87.3	7.5	3.5	11.0	1.2
Ain Sokhna	8	20	Onshore	36.0	2	600	232.9	19.9	9.3	29.2	0.8
Suez	9	20	Onshore	10.3	1	600	116.4	10.0	4.7	14.6	1.4
North Cairo	10	20	Onshore	4.7	1	400	58.5	5.0	2.3	7.3	1.6
Shabab	11	20	Onshore	1.8	1	250	30.5	2.6	1.2	3.8	2.1
Mansoura	12	20	Onshore	4.2	1	400	58.5	5.0	2.3	7.3	1.7
Damietta	13	53	Onshore	6.9	1	450	188.6	16.1	7.5	23.7	3.4

Table 39: Local dense phase pipelines for upstream plants.

Local Hub	Upstream Plant Source	Industry	Length (km)	Total CO_2 Flow (Mtpa)	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Ain Sokhna	Misr Cement Company SAE	Cement	5	0.6	300	11.0	0.9	0.4	1.4	0.5
Helwan	Misr Beni Suef Cement Co SAE	Cement	5	2.8	350	12.9	1.1	0.5	1.6	0.4
Beni Suef	South Valley Cement Co SAE	Cement	5	3.9	300	11.0	0.9	0.4	1.4	0.7
Beni Suef	Wadi El Nile Cement Co	Cement	5	2.1	300	11.0	0.9	0.4	1.4	0.6
Helwan	Kuriemat Solar/Thermal	Power	5	2.5	100	2.4	0.2	0.1	0.3	1.5
Helwan	Kuriemat 2	Power	5	0.2	400	16.0	1.4	0.6	2.0	0.4
Ain Sokhna	Lafarge Cement Co Egypt SAE	Cement	5	4.5	600	31.1	2.7	1.2	3.9	0.3
Ain Sokhna	Suez Cement Company SAE (2)	Cement	5	14.6	450	19.3	1.7	0.8	2.4	0.4
Ain Sokhna	Arabian Cement Company SAE	Cement	5	5.8	450	19.3	1.7	0.8	2.4	0.4
Mansoura	Talkha	Power	5	6.9	300	11.0	0.9	0.4	1.4	0.6
Mansoura	El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	5	2.4	250	8.5	0.7	0.3	1.1	0.6

Table 40: Local gas phase pipelines for upstream plants.

Local Hub	Upstream Plant Source	Industry	Length (km)	Total CO_2 Flow (Mtpa)	Nominal Line Diameter (mm)	Capex (USDM)	Annualised Capex (USDM/ Year)	Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Beni Suef	Helwan Fertilizers Company El Tabbin Complex	Fertilizer	5	1.19	600	15.9	1.4	0.6	2.0	1.7
Beni Suef	El-Tebeen	Power	5	1.15	600	15.9	1.4	0.6	2.0	1.7
Beni Suef	Egyptian Iron & Steel Company Cairo plant	Steel	5	4.62	900	24.9	2.1	1.0	3.1	0.7
Beni Suef	Helwan Cement Co SAE	Cement	5	4.97	900	24.9	2.1	1.0	3.1	0.6
Beni Suef	Cairo South	Power	5	1.17	600	15.9	1.4	0.6	2.0	1.7
Beni Suef	Wadi Hof	Power	5	0.16	400	9.3	0.8	0.4	1.2	7.1
Beni Suef	Egyptian Tourah Portland Cement Co SAE	Cement	5	6.36	900	24.9	2.1	1.0	3.1	0.5
Helwan	Suez Gulf	Power	5	1.12	600	15.9	1.4	0.6	2.0	1.8
Helwan	Soukhna	Refinery	5	0.61	600	15.9	1.4	0.6	2.0	3.3
Helwan	Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	5	2.44	900	24.9	2.1	1.0	3.1	1.3
Helwan	Ezz Flat Steel Ain Sokhna plant	Steel	5	4.60	900	24.9	2.1	1.0	3.1	0.7
Helwan	Ataka	Power	5	1.48	600	15.9	1.4	0.6	2.0	1.4
Helwan	El Suez I	Refinery	5	0.62	450	10.9	0.9	0.4	1.4	2.2
Helwan	El Suez II	Refinery	5	0.75	600	15.9	1.4	0.6	2.0	2.7
Ain Sokhna	Suez I	Refinery	5	0.63	600	15.9	1.4	0.6	2.0	3.2
Ain Sokhna	Suez II	Refinery	5	0.32	450	10.9	0.9	0.4	1.4	4.3
Ain Sokhna	El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	5	2.38	800	21.3	1.8	0.9	2.7	1.1
Ain Sokhna	Suez Steel Solb Misr Attaka plant	Steel	5	4.10	900	24.9	2.1	1.0	3.1	0.8
Ain Sokhna	Mostorod I	Refinery	5	0.51	450	10.9	0.9	0.4	1.4	2.7
Ain Sokhna	Mostorod II	Refinery	5	0.95	600	15.9	1.4	0.6	2.0	2.1
Ain Sokhna	Cairo West	Power	5	2.23	800	21.3	1.8	0.9	2.7	1.2
Suez	Abu Sultan	Power	5	0.98	600	15.9	1.4	0.6	2.0	2.0
Suez	Shabab	Power	5	0.16	400	9.3	0.8	0.4	1.2	7.1
Suez	New Gas Shabab	Power	5	1.64	800	21.3	1.8	0.9	2.7	1.6
Suez	MISR Fertilizer Production Company Damietta Complex	Fertilizer	5	3.57	900	24.9	2.1	1.0	3.1	0.9
Suez	Damietta	LNG	5	0.95	600	15.9	1.4	0.6	2.0	2.1
Suez	New Gas Damietta	Power	5	0.82	600	15.9	1.4	0.6	2.0	2.4
Suez	Damietta West	Power	5	0.82	600	15.9	1.4	0.6	2.0	2.4
Cairo North	Blue Hydrogen Facility	Hydrogen	5	0.72	600	15.9	1.4	0.6	2.0	1.7

Table 41: Local Hub compression costs.

Compression Location	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD /tCO_2
Helwan	3 stage + pump	5	172.62	352.5	126.5	126.5	14.1	170.7	8.7
Ain Sokhna	3 stage + pump	2	78.82	151.9	57.7	57.7	6.1	76.8	8.8
Suez	3 stage + pump	3	83.15	177.5	60.9	60.9	7.1	83.2	8.1
Cairo North	3 stage + pump	1	38.62	70.9	28.3	28.3	2.8	37.2	8.0
Shabab	3 stage + pump	1	15.06	45.1	11.0	11.0	1.8	16.7	9.3
Mansoura	3 stage + pump	1	34.49	66.4	25.3	25.3	2.7	33.6	8.0
Damietta	3 stage + pump	2	57.08	120.4	41.8	41.8	4.8	56.9	8.3

Table 42: Compression costs for upstream plants.

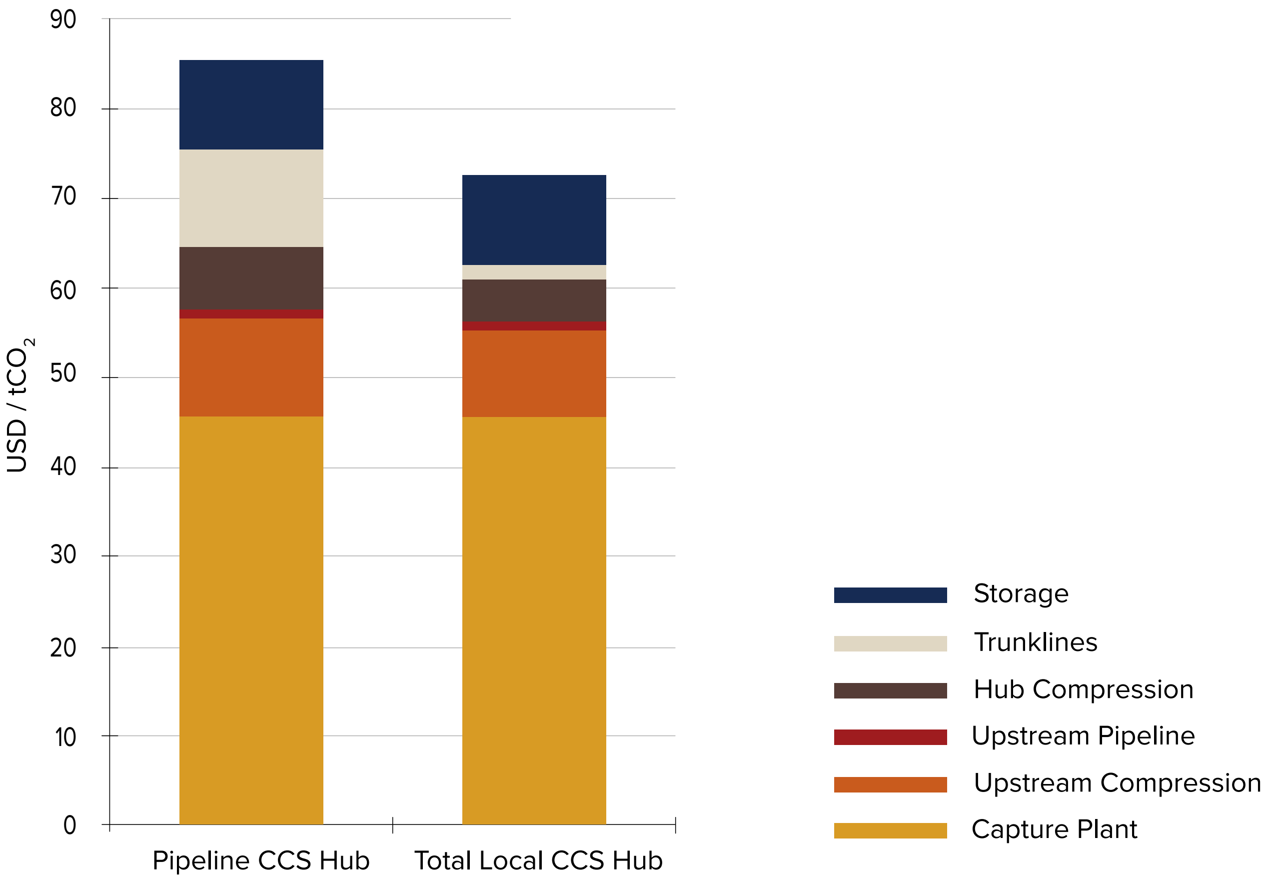
Local Hub	Compression Location	Industry	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Beni Suef	Royal El Minya Cement	Cement	5 stage + pump	9.43	1	40.6	3.5	6.9	1.6	12.0	19.4
Beni Suef	Misr Cement Company SAE	Cement	5 stage + pump	41.96	2	117.8	10.1	30.7	4.7	45.5	16.5
Beni Suef	Misr Beni Suef Cement Co SAE	Cement	5 stage + pump	57.51	2	135.9	11.6	42.1	5.4	59.2	15.4
Beni Suef	South Valley Cement Co SAE	Cement	5 stage + pump	29.11	1	66.2	5.7	21.3	2.6	29.6	14.4
Beni Suef	Wadi El Nile Cement Co	Cement	5 stage + pump	35.01	1	72.2	6.2	25.7	2.9	34.7	14.0
Beni Suef	Kuriemat Solar/ Thermal	Power	5 stage + pump	2.80	1	24.1	2.1	2.1	1.0	5.1	25.9
Beni Suef	Kuriemat 2	Power	5 stage + pump	64.04	2	138.8	11.9	46.9	5.6	64.3	14.3
Helwan	Helwan Fertilizers Company El Tabbin Complex	Fertilizer	2 stage, gas phase	7.34	1	17.5	1.5	5.4	0.7	7.6	6.4
Helwan	El-Tebeen	Power	2 stage, gas phase	7.04	1	17.1	1.5	5.2	0.7	7.3	6.4

Local Hub	Compression Location	Industry	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Helwan	Egyptian Iron & Steel Company Cairo plant	Steel	2 stage, gas phase	30.12	1	32.1	2.7	22.1	1.3	26.1	5.6
Helwan	Helwan Cement Co SAE	Cement	2 stage, gas phase	33.00	1	33.8	2.9	24.2	1.4	28.4	5.7
Helwan	Cairo South	Power	2 stage, gas phase	7.22	1	17.3	1.5	5.3	0.7	7.5	6.4
Helwan	Wadi Hof	Power	2 stage, gas phase	0.92	1	7.1	0.6	0.7	0.3	1.6	9.6
Helwan	Egyptian Tourah Portland Cement Co SAE	Cement	2 stage, gas phase	45.11	2	61.5	5.3	33.1	2.5	40.8	6.4
Ain Sokhna	Suez Gulf	Power	2 stage, gas phase	6.84	1	16.8	1.4	5.0	0.7	7.1	6.4
Ain Sokhna	Soukhna	Refinery	2 stage, gas phase	3.49	1	12.2	1.0	2.6	0.5	4.1	6.7
Ain Sokhna	Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	2 stage, gas phase	14.25	1	21.6	1.9	10.4	0.9	13.2	5.4
Ain Sokhna	Ezz Flat Steel Ain Sokhna plant	Steel	2 stage, gas phase	29.96	1	32.0	2.7	21.9	1.3	26.0	5.6
Ain Sokhna	Lafarge Cement Co Egypt SAE	Cement	5 stage + pump	210.15	6	439.0	37.5	154.0	17.6	209.1	14.3
Ain Sokhna	Suez Cement Company SAE (2)	Cement	5 stage + pump	83.02	3	196.1	16.8	60.8	7.8	85.4	14.8
Ain Sokhna	Arabian Cement Company SAE	Cement	5 stage + pump	99.11	3	213.5	18.3	72.6	8.5	99.4	14.5
Suez	Ataka	Power	2 stage, gas phase	9.51	1	20.1	1.7	7.0	0.8	9.5	6.4
Suez	El Suez I	Refinery	2 stage, gas phase	4.17	1	15.1	1.3	3.1	0.6	5.0	8.0
Suez	El Suez II	Refinery	2 stage, gas phase	4.32	1	13.4	1.1	3.2	0.5	4.9	6.5
Suez	Suez I	Refinery	2 stage, gas phase	3.61	1	12.3	1.1	2.6	0.5	4.2	6.6
Suez	Suez II	Refinery	2 stage, gas phase	1.83	1	9.5	0.8	1.3	0.4	2.5	8.0
Suez	El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	2 stage, gas phase	14.46	1	22.5	1.9	10.6	0.9	13.4	5.6
Suez	Suez Steel Solb Misr Attaka plant	Steel	2 stage, gas phase	26.03	1	29.6	2.5	19.1	1.2	22.8	5.6

Local Hub	Compression Location	Industry	Compression Type	Number of Compression Trains	Overall Power (MW)	Overall Capex (USDM)	Annualised Capex (USDM/ Year)	Energy Opex (USDM/ Year)	Other Opex (USDM/ Year)	Total Annualised Cost (USDM/ Year)	USD / tCO_2
Cairo North	Mostorod I	Refinery	2 stage, gas phase	3.08	1	12.2	1.0	2.3	0.5	3.8	7.5
Cairo North	Mostorod II	Refinery	2 stage, gas phase	5.66	1	15.3	1.3	4.1	0.6	6.1	6.4
Cairo North	Cairo West	Power	2 stage, gas phase	13.41	1	21.7	1.9	9.8	0.9	12.5	5.6
Cairo North	Abu Sultan	Power	2 stage, gas phase	5.89	1	15.6	1.3	4.3	0.6	6.3	6.4
Shabab	Shabab	Power	2 stage, gas phase	0.92	1	7.1	0.6	0.7	0.3	1.6	9.6
Shabab	New Gas Shabab	Power	2 stage, gas phase	9.50	1	18.3	1.6	7.0	0.7	9.3	5.6
Mansoura	Talkha	Power	5 stage + pump	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Mansoura	El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	5 stage + pump	0.00	0	0.0	0.0	0.0	0.0	0.0	0.0
Damietta	MISR Fertilizer Production Company Damietta Complex	Fertilizer	2 stage, gas phase	22.04	1	27.0	2.3	16.1	1.1	19.5	5.5
Damietta	Damietta	LNG	2 stage, gas phase	5.70	1	15.3	1.3	4.2	0.6	6.1	6.4
Damietta	New Gas Damietta	Power	2 stage, gas phase	4.80	1	14.1	1.2	3.5	0.6	5.3	6.4
Damietta	Damietta West	Power	2 stage, gas phase	4.80	1	14.1	1.2	3.5	0.6	5.3	6.4
Damietta	Blue Hydrogen Facility	Hydrogen	2 stage, gas phase	4.16	1	13.2	1.1	3.1	0.5	4.7	6.5

Combining the capture costs, pipeline, compression and storage costs, the overall levelised cost for the local CCS hubs enables a comparison to the pipeline CCS hub to demonstrate the potential benefit that local CCS hubs could offer.

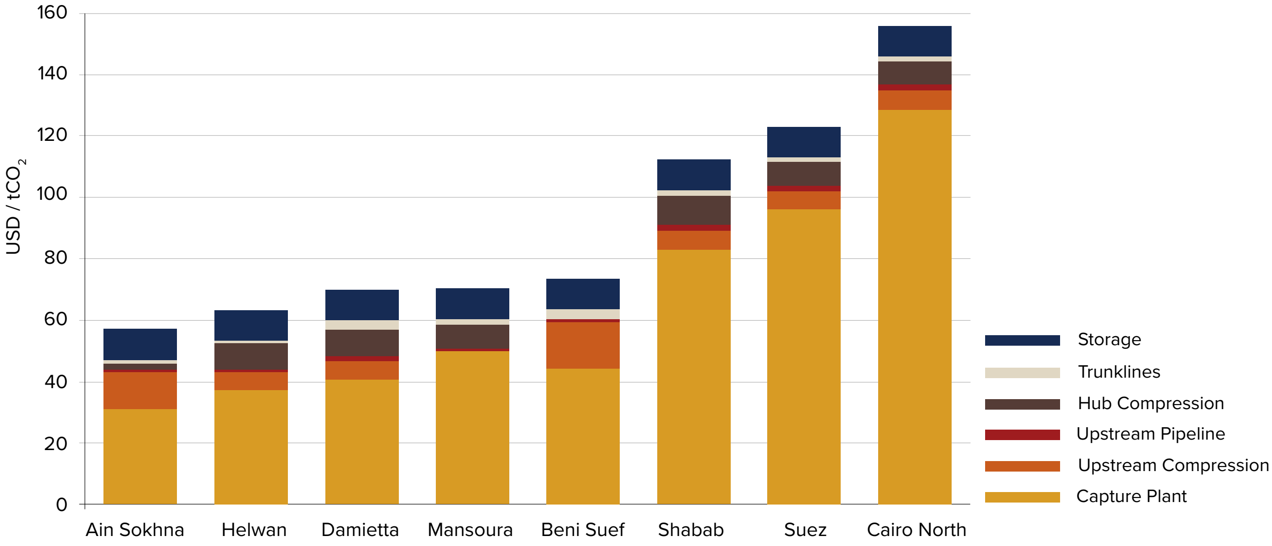
Figure 17: Levelised cost per tonne of CO_2 for each component in the CCS value chain for the Egypt pipeline CCS hub and the total for all local CCS hubs.



The cost of capture remains the same, however the move to local CCS hubs demonstrates the cost benefit through the reduction in trunkline requirements, and therefore costs, and hub compression. For Egypt this provides a USD13/tCO_2 reduction in costs to capture and store the CO_2 considered in this study.

The levelised cost for each element of the value chain for each of the local CCS hubs can also be produced.

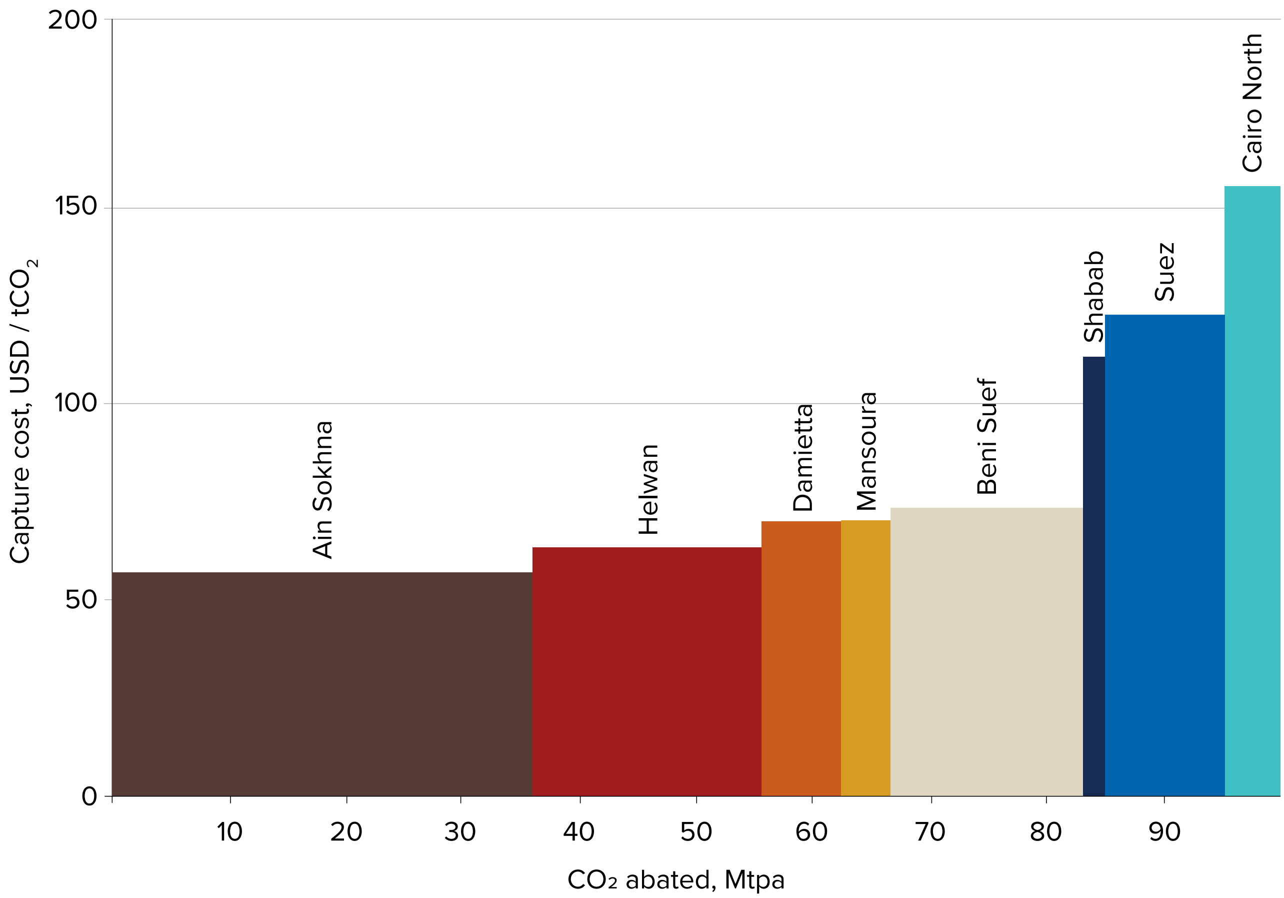
Figure 18: Levelised costs per tonne of CO_2 for each component in the CCS value chain for the Egypt local CCS hubs.



