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Report on
Carbon Capture Utilization and Storage
Challenges and Opportunities for the Arab Region

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Acronyms

°C	degree Celsius
ACTL	Alberta Carbon Trunk Line
ADCO	Abu Dhabi Company for Onshore Petroleum Operations Ltd
ADNOC	Abu Dhabi National Oil Company
CaCO3	calcium carbonate
CaO	calcium oxide
CCF	carbon capture facility
CCS	Carbon Capture and Storage
CCS-PI	CCS Policy Indicator
CCU	Carbon Capture and Use
CCUS	Carbon Capture, Utilisation and Storage
CDM	Clean Development Mechanism
CDR	Carbon Dioxide Recovery
CECCR	Centre of Excellence for Climate Change Research
CEM	Clean Energy Ministerial
CMP	Conference of the Parties serving as the Meeting of the Parties
COP	Conference of the Parties
CO_2	Carbon dioxide
CSLF	Carbon Sequestration Leadership Forum
CTCN	Climate Technology Centre and Network
DNA	Designated National Authority
EB	Executive Board
EGR	Enhanced Gas Recovery
EOR	Enhanced Oil Recovery
ES	Emirates Steel
ESCWA	Economic and Social Commission for Western Asia
EU	European Union
FEED	Front-End Engineering Design
GCC	Gulf Cooperation Council
GCCSI	Global CCS Institute
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse Gas
GPC	Gas Processing Centre
GPIC	Gulf Petrochemical Industries Companies
GTL	Gas-to-Liquid
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPIECA	International Petroleum Industry Environmental Conservation Association
ISG	In Salah Gas
JIP	Joint Industry Projects
JV	Joint Venture
KACST	King Abdulaziz City for Science and Technology
KACST-TIC CCS	Technology Innovation Centre for CCS

KAIST	Korea Advanced Institute of Science and Technology
KAPSARC	King Abdullah Petroleum Studies and Research Centre
KAU	King Abdulaziz University
KAUST	King Abdullah University of Science and Technology
KFUPM	King Fahd University of Petroleum & Minerals
KSA	Kingdom of Saudi Arabia
LCOE	Levelized cost of electricity
LEDS	Low Emissions Development Strategies
M	Million
Masdar	Abu Dhabi Future Energy Company PJSC
MgCO3	magnesium carbonate
MgO	magnesium oxide
MMscf/d	Million standard cubic feet per day
MMV	measurement, monitoring and verification
MRV	Monitoring, Reporting and Verification
MW	Megawatt
NAMA	Nationally Appropriate Mitigation Actions
NC	National Communication
NDC	Nationally Determined Contribution
Nox	nitrogen oxide
OGCI	Oil and Gas Climate Initiative
PFB	pressurised fluidised bed
Ppm	parts per million
QAFAC	Qatar Fuel Additives Company
QCCRS	Qatar Carbonates and Carbon Storage Research Center
QP	Qatar Petroleum
R&D	Research and development
SABIC	Saudi Basic Industries Corporation
SBSTA	Subsidiary Body of Scientific and Technological Advice
SDG	Sustainable Development Goals
SO_2	sulfur dioxide
TAP	Technology Action Plans
TEC	Technology Executive Committee
TEM	Technical Expert Meetings
TEP	Technical Examination Process
TNA	Technology Needs Assessments
UAE	United Arab Emirates
UNFCCC	United Nations Framework Convention on Climate Change
UNITED	Jubail United Petrochemical Company
USA	United States of America

1. **Introduction:**

The international community, represented by the Heads of State and Government and High Representatives, has adopted in their meeting at the United Nations Headquarters in New York from 25 to 27 September 2015, a new global Sustainable Development Goals agenda; the "2030 Agenda for Sustainable Development" [1]. In this agenda, the international community made a commitment to achieve "*sustainable development in its three dimensions —economic, social and environmental —in a balanced and integrated manner*"[2].

Three months after the adoption of the Sustainable Development Goals, at the 2015 Paris Climate Conference (COP21) in December 2015, 195 nations negotiated a historic climate agreement that sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C.

CO_2 emissions from energy production, transformation, and use are at the heart of the challenge, making up about two thirds of anthropogenic emissions. The efforts to limit rising atmospheric CO_2 concentrations while meeting increasing global energy demand, can only be achieved by deploying a comprehensive portfolio of technologies that include alternative energy sources, energy efficient systems, and Carbon Capture, Utilization and Storage (CCS or CCUS) measures which became a proven technology in meeting climate change mitigation.

Certainly, Carbon Capture and Storage and Utilisation technology has begun to transform into the boom of CO_2 utilization technology. CCS is able to adequately displace CO_2 from fossil-fuel fired power stations and is the only technology capable of reducing large-scale emissions from myriad industrial sources. CCS is a key component in reconciling the so-called 'energy trilemma' – the challenges associated with meeting international climate change commitments, keeping the lights on, and reducing electricity costs, all at the same time.