The local CCS hubs are ranked from lowest to highest overall cost. Capture costs are a key differentiator between local CCS hubs and upstream compression is also significant.

Figure 18 provides an understanding of the relative costs for each of the local CCS hubs, as well as the costs of each element in the value chain, however the scale is also important. The marginal abatement curve for the local CCS hubs can assist with this in Figure 19.

Figure 19: Egypt local CCS hub marginal abatement curve.



6.2.9.3.4 Blue hydrogen

To account for the change in hub design to local CCS hubs on the cost of blue hydrogen production, Table 43 provides the overview of costs. Appendix E provides the methodology for cost estimation for blue hydrogen.

Table 43: Summary of blue hydrogen plant costs considering local CCS hub transport and storage costs.

Cost item	USDM/year
Annualised capital cost	37.38
Utilities / variable opex (excluding natural gas)	7.26
Natural gas cost (@USD6.79/GJ)	74.26
Fixed operations & maintenance opex	17.49
CO_2 transport and storage costs	31.01
Total	**167.41**

This means the decarbonized hydrogen is USD 2.23/kg or on an energy basis USD 15.73/GJ (@142 MJ/kg HHV), marginally cheaper for local CCS hubs than the larger pipeline CCS hub.

6.2.10 CCS deployment in Egypt

Building a new CCS facility or retrofitting CCS to an existing facility is a major industrial project and has many similarities with large scale oil/gas production and mining and mineral processing projects.

Projects of this scale and complexity require the full suite of engineering studies, from concept through pre-feasibility, feasibility and front end engineering design (FEED) before detailed engineering and construction commences that can take several years to complete. Geological assessments will be completed in parallel to ensure that suitable storage is identified and characterised.

Aside from the engineering development and geological assessments involved in a complex CCS project, there are further complexities that need to be front of mind, both for industrial emitters looking to develop projects and governments looking to support them.

Project proponents must focus on community engagement and consultation where trust and understanding of the project amongst local communities through the implementation of a structured program of communication and consultation, based upon a genuine intent to provide significant stakeholders with some influence over aspects of the project most relevant to their concerns. Community engagement and consultation should commence at the onset of project development to help win ongoing support for the project from host communities.

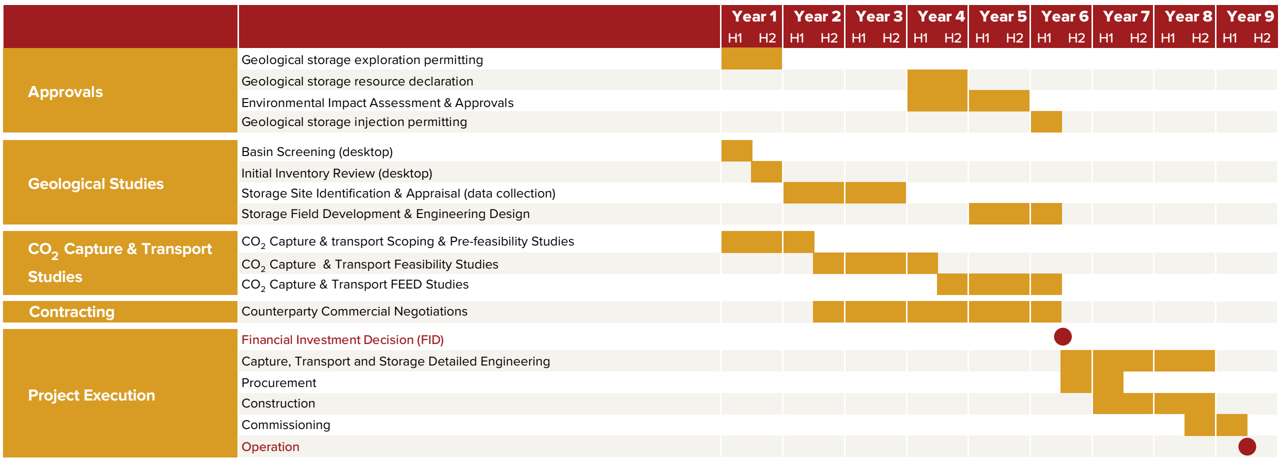
Project proponents need to undertake government engagement and consultation to identify legal, regulatory and policy risks and opportunities of relevance to the project and to work with the government to mitigate them to enable a project to proceed. As with community engagement, this should commence during the early stages of the project to ensure that the necessary steps are taken to obtain community by-in as the project proceeds.

Project proponents will participate in industry stakeholder engagement and consultation to identify potential business partners and successfully undertake and conclude negotiations in order to maximise profitability and reduce risk for a project. However, in addition to identifying potential business partners, stakeholder engagement and consultation must aim to build trusting and positive working relationships with businesses that may be impacted by the projects.

Assuming appropriate CCS regulation is in place and the community is on board with the development, a large complex CCS project may still take upwards of a decade to progress from concept development to operation.

Figure 20 provides a simplified timeline for the development of a generic complex CCS project. The timeline assumes there is no pre-existing studies available, all phases run to plan with no delay, appropriate CCS regulation is in place and the community is on board with the development.

Figure 20: Generic complex CCS project development timeline.



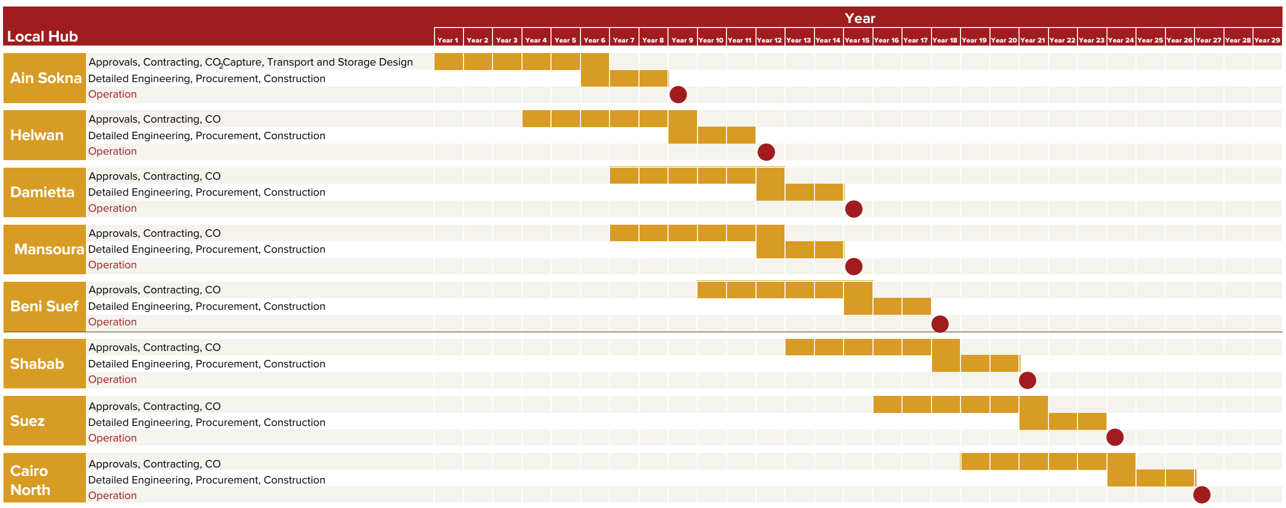
For the purpose of project timing, the local CCS hubs in Egypt have been considered. Besides being lower cost (overall) than the pipeline CCS hub they offer additional flexibility for development, particularly given the large scale nature of development that would be required. The timeline given in Figure 20 has been considered for each of the local CCS hubs.

The following assumptions have been considered in the development of the project timeline for execution of the Egypt local hubs:

- Development of the CCS hubs is staggered by three years (the length of construction for a generic CCS hub). This enables Egypt to use a consistent workforce for the duration of the development and execution of all local CCS hubs;
- CCS hub development is based on overall cost per tonne CO_2 of stored. The lowest cost CCS hub is developed first followed by hubs of increasing cost per tonne CO_2 stored;
- Given the value and scale of the Mansoura and Damietta local hubs are similar, it is assumed that they all developed in parallel;
- All project phases run to plan with no delays.

Based on the assumptions, Figure 21 provides the indicative timeline for the development of the Egypt local CCS hubs. We assume that the hubs are phased in such that each hub takes three years to build.

Figure 21: High level development timeline of the Egypt local CCS hubs.

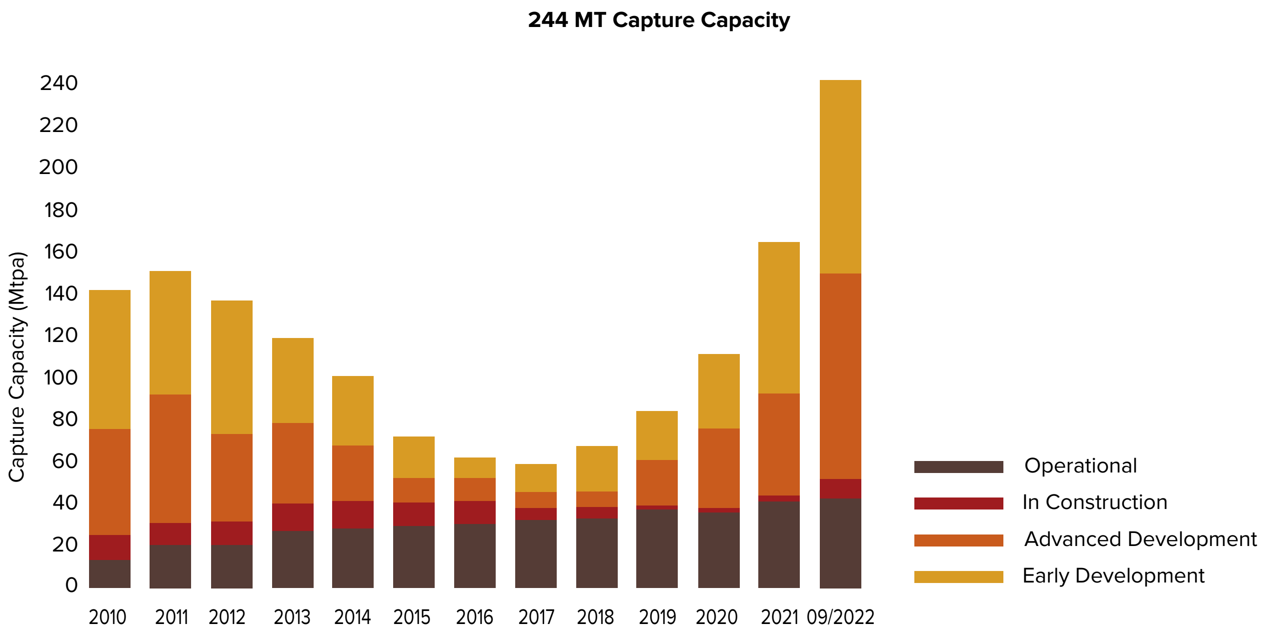


As stated above, the timing in this section is indicative only for the purpose of this study. Any project CCS hub project can be brought forward (bar stage one), delayed or consolidated (eg multiple CCS projects become a single project for execution) and is subject to the project proponents involved. The purpose here is to emphasise the duration for large scale complex CCS projects, particularly if considering staged development and/or multiple CCS hubs.

The timelines above consider no delays in each stage of project development, however there is a strong possibility that one or more of the activities involved will be delayed that could result in this duration extending. The infrastructure for each CCS hub project is independent and therefore delays may not appear to have an impact on subsequent CCS hub projects, however the resources required to support project development and construction could be. If a project extends out, resources that may be required to execute a subsequent project may no longer be available resulting in delays.

Figure 22 from the GCCSI Global Status Report in 2022 (GCCSI, 2022) shows the progress of commercial CCS facilities from 2010 to September 2022.

Figure 22: Pipeline of commercial CCS facilities from 2010 to September 2022 by capture capacity.



The project pipeline capacity annual average growth rate since 2017 has been 34%. This growth rate could put further constraints on materials and labor supporting the development and construction of CCS projects that could raise project costs and delay projects coming online.

7.0 ECONOMICS

7.1 Value added and jobs created from local CCS hubs

The proposed hubs represent a significant investment for Egypt, equivalent to more than 7% of Egypt's 2022 GDP (World Bank, 2022a). For the economic analysis, we focus on the local hub model and assume that the hubs are phased in such that each hub takes three years to build, and the first begins construction in 2027 and commences operation in 2030. Each subsequent hub is built every three years, beginning operation once finished. We assume that hubs are built in order from lowest to highest average cost per tonne CO_2 captured and stored.

The economic analysis is based on economic multipliers derived from a social accounting matrix (SAM) for Egypt (Serag et al., 2021), rather than a full macroeconomic model. Economic multipliers are a concept used to measure the impact of a change in economic activity on the overall economy. Essentially, when money is spent in an economy, it leads to further spending, creating a chain reaction of economic activity. This effect is quantified using multipliers. Because we use multipliers, we are unable to account for changes in prices, demand elasticities and income elasticities. We are also unable to account for the impacts of international borrowing on balance of payments or other macroeconomic feedback. We are also not comparing the investment in CCS hubs to an alternative investment to determine which may result in greater value added or more jobs created.

We estimate the direct and indirect value added from the additional spending within the Egyptian economy that results from the construction and operation of the local CCS hubs. The direct spending is the amount of Egyptian pounds spent in various sectors representing the capital investment for and operation of capture equipment, compressors, pipelines and storage. As a given sector, such as machinery, expands output to provide the equipment or services needed, that sector in turn purchases goods and services from other sectors, and those sectors in turn purchase goods and services from sectors, and so on. Taken together, this additional economic activity represents the indirect impact of the CCS hubs. While it is possible to go further and estimate the additional household consumption that results from the increase in income from the jobs that are created as a result of this spending, these induced effects, as they are referred to, tend to overestimate the economic impact. Therefore, we have only calculated the direct and indirect effects to be conservative.

We estimate the jobs impact in a similar way. Whether during construction or operation, spending related to the CCS hubs within various sectors of the Egyptian economy results in an increase in economic output, and a portion of this increased output goes to household income. To estimate the total number of jobs created from the CCS hub, we divide the increase in household income by a typical salary. We separately estimate the direct jobs created during construction and during operation based on a review of the literature (Huizeling, 2011; IEAGHG, 2013; DECC, 2014; Gassnova, 2016; ILO, 2016; Norwegian Ministry of Petroleum and Energy, 2020b; Elliott et al., 2022). We then assume that the indirect jobs created are the difference between total jobs created and direct jobs needed to build or operate the CCS hubs.

When interpreting the results of jobs created, the indirect jobs are not directly associated with the CCS hubs but are created throughout the economy as a result of the increased output across sectors. For example, the companies involved in making machinery needed for the hubs must expand output, and they then hire additional employees. A food truck vendor may expand and hire additional people to serve the additional staff working in machinery. In turn, the agricultural sector will increase its output and hire additional workers to supply the food truck vendor. The machinery sector will also increase its energy use, and the energy sector will increase its output and hire additional workers. Agriculture and energy will also need additional equipment and demand more output from the machinery sector, and the cycle repeats, though diminishes each round. All of these sector linkages lead to round after round of additional output and need for additional workers.

We evaluated a number of front-end engineering and design (FEED) studies and relevant literature (Huizeling, 2011; IEAGHG, 2013; DECC, 2014; Gassnova, 2016; ILO, 2016; Norwegian Ministry of Petroleum and Energy, 2020b; Elliott et al., 2022) and used this review to develop a share by sector of spending for the installation or construction of capture equipment, compressors, pipelines and storage (Figure 23), as well as for the

operation of these different components (Figure 24). The operation breakout applies to non-energy OPEX. We ignore the energy consumed by the capture equipment because much of this energy can be supplied from waste heat captured onsite and therefore would not require additional spending in the electricity, gas and steam sector. Determining the how much energy may be supplied through waste heat is beyond the scope of this analysis; therefore, to be conservative, we have ignored the potential economic impact of providing this energy. The electricity needed for compression, however, is clearly additional energy that the electricity, gas and steam sector (as defined within the SAM framework) must provide, and so we do account for the economic impact of the resulting increase in energy output. We also make assumptions about imported equipment and expertise and ignore those values as leakages with respect to Egyptian economic impact.

For the domestic economic impact analysis, we convert from US Dollars (USD) to Egyptian Pounds (EGP), but rather than an exchange rate of approximately 19 EGP to 1 USD, we convert using a purchasing power parity of 4.57 EGP to 1 USD. Egypt devalued its currency in 2016, and the long-term historical exchange rate was closer to 5 to 1. Also, using a 19 to 1 exchange rate as a basis for how many Egyptian pounds are purchasing goods and services in the domestic economy would significantly overestimate the domestic impact, especially jobs.

Figure 23: Sector mix for construction.

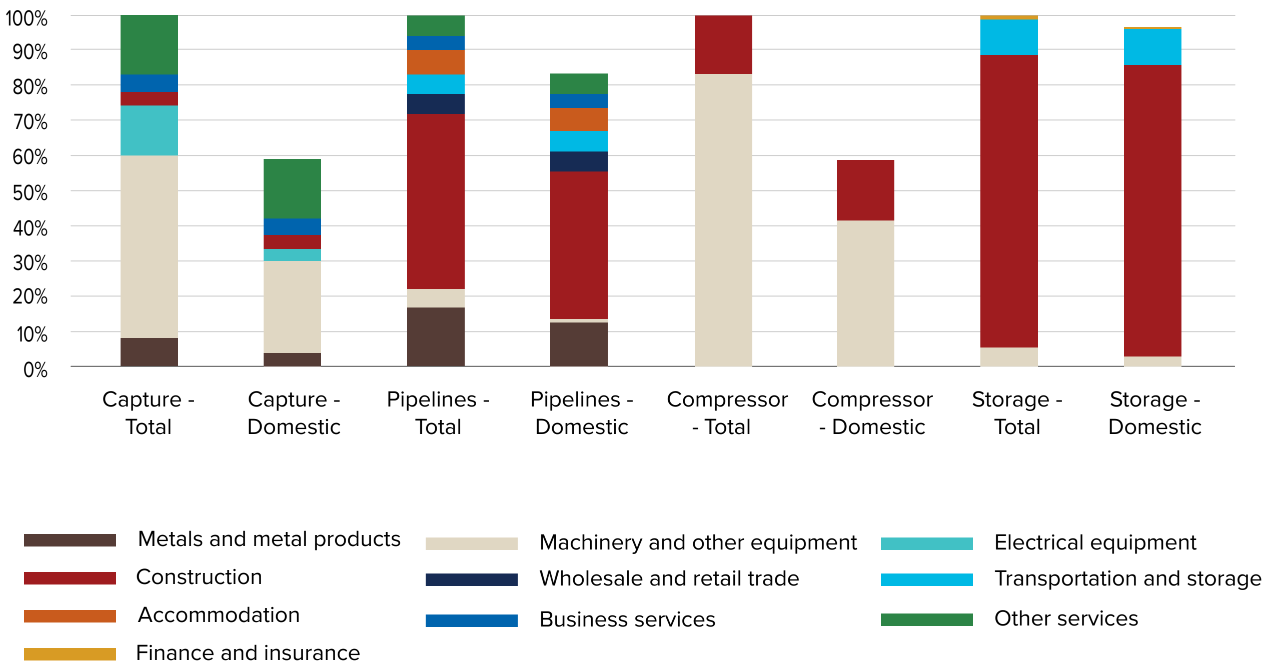
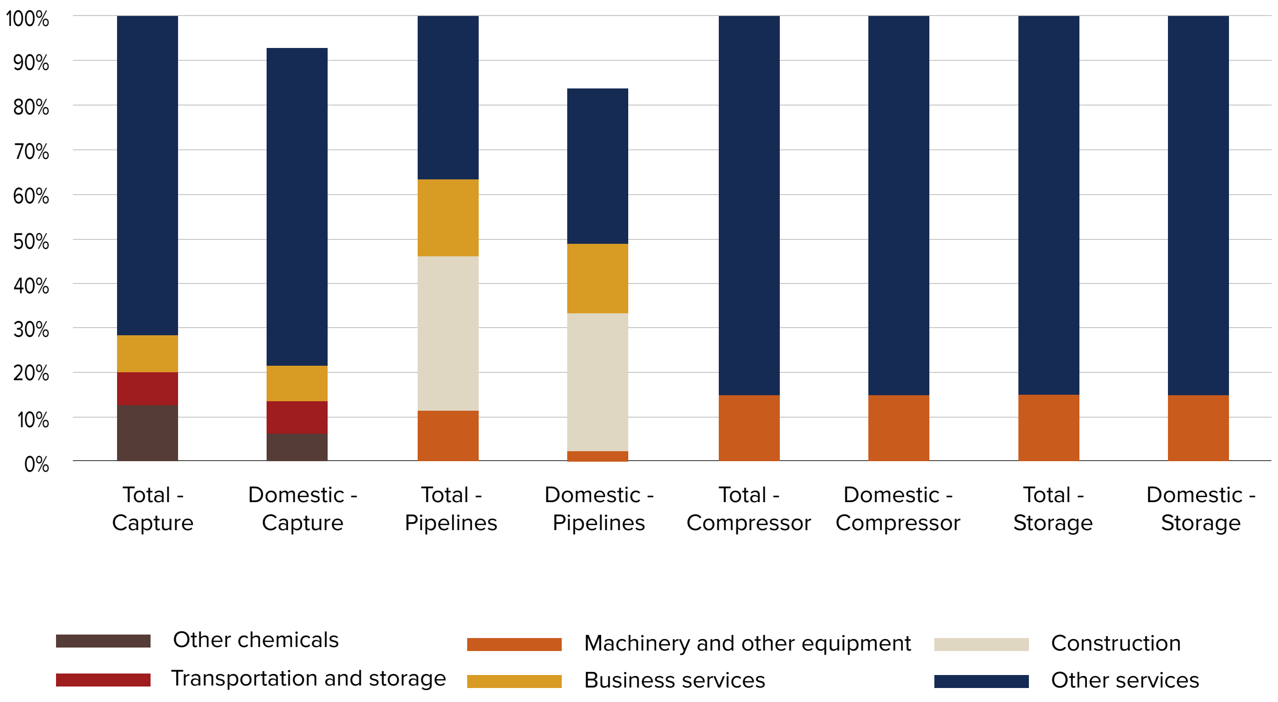


Figure 24: Sector mix for operation (excluding energy).



The results of our economic analysis of the proposed local CCS hubs are presented in Table 44 and Table 45 below. Operations result in greater proportional effects on the economy than construction because most of the activity in operations, including energy for compression, comes from sectors of the Egyptian economy with mostly domestic inputs. In contrast, the construction phase, even after accounting for direct imports, has significant components from domestic sectors like machinery and electrical equipment that import much of their inputs, so the indirect economic impact of spending going into these import-heavy domestic sectors is lower than spending going into domestic sectors with primarily domestic inputs.

Table 44: Economic impact from construction.

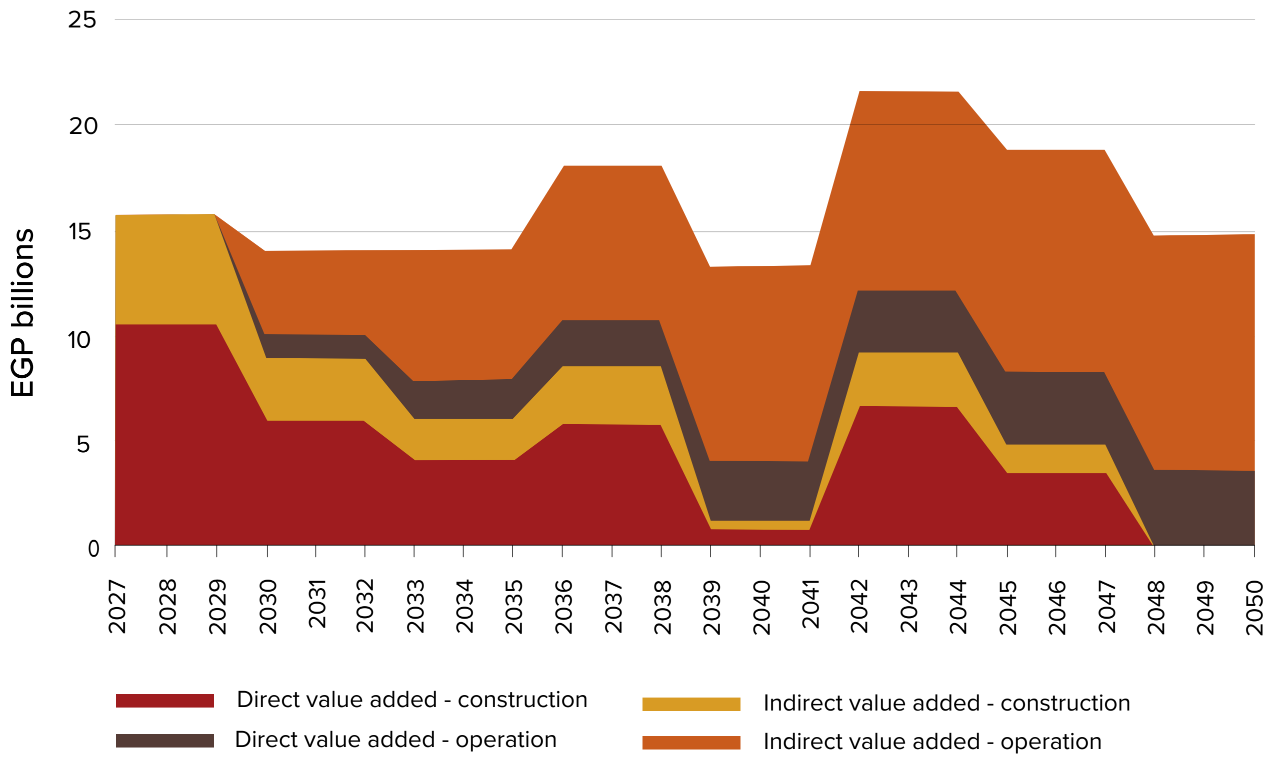
	Ain Sokna Hub	Halwan Hub	Mansura & Damietta hubs	Beni Suef	Shabab Power Hub	Suez Hub	Cairo North Hub
Years Construction	2027 - 2029	2030 - 2032	2033 - 2035	2036 - 2038	2039 - 2041	2042 - 2044	2045 - 2047
Total capital investment (USD millions)	9,321	5,397	3,796	5,259	896	6,718	3,640
Leakge from imports (USD millions)	2,384	1,430	1,061	1,427	286	2,313	1,287
Total domestic capital Investment (USD millions)	6,937	3,967	2,735	3,833	611	4,404	2,353
Total domestic capital Investment (EGP millions)	31,702	18,128	12,500	17,515	2,790	20,129	10,754
Annual domestic capital investment during construction (EGP millions)	10,567	6,043	4,167	5,838	930	6,710	3,585
Annual indirect value added during construction (EGP millions)	5,183	2,908	1,952	2,764	386	2,557	1,320
Annual direct + indirect value added during construction (EGP millions)	15,751	8,951	6,118	8,602	1,316	9,266	4,904
Annual direct jobs during construction	20,339	8,730	5,724	8,072	1,516	10,159	5,332
Annual indirect jobs during construction	20,559	14,536	10,036	14,064	1,888	14,004	7,461
Annual direct + indirect jobs during construction	40,899	23,266	15,760	22,136	3,404	24,163	12,793

Table 45: Economic impact from operation.

	Ain Sokna Hub	Halwan Hub	Mansura & Damietta hubs	Beni Suef	Shabab Power Hub	Suez Hub	Cairo North Hub
Years Operation	2030 - 2050	2033 - 2050	2036 - 2050	2039 - 2050	2042 - 2050	2045 - 2050	2048 - 2050
Annual OPEX (USD millions)	1,092	675	367	653	101	522	317
Annual leakge from imports (USD millions)	474	321	195	344	64	321	214
Annual domestic OPEX (USD millions)	619	353	172	309	38	201	102
Annual domestic OPEX after leakage (EGP millions)	2,828	1,615	785	1,413	172	916	468
Annual indirect value added during operation (EGP millions)	2,296	1,313	634	1,144	140	744	380
Annual direct + indirect value added during operation (EGP millions)	5,124	2,928	1,419	2,557	312	1,660	848
Annual direct jobs during operation	998	631	385	625	106	536	325
Annual indirect jobs during operation	11,753	6,652	3,168	5,779	683	3,640	1,824
Annual direct + indirect jobs during operation	12,751	7,282	3,554	6,404	789	4,176	2,149

Figure 25 plots value added from Table 44 and Table 45 over time as the local hubs are assumed to be phased in. We assume that the value added from construction for a hub occurs only during the active years of construction. We assume that once a hub begins operating, it operates at least until 2050. We also assume that the full value added from the operation of each operating hub is summed, which may overestimate value added in later hubs as the Egyptian economy is likely to evolve via economies of scale in supporting on-going CCS operations such that the marginal spending in subsequent CCS hubs may be a little less than the first CCS hubs. Again, by not including induced value added, we are, to an extent, counterbalancing any potential overestimate. Over time, the proportion of imported equipment and materials needed for CCS hubs may also decline as local producers begin to offer more domestic alternatives, which could increase value added to the Egyptian economy; we do not attempt to account for any such structural changes.

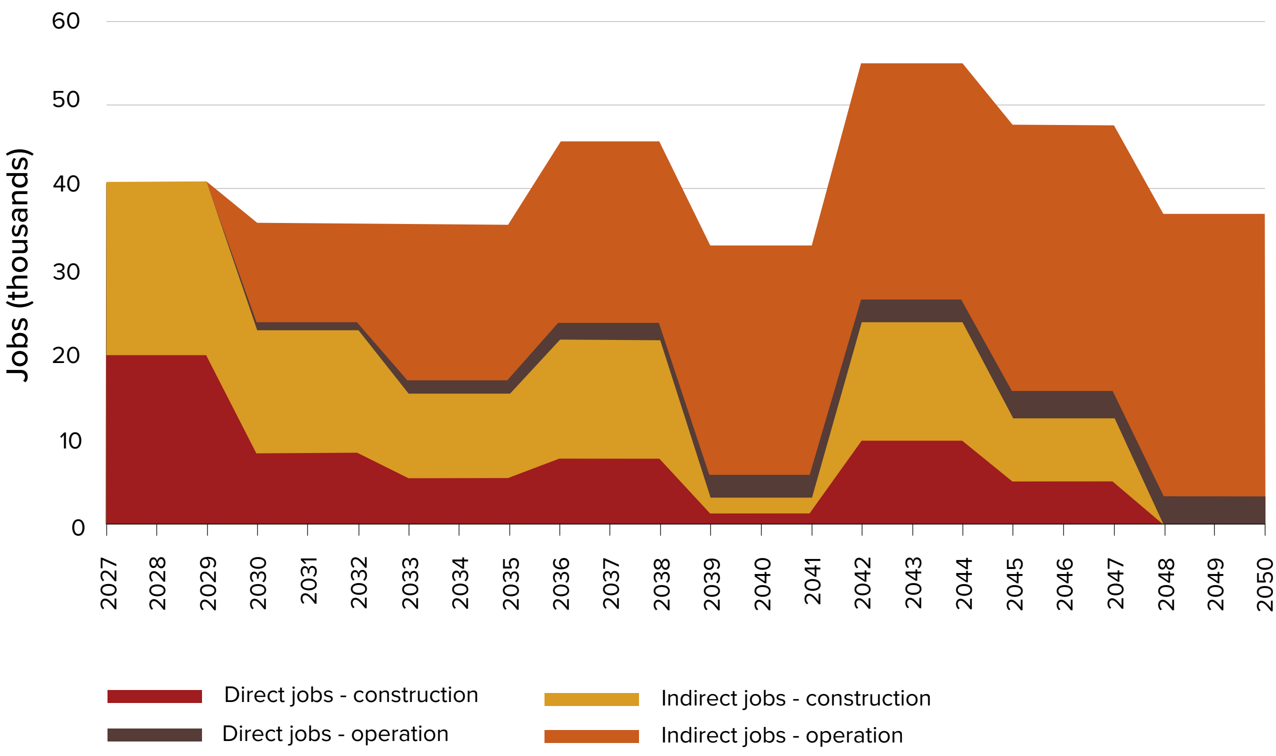
Figure 25: Value added from construction and operation of phased local hubs through 2050.



At a 5% discount rate, the present value (PV) through 2050 of the total value-added is EGP 221 billion, of which EGP 137 billion is direct and EGP 84 billion is indirect. Converting these figures back to USD using a PPP of 4.57 results in a PV of total value-added of USD 48 billion, of which USD 30 billion is direct and USD 18 billion is indirect. Egypt's 2021 GDP is USD 404 billion (World Bank, 2022). At peak, the direct and indirect value added from the CCS hubs is the equivalent of USD 4.7 billion or about 1.2% of current GDP. A recent agreement has been signed to build a USD 8 billion green hydrogen facility in Egypt. All the hubs combined, phased in over 20+ years, are only about 4.5 times the size of this one green hydrogen facility. The CCS hubs, therefore, are not out of scale with other large infrastructure projects planned in Egypt.

Figure 26 shows direct and indirect jobs from Table 44 and Table 45 over time as the hubs are assumed to be phased in.

Figure 26: Jobs from construction and operation of phased local CCS hubs through 2050.



The current labor force in Egypt is 28.5 million (World Bank, 2022); at peak the CCS hubs will create 55 thousand direct and indirect jobs, which is 1.9% of the current labor force.

Although the CCS hubs do represent a significant investment, phasing them in over time can make them manageable from a total cost perspective as well as from a labor force perspective. By phasing CCS hubs, engineers, suppliers, construction crews – all of the businesses and personnel needed to build out the CCS infrastructure – can be deployed over a 20-year period beginning in 2027, enabling Egypt to develop local capacity. Building one large CCS system all at once would require more imports of expertise and goods and services because it would not be practical to train local labor for one round of construction and thus would result in less value added than a phased in approach.

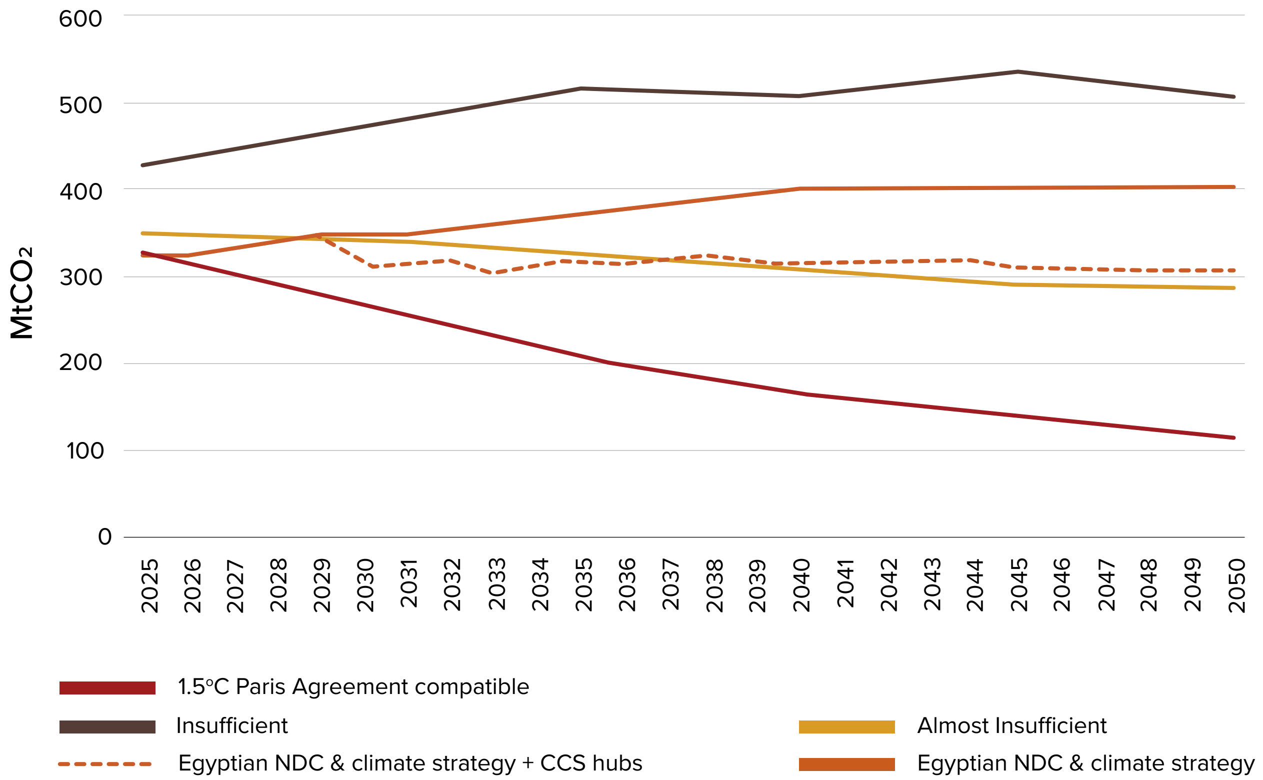
7.2 Contribution of CCS hubs towards Egypt's NDCs and Net Zero ambition

We examine Egypt's updated nationally determined contribution (NDC) submitted to the UNFCCC this year (Government of Egypt, 2022) and Egypt's new National Climate Change Strategy (NCCS) (Government of Egypt, 2022). The updated NDC does not mention CCS and focuses primarily on CO_2 reductions in the electricity sector, but also includes reductions in the Oil & Gas sector (but not CCS) and in transportation. The NCCS mentions carbon capture briefly as an opportunity to explore as a way to reduce CO_2 emissions from fossil fuels.

We constructed an emissions trajectory that begins with current CO_2 emissions in Egypt based on data from the Climate Action Tracker (CAT), a collaboration between Climate Analytics and NewClimate Institute (CAT, 2022) and project CO_2 emissions to reflect reduction goals within the NDC that focuses on reductions up to 2030 and reduction aspirations in the NCCS that extends out to 2050. We plot this CO_2 emissions trajectory along with an alternative trajectory that reflects the additional CO_2 reductions from the local CCS hub approach phased in over time. For context, we also include CO_2 projections for Egypt from the CAT (CAT, 2022). The CAT CO_2 projections are categorised as "insufficient", "almost sufficient" and "1.5°C Paris Agreement compatible."

We plot each of the projections in Figure 27. Without the CCS hubs, the Egyptian NDC and NCCS are expected to result in CO_2 emissions that are about midway between "insufficient" and "almost sufficient" according to the CAT. The CCS hubs offer a substantial reduction in Egypt's CO_2 emissions to be in line with what CAT deems "almost sufficient." Although this level of emissions still exceeds a trajectory compatible with a 1.5°C Paris Agreement, CCS hubs would put Egypt in a far better position to achieve a Paris compatible emissions trajectory than without CCS hubs.

Figure 27: CO_2 projections for Egypt.



For industries to consider CCS as a means of abatement they would need to commence development as soon as possible in order to meet targets set internally and by the government. Project proponents need to ensure that risks are identified early, be it design and geological assessment or through the various stakeholder engagement and consultation, to ensure they are able to be addressed and avoid delays, or worse project cancellation.

Regulators and policy makers must take these timelines into account and develop regulations and policy that incentivises investment in complex, and less complex, CCS projects to support net-zero strategies.

7.3 Identify potential for low-carbon product market development and hydrogen-based energy vectors that would be enabled by CCS

The Egyptian government has partnered with the European Bank for Reconstruction and Development (EBRD) to develop a green hydrogen strategy. As part of this strategy, Egypt has planned USD 40 billion in green hydrogen investment, financed by EBRD and other international partners. Egypt has signed numerous MOUs with private companies to develop green hydrogen projects; the project pipeline represents a production capacity of at least 11.62 GW (1.57 million tons of hydrogen). Identified projects in this pipeline, expected to be online by 2035, amount to USD 20 billion (Egypt Today staff, 2022; Smith, 2022).

The primary market for this green hydrogen is Europe. Europe is still in the process of defining its hydrogen import requirements, whether they must be renewable hydrogen or can also be low-carbon hydrogen from fossil fuels with CCS. In December 2021, the EC published its legislative Package on Hydrogen and Decarbonized Gas Markets that calls for blue hydrogen to be used until 2030, provided the blue hydrogen achieves a 70% CO_2 reduction (European Commission, 2021a). More recently, Europe's REpowerEU plan calls for up to 10 million tonnes of renewable hydrogen imports, and the REpowerEU plan is clear that the hydrogen should be produced from renewables rather than fossil fuels (European Commission, 2022d). At this point, Europe's limited interest in importing blue hydrogen appears to be short-term up to 2030.

With the proposed Egyptian CCS hubs coming online in the 2030s, after Europe's potential interest in blue hydrogen ends, the market potential for blue hydrogen exports to Europe in conjunction with the proposed hubs may be limited. Nevertheless, there may be domestic market opportunities to use blue hydrogen; blue hydrogen production in 2030 is likely to be less expensive than green hydrogen and so is better suited to decarbonize hard-to-abate domestic industries, keeping green hydrogen that can be sold at a premium price for export. Even if Europe decides to allow blue hydrogen imports beyond 2030, green hydrogen will likely enjoy a price premium over blue hydrogen in Europe given Europe's apparent preferences for green hydrogen.

Export of blue hydrogen beyond Europe is possible, but the cost of long-distance hydrogen transport is high. The energy density by volume of hydrogen is very low, so hydrogen must be liquefied to make transport by ship practical, but the temperatures required to keep hydrogen in a liquid state (-253°C) are far lower than what is needed for LNG (-162°C) or ammonia (-33°C). Onboard liquefaction would be needed to capture and re-liquefy hydrogen boil off and would reduce cargo volume and add to shipping costs. Converting hydrogen to ammonia and then shipping ammonia may prove less costly for longer distances. Ammonia can be used in some applications but is not as flexible as hydrogen; converting ammonia back to hydrogen at end-use also adds to the cost. The most likely markets for blue hydrogen or ammonia beyond Europe are Japan, South Korea, and Singapore. The shipping distance between Egypt and Japan is 9,100 nautical miles compared to 3,376 nautical miles between Australia and Japan, giving Australia a competitive advantage over Egypt in supplying the East Asian market, suggesting that the cost of blue hydrogen production in Egypt would need to be well below the cost in Australia to be competitive.