Several Arab countries are experienced with (CCS or CCUS) projects applications, such as Enhanced Oil Recovery (EOR) and industrial facilities or are considering CCS and CCUS as integrated with energy and other industries (other than oil and gas) as a key option in carbon management. However, deployment of CCS and CCUS could be enhanced by overcoming political and commercial barriers via designing and implementing appropriate policy and financing measures. Opportunities also do exist not only to learn from international experience but to gain from regional cooperation within the Arab region. An area to be further explored.

This report falls under ESCWA's overall program of work and strategic framework aiming to achieve the integrated management of natural resources leading to improved food, water

[1] Transforming our world: the 2030 Agenda for Sustainable Development, UN Resolution A/RES/70/1, adopted by the General Assembly on 25 September 2015

[2] The Millennium Development Goals Report 2015, http://www.un.org/millenniumgoals/2015_MDG_Report/pdf/MDG%202015%20rev%20(July%201).pdf

and energy security and enhanced resilience to climate change, and to mainstream sustainable development goals into regional and national level.

The sub-program also fosters regional approaches on climate change adaptation and mitigation by supporting the development of mechanisms to deal with climate change impacts, conduct impact and vulnerability assessments, and examine associated socioeconomic and environmental issues to inform policymaking processes and support member States in their negotiations. Thus, the purpose of the present report.

This report focusses on Carbon Capture, Utilization and storage as an important part of decarbonizing the global energy systems. The report explores the opportunities and challenges for wide deployment of CCUS in the Arab region in the context of international and regional environmental law. It also discusses opportunities and challenges for technology transfer, provides policy measures, financial gaps, regulations and incentives for the large use of the CCUS within the Arab countries.

2. Carbon Management Technologies for Climate Change Mitigation

In order to combat future climate change impacts, the 2015 Paris Agreement has raised the level of climate ambition and signaled a collective global commitment to limit future temperature increases to ‘well below 2°C’. The success of the Paris Agreement requires identifying and implementing the technology pathways and associated policies required to achieve this target. In fact, the importance of carbon management arises from the concerns over the climate change at international, regional and national levels.

A portfolio of carbon management technologies could essentially facilitate limitation of rising atmospheric CO_2 concentrations. CCS and CCUS are two key methods for carbon or specifically CO_2 management in energy and emission intensive industries, processes and operations. Thus, CCS and CCUS integrated with fossil-fueled energy and other industrial processes could limit temperature well below 2^0C by 2100 while meeting increasing global energy demand.

Building on current CCS and CCUS’s development and deployment, modelling has been carried out in order to assess the future potential contribution of CCS and CCUS in reducing emissions of CO_2 from economic activities. In fact, CCS has the capacity to enhance the sustainability of the global energy system and is projected to achieve 14% cumulative reduction of CO_2 emissions by 2050[3]. Modelling of global climate change mitigation indicates limiting 450 parts per million (ppm) CO_2-eq concentration by 2100 in the absence of CCS is problematic according to IPCC 5th Assessment Report[4].

Introducing CCS and CCUS in fossil fuel-based energy and industrial facilities could substantially reduce CO_2 emissions by the end of 2100. In fact, the share of low-carbon electricity supply could increase from the current share of approximately 30% to more than 80% by 2050, with fossil fuel power generation without CCS phased out almost entirely by 2100[5]. Application of CO_2 capture processes in industrial facilities can be more effective and can lead to competitive cost of the CO_2 avoided with respect to power plants[6].

The total emission reduction potential for CCS is estimated at 2.03 GtCO_2/year in 2030, which includes a reduction of 0.8 GtCO_2/year in 2030 for CO_2 for EOR and 0.1 GtCO_2/year in 2030 for CCU in 2030[7]. However, in the absence or under limited availability of carbon mitigation technologies like CCS, mitigation costs can increase substantially (from 1.5 times to 4 times) depending on the technology considered[8].

At the recent meetings of the Carbon Sequestration Leadership Forum (CSLF) it was emphasized that CCUS is crucial technology and by 2050 will need to contribute to 12-14% of CO_2 emissions avoidance[9]. However, currently, the contribution of CCUS is less than 0.1%. This implies that there is a strong sense of urgency in materialization of CCUS.

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[3] IEA (2016a), GCCSI (2017a).
[4] IPCC (2014), p 24.
[5] IPCC (2014), p28
[6] Romano et al (2013)
[7] UNEP (2017)
[8] CSLF (2017)
[9] Romano et al (2013)

In addition to significantly reducing environmental impact, CCUS is uniquely placed to support energy security and diversity in power generation and to protect substantial capital investments in existing infrastructure. CCUS is also one of the only solutions for deep emission reductions in the industrial sectors that provide building blocks for modern society, such as steel, cement and chemicals production. Investment in CCUS can also support future employment and economic prosperity in regions that rely on these industries.