An alternative to shipping hydrogen or ammonia is to use hydrogen to create a synthetic fuel that can be shipped using existing infrastructure and used in existing vehicles and other applications that use conventional fuel. The way that synthetic fuels can be considered carbon neutral is if the carbon added to hydrogen to produce the fuel is taken from the atmosphere via direct air capture (DAC); when the fuel is combusted, the carbon is released back to the atmosphere. The only additional carbon released in the process is the carbon not captured in producing blue hydrogen. However, DAC can capture additional CO_2 as an offset to make the whole value chain carbon neutral. While the latest IPCC acknowledges the need for carbon removal, including industrial DAC, the UNFCCC process will need to establish how synthetic fuels made via DAC are treated with respect to international trade and emissions accounting.

One strategy Egypt may consider is to develop DAC facilities – building on the proposed CCS hubs – to capture carbon to combine with blue or green hydrogen to make a synthetic fuel. Up-front costs would be higher than hydrogen costs alone, but transport and storage would be much less costly. End uses for synthetic fuels would also be much less expensive than for hydrogen or ammonia. For example, existing vehicles that use gasoline and diesel would be able to use a synthetic fuel directly without modification, whereas an entirely new type of vehicle is required to use hydrogen or ammonia. The key to making synthetic fuels economically viable is low-cost DAC. Current reported costs of DAC suggest that synthetic fuels may be too costly now, but the costs of DAC are declining. An even simpler strategy may be to use DAC to generate offset credits and link those offset credits to fossil fuels exported by Egypt to make those fuels effectively carbon neutral.

Another potential low-carbon product with export potential in Egypt is cement. In 2020, Egypt was the 19th largest exporter of cement, exporting USD 182 million, 70% of which went to Kenya, Libya, the US, Sudan and Uganda; only 3.75% of exports went to the EU (OEC, 2021). The carbon border adjustment mechanism (CBAM) may be an opportunity for Egypt to expand exports with low-carbon cement to the EU, as it would face lower costs and have an advantage over full-cost cement imported by Europe.

For countries outside the EU without the CO_2 border adjustment, Egypt could bundle verifiable emission reduction credits along with low-carbon cement. Companies in other countries facing their own emission reduction requirements would be willing to pay a premium for these low-carbon products, opening up the export potential to other countries. The downside to Egypt is that Egypt could no longer claim these reductions itself, but it could be a way in the near-term to recoup some costs of the CCS infrastructure.

7.4 Identify international and local funding mechanisms to support the large-scale deployment of CCS in Egypt

7.4.1 Non-market-based mechanisms

The UNFCCC has several funds dedicated to climate finance, but its two most important are the Global Environment Facility (GEF) and the Green Climate Fund (GCF). Both pool financial resources from donor countries and administer them to developing countries, usually through third parties.

The GEF funding cycles last six years. At the beginning of each cycle, donor countries commit resources to the GEF, which then allocates those resources to recipient countries. Recipient countries must propose projects that are aligned with their NDCs to access funds. Given that Egypt has removed mention of CCS in its updated NDC submitted this year, access to GEF funds for CCS may not be possible until Egypt updates its NDC again, including CCS. Nevertheless, the projects financed by the GEF are small compared to the size of the proposed hubs, with the largest GEF projects up to USD 15 million. Because of the smaller size of project funded by the GEF, it is better suited to support the development of legal, regulatory and policy frameworks for CCS in Egypt rather than CCS projects directly. To date, the GEF has not approved any CCS projects.

The GCF is a financial mechanism of the UNFCCC dedicated to developing countries. The GCF has built a portfolio of more than 100 projects since 2015. The GCF operates at a much larger scale than the GEF and has the capacity to deliver large-scale infrastructure projects, including CCS, through several financial instruments including grants, loan guarantees, concessional loans and equity investments. The process for project approval is lengthy and can take several years depending on the size and complexity of the project in question. The GCF has not yet approved a CCS project. Unanimous support of the GCF board is necessary to gain approval, which has proved difficult for fossil fuel-based projects. Recently, the board approval requirement changed from unanimous to majority, increasing the possibility that CCS projects could get GCF funding. The GCF can help projects meet their capital requirement, but it does not necessarily bridge the full financing gap and revenue risk. Carbon markets can potentially fill this gap by providing revenue for CCS projects. The GCF recently approved its first project that relies on carbon market revenues. The project, submitted by the European Bank of Reconstruction and Development, indicates a shift towards more innovative projects.

7.4.2 Market-based mechanisms

The incentive to invest in CCS comes from placing a value on CO_2. Developing countries, Egypt included, generally do not have policies that place a sufficient value on CO_2 to drive investment in CCS. Carbon crediting may be one way to provide an incentive to invest in CCS in Egypt. Carbon crediting is a form of carbon pricing that relates to the process of issuing a credit for one tonne of CO_2 mitigated. Crediting schemes serve the broader function of carbon offsetting, whereby carbon credits are used to offset an equivalent amount of emissions either locally or elsewhere in the world. A crediting scheme in Egypt could pave the way to finance the development of CCS hubs, and the credits they generate are then used to offset emissions in more industrialised countries (Annex I parties). Egypt would not, however, be able to claim credit for those reductions under its UNFCCC commitments, as those credits would transfer to the country purchasing them.

Article 6 of the Paris Agreement comprises three approaches for cooperation between Parties:

- Cooperative approaches;
- A new mechanism to promote mitigation and sustainable development; and
- A framework for non-market approaches

The framework that is set to be defined under Article 6 is an outstanding issue for negotiations at the UNFCCC. Article 6 provides a framework for two distinct approaches to market-based mechanisms and one approach for non-market-based mechanisms.

Article 6.2 Allows countries to strike bilateral and voluntary agreements to trade units (Internationally Transferred Mitigation Outcomes – ITMOs). It establishes an accounting framework that also applies to Article 6.4. Article 6.4 creates a centralised governance system for countries and the private sector to trade emissions reductions anywhere in the world. This system is due to replace the clean development mechanism (CDM). The system will be supervised by a UN Supervisory Body, suggesting that Article 6.2 may be easier to use since it avoids UNFCCC bureaucracy. Article 6.8 develops a framework for cooperation between countries to reduce emissions outside market.

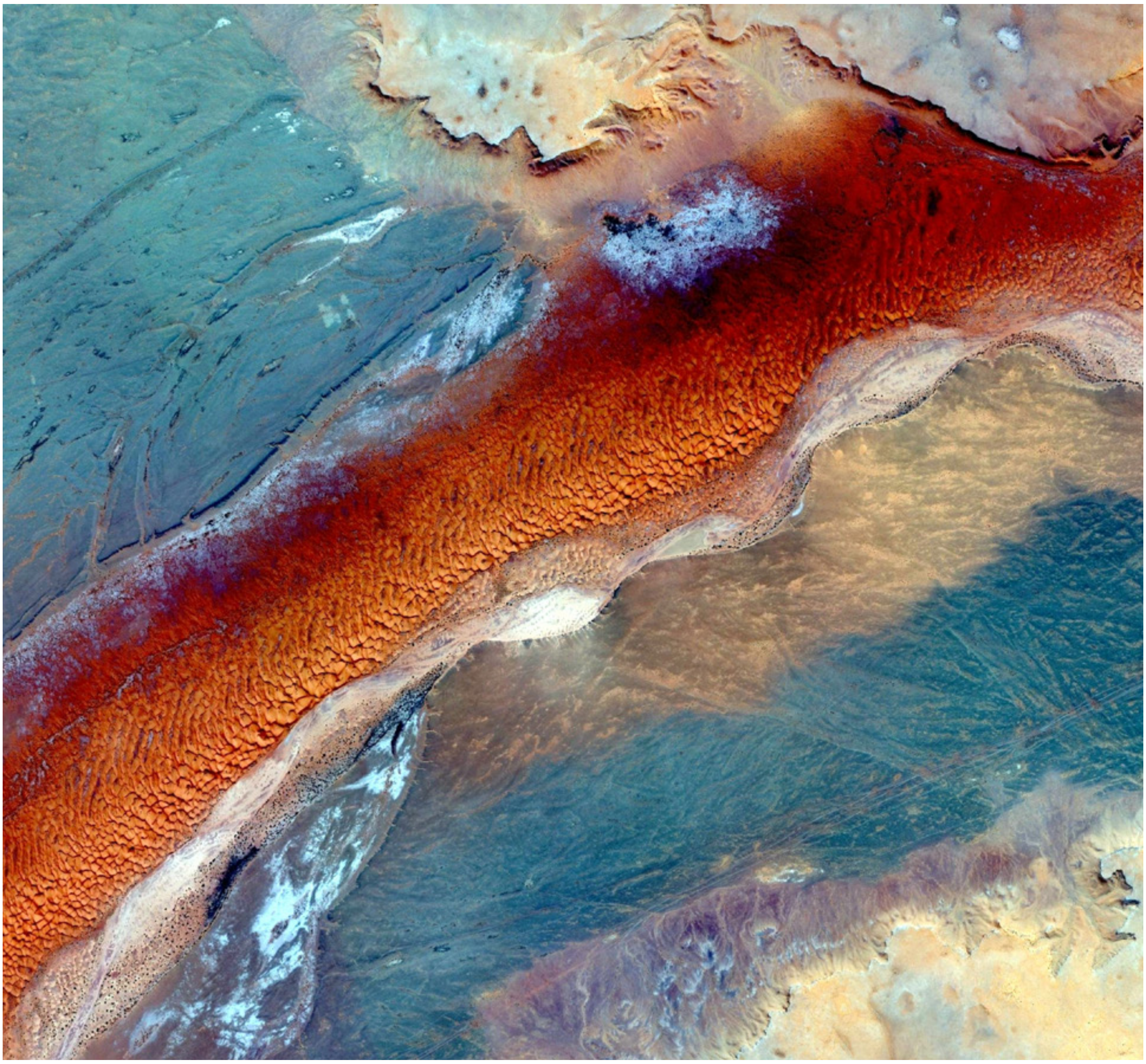
7.4.3 Traditional development financing

The World Bank, the European Investment Bank, the EBRD and various country development agencies, as well as country export credit agencies, are all potential sources of financing for the CCS hubs.

7.4.4 Domestic Egyptian financing

Egypt launched the first Sovereign Green Bonds (September 2020) in the Middle East and North Africa region, at a value of USD 750 million listed in the London Stock Exchange. Of the eligible green projects, 39% cover pollution reduction and control. Egypt has also established the Environmental Sustainability Criteria Guideline, which has led to an increase of green investments from 15% in FY2019/20 to 30% in FY 2020/21, with projections to reach 50% in FY2024/25. The Financial Regulatory Authority Decree 107 and 108 in 2021 mandates that companies listed in the Egyptian Stock Exchange and companies operating in the non-banking sector must submit environmental, social and governance (ESG) disclosure reports, including financial impacts of climate change. The Egyptian companies involved in the proposed hubs may be able to access financing through sustainability linked loans, which use ESG reporting as a criteria for discounts in interest rates charge for meeting sustainability goals.

The Green Economy Financing Facility (GEFF), implemented by the EBRD, is a EUR 150 million fund aimed at assisting with green economy transition investments and may be a potential source of financing for the CCS hubs, though the scale of the hubs exceeds that of the GEFF.



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APPENDIX A INTERNATIONAL CCS POLICY

A.1 International CCS policy developments

There have been several policy developments from jurisdictions around the world that support CCS projects (Global CCS Institute et al., 2021). This section is a discussion of developments in policy regimes from key jurisdictions. These policies are in varying stages of implementation. Many of them can be adapted to Egyptian context.

A.1.1 North America

A.1.1.1 United States

The bipartisan Infrastructure Investment and Jobs Act passed in 2021 contains "the single largest appropriation for CCS in the history of the technology" (Global CCS Institute, 2021). The bill appropriates a total of USD 7 billion; USD 2.5 billion for demonstration projects, USD 1 billion for large scale CCS pilot projects, and USD 3.5 billion for regional Direct Air Capture (DAC) hubs. The bill also contains the SCALE Act which allocates nearly USD 5 billion to support the development and financing of CO_2 transport and storage infrastructure and sites (International Energy Agency, 2022). The US Energy Act of 2020 allocated more than USD 6 billion for research, development and demonstration through the US Department of Energy and the Environmental Protection Agency. The construction deadline of the demonstration projects has been extended to January 1, 2026. In addition, Section 45Q of the IRS Tax Code (National Archives and Federal Register, 2021) provides tax credits for CO_2 sequestration. In January of 2021, the IRS released final rules and regulations that governs the efficient administration of the tax credit (Global CCS Institute and Matt Bright, 2021).

In August 2022, the United States Congress passed the Inflation Reduction Act (IRA) that was signed into law by the President (Clean Air Task Force 2022; United States Department of Energy and Department of Energy Office of Policy 2022). The IRA contains significant improvements to the policy support offered at the federal level in the US. A short summary of these changes is included here. Further details on the tax credit are provided in the section on tax credits in the US.

1. The IRA increases the tax credit for geologic storage (and for utilisation) from industrial facilities and power generation facilities. It also more than doubles the tax credit for geologic storage (and for utilisation) from DAC facilities.
2. The new law also increases the timeframe in which the projects can be initiated.
3. Notably, the IRA provides for a direct payment option to receive the tax credit. In the past, the tax credits were often monetised through a tax equity investment partnership. The IRA now allows a CCS project developer to receive a tax refund as a direct payment, like one they would receive if they overpaid taxes.
4. The IRA includes more types of qualified activities by lowering the threshold on the tonnes of emitted CO_2 that would need to be captured.

A.1.1.2 Canada

The government of Canada proposed a comprehensive Carbon Capture, Utilisation and Storage (CCS) Policy in 2020 (Global CCS Institute et al., 2021). The policy titled, A Healthy Environment and a Healthy Economy, encourages large emitters to aspire to net zero emissions by 2050 (Government of Canada, 2020). It allocates CAD 3 billion over five years for decarbonization projects. CCS is also mentioned as a part of the

Hydrogen Strategy for Canada (Government of Canada and Natural Resources Canada, 2020). Compliance credits for Canada's Clean Fuel Standard can be created through projects that use CCS as a carbon reduction technology (Government of Canada, 2022b). Canada's Greenhouse Gas Pollution Pricing Act, passed in 2018 was challenged in the courts but found constitutional by Supreme Court of Canada in 2021 (Government of Canada, 2022b). It has the potential to raise Canada's carbon price of CAD 40 per tonne of CO_2 to CAD 170 per tonne of CO_2 by 2030 (Global CCS Institute et al., 2021). The province of Alberta plans to invest CAD 750 million for emissions reduction through its Technology Innovation and Emissions Reduction (TIER) program of which CAD 80 million could be for CCS projects (Global CCS Institute et al., 2021), (Government of Alberta, 2022d).

A.1.2 Asia Pacific

A.1.2.1 Australia

The Australian government through its Technology Investment Roadmap allocated AUD 263.7 million in new funding to support CCS projects. In addition, the AUD 50 million CCS Development Fund allocated monies to six projects covering several heavy and primary industries (Australian Government, 2022), (Global CCS Institute et al., 2021). The Australian government also includes CCS as a greenhouse gas emissions reduction technology under the Emissions Reduction Fund whereby CCS projects can create Australian Carbon Credit Units (Australian Government and Clean Energy Regulator, 2021).

A.1.2.2 Indonesia

Indonesia has indicated that CCS is an emission reduction strategy that will assist the country with achieving net zero emissions by 2060 (Upstream Online and Amanda Battersby, 2022). Legislation is presently being drafted and the country is working on a carbon pricing scheme that will come into effect through a Presidential Decree (Global CCS Institute et al., 2021). This process can trigger Indonesia's Ministry of Energy and Natural Resources to draft CCS-specific regulations.

A.1.2.3 Malaysia

While Malaysia has begun developing a CCS-specific regulatory framework, it will be based upon the existing oil and gas regulatory regime (Azmi and Associates, Dhanya Laxmi Sivanantham and Alfred Tan Hsiong Vei, 2022), (Global CCS Institute et al., 2021).

A.1.2.4 China

The 14th Five-Year Plan that China released in 2021 includes the implementation of CCS demonstration projects (Columbia SIPA Center on Global Energy Policy et al., 2022), (Global CCS Institute et al., 2021). In 2021, the Ministry of Ecology and Environment (MEE), with several other ministries, indicated support for CCS technology and that it is essential for China to achieve carbon neutrality (Global CCS Institute, 2022a). CCS was also included in the China-US Joint Statement Addressing the Climate Crisis, issued in April 2021 (United States Department of State and Office of the Spokesperson, 2021). In 2021, the National Development and Reform Commission issued an action plan with support for CCS as a decarbonization technology for several sectors (National Development and Reform Commission and People's Republic of China, 2021).

A.1.2.5 Japan

Japan's federal government promotes cooperation with developing countries to reduce and remove greenhouse gas emissions through the Joint Crediting Mechanism (JCM). It has partnered with 17 countries around the world (Ministry of Foreign Affairs of Japan, 2020), (Global CCS Institute et al., 2021). In June 2021, Japan launched the Asia CCS Network to begin the development of CCS in Asia (Ministry of Economy Trade and Industry of Japan, 2021).

A.1.3 Europe

A.1.3.1 European Union

In 2021, the EU released its Fit for 55 legislative proposals which had modifications for the EU's emissions trading scheme (ETS) (Global CCS Institute et al., 2021). The EU's ETS covers 40% of the EU's emissions and the new legislative proposals simplify the accounting and compliance rules while enhancing monitoring (European Union and European Council, 2022).

A.1.3.2 Norway

The Norwegian government subsidises carbon capture and storage projects by supporting around 67% of the cost of projects like Langskip (Global CCS Institute et al., 2021; Norwegian Ministry of Petroleum and Energy, 2022). Langskip is a full-scale CCS project which includes the capture, transport, and storage of CO_2.

A.1.3.3 Denmark

The Danish government made an announcement in December 2021 that it had reached an agreement with several political parties to provide EUR 2.2 billion to the development of carbon capture, utilisation, and storage (CCS) projects (Global CCS Institute, 2022c). Earlier that month, the government announced funding of USD 41 million for two CCS projects in the Danish sector of the North Sea (Offshore Energy and Nermina Kulovic, 2021).

A.1.3.4 Germany

The federal government of Germany has made a binding statement to reduce greenhouse gases by 55% by 2030 with the Climate Action Programme 2030 and the Climate Change Act (The Federal Government of Germany and Press and Information Office of the Federal Government, 2022). The Climate Action Programme 2030 includes a price on carbon, which starts at EUR 25 in 2021 and rises to EUR 55 in 2025 (Federal Government of Germany and Press and Information Office of the Federal Government, 2022). To support the demonstration of CCS projects at scale, the German federal government agreed to provide funding through the CO_2 capture and utilisation in primary industry program[5] (Federal Ministry for Economic Affairs and Climate Protection, 2021; Global CCS Institute et al., 2021).

A.1.3.5 Sweden

Driven by the requirements of the Paris Agreement and the London Protocol, the government of Sweden announced an agreement with Norway to cooperate on CCS technology. The announcement mentioned the importance of CCS in reducing emissions from fossil fuels and as a complementary measure in bio-CCS, also known as bioenergy with carbon capture and storage (BECCS) (Government Offices of Sweden and Prime Minister's Office, 2022).

A.1.3.6 United Kingdom

The government of the UK has extensive guidance on the approach the UK is taking to CCS, its deployment as an emissions reduction technology, to innovation, and to international collaboration (Government of the United Kingdom and Department for Business, 2019). Presently, the UK government is testing the feasibility of CCS technology in decarbonization clusters with industrial partners (Government of the United Kingdom and Department for Business, 2018; Global CCS Institute et al., 2021).

[5] CO_2-Abscheidung und -Nutzung in der Grundstoffindustrie in German

A.2 Fiscal and commercial mechanisms for CCS – an international overview

There are several examples of incentives that have enabled technical demonstrations and trials, and commercial developments for CCS projects. Some examples of various incentivisation schemes and regimes are presented below. Jurisdictions have employed a combination of tax credits, grants, loans, and participation in trading systems to spur innovation and the deployment of capital to CCS. In addition, taxes have also been used by governments to motivate industry and to align policy and regulatory frameworks to meet the goals of the Paris Climate Agreement and the Glasgow Climate Pact.

A.2.1 Tax credits

A.2.1.1 United States

The US Federal Internal Revenue Code (Federal tax code section 45Q) provides a specific federal tax credit for geologically sequestered CO_2 (Global CCS Institute and Matt Bright, 2021; United States Congress and Congressional Research Service, 2021). A summary of the key elements of the tax credit is included in Figure 28, excerpted from the analysis conducted by the Congressional Research Service (CRS).

Having been first introduced in 2008 as part of the Energy Improvement and Extension Act, the 45Q tax credit was expanded ten years later when the Bipartisan Budget Act of 2018 and the Taxpayer Certainty and Disaster Tax Relief Act of 2020 were enacted(United States Congress and Congressional Research Service, 2021). Summarised here, they include:

- Increased tax credits (up to USD 50 per metric ton of geologically sequestered CO_2 by 2026).
- Allowing tax credits to be claimed for 12 years from the time the equipment begins service (previously claims would cease after 75 million tons of CO_2 were captured and stored).
- Expanding tax credits to utilisation of CO_2 (tax credit amount is different).
- Allowing facilities that capture less than 500,000 tons annually to also avail of the tax credit.
- Allowing owners of the capture equipment to claim the tax credits so long as they also ensure that the CO_2 is disposed, utilised, or used for injection.
- A deadline to begin construction by January 1, 2026.

Figure 28: Key elements of IRS Section 45Q tax credit excerpted from the analysis by the CRS.

Table I. Key Elements of the Section 45Q Credit

Equipment Placed in Service Before 2/9/2018	Equipment Placed in Service on 2/9/2018 or Later
Credit Amount (per Metric Ton of CO_2)*	
Geologically Sequestered CO_2	
$28.82 in 2020. Inflation-adjusted annually.	$31.77 in 2020. Increasing to $50 by 2026, then inflation-adjusted.
Geologically Sequestered CO_2 with EOR	
$11.91 in 2020. Inflation-adjusted annually.	$20.22 in 2020. Increasing to $35 by 2026, then inflation-adjusted.
Other Qualified Use of CO_2	
None	$20.22 in 2020. Increasing to $35 by 2026, then inflation-adjusted.
Claim Period	
Available until 75 million tons of CO_2 have been captured and sequestered.	12-year period once facility is placed in service.
Qualifying Facilities	
Capture at least 500,000 metric tons.	*Power plants:* capture at least 500,000 metric tons. *Facilities that emit no more than 500,000 metric tons per year:* capture at least 25,000 metric tons. *DAC and other caputre facilities:* capture at least 100,000 metric tons.
Eligibility to Claim Credit	
Person who captures and physically or contractually ensures the disposal, utilization, or use as a tertiary injectant of the CO_2.	Person who owns the capture equipment and physically or contractually ensures the disposal, utilization, or use as a tertiary injectant of the CO_2.

Source: CRS analysis of IRC Section 45Q.

After the passage and enactment of the Inflation Reduction Act in August 2022, the carbon capture provisions that provide incentives for CCS projects were significantly enhanced (Clean Air Task Force, 2022; United States Department of Energy and Department of Energy Office of Policy, 2022). The details are summarised below.

a. The new law now provides entities an option to receive the 45Q tax credit as a direct payment. This is like the entity receiving a tax credit for overpaid taxes. The durations are different depending on the type of entity.

    a. Five years for for-profit entities after initiation of the project.

    b. 12 years for tax-exempt entities.

b. Further increases in tax credits for geological storage of CO_2:

    a. To USD 85/ton from power generation and industrial facilities.

    b. To USD 180/ton from direct air capture (DAC) facilities.

c. Further increases in tax credits for utilisation of CO_2:

    a. To USD 60/ton from power generation and industrial facilities.

    b. To USD 130/ton from direct air capture (DAC) facilities.

d. More types of facilities can now qualify since the IRA reduced the annual CO_2 capture threshold to:

    a. 1,000 tons for DAC facilities.

    b. 12,500 tons for industrial facilities.

    c. 18,750 tons for power generation facilities (at least 75% of the CO_2 must be from a unit that generates electricity and has capture equipment installed).

e. Extends the deadline to begin construction by January 1, 2033.

f. Continue allowing tax credits to be claimed for twelve years from the time the equipment begins service.

The new law broadens the ability to transfer the 45Q tax credit. During the 12-year period mentioned above, the entity that originally receives the 45Q tax credit can transfer the entire amount or any portion of it to another tax-paying entity in exchange for a cash payment. Furthermore, this cash payment will not be taxed.

A.1.1.2 Canada

Canada's Federal Budget for 2022 released in April 2022 proposed an investment tax credit for CCS projects (Government of Canada and Department of Finance, 2022). Starting on January 1, 2022 (start of the year), the tax credit covers costs related to the equipment that is used in validated and verified projects that capture and store CO_2.

Eligible projects must have the following characteristics:

- A new CO_2 capture, use, or storage project, that if not commissioned would have resulted in CO_2 release.
- CO_2 must be captured in, and the equipment must be used in Canada (storage or utilisation can be outside Canada).
- CO_2 captured must be tracked and accounted.
- Usage includes geological and concrete storage.
- Subject to a determination by Environment and Climate Change Canada, geological storage qualifies for the tax credit in those jurisdictions that have sufficient regulatory oversight (Government of Canada, 2022c).
- Ineligible project components will reduce the tax credit.
- The tax credits for eligible projects incurring:
- Expenses between 2022 to 2030 are:
    - 60% for DAC projects.
    - 50% for capture equipment.
    - 37.5% for utilisation, storage, and transportation.
- Expenses between 2030 to 2040 are:
    - 30% for DAC projects.
    - 25% for capture equipment.
    - 18.75% for utilisation, storage, and transportation.

A.2.2 Carbon taxes

A.2.2.1 Canada – Federal level

In 2018, the Canadian federal government passed the Greenhouse Gas Pollution Pricing Act which went into effect in 2019 (Government of Canada and Department of Justice 2018b). After the Act's passage, every Canadian authority (Province or Territory) was required to establish a price on carbon or be subject to the federal carbon price. The Act is flexible, giving all jurisdictions the authority to set up its own pricing system that meets the federal standard. The Act comes into effect for those jurisdictions that either choose the federal system or choose to not price carbon (Government of Canada 2022c.)

The federal law has two parts, the first being the fuel charge which is a charge (or tax) on gasoline, natural gas, and other fossil fuels. The second is called the Output-Based Pricing System (OBPS) which is a performance-based system. Those facilities that emit more than 50,000 tonnes of CO_2-equivalent are required to register in the OBPS, which simultaneously sets the price for carbon and ensures that carbon leakage does not occur. The mechanism is like other trading systems whereby, each facility is assigned an emissions limit. Facilities can trade credits and those facilities emitting less than their limit generate credits, while those that emit more must either pay the carbon price or remit credits (Government of Canada 2021). This creates a secondary market for those credits.

To alleviate the cost of the carbon tax to individuals, Canada's federal government offers a climate action incentive payment (or a tax credit) for eligible individuals (Government of Canada 2022a.

A.2.2.2 British Columbia (CCS Framework)

The British Columbia (BC) Oil and Gas Commission has a framework to regulate CCS projects (BC Oil and Gas Commission 2021). The province is developing a pricing and offset protocol and ensuring that BC's Oil and Gas Activities Act applies to geological storage of CO_2 captured from all sectors, not only those pertaining to oil and gas operations (BC Oil and Gas Commission 2021; Government of British Columbia 2010; Government of British Columbia, Ministry of Energy Mines and Low Carbon Innovation, and Vida Ramin 2022). While BC administers a carbon tax, it also provides a climate action tax credit (Carbon Tax Center 2021; Government of Canada 2022d).

A.2.2.3 European Union & EEA-EFTA countries

As mentioned in section A.2.6.11 below, the EU Emissions Trading System (ETS) and its CCS Directive applies in all EU countries as well as in Norway, Iceland, and Liechtenstein (European Commission, 2015, 2022b, 2022a). Norway, Iceland, and Liechtenstein are part of the European Free Trade Association (EFTA) in the European Economic Area (EEA).

While there are carbon taxes in EU and EFTA member states (Denmark, Finland, France, Iceland, Latvia, Liechtenstein, Luxembourg, Norway, Poland, Portugal, Slovenia, Spain, and Sweden), these jurisdictions can also participate in the ETS while the European Commission works to implement the CCS Directive across the EU (European Commission, 2022c).

A summary of the scope of the carbon tax in each jurisdiction sorted by year of introduction is included in Table 46 (The World Bank, 2022).

Table 46: Scope of carbon taxes in the EU and in the EFTA.

Year	Country	Jurisdiction	Scope
1990	Finland	EU	Covers all fossil fuels except peat. Estimated 37% overlap of GHG emissions covered under EU ETS.
1990	Poland	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
1991	Norway	EEA EFTA	Covers liquid and gaseous fossil fuels. Estimated 43% overlap of GHG emissions covered under EU ETS. Emissions covered under EU ETS are exempt.
1991	Sweden	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
1992	Denmark	EU	Covers all fossil fuels. Due to lack of data, overlaps with the EU ETS are unavailable. Emissions covered under EU ETS are exempt.
1996	Slovenia	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
2004	Latvia	EU	Covers all fossil fuels and CO_2 emissions not covered by the EU ETS. Due to lack of data, overlaps with the EU ETS are unavailable. Emissions covered under EU ETS are exempt.
2008	Liechtenstein	EEA EFTA	Covers all fossil fuels and incorporated because of a bilateral treaty with Switzerland. Emissions covered under EU ETS are exempt.
2010	Iceland	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.
2014	France	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.
2014	Spain	EU	Applied to fluorinated GHG emissions only.
2015	Portugal	EU	Covers all fossil fuels. Emissions covered under EU ETS are exempt.
2021	Luxembourg	EU	Covers all fossil fuels and is complimentary to the EU ETS. Emissions covered under EU ETS are exempt.

A.2.3 Bonds

Debt financed through fixed-income securities is crucial component of global capital markets. Under the international capital market umbrella, the total size of the global debt market in 2020 was USD 123.5 trillion (Securities Industry and Financial Markets Association (SIFMA), 2021). It is larger than the global equity market, valued at nearly USD 106 trillion in 2020. There are many organisations that classify debt capital. There are various international organisations that provide services to categorise, standardise, or classify debt capital (International Council of Securities Associations (ICSA), 2022). In some cases, these associations also assist with regulating securities markets.

The International Capital Market Association is a debt securities association that helps promote market resiliency (International Capital Market Association (ICMA), 2022a). ICMA has developed voluntary frameworks or principles for two broad categories of bonds that are underpinned by financial guidance to support the energy transition considering climate change (International Capital Market Association (ICMA), 2021). Namely, they are:

1. Sustainability bonds.
    a. Green bonds;
    b. Social bonds.
2. Sustainability-linked bonds.

The frameworks for these types of bonds are supported by multilateral development banks like the World Bank's International Bank for Reconstruction and Development (IBRD, and the International Finance Corporation (IFC) and the Asian Development Bank (ADB) as well as by securities organisations like the Climate Bonds Initiative (Asian Development Bank (ADB), 2021b; Climate Bonds Initiative, 2022; International Finance Corporation (IFC) and World Bank Group, 2022).

Green bonds, social bonds, and sustainability bonds have four core components (International Capital Market Association (ICMA), 2021), which are namely:

1. Use of Proceeds;
2. Process for Project Evaluation and Selection;
3. Management of Proceeds;
4. Reporting.

This section will cover some of these bonds and if CCS projects can potentially be financed through these securities.

A.2.4 ICMA Green Bonds

Green bonds, defined and described by the International Capital Market Association (ICMA) in its Green Bond Principles (GBP), are debt security instruments whose proceeds are used to either finance or re-finance green projects, summarised above (International Capital Market Association (ICMA), 2022b). There are several types of Green Bonds, summarised in section A.2.4.2 below.

The activities relating to CCS projects can potentially fit under the pollution prevention and control category. However, the project's eligibility will be determined by comparing it against the GBP's core components, summarised in a matrix in Table 47.

A.2.4.1 ICMA Green Projects

Arranged alphabetically, green projects must fall under the following categories to be eligible. While this is a descriptive list, it is not exhaustive as green projects are not limited to this list alone.

1. Clean transportation.
2. Climate change adaptation.
3. Circular economy adapted products, production technologies and processes.
4. Energy efficiency.
5. Environmentally sustainable management of living natural resources and land use.
6. Green buildings.
7. Pollution prevention and control.
8. Renewable energy.
9. Sustainable water and wastewater management.
10. Terrestrial and aquatic biodiversity (conservation).

Table 47: GBP Core Components Matrix.

Green Bonds	
Core component	**Summary**
Use of Proceeds	GBP eligible green projects contribute to supporting environmental objectives like climate change mitigation, climate change adaptation, natural resource conservation, biodiversity, conservation, and pollution prevention and control.
Project Evaluation & Selection Process	Bond issuer should communicate the project's environmental sustainability objectives, the process used to determine how the projects fits under the green projects category, and processes for identifying and managing social and environmental risks.
Proceeds Management	Net proceeds must be tracked with a high level of transparency through a sub-account or a sub-portfolio.
Reporting	Issuers should keep records with a list of projects for which bond proceeds are used.

A.2.4.2 ICMA Green Bond Types

There are four types of green bonds, all of which must be aligned with the GBP and the proceeds must be used for green projects (International Capital Market Association (ICMA), 2022b). They are listed below:

1. Standard green use of proceeds bond: this type of bond is an unsecured debt instrument/obligation with full recourse to the issuer only.
2. Green revenue bond: credit exposure is only to the bond's cash flows with no recourse to the issuer.
3. Green project bond: the investor has direct exposure to project risk with or without recourse to the issuer.
4. Secured green bond: secured bond where the proceeds are used to finance either green projects that secure the bond or other green projects.

A.2.4.3 IBRD Green Bonds

The World Bank through the IBRD's Funding Program raises fixed-income funds from investors through its Green Bonds program. These bonds are used to find eligible projects in the IBRD's member countries (World Bank Group (WBG), 2022d, 2022b). The program was developed together with the Skandinaviska Enskilda Banken (SEB) to offer investors a triple-A rated fixed-income product that would meet the needs of financing projects that tackle climate change (Skandinaviska Enskilda Banken (SEB), 2022; World Bank Group (WBG), 2022b).

CCS projects could potentially qualify as mitigation projects. IBRD green bonds have specific criteria that need to be met so that funds can be allocated to eligible projects (World Bank Group (WBG), 2022b). They are summarised below:

1. **Project selection criteria:** projects are selected by environmental specialists through a process that has undergone independent verification by the Center for International Climate and Environmental Research at the University of Oslo (CICERO) (Center for International Climate and Environmental Research at the University of Oslo (CICERO), 2015).
2. **Use of Proceeds:** All eligible projects that are funded by the IBRD must be climate resilient and must promote the transition to a low-carbon economy. Some examples of eligible projects are:
    a. Mitigation projects:
        i. Solar and wind installations;
        ii. Funding new technologies that significantly reduce greenhouse gas (GHG) emissions;
        iii. Rehabilitating power plants and transmission facilities to reduce GHGs;
        iv. Transportation efficiency including fuel switching and mass transport;
        v. Waste management (which includes methane emissions) and constructing energy-efficient buildings;
        vi. Reforestation and limiting new deforestation.
    b. Adaptation Projects:
        i. Flooding protection which includes reforestation and watershed management;
        ii. Improving food security and implementing

stress-resilient agricultural systems that helps to reduce deforestation;

iii. Sustainable forest management and avoiding deforestation.

3. **Review and approval:** after projects are deemed to meet the program's eligibility criteria, they must undergo a rigorous review and approval process and meet the member country's development needs. A screening phase will look for potential environmental and/or social risks.
4. **Allocating funds:** The proceeds from green bonds are allocated to a separate cash account through which funds are disbursed over the project's timeframe.
5. **Reporting and monitoring:** The member country's government and the World Bank monitors the progress of the project. It is also supervised and requires the compilation of several reports over the timeframe.
6. **Compliance:** Each project is assessed and reviewed by the bank's experts and its outcomes are measured against the intended objectives.

A.2.4.4 IBRD Sustainable Development Bonds

The IBRD also maintains a sustainable development bonds program (International Bank for Reconstruction and Development, 2021). These bonds are aligned with the Sustainability Bond Guidelines (SBG). These bonds also have specific requirements, listed below. CCS projects could potentially qualify through green projects which are related to mitigation projects that qualify for IBRD green bonds.

1. **Use of Proceeds:** Funds must be used for green or social projects that are designed to improve social and environmental outcomes in member countries. Some examples of projects include:
   a. Social projects that deliver improvements in:

      i. Health, nutrition, childhood development;

      ii. Access to education, school conditions, learning outcomes, teacher training;

      iii. Food security;

      iv. Long term security financial, social, and legal security;

      v. Access to affordable financial products that deliver credit, savings, insurance, transactions, and payments services;

      vi. Affordable housing by reforming regulations and policy and by better access to finance;

      vii. Quality of jobs, skill-building, and in eliminating barriers to jobs for disadvantaged people;

      viii. Effectiveness of formal training (vocational and technical), in developing short-term skills, and in access to apprenticeship programs;

      ix. Providing financial, technical, and advisory support to countries transitioning from coal to cleaner sources of energy.

   b. Green projects that deliver improvements in:

      i. Agricultural infrastructure and support services while also increasing climate resiliency and market access for small farm holders, advancing climate-smart agriculture, and strengthening food value chains;

      ii. Holistic water management and service delivery, while building resilience;

      iii. Conserving biodiversity while addressing pollution and the degradation of natural resources;

      iv. Market access for minerals and metals from resource-rich developing countries, while minimising the climate and environmental footprint of mining operations;

      v. Disaster risk legislation and national planning;

      vi. Climate change mitigation through projects listed in section A.2.4.3 above.
2. **Evaluation and selection process:** To support sustainable development, the World Bank follows its Environmental and Social Framework. The framework has 10 environmental and social standards that must be met (mandatory requirements) by projects that win funding (World Bank Group (WBG), 2022a). Other mandatory requirements include compliance with the environmental and social policy for investment project financing (World Bank Group (WBG), 2019).
3. **Management of proceeds:** The IBRD follows a liquidity asset management investment policy to ensure that bond proceeds are disbursed when milestones are reached over the timeframe of the project.
4. **Reporting:** The World Bank publishes an annual impact report with details on projects financed over the previous financial year (World Bank Group (WBG), 2021).

A.2.4.5 IFC Green Bonds

While the IBRD lends to governments, the IFC lends to the private sector (International Finance Corporation (IFC) and World Bank Group (WBG), 2022a). The IFC's Green Bond Program is aligned with the ICMA's Green Bond Principles (GBP), see section A.2.4 above for details (International Finance Corporation (IFC) and World Bank Group (WBG), 2022c). The IFC's Green Bond Program's process (International Finance Corporation (IFC) and World Bank Group (WBG), 2022e) is summarised below:

1. **Use of Proceeds and Project Evaluation:** the IFC maintains a climate-related loan portfolio from which eligible project are selected. All projects must comply with the IFC's performance standards and the IFC's corporate governance framework (International Finance Corporation (IFC) and World Bank Group (WBG), 2022f, 2022b).
2. **Green bond project investments may include:**
    a. Cogeneration, reducing energy loss in transmission and distribution, waste heat recovery, and building insulation;
    b. Geothermal, solar, hydro, and wind;
    c. Reducing source impacts while enhancing conversion efficiency of energy, water, and raw materials to saleable outputs;
    d. Components used in renewable energy, cleaner production, energy efficiency, solar photovoltaics, manufacture of turbines, and building insulation materials;
    e. Sustainable forestry.
3. **Due Diligence:** All financed projects must go through a rigorous due diligence process, with responsibilities outlined in the IFC's Environmental and Social Performance Standards (International Finance Corporation (IFC) and World Bank Group (WBG), 2022d, 2022f).
4. **Management of Proceeds:** Bond proceeds are disbursed through a sub-portfolio over the course of the project's timeline.
5. **Reporting:** The IFC follows the principles set out in the ICMA's Green Bond Principles (International Capital Market Association (ICMA), 2022b).
6. **Monitoring:** The IFC supervises and monitors all projects/investments including those in the Green Bond program over the project's timeframe (International Finance Corporation (IFC) and World Bank Group (WBG), 2022g).
7. **Portfolio Management:** All projects are independently reviewed and consider environmental and social impacts.
8. **Evaluation:** The World Bank Group through its Independent Evaluation Group (IEG) evaluates about 25% of the projects, while measuring them against their original objectives (World Bank Group (WBG), 2022c).
9. **Accountability:** Any investigations at the project level are conducted by the Office of the Compliance Advisor/Ombudsman (CAO). The intention is to enhance the project's outcomes; however, the CAO also addresses complaints.

A.2.4.6 ADB Green Bonds

The ADB's green bonds are used for investments in projects that contribute to climate change mitigation and adaptation. The categories are summarised below:

1. **Climate change mitigation:** These projects target reductions in or the sequestration of GHGs from the atmosphere. GHG emission levels are measured against the business-as-usual case.
    a. Renewable energy.
    b. Energy efficiency.
    c. Sustainable transport.
2. **Climate change adaptation:** These projects target reductions in the vulnerability of human and/or natural systems to climate change while improving resiliency and adaptation.
    a. Energy infrastructure resilience.
    b. Water supply and other urban infrastructure and services.
    c. Sustainable transport.
    d. Agriculture.

A.2.4.7 ADB Bond Framework

All projects that receive funding must comply with the Green and Blue Bond Framework. The areas of compliance are like the World Bank's offerings and are in alignment with the ICMA's Principles.

1. **Principles:** the ADB's green and blue bonds are in alignment with the ICMA's Green Bond Principles (Asian Development Bank (ADB), 2021a; International Capital Market Association (ICMA), 2022b).

2. **Project eligibility:** eligible project categories are listed in section A.2.4.6 above.
3. **Process for project evaluation and selection:** all projects are selected in alignment with the ADB's Safeguards Policy Statement (SPS) (Asian Development Bank (ADB), 2009). The SPS aims to achieve sustainable project outcomes.
4. **Allocation of proceeds:** bond proceeds are allocation to sub-portfolios from which they are disbursed to the project.
5. **Monitoring and reporting:** the ADB monitor all projects over their timeframes including measuring effectiveness against ESG aspects.
6. **Ensuring compliance:** borrowers must take corrective action if compliance issues arise during the project's timeframe.
7. **External review/second party opinion:** the ADB's framework has been reviewed by CICERO, like the IBRD's offering (Center for International Climate and Environmental Research at the University of Oslo (CICERO), 2015; Asian Development Bank (ADB), 2021a).

A.2.5 Grants

A.2.5.1 Alberta, Canada

The Province of Alberta's Technology Innovation and Emissions Reduction (TIER) Regulation is a Provincial pricing regulation for GHGs. The regulation covers about 60% of the emissions within the province. TIER regulated facilities must keep emissions below a benchmark value and functioning like other trading systems, facilities generate performance credits if emissions are below the benchmark (Government of Alberta, 2022d). If emissions are above the benchmark, facilities comply through generating Alberta Emissions Offsets, submitting emissions performance credits or buying TIER fund credits, priced at CAD 40 in 2021 and at CA$ 50 in 2022 (Alberta Environment and Parks, 2021; Government of Alberta, 2022a).

Revenue from the purchase of TIER credits (see section A.2.5.6 below) provides the funding for the CAD 750 million TIER fund (Government of Alberta, 2022c). The Industrial Energy Efficiency and Carbon Capture Utilisation and Storage (IEE CCS) grant program is a part of the TIER fund and is supported by CAD 131 million in funding. As of November 2021, seven projects have been funded with CAD 31 million remaining in the IEE CCS grant program.

A.2.5.2 Denmark

The Danish government made an announcement in December 2021 that it had reached an agreement with several political parties to provide EUR 2.2 billion to the development of carbon capture, utilisation, and storage (CCS) projects (Global CCS Institute, 2022c). Earlier that month, the government announced funding of USD 41 million for two CCS projects in the Danish sector of the North Sea (Offshore Energy and Nermina Kulovic, 2021).

A USD 30 million grant has been awarded to INEOS for the Greensand CCS project in the Danish sector of the North Sea. Greensand has the potential to store up to 8 million tonnes of CO_2 annually by 2030. The rest of the funding (DKK 75 million) is for a second smaller project called Bifrost led by TotalEnergie has the capacity to store 3 million tonnes of CO_2 annually by 2027 (Reuters, 2021).

A.2.5.3 Norway

The Norwegian government subsidises carbon capture and storage projects by supporting around 67% of the capital cost of projects like Langskip (Global CCS Institute et al., 2021; Norwegian Ministry of Petroleum and Energy, 2022). Langskip is a full-scale CCS project which includes the capture, transport, and storage of CO_2. Northern Lights is a component of Langskip that is open to third parties (Northern Lights, 2022).

The Norwegian government has contributed NOK 10.4 billion to Northern Lights. Together with Norcem and Fortum Oslo Varme, the Norwegian Government has contributed NOK 16.8 billion or USD 1.69 billion (June 23, 2022, exchange rates) (Norwegian Ministry of Petroleum and Energy, 2020a).

A.2.5.4 United States (DOE Programs)

The passing of the bipartisan Infrastructure, Investment, and Jobs Act (a US Federal legislation) in 2021 provided the US Department of Energy (DOE) over USD 62 billion in funding for investments in new technologies, energy efficiency, power, and manufacturing (United States Department of Energy, 2021b).

The bill authorises USD 21.5 billion of this funding to be used for research hubs and clean energy demonstrations. Almost half of this amount, more than USD 10 billion is earmarked for industrial emissions reduction, carbon capture and DAC (United States Department of Energy,

2021b). The DOE refers to this area of infrastructure development as carbon management, renaming the Office of Fossil Energy as the Office of Fossil Energy and Carbon Management, or FECM (Office of Fossil Energy and Carbon Management and Department of Energy, 2021).

A breakdown of the funding available for CCS related technological development is listed in Table 48 (Kelly Johnson et al., 2021; United States Department of Energy and Office of Fossil Energy and Carbon Management, 2021). The funding is disbursed through a combination of grants, loans, and cooperative agreements. In addition, the DOE's Office of Clean Energy Demonstrations (OCED) has also been allocated USD 8 billion for hydrogen hub development. The DOE also plans to assist states with their efforts to accelerate the development of CCS projects by making USD 20 million in funding available to four projects (United States Department of Energy, 2021a).

Table 48: DOE Funding from the Infrastructure, Investment, and Jobs Act.

Program	Funding, USD	Fiscal Years
Direct air capture (DAC)	3.5 billion	2022 – 2026
DAC Technology Prize Competition	115 million	2022
Carbon Capture Technology Program (CCS FEED[6])	100 million	2022 – 2026
Carbon Storage Validation and Testing (for large scale commercial carbon sequestration projects)	2.5 billion	2022 – 2026
Carbon Utilisation Program (for lowering GHG emissions through CO_2 utilisation)	310 million	2022 – 2026
Carbon Capture Demonstrations and large pilots through the OCED	3.5 billion	Not specified
CO_2 Transportation Infrastructure Finance and Innovation Program through the DOE's Loan Program Office and FECM	2.1 billion	Not specified

1.1.1 Regulations

While few jurisdictions around the world permit and regulate CCS projects, those that do have some similarities in their characteristics. The regulatory requirements that cover CCS projects typically govern the pre-site evaluation of the storage well, injection operations, testing and monitoring, and site closure. Pore space rights are also regulated but are part of a different regulatory regime. Some examples of regulatory regimes are provided below.

[6] Front-End Engineering and Design.

A.2.5.5 Alberta, Canada

The government of Alberta plans to issue rights to sequester or store CO_2. The rights to inject and store CO_2 (not for EOR) will be issued and managed through a tenure management process (Government of Alberta, 2022b).

For the transportation of CO_2, new pipelines that require 75 km or more in right-of-way could also be subject to a federal environmental impact assessment under the Impact Assessment Act (Government of Canada, 2022e). Regulations in each province regulate pipelines within provincial borders along with associated agencies that provide oversight. In Alberta, pipelines that are within the provincial borders are regulated by the Alberta Pipeline Regulation with the Alberta Energy Regulator as the regulating authority (Government of Alberta, 2021b; Alberta Energy Regulator, 2022). The legal authority is provided by the Alberta Pipeline Act (Government of Alberta, 2021a). Provincial rules in all Canadian provinces are also complemented by standards set by the Canadian Standards Association (CSA). Canadian CO_2 pipelines are built to CSA design standard Z662.

Alberta's Regulatory Framework Assessment is comprehensive, covering all aspects of the CCS project by phase. Before injection: the transportation of CO_2 by pipeline; the site selection; pore space tenure; permitting of the well and its classification. During construction: the pre-injection monitoring, measurement, and verification (MMV) and the drilling, installation, and testing of the well. During the injection: MMV and reporting. There are additional requirements that need to be met during the closure and post-closure periods (Government of Alberta, 2013a).

A.2.5.6 Alberta (CCS Regulations)

CCS projects are supported in Alberta through several acts and regulations and the province also assessed its regulatory framework with CCS experts between 2011 and 2013 (Government of Alberta 2013a, 2013b, 2016, 2020, 2021). To develop carbon storage hubs, Alberta plans to conduct a competitive process to issue rights to developers for storing carbon without associated oil and gas production or recovery (known as tenure) (Government of Alberta 2022b). Alberta does not administer a provincial carbon tax, having repealed it in 2019 (Government of Alberta 2019). Alberta instead regulates industrial emitters through the Technology, Innovation, and Emissions Reduction Regulation (TIER) (Government of Alberta 2022c. TIER covers about 60% of Alberta's emissions and is a GHG emissions pricing and trading system.

A.2.5.7 Saskatchewan (CCS Priorities)

While the province of Saskatchewan does not apply its own carbon tax, emitters within the province are subject to the OBPS (Government of Saskatchewan, 2018b). The province envisions an emissions reduction of 10% by 2030 by implementing Prairie Resilience, its climate change strategy (Government of Saskatchewan, 2018a).

Saskatchewan outlined its priorities for CCS development that include amending and clarifying regulations, evaluating the royalty regimes, and seeking federal funding for CCS opportunities (Government of Saskatchewan, 2021).

A.2.5.8 Norway

In Norway, storage of CO_2 is permitted on the continental shelf. Norway also has a comprehensive regulatory framework that covers site surveying, exploration licensing and permitting, licensing a subsea reservoir to inject and store CO_2, transporting, injecting, and storing the CO_2 (Norwegian Petroleum Directorate and Ministry of Petroleum and Energy, 2014). There are additional requirements after CO_2 injection and storage has ceased with liabilities for any damages caused by pollution. There are also special provisions for safety overall and compensation to Norwegian fishermen.

The Norwegian regulations have detailed requirements for the collection of data, establishing a geological model, characterising storage capabilities, and monitoring. The Langskip project in the Norwegian North Sea complies with this regulation (Norwegian Ministry of Petroleum and Energy 2022).

A.2.5.9 United Kingdom

Like Norway, the UK also allows for the storage of CO_2 offshore. Originally authorised by the Energy Act of 2008, the UK licensing authority for offshore CO_2 storage was transferred to the Oil and Gas Authority in 2016 (UK Government, 2022). Now known as the North Sea Transition, it is authorised by the Energy Act of 2016 to have jurisdiction over CO_2 storage. The regulation covers licensing of geological storage and the recent CO_2 appraisal and storage licensing round closed in May 2022. The awarding of licences is based on technical capability, corporate governance, legal fitness, and financial fitness viability and capability (North Sea Transition Authority, 2022).

A.2.5.10 United States

In the US, underground sources of drinking water (USDWs) are required to be protected from underground injection. Known as underground injection control (UIC), these activities are regulated by a US federal agency, the US Environmental Protection Agency (EPA) (United States Environmental Protection Agency, 2022c). Underground injection ranging from industrial and municipal waste, oil and gas related injection, solution mining, shallow hazardous and radioactive waste, non-hazardous fluids and finally CO_2 is done through wells of different class permits.

CO_2 is injected in Class VI wells. The EPA defines CO_2 injection as long-term underground storage or geological sequestration. The regulations are extensive and cover siting of the location, well construction, operations, testing before injection begins, monitoring after and during injection, and finally site closure (United States Environmental Protection Agency, 2022a). Out of a total of 18 Class VI well permit applications submitted to the EPA, two are active, one has been withdrawn and 15 are pending (United States Environmental Protection Agency, 2022b).

Regulations governing the right of ownership of the subsurface pore space where the CO_2 will be stored is governed by a fragmented regulatory regime in the US. Differing by state, pore space rights are owned by the owner of the surface rights, or the owner of the mineral rights, or is undecided (Global CCS Institute, 2022b).

The transportation of CO_2 through pipelines is regulated by the Pipeline and Hazardous Materials Safety Division (PHMSA) (United States Department of Transportation, 2022). CO_2 pipelines are regulated through a mix of federal and state regulations. The federal government's regulation from the Code of Federal Regulations (CFR), Title 49 Part 195 is broad in scope covering the compliance, general inspection, repair, material inspection, transportation of pipe, welding, pipeline location, installation, valving, associated equipment (pumping), protection and record keeping (National Archives and Records Administration and United States Government Publishing Office, 2022). However, the state and state agencies are typically responsible for right of way, inspection and enforcement of pipeline safety are conducted by state agencies that adhere to rules and regulations that are built on the federal CFR's requirements. State agencies manage this through state programs and partnerships developed by the PHMSA (Pipeline and Hazardous Materials Safety Administration and United States Department of Transportation, 2022; Pipeline and Hazardous Materials Safety Division and United States Department of Transportation, 2022).

A.2.6 International carbon trading mechanisms

There are several examples of incentives that have enabled technical demonstrations and trials, and commercial developments for CCS projects. Some examples of compliance and voluntary carbon trading systems are presented below. Jurisdictions have employed them in combination with tax credits, grants, or loans, to spur innovation and to deploy capital to CCS projects. In addition, taxes have also been used by governments to motivate industry and to align policy and regulatory frameworks to meet the goals of the Paris Climate Agreement and the Glasgow Climate Pact.

There are several cap-and-trade systems that are functioning globally. This section will cover those in the European Union, California, Quebec, Washington state, and Tokyo. While Tokyo's and Quebec's cap-and-trade systems do not have specific CCS protocols, they are covered in this section for information and because there are CCS projects in their national jurisdictions. It is worth noting, that the European Union and California also did not have CCS protocols when their respective cap-and-trade systems were first initiated.

A.2.6.11 European Union (2005, CCS in 2015)

The EU's ETS is the main driver for investments in CCS projects since 2015 (European Environmental Agency, 2015). The EU's legal framework states that the ETS considers captured CO_2 that has been geologically stored (or safely stored) to be "not emitted." Environmental impact assessments and storage permits are required, in addition to stringent requirements for site selection according to the CCS Directive (European Parliament and European Council, 2009; European Commission, 2022a). The directive also requires verifying that the emission stream is mostly comprised of CO_2. Financial security of the operator is also needed before injection of CO_2 can commence (European Commission, 2022a).

Known as the European Union Emissions Trading System, the EU ETS is the world's first carbon market system. It is also the world's largest carbon market with jurisdiction over all 27 EU member states and Norway, Iceland, and

Liechtenstein (European Commission, 2022b). The EU requires mandatory participation for companies that operate in energy intensive sectors and especially those that generate GHG emissions as part of their operations. The ETS cap and trade works by setting a cap on the total GHGs that can be emitted by all the entities under its jurisdiction. The cap is dynamically reduced over time to reduce annual emissions over time. Entities can trade allowances within the ETS that are allocated through auction sales or allocated for free. The free allocation of allowances is meant to address high-risk sectors and those sectors that are deemed to be at risk for carbon leakage. Some examples of high-risk sectors include refining, mining, manufacturing, and petrochemicals to name a few (EUR-Lex Access to European Union law and Official Journal of the European Union, 2019). Free allocation of allowances is also used as a policy tool to incentivise the modernisation of the EU's energy sector through investments in clean technologies, diversifying energy sources, upgrading existing infrastructure, and modernising energy production and transmission (European Commission, 2021b).

A.2.6.12 California (2013, CCS in 2018)

The US state of California's cap and trade program began in 2013, with the initial cap being set at 2% below the forecast of 2012's total emissions (State of California, California Environmental Protection Agency and California Air Resources Board, 2015). Currently in its 10th year, the cap-and-trade program has become an important strategic element in the state's plan to reduce emissions from greenhouse gases. The program's yearly permissible emissions levels (or the cap) are set with a dynamically declining profile and adapt to the state's emissions levels. The cap declined by 2% in 2014 and by an annual 3% decline for each year between 2015 and 2020.

The program is broad and covers 80% of the state of California's emissions (State of California and California Air Resources Board, 2022). It is administered by the California Air Resources Board (CARB), an agency within the California Environmental Protection Agency. After the cap has been set, CARB creates allowances equal to the cap. Each allowance is equal to one metric ton of CO_2-equivalent emissions . Since the cap declines every year, the number of available allowances also declines yearly. CARB provides an economic incentive to businesses by making allowances available for purchase in an auction. Each year the total number of allowances decreases while the allowance floor price is increased.

CARB also administers a Compliance Offset Program that permits entities to meet a small percentage of their obligations; 8% until 2020, 4% from 2021 to 2025, and 6% from 2026 to 2030. Offset credits require additional scrutiny and are only offered to projects that qualify to reduce or sequester GHGs in accordance with board-approved compliance offset protocols. The offset credits can be traded since they represent reductions in GHG emissions, GHG removals or enhancements that are verified. Offset credits provide approved entities with flexibility to comply, limit their cost outlays while also providing environmental benefits.

California has a Low Carbon Fuel Standard (LCFS) that encourages the usage of transportation fuels with a lower carbon intensity over time. The LCFS standard requires expressing the carbon intensity (or CI) of a fuel which is a representation of the fuel's life-cycle emissions. This includes fuel production, transportation, and combustion (usage). Each fuel score is referenced to an annually declining benchmark. Lower CI fuels generate credits while higher CI fuels generate deficits (California Air Resources Board, 2011). California also has a CCS Protocol under its Low Carbon Fuel Standard (LCFS) that pertains specifically to new or existing CCS projects that are captured and stored in onshore California. CO_2 can be stored in either saline reservoirs or in depleted oil or gas reservoirs for enhanced oil recovery (EOR) projects (California Air Resources Board, 2018).

A.2.6.13 Washington state (2023, CCS in advisory panel)

The state of Washington passed the Climate Commitment Act in May 2021 (Climate Xchange and Zac Pinard, 2021) The provisions of the Act require the state's Department of Ecology to develop rules to institute a cap on carbon-based emissions (State of Washington and Department of Ecology, 2022a). Currently (May 2022), the state is entering the public comments period (State of Washington and Department of Ecology, 2022b). Rules require that the department create a cap and invest program that begins on January 1, 2023, with jurisdiction over entities that emit greater than 25,000 metric tons of GHGs annually. Typical entities would include natural gas distributors, industrial facilities, electricity generators, large fuel suppliers, waste-to-energy providers/entities (by January 1, 2027) and large landfills and railroad companies (by January 1, 2031).

In its rulemaking timeline, the state has convened an Agriculture and Forestry Carbon Capture & Sequestration Advisory Panel (Department of Ecology and State of Washington, 2022). Washington State joined the Western Climate Initiative, a large North American carbon market in 2021 in advance of its cap and invest program going live in 2023 (Western Climate Initiative Inc., 2022b).

The state also elaborates greenhouse gas limits in regulation RCW 70A.45.020 (Washington State Legislature, 2020). The state's regulation requires reducing GHG emissions, to 1990 levels by 2020, to 45% below 1990 levels by 2030, to 75% below 1990 levels by 2040 and finally to 95% below 1990 levels by 2050. The program is like California in that entities will be required to reduce emissions or obtain allowances for those emissions that are not reduced. The law also requires that the total number of allowances (or the cap) reduce over time. Washington state's program also includes offsets. A small number of obligations can be met with offset credits that are generated by projects that prevent GHG emissions; 5% until 2026 and 4% from 2027 to 2030 (for most projects). There are additional offset credits for projects on tribal lands. Offset projects require additional verification and scrutiny, they must result in "real, permanent, quantifiable, verifiable, and enforceable" GHG emissions reductions (State of Washington and Department of Ecology, 2022a).

Washington state has a clean fuel standard, which came into law in 2023. Like California's LCFS, it will require fuel suppliers to reduce the carbon intensity of transportation fuels to 20% below their 2017 levels. The requirement has a timeframe until 2038. Suppliers can accomplish this through efficiency improvements, blending with low-carbon biofuels, and/or purchasing credits that were generated by low-carbon fuel or electric charging providers.

A.2.6.14 Tokyo (2010, no CCS protocol)

Tokyo's cap-and-trade system does not have a specific CCS protocol; however, it is the world's first urban cap-and-trade system (United Nations, 2010). Japan does support CCS projects with the Tomakomai CCS Demonstration Project having successfully demonstrated CO_2 capture and storage between 2016 to 2019 (International Energy Agency, 2019). Tokyo's mandatory cap-and-trade program began in the second quarter of 2010, now with over a decade of being in force it is Japan's first emissions trading scheme (Bureau of Environment and Tokyo Metropolitan Government, 2022). Proposed in 2007 and legislated in 2008, the scheme requires large emitters to contribute to emissions reductions through the setting of mandatory targets.

The scheme is designed for Tokyo's urban environment and is flexible to cover buildings in addition to factories. It allows facilities with emissions reduction gains to trade with those that have deficiencies during the five-year compliance period (Bureau of Environment and Tokyo Metropolitan Government, 2020). Those facilities that consume at least 1,500 kL[8] of crude oil equivalent (COE) of fuel, heat, or electricity annually are required to report their emissions, while those that consume the same amount for three consecutive fiscal years fall under the scheme's compliance protocol. However, facilities owned by small and medium enterprises (SMEs) are exempt from compliance but are required to report. With the goal of promoting the reduction of CO_2, the scheme encourages using a combination of energy efficiency and renewable energy (Bureau of Environment and Tokyo Metropolitan Government, 2020). During the first two five-year compliance periods (2010-2020), the goal was to reduce energy consumption through energy efficiency gains, while in the current period, the scheme encourages expanding the utilisation of renewable energy. The required emissions reductions or compliance factors for office buildings with respect to the base year were set at 8%, 17%, and 27% respectively for the first (2010-2014), second (2015-2019), and third (2020-2024) compliance periods. The compliance factors for factories are 2% less than these values (Bureau of Environment and Tokyo Metropolitan Government, 2015). Emissions are measured in tons of CO_2-equivalent per year.

While there is not a specific protocol that incentivises investments in CCS projects, the cap-and-trade system has mechanisms in place for the use of credits. Emissions trading participants use the Tokyo Cap-and-Trade Registry System. Facilitates that generate emissions reductions more than the mandatory amount can trade them. However, emissions reductions less than the mandatory amount (base year emissions × compliance factor) are excluded. Renewable energy certificates (credits) can be obtained for the use of solar, wind, geothermal, hydro, or biomass. Credits that account for up to one third of the mandatory reductions can be obtained by facilities outside of Tokyo (but within Japan), so long as Tokyo standards apply. A separate credit feature for emissions reductions generated in Saitama prefecture is also available to trading participants so long the Tokyo Government's compliance goals have been achieved (Bureau of Environment and Tokyo Metropolitan Government, 2015, 2020).

[8] Kiloliters.

A.2.6.15 Quebec, Canada (2013, no CCS protocol)

The province of Quebec set up a cap-and-trade system in 2013 and joined the Western Climate Initiative (WCI) which also includes the Canadian province of Nova Scotia and the US states of California and Washington (Gouvernement du Québec and Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2022a; Western Climate Initiative Inc., 2022a). The WCI is North America's largest carbon market. Industrial facilities, electricity importers and producers, importers that emit at least 25,000 metric tons of CO_2-equivalent and fossil fuel distributors are required to participate (Gouvernement du Québec and Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2022d). This mandatory participation covers about 80% of Quebec's GHG emissions.

Since 2019, voluntary registration, also known as an opt-in has been available to emitters that emit between 10,000 and 25,000 metric tons of CO_2-equivalent (Gouvernement du Québec and Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2022e). Individual investors can also participate.

The carbon market in Quebec bears many similarities to those in California and Washington state. Registered emitters and other entities can buy allowances per ton of emitted GHGs, sold to them through quarterly government auctions. The provincial government sets the annual cap and lowers it progressively to achieve its desired effect of lowering provincial GHG emission levels. Quebec also tackles carbon leakage by allocating free allowances to large emitters (with national and international exposure) but reduces the free allowances each year requiring them to purchase the balance. The allocation of free allowances formally registers the emissions in Quebec. Surplus allowances can be traded in the carbon market to emitters can need them.

Quebec's carbon market also makes use of offset credits. It falls under the broader voluntary market (or opt-in) and covers those sectors not formally covered by the cap-and-trade system. GHG emission reduction projects fall under this scheme with each offset credit equivalent to one ton of otherwise emitted GHGs (Gouvernement du Québec and Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2022b). The Government is in a public consultation until June 18, 2022, to amend the regulation with provisions to accelerate investments (Gouvernementdu Québec and Ministère de l'Environnement et de la Lutte contre les changements climatiques 2022c.)

In 2016, Quebec announced a partnership with the province of Saskatchewan to develop research and technology for CCS given Saskatchewan's expertise (Province of Saskatchewan 2016).

APPENDIX B
EGYPT EMISSIONS SOURCES

Industrial emissions have been sourced from the following sources in Table 49

Table 49: Data sources for industrial emissions.

Sector	Source	Year
Power Generation	WRI	2022
Iron and Steel	Global Steel Plant Tracker	2022
Cement and Concrete	Spatial Finance Initiative Global Cement	2021
Chemical and Petrochemical	GlobalData	2022
Refinery	GlobalData	2022
Natural Gas Processing	GlobalData	2022
LNG	GlobalData	2022

Based on the capacity/production rates of each facility, estimates for the emissions sources and rates have been generated based on analysis . The methodology to estimate emissions sources and flowrates uses GCCSI internally derived models or industrial facility retrofit studies, including:

- Global Capture Plants: IEAGHG 2011-02 retrofitting CO_2 capture to existing power plants
- Refinery: IEAGHG 2017-TR8 Understanding the Cost of Retrofitting CO_2 Capture in an Integrated Oil Refinery Natural Gas and LNG
- Cement: IEAGHG 2008:3 CO_2 Capture in the Cement Industry, 2008
- Steel: IEAGHG 2013-TR4 Iron and Steel in the CCS Industry
- Petrochemical:
  - IEAGHG 2017a, 2017-03 Techno-Economic Evaluation of Hyco Plant Integrated to Ammonia / Urea or Methanol Production with CCS, Cheltenham, United Kingdom.
  - IEAGHG 2017b, Techno - Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS.

Table 50: Industrial facilties and emissions considered in the Egypt CCS hub design. Depending on the accuracy of the database used this may not be an exhaustive list of industrial facilities for Egypt.

Facility ID (for maps)	Plant Name	Plant Type	Operator	Total CO_2 Emissions (Mtpa)	Weighted Average CO_2 Partial Pressure (kPa abs)
1	Mostorod I	Refinery	Cairo Oil Refining Co	0.51	7.9
2	El Suez I	Refinery	El-Nasr Petroleum Refining Co	0.62	7.9
3	El Mex	Refinery	Alexandria Petroleum Co	0.46	7.94
4	Alexandria	Refinery	Middle East Oil Refinery	2.20	15.95
5	Mostorod II	Refinery	Egyptian Projects Operation and Maintenance	0.95	15.2
6	Assiut I	Refinery	Assiut Oil Refinery Co	0.36	7.94
7	Amreya	Refinery	Amerya Petroleum Refining Co	0.31	7.94
8	El Suez II	Refinery	Suez Oil Processing Co	0.75	11.8
9	Tanta	Refinery	Cairo Oil Refining Co	0.09	7.94
10	Wadi Feiran	Refinery	El-Nasr Petroleum Refining Co	0.02	7.94
11	Soukhna	Refinery	Soukhna Refinery and Petrochemicals Co	0.61	7.9
12	Suez I	Refinery	Egyptian Petrochemicals Holding Co	0.63	7.9
13	Assiut II	Refinery	Assiut National Oil Processing Co	0.65	15.95
14	El Alamein	Refinery	Egyptian Petrochemicals Holding Co	0.20	7.89
15	Suez II	Refinery	Red Sea National Co	0.32	7.9
16	MISR Fertilizer Production Company Damietta Complex	Fertilizer	MISR Fertilizer Production Co SAE	3.57	117.9
17	Egyptian Fertilizers Company Ain Sukhna Complex	Fertilizer	Egyptian Fertilizers Co	2.44	117.9
18	Abu Qir Fertilizers and Chemical Industries Alexandria Complex	Fertilizer	Abu Qir Fertilizers and Chemical Industries Co	5.31	117.91
19	El Delta Company for Fertilizers & Chemical Industries Talkha Complex	Fertilizer	El Delta Co. for Fertilizers & Chemical Industries	1.82	117.5
20	Helwan Fertilizers Company El Tabbin Complex	Fertilizer	Helwan Fertilizers Co	1.19	117.9
21	Alexandria Fertilizers Company Alexandria Complex	Fertilizer	Alexandria Fertilizers Co	1.17	117.91
22	Egyptian Ethylene & Derivatives Company Alexandria Complex	Petrochemical	Egyptian Ethylene & Derivatives Co	0.49	8.60
23	Egyptian Propylene and Polypropylene Company Port Said Complex	Petrochemical	Egyptian Propylene and Polypropylene Co	0.33	8.60
24	Egypt Basic Industries Corporation Ain Sukhna Complex	Fertilizer	Egypt Basic Industries Corp	3.12	117.91
25	Sidi Kerir Petrochemicals Amiriya Complex	Petrochemical	Sidi Kerir Petrochemicals Co	0.68	8.60
26	Egyptian Chemical Industries Aswan Complex	Petrochemical	Egyptian Chemical Industries SAE	1.81	117.91
27	Oriental Petrochemicals Company Suez Complex	Petrochemical	Oriental Petrochemicals Co	0.41	8.60

Facility ID (for maps)	Plant Name	Plant Type	Operator	Total CO_2 Emissions (Mtpa)	Weighted Average CO_2 Partial Pressure (kPa abs)
28	El Nasr Fertilizers and Chemical Industries Company Suez Complex	Fertilizer	El Nasr Fertilizers and Chemical Industries Company	2.38	117.9
29	Anchor Benitoite Suez Complex	Petrochemical	Anchorage Investments Ltd	0.59	8.60
30	Tahrir Petrochemicals Company Ain Sokhna Complex	Petrochemical	Multiple	4.48	52.98
31	Alexandria National Refining and Petrochemicals Company Alexandria Complex	Petrochemical	Alexandria National Refining and Petrochemicals Co	1.34	117.91
32	El Nasr Company For Intermediate Chemicals Ain Sokhna Complex	Petrochemical	El Nasr Company For Intermediate Chemicals	1.56	117.91
33	Damietta	LNG	Spanish Egyptian Gas Co SAE	0.95	1,945.3
34	Egyptian Train I	LNG	The Egyptian Operating Company for Natural Gas Liquefaction Projects SAE	0.62	1,945.32
35	Egyptian Train II	LNG	The Egyptian Operating Company for Natural Gas Liquefaction Projects SAE	0.62	1,945.32
36	Arabian Cement Company SAE	Cement	Arabian Cement Company SAE	6.88	20.6
37	Sinai White Portland Cement Co	Cement	Sinai White Portland Cement Co	0.56	20.60
38	Assiut Cement Co SAE	Cement	Assiut Cement Co SAE	6.54	20.60
39	El Nahda Cement	Cement	El Nahda Cement	2.06	20.60
40	Helwan Cement Co SAE	Cement	Helwan Cement Co SAE	4.97	20.6
41	Suez Cement Company SAE (2)	Cement	Suez Cement Company SAE (2)	5.78	20.6
42	Egyptian Tourah Portland Cement Co SAE	Cement	Egyptian Tourah Portland Cement Co SAE	6.36	20.6
43	Ameriyah Cement Co SAE	Cement	Ameriyah Cement Co SAE	6.88	20.60
44	Lafarge Cement Co Egypt SAE	Cement	Lafarge Cement Co Egypt SAE	14.58	20.6
45	Misr Beni Suef Cement Co SAE	Cement	Misr Beni Suef Cement Co SAE	3.85	20.6
46	Misr Cement Company SAE	Cement	Misr Cement Company SAE	2.75	20.6
47	MISR Engineering Development Co SAE	Cement	MISR Engineering Development Co SAE	2.57	20.60
48	Royal El Minya Cement	Cement	Royal El Minya Cement	0.62	20.6
49	Sinai Cement Co SAE	Cement	Sinai Cement Co SAE	5.23	20.60
50	South Valley Cement Co SAE	Cement	South Valley Cement Co SAE	2.06	20.6
51	Alexandria Portland Cement Co SAE	Cement	Alexandria Portland Cement Co SAE	1.80	20.60
52	Wadi El Nile Cement Co	Cement	Wadi El Nile Cement Co	2.48	20.6
53	Egyptian American Steel Rolling Company Sadat City plant	Steel	Egyptian American Steel Rolling Co	1.08	19.19
54	Egyptian Iron & Steel Company Cairo plant	Steel	Egyptian Iron & Steel Company SAE	4.62	13.1

Facility ID (for maps)	Plant Name	Plant Type	Operator	Total CO_2 Emissions (Mtpa)	Weighted Average CO_2 Partial Pressure (kPa abs)
55	Egyptian Sponge Iron and Steel Company Sadat City plant	Steel	Egyptian Sponge Iron & Steel Co	6.00	19.19
56	Al-Ezz Dekheila Steel Alexandria plant	Steel	Al Ezz Dekheila Steel Company Alexandria SAE	6.40	19.19
57	Ezz Flat Steel Ain Sokhna plant	Steel	Al Ezz for Flat Steel Industries Company SAE	4.60	19.2
58	Ezz Steel Rebar Sadat City plant	Steel	Ezz Steel Co SAE	0.90	19.19
59	Suez Steel Solb Misr Attaka plant	Steel	Suez Steel Company SAE	4.10	19.2
60	Abu Kir	Power	West Delta Electricity Production Company	3.66	4.24
61	Abu Sultan	Power	East Delta Electricity Production Company (EDEPC)	0.98	4.2
62	Arish	Power	East Delta Electricity Production Company (EDEPC)	0.11	4.24
63	Ataka	Power	East Delta Electricity Production Company (EDEPC)	1.48	4.2
64	Banha	Power	Middle Delta Electricity Production Company	0.82	4.24
65	Cairo North	Power	Cairo Electricity Production Company (CEPC)	2.46	4.24
66	Cairo South	Power	Cairo Electricity Production Company (CEPC)	1.17	4.2
67	Cairo West	Power	Cairo Electricity Production Company (CEPC)	2.23	4.2
68	Damanhour	Power	West Delta Electricity Production Company	0.75	4.24
69	Damietta	Power	East Delta Electricity Production Company (EDEPC)	1.97	4.24
70	Damietta West	Power	East Delta Electricity Production Company (EDEPC)	0.82	4.2
71	El-Atf	Power	Middle Delta Electricity Production Company	1.23	4.24
72	El-Seiuf	Power	Egyptian Electricity Holding company (EEHC)	0.33	4.24
73	El-Tebeen	Power	Cairo Electricity Production Company (CEPC)	1.15	4.2
74	Kafr El-Dawar	Power	West Delta Electricity Production Company	0.72	4.24
75	Kuriemat 2	Power	Upper Egypt Electricity Production Company	4.51	4.2
76	Kuriemat Solar/Thermal	Power	Upper Egypt Electricity Production Company	0.20	4.2
77	Mahmoudia	Power	Middle Delta Electricity Production Company	0.52	4.24
78	Matrouh	Power	West Delta Electricity Production Company	0.10	4.24
79	New Gas Damietta	Power	East Delta Electricity Production Company (EDEPC)	0.82	4.2
80	New Gas Shabab	Power	East Delta Electricity Production Company (EDEPC)	1.64	4.2
81	North Giza	Power	Cairo Electricity Production Company (CEPC)	3.69	4.24
82	Nubaria	Power	Middle Delta Electricity Production Company	3.69	4.24
83	October 6th	Power	Cairo Electricity Production Company (CEPC)	0.98	4.24

Facility ID (for maps)	Plant Name	Plant Type	Operator	Total CO_2 Emissions (Mtpa)	Weighted Average CO_2 Partial Pressure (kPa abs)
84	Oyoun Mousa	Power	East Delta Electricity Production Company (EDEPC)	1.05	4.24
85	Port Said	Power	China Southern Power Grid	0.08	4.24
86	PortSaid East	Power	China Southern Power Grid	1.12	4.24
87	Shabab	Power	East Delta Electricity Production Company (EDEPC)	0.16	4.2
88	Shoubra El-Kheima	Power	Cairo Electricity Production Company (CEPC)	2.12	4.24
89	Sidi Krir	Power	West Delta Electricity Production Company	3.43	4.24
90	Suez Gulf	Power	China Southern Power Grid	1.12	4.2
91	Talkha	Power	Middle Delta Electricity Production Company	2.39	4.2
92	Wadi Hof	Power	Cairo Electricity Production Company (CEPC)	0.16	4.2

APPENDIX C CARBON CAPTURE TECHNO-ECONOMIC ASSESSMENT METHODOLOGY

To provide insight into the current cost of carbon capture in various industries, a detailed techno-economic study using chemical absorption-based solvent capture technology was performed. The chemical solvents, especially the amine-based solvents, are the current state-of-the-art technologies for carbon capture. They have been extensively used and studied in natural gas sweetening and post-combustion capture in power plants (GCCSI, 2021b). The 30 wt% aqueous monoethanolamine (MEA) is used for the cost benchmarking study, due to its commercial availability and preferred properties for carbon capture of flue gases under ambient pressures (Rochelle, 2009; Bains, Psarras and Wilcox, 2017; IEAGHG, 2019).

The capture cost studied here does not consider downstream CO_2 compression, which is discussed separately in the compression section. It should be noted that there are other project-specific factors impacting the capture cost, such as business model, location, labor, heating/cooling supply strategies, process variations, different technologies etc (GCCSI, 2017), which are not extended in this analysis.

The flue gas streams with CO_2 concentrations ranging from 1 vol% to 20 vol% were considered and the maximum volume of flue gas flow was limited by the absorber size (Ø11 x 20 m) in a single CO_2 capture train (one absorber and one desorber configuration). This corresponds to a 90% CO_2 capture plant at the capture capacity of 0.6 Mtpa in a 240 MW NGCC plant (4 vol% CO_2 gas stream), and 1.4 Mtpa in a 230 MW supercritical pulverised coal (SCPC) power plant (14 vol% CO_2 gas stream) (James et al., 2019). Larger scales of power and industrial plants can be equipped with multiple trains of capture plants (Feron et al., 2019).

A rigorous, rate-based model developed in Aspen Plus® was applied to evaluated technical performance. This is a bottom-up approach based on a detailed process flow sheet. The whole amine CO_2 capture process is described below and shown in Figure A1:

1. The flue gas is initially cooled in the direct contact cooler using the water wash. The caustic scrubbing in the direct contact cooler is included for flue gas streams containing SO_2.
2. The cooled flue gas is then fed to the bottom of the absorber column, which consists of packed beds in the CO_2 absorption section(s), and a water wash section.
3. The flue gas is contacted with a semi-lean amine solvent in the packed bed where the CO_2 in the flue gas is absorbed. The intercooling process is applied improves the efficiency of the absorption process.
4. The flue gas leaving the CO_2 absorption section is scrubbed in the top water wash section and passes through a demister section to remove any MEA and/or degraded solvent.
5. The rich amine solvent leaves the bottom of the absorber. This is divided into two different streams (rich amine split process). The first rich amine stream enters the Lean-Rich Heat Exchanger and is heated by the hot lean amine coming from the bottom of the desorber. The heated rich amine is then sent to the top of the desorber. The second rich amine stream is sent directly to the top of the desorber above the first rich amine stream.

6. The rich amine solvent is regenerated in the desorber column which is heated by a reboiler situated at the base of the desorber column. The reboiler is heated by the low-pressure steam.
7. Periodically, some of the circulating amines are sent to the filtration unit to remove any heat-stable salts and trace impurities. Fresh MEA from the amine storage tanks is added to replenish the lost solvent.
8. The overhead vapour from the desorber column passes through a demister and is sent to the condenser which is cooled by the cooling water. The wet CO_2 is separated in a reflux drum, while the separated liquid is recycled back to the column as reflux or water storage tank for water balance.

A comprehensive techno-economic analysis model was used to determine the required capital investment and economic performance using the Aspen Capital Cost Estimator (ACCE) V12, based on the equipment parameters, materials and energy balance from process simulation. The lean-rich heat exchanger is the major cost component in the carbon capture plant. It was optimised using the Aspen Exchanger Design Rating (EDR) V12 to produce the feasible and economically optimal design for cost analysis. ACCE uses the equipment models contained in the Icarus Evaluation Engine to generate preliminary equipment designs and simulate vendor-costing procedures to develop detailed cost estimates. The association for the Advancement of Cost Engineers (AACE) international Recommended Practice (Class IV) and the DOE economic analysis were used here to guide estimates of capital costs and calculate the total capital investment within an expected accuracy range of ±40%.

Table A1 lists the key assumptions, parameters and methodologies for the techno-economic analysis in CO_2 capture.

Figure 29: Conventional aqueous amine solvent plant process flowsheet integrated with process optimisation using the intercooling and rich split processes.

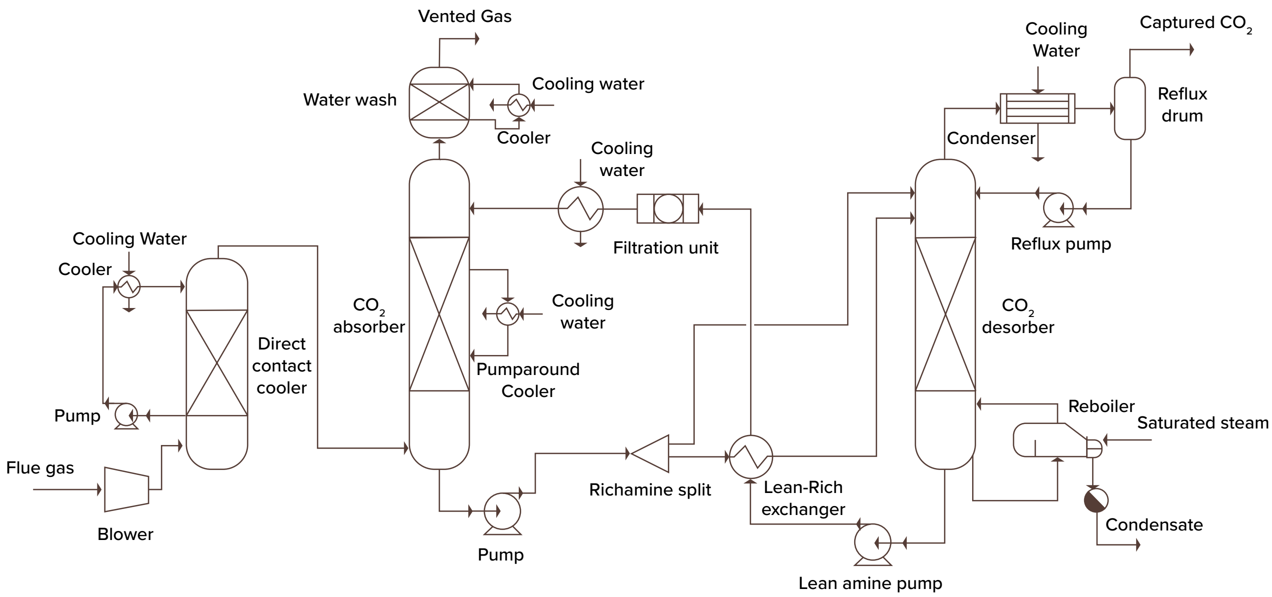


Table 51: Carbon capture technoeconomic analysis parameters, assumptions and methods.

Design Parameters	
Location	Egypt
Present Value	2022 USD cost escalated[9] from Aspen V12 2019 USD cost basis
Construction years	3
Egypt : Texas US Location Factor	1.34
Cost Recovery Factor (CRF)	8.55% based on a Weighted Average Cost Factor (WACC) of 7.6%
Operating life	30 years
Capacity factor	90 %
CO_2 capture rate	90 %

Total Capital Requirement[10]	
Bare Erected Cost (BEC)	• Process equipment • Installation • Supporting facilities Direct and indirect labor
Engineering Procurement and Construction (EPC)	• 0.15 BEC
Process Contingency	0.25 BEC
Project Contingency	0.05 BEC + 0.2 EPC
Total Plant Cost (TPC)	**Sum of the above**
Start-up costs	• 6 months operating labor • 1 month maintenance materials • 1 month chemical and consumables • 1 month waste disposal • 25% of one month fuel cost • 2% TPC
Inventory Capital	• 2 months fuel • 0.5% TPC
Other Owners' costs	• 15% TPC
Owner's Cost	**Sum of the below**

[9] Using the annual Produce Price Index (PPI)

[10]

Fixed Operating Cost	
Maintenance costs	2.2% of TPC/year
Maintenance labor	40% of maintenance costs
Maintenance materials	60% of maintenance costs
Operating labor cost	USD 85,000/person-year
Number of operators	3 (base case)
Number of shifts	5
Administrative/support labor	30% operating labor + 12% of maintenance cost
Insurance cost	0.5% TPC
Local taxes and fees	0.5% TPC

Variable Operating Cost	
Raw process water	USD0.4/cubic metre
Activated carbon	USD2.2/kg
Diatomaceous Earth	USD2.75/kg
MEA amine	USD2/kg
Corrosion Inhibitor	20% of MEA cost
Soda ash	USD0.68/kg
Special waste disposal costs (non-hazardous)	USD50/tonne
Sewage cost	USD0.4/cubic metre (92% of consumed water)

Utility Cost	
Natural gas	USD 5.01/GJ[11]
Electricity	USD 84/MWh[12]

Note that parameters used to calculate the total capital investment were under guideline of Association for the Advancement of Cost Engineers International Recommended Practice (AACE International, 2011), the United States National Energy Technology Laboratory (NETL) Quality Guidelines for Energy Systems Studies: Cost Estimation Methodology for NETL Assessments of Power Plant Performance (US DoE/NETL, 2019a) and Process Modelling Design Parameters (US DoE/NETL, 2019b).

[11] Gas price taken from the Egypt Gas Regulation Authority for fertilizers, petrochemicals, cement, iron and steel for 2021 converted to USD

[12] Electricity prices based on 'other subscribers' for high voltage connection including the average energy price and demand charge converted to USD

APPENDIX D PIPELINE AND COMPRESSION COST ESTIMATE METHODOLOGY

Capital cost estimating of compression facilities:

The key reference used for capital cost estimation was (Mccollum & Ogden 2006). This extensive techno-economic reference itself derived CO_2 compression cost estimates from an earlier IEAGHG report (Woodhill Engineering Consultants, 2002a). We have validated this against verbal advice on CO_2 compression pricing in Australia and found its estimates are comparable.

CO_2 compression systems are unusual in that they are usually divided into two parts – compression (for pressures below and up to the critical pressure of CO_2, 73.8 bar) and pumping (for pressures above the critical pressure).

Compressors are staged (multiple stages of compression, each followed by an aftercooler). It was assumed the maximum pressure ratio is 3.0.

The capital cost of a compression facility was estimated using Equation C-1 (Mccollum and Ogden, 2006):

Equation C-3 – Capital cost of compression system (USD 2005)

$$C_{comp} = m_{train}\, N_{train}\, [0.13 \times 10^6\, (m_{train})^{-0.71} + 1.40 \times 10^6\, (m_{train})^{-0.60} \ln (P_{cut\text{-}off}/P_{initial})]$$

Where:

C_{comp} = cost of compression system (US dollars, 2005)

m_{train} = mass flowrate through compression train (kg/s)

N_{train} = number of compression trains in compression system (integer)

$P_{cut\text{-}off}$ = the discharge pressure of the system (absolute) (any pressure units)

$P_{initial}$ = the inlet (initial) pressure of the system (absolute) (same pressure unit at $P_{cut\text{-}off}$)

The term inside square brackets is the capital cost per kg/s.

Capital cost estimation for compression to the critical pressure only requires knowing the mass rate per train, the number of trains, and the inlet and outlet pressures.

It was assumed the maximum power demand for a compression train was 40,000 kW (Woodhill Engineering Consultants, 2002b). For systems requiring more power than this, multiple trains are required.

Hence if 60,000 kW of compression power is needed, two trains would be required to keep them both under the 40,000 kW threshold. It should be noted that this threshold is now almost 20 years old and it is possible that more compression could occur within one train. However we have retained this limit for this work, as the cost equation has only been validated up to 40,000 kW.

Work of compression was calculated using the following assumptions:

- Aftercooling to 50°C after each stage.
- 75% adiabatic efficiency for each compression stage and for pumping.
- 90% drive (motor & gearbox) efficiency (i.e. 90% of energy fed to the motor is transferred to the compressor shaft). This makes electricity consumption 1/0.9 = 1.11 times higher than the compression energy.

- Pressure ratio of each stage is the same

Aspen HYSYS (by AspenTech) was used to estimate work of compression and pumping for all compression/ pumping systems in this report.

The location, currency and inflation conversions were based on:

Egypt location factor: 1.34 (Richardson)

Producer Price Index 2005 USA: 81.3

Producer Price Index 2022 USA: 131.5

Adjustment factor to convert capex in Equation C-3 is 1.34 x 131.5 / 81.3 = 2.17.

Annualised capital costs

Capital costs are converted to annualised costs using a Capital Recovery Factor (CRF) of 8.55% based on a Weighted Average Cost of Capital (WACC) of 7.6% for a 30 year project life.

Operating cost of compression systems

Opex for compression/pumping systems is dominated by energy cost. Compressor and pump power estimates are already available from the capital cost estimation section.

Energy operating cost

An electricity price of USD 84/MWh was assumed for energy. Energy price was estimated by multiplying this price by MWh for the year for each compression system, in turn assuming 24/7/365 operation. In practice this will be a slight overestimate as most compression facilities will have some planned downtime.

Other operating costs

Annual operation and maintenance (O&M) costs were estimated at 4.0% of total capital cost (Mccollum and Ogden, 2006).

Capital cost estimating of pipelines - onshore:

Once length, pipe diameter and schedule were determined, cost estimates were made for each pipeline in this study. An AEMO-published report on gas production and transmission costs (Core Energy Group, 2015, p. 10), regressed from the costs of 11 major gas transmission lines across 5 states, was used as the source of pipeline costs (in 2015 USD):

Cost of steel line pipe:	2,500/tonne
Coating cost:	45.00/square metre
Construction cost:	30,000/inch-kilometre
Other (insurance, engineering, legal etc.)	15%
Contingencies	10%

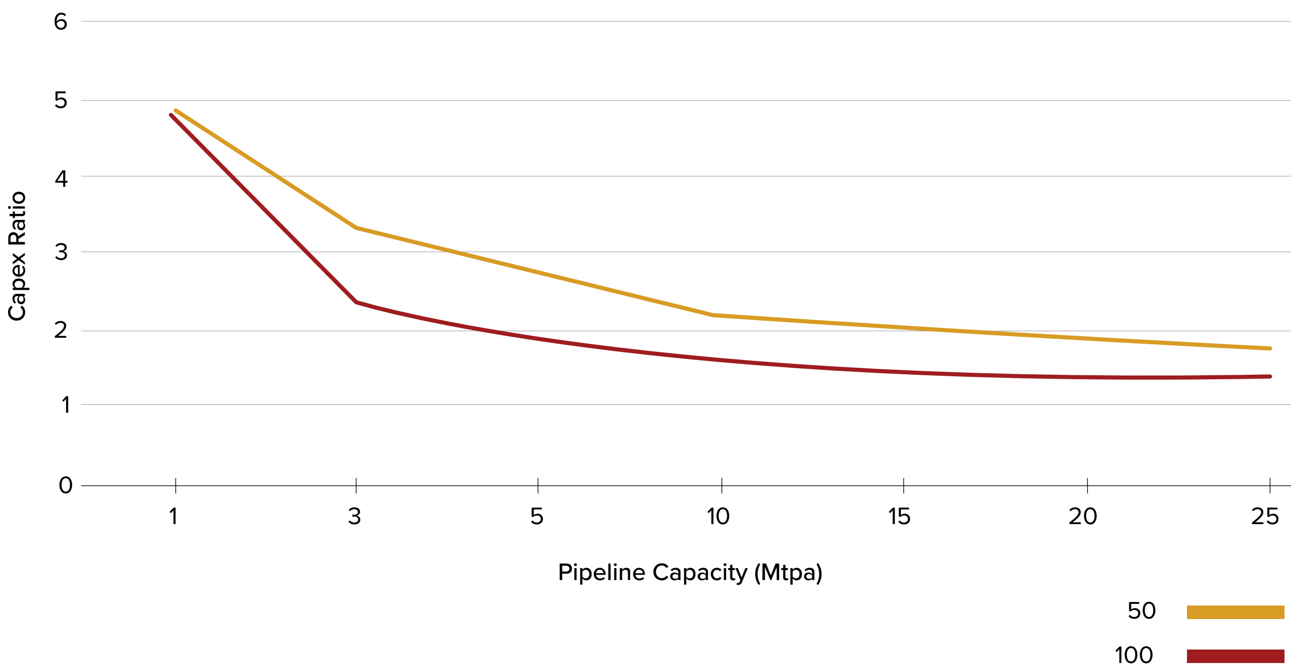
All costs were calculated per metre of pipe length. As inputs, the following were calculated or obtained:

- Pipe weights were obtained online for all pipes (Steel pipes schedule 40 chart: wall thickness and weight, 2020; Steel pipes schedule 160 chart: wall thickness and weight, 2020). This enabled steel pipe cost per metre to be estimated for all line sizes.
- Surface area was calculated based on outside diameter of each pipe, as obtained from online charts mentioned above. This enabled coating cost to be estimated for all line sizes.
- Inch-kilometres are simply nominal pipe sizes in inches (mm size divided by 25) multiplied by pipe length. This enabled construction cost to be estimated.
- Other and Contingencies are simple percentages based on the sum of piping, coating and construction costs.

A final factor in cost estimation is onshore vs onshore pipelines. The public data on offshore pipelines is much more variable than that for onshore due to offshore factors like ocean floor topography and depth. The Institute's experience is that offshore piping costs can be highly variable and that accurate estimates can be obtained only through detailed bottom-up costings. Additionally, there is some anecdotal evidence that offshore pipeline costs have been falling over the past twenty years.

One comparative source of data on offshore piping costs is from the Australian Power Generation Technology Report (CO_2CRC and Gamma Energy Technology, 2015a). This report gave pipeline cost estimates for

Figure 30: Offshore to onshore capital cost ratio for pipelines.



onshore and offshore lines of various flow capacities and lengths. Figure 30, derived from this report, shows the ratio of offshore to onshore capital costs (per km) for pipelines across a range of capacities. The yellow line represents a pipe length of 50 km, and the red line a length of 100 km.

In the range of capacities of interest in this study (> 5 Mtpa, and over 100 km) then it is conservative to say that offshore lines will be 2.0 times the cost of equivalent onshore lines. For this report, offshore line capital costs per metre are estimated in the same manner as onshore lines, then multiplied by 2.0.

Operating cost of pipelines

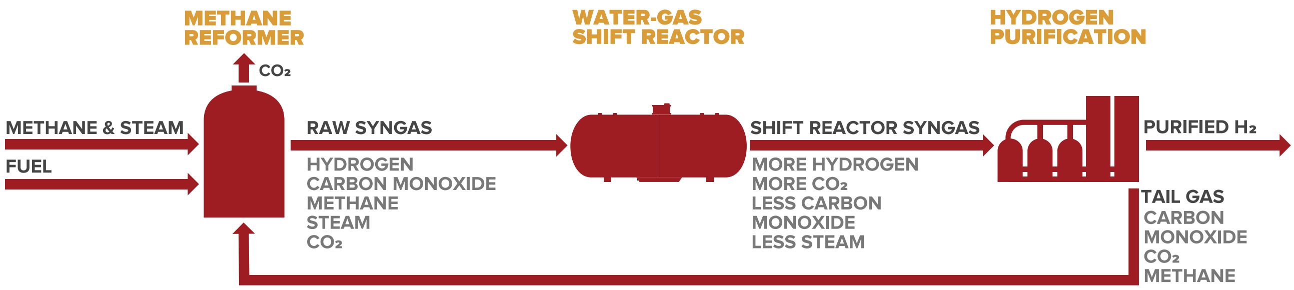
A straightforward estimate of 1% of capex was used as the annual fixed operations and maintenance (O&M) operating cost for all pipelines in this study (CO_2CRC and Gamma Energy Technology, 2015b). Pipelines have little or no variable O&M operating costs, so these were taken to be zero.

APPENDIX E STEAM METHANE REFORMER COST ESTIMATE METHODOLOGY

Background

Hydrogen is an industrial and energy commodity most commonly manufactured using the steam-methane reforming (SMR) process. A simple flow diagram representation of a typical SMR process is shown in Figure 31.

Figure 31: Flow diagram of conventional SMR process for hydrogen manufacturing (Global CCS Institute, 2019).



Technology routes for hydrogen production

Presuming the hydrogen is to be manufactured from natural gas, there are two key pathways that could be used:

- Steam-methane reforming (SMR) with water-gas shift (WGS) (as described above)
- Autothermal reforming (ATR)

The chemical reactions in both processes are identical. The main difference is the source of heat.

In SMR/WGS, heat for the reforming reaction is provided by burning natural gas in a furnace while the process gas runs inside tubes inside that furnace. The fuel gas and feedstock gases never come into direct contact and remain as discrete streams. SMR-based hydrogen production is a mature technology, having been used for many decades in the oil refining, chemicals and related industries.

In ATR, fuel and oxygen is mixed with the feedstock gases. As such the whole operation is carried out in one mixed phase inside reactor tubes. The potential advantage of ATR is that it can boost the CO_2 concentration in the outlet gas, relative to that seen in SMR. This could in principle reduce the costs of carbon capture.

However, reliable mass and energy balance data for ATR coupled with CCS is not available in the public domain. Also, ATR has a much shorter operating history in industrial plants.

To minimise risk and facilitate reliable results, the SMR/WGS route with CCS was assessed for this study.

In SMR/WGS plants, Hydrogen is manufactured in two discrete reactors.

The first reactor is the methane reformer. Here, methane and water (as steam) react at high temperature on a nickel catalyst with the following reaction. Hydrogen gas (H_2) and carbon monoxide (CO) are formed.

The reaction is endothermic (i.e. it absorbs heat). A substantial amount of natural gas must be combusted outside the reactor tubes to provide the heat of reaction and to get the reactants up to temperatures that favour hydrogen production (700-1000°C).

CH_4 + H2O → CO + 3H2 (ΔH = 206 kJ/mol)

Equation 4 – methane reforming reaction

Not all the methane reacts, so some unreacted methane leaves the reformer. The mix of hydrogen, carbon monoxide, unreacted methane, unreacted steam and small amounts of CO_2 (collectively "raw syngas") flow to the second reactor: the water-gas shift reactor.

In the water gas shift reactor, carbon monoxide reacts with steam to form CO_2 and more hydrogen. This reaction is slightly exothermic, so no or little fuel is required to keep the mix at the required temperature.

CO + H2O → CO_2 + H2 (ΔH = -41 kJ/mol)

Equation 5 – water-gas shift reaction

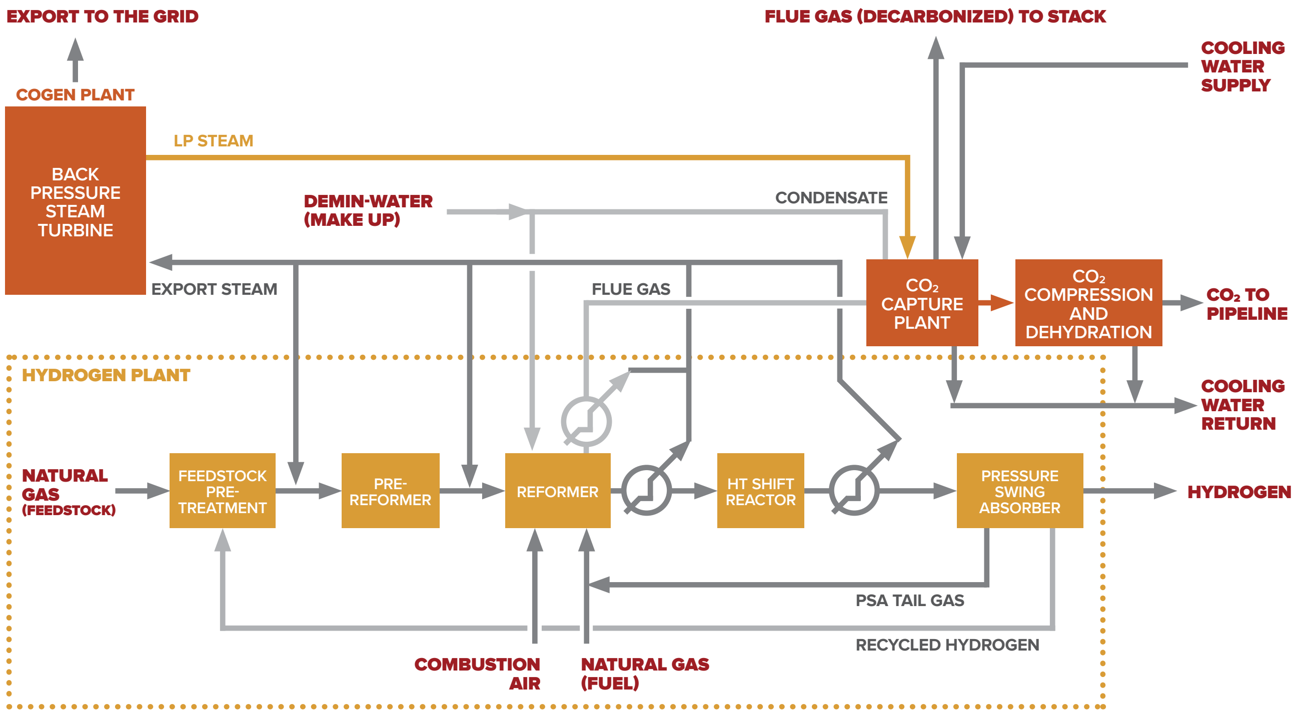
From the water-gas shift reactor, the shift reactor syngas is a mix of hydrogen, unreacted methane and steam, CO_2, and carbon monoxide. A pressure swing adsorption (PSA) unit is used to separate out purified hydrogen gas (> 99% pure). The remaining gases are typically sent back to the reformer for combustion as fuel – this destroys to carbon monoxide and unreacted methane.

Data source for mass and energy balance and financial information

Key data for this report section has been obtained from the IEAGHG study Techno - Economic Evaluation of SMR Based Standalone (Merchant) Hydrogen Plant with CCS (IEAGHG, 2017a). This report is a valuable resource for this report, as it provides detailed flowsheets, costings and mass and energy balance data for SMR plants that incorporate CCS.

The IEAGHG report contains multiple assessments of SMR plants with varying degrees of CO_2 capture – from only tail gas, from only raw syngas. This study wanted to be comprehensive, so "Case 3" from the IEAGHG report was used – this case involves MEA-based solvent capture of CO_2 from reformer flue gas. This includes process CO_2 as well as CO_2 from fuel combustion. The block flow diagram from the IEAGHG report is shown as Figure 32.

Figure 32: Block flow diagram of the SMR plant with CO_2 capture from flue gas and process sources.



Key points on this process arrangement:

- SMR plants produce high-pressure steam as a by-product. This is used to produce electricity for the process in backpressure steam turbines, with the resulting low-pressure steam used to provide heat in the capture plant. The heat and electricity are sufficient to meet the energy requirements of the CO_2 capture plant, so no additional external energy supplies are required.
- The capture fraction of the process is 90%. This means that 90% of the CO_2 produced by the SMR plant (including combustion of fuel) is captured in the CO_2 capture plant and sent to storage.

Gas stream for capture

In the IEAGHG Case 3 process, all CO_2 is captured from the combined tail gas / fuel gas combustion products leaving the reformer. A summary of properties and composition of this stream are given in Table 52 (IEAGHG 2017). The flow is scaled from the IEAGHG case to match the capacity used in this report.

A substantial fraction of the water content of the gas stream is knocked out by cooling and condensation.

The advantage of doing CO_2 capture from the combined flue gas (as described above) is that only a single source of gas needs to be processed.

In alternative capture arrangements, separate capture plants are required for flue gas (combustion) and process gas, with different CO_2 compositions. They also require substantial additional gas processing to remove carbon monoxide. The option selected here ensures carbon monoxide is converted to CO_2 by combustion in the reformer burners. It also ensures that useful heat is recovered from this conversion.

Table 52: Composition of combined flue gas sent to capture plant in the reference IEAGHG Case 3.

Description	Value
Temperature (°C)	136
Pressure (kPag)	20
Flowrate (kg/h)	312,928
Compositions (mol fraction)	
CO_2	0.1897
Nitrogen	0.6282
Oxygen	0.0109
Water	0.1712

Capital cost estimate – plant excluding CO_2 compression

Costs in this report have been scaled, currency-converted and inflated from those in the IEAGHG report.

The IEAGHG Case 3 hydrogen basis was 8.994 tonnes/h of hydrogen production (IEAGHG, 2017b). At a 95% availability, that is an annual production of 74848 tonnes of hydrogen.

The "rule of six-tenths" or "0.6 scaling factor" have been used to scale the IEAGHG capital costs up to match our basis. The "rule" is approximate, but it's generally suitable when scaling by modest amounts.

This rule uses Equation 6:

$$Capex_{plant\ 2} = Capex_{plant\ 1} \times (Capacity_{plant\ 2} / Capacity_{plant\ 1})^{0.6}$$

Equation 6 – applying rule of six-tenths to estimate capital cost of plant 2 based on capex and capacity of plants 1 and 2

IEAGHG case location: Netherlands.

IEAGHG total Capital cost (IEAGHG, 2017b): 398.48 million Euro (2015 basis).

Note that this cost includes CO_2 compression, which for this report has been estimated separately.

IEAGHG compression cost: 9.18% of base plant cost.

So IEAGHG total capital cost (excluding CO_2 compression) = (1-0.0918) x 398.48 = 361.89 million Euro

Adjustment for currency, location and inflation

Egypt location factor: 1.34 (Richardson)
Netherlands location factor: 1.46 (Richardson)
EUR/USD exchange rate: 1.03 (Richardson)
Producer Price Index 2015 Netherlands: 100
Producer Price Index 2022 Netherlands: 135
Adjustment factor to convert capex in Equation C-3 is 1.34 / 1.46 x 1 / 1.03 x 135 / 100 = 1.21.

Annualised capital costs

Capital costs are converted to annualised costs using a Capital Recovery Factor (CRF) of 8.55% based on a Weighted Average Cost of Capital (WACC) of 7.6% for a 30 year project life.

Operating costs

The IEAGHG paper gives the consumption of various utilities: electricity, water, cooling and natural gas for the hydrogen plant.

Fuel and utilities (variable operating costs)

Because the plant produces electricity from high pressure steam as a byproduct, and the resulting low pressure steam meets the needs of the capture plant, the net utility requirements are relatively modest.

Cooling duty was inferred from the IEAGHG utility (seawater) with a temperature rise of 7°C (as per IEAGHG assumptions). This application would most likely use air cooling rather than seawater cooling. Little reliable data was found for air cooling, so an assumed value of 10% of gas costs was inferred. Cooling duty rises and falls with gas consumption, so gas costs are a reliable basis for estimating cooling costs.

The electricity was assumed to be USD 84/MWh consistent with the price for capture plants and compression.

Raw water price was as quoted on the Power and Water Corporation website (Power and Water Corporation, 2020) for commercial water customers.

Natural gas price was taken to be USD 5.01/GJ (WA Government, 2020).

Fixed operations and maintenance

Fixed operations and maintenance (Fixed O&M) include costs such as wages/salaries of staff, spare parts and chemicals, warehousing, and other costs that do not rise and fall with production.

The IEAGHG report is very Netherlands-specific with these costs. As a broad assumption, this report takes fixed O&M to be 4% of capex every year, consistent with this figure used for the CO_2 compression operations (CO_2CRC and Gamma Energy Technology, 2015b). This fixed O&M is for compression systems, which are considered to be as complex as the overall SMR plus capture plant, so this percentage is reasonably conservative and was applied.

OIL AND GAS CLIMATE INITIATIVE

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