3. **CCS and CCUS Technologies:**

CCS is a proven technology and has been in safe, commercial operation for 45 years[10]. Until today, there are 17 large-scale CCS projects operating worldwide which inject a total of 22 $MtCO_2$ /yr. 13 of the 17 large-scale CCS projects are linked with EOR. Only two projects are capturing CO_2 from power generation and one project is capturing CO_2 from iron and steel production. **Annex 1** provides details of all CCS projects. Advances in CCS component technologies – CO_2 capture, CO_2 transport and CO_2 storage, have been achieved at different rates. The following section provides updates on each technology components.

CO_2 capture:

CO_2 can be captured in a variety of ways. There are two types of CO_2 emissions from industrial point sources – combustion and process CO_2. Combustion emissions occur from burning carbonaceous fuels, such as natural gas, coal and petroleum, while process emissions account for other CO_2 releases – primarily from chemical reactions that are required to produce desired products.

Although power plants are the first point sources to be targeted for CCS there are many other types of industry that can use CCS to reduce their emissions, for example gas processing, steel and cement works, and glass making. The CO_2 is removed from the emissions gases using solvents and membranes with similar processes to power plants.

Within each of these basic capture technologies there are multiple design choices – all impacted by the type of fuel being used, the environmental conditions, the availability of resources (such as water) at the chosen locations, and the operational requirements of the plant.

CO2 transport:

Transportation of CO_2 and other gases already occurs in many parts of the world and is not expected to be a major barrier to the deployment of CCS. Captured CO_2 can be transported as a solid, liquid, gas, or a dense-phase liquid by a variety of means, including by ship and truck. For most large-scale projects, pipelines are the favoured method of moving the CO_2 between capture and storage sites, providing the lowest cost, safest and most efficient option. In such cases the CO_2 is usually compressed to a dense phase (where it has the density of a liquid, but the viscosity of a gas), as this is the most efficient state for pipeline transport. This compression also greatly reduces the volume of CO_2, allowing smaller pipes to be used. However, several issues require to be considered when designing CO_2 transport systems.

[10] Hill et al (2013)

CO_2 storage:

The safe and permanent storage of CO_2 is part of the most important factor in ensuring that CCS can achieve its potential as a key climate change mitigating technology. Several storage sites are being developed both offshore and onshore as well as depleted oil and gas fields.

4. **CO_2 Valorisation:**

CO_2 can be valorised with three main routes. The 'No Transformation' route – EOR, EGR (Enhanced Gas Recovery), refrigerant gas replacement, supercritical CO_2.

While CO2-EOR (CO_2 capture, transport and storage in enhanced oil recovery) has been commercially successful by enhancing additional oil production, CO_2 capture from fossil-fuel fired power stations and industrial facilities could potentially be economical if captured CO_2 is being used as alternative feedstock in downstream industrial facilities and/or if there is a price signal on permanent storage of captured CO_2. In fact, in the power sector, fossil-fuelled power station with integrated CCS can provide the necessary backup and other services to complement intermittent renewables, and costs continue to decrease as more such facilities commercialise. In contrast with power sector, industrial facilities such as steel making, cement manufacturing as well as several petro-chemical facilities do not have good options for lowering emissions other than CCUS.

With a 'Chemical CO_2 conversion' route, it is technically possible to use CO_2 as a carbon source for the synthesis of commodity products, from simple CO_2 to liquid fuels and high-molecular-weight polymers [11].

Biologic transformation path includes production of microalgae and using as biocatalyst. Carbon mineralisation is the conversion of CO_2 to solid inorganic carbonates using chemical reactions. In this process, alkaline and alkaline-earth oxides, such as magnesium oxide (MgO) and calcium oxide (CaO), which are present in naturally occurring silicate rocks such as serpentine and olivine or in natural brines, are chemically reacted with CO_2 to produce compounds such as magnesium carbonate ($MgCO_3$) and calcium carbonate ($CaCO_3$), commonly known as limestone) using a pressurised fluidised bed (PFB) reactor [12]. CO_2 valorisation thus creates an industry complementarily to CCS. However, the potential for use of CO_2 in industrial facilities is rather small and the storage time of CO_2 in industrial products is often short[13].

Current large-scale uses (in the millions of tonnes per year) include urea yield boosting, carbonated drinks, water treatment and pharmaceutical processes. However, these uses are relatively limited when considered from the perspective of tackling climate change: for example, the global beverage industry uses around 8 Mt CO_2 each year, which is approximately 0.5% of the CO_2 that would need to be captured and stored by 2030 to meet 2^0C target[14]. Most of these alternative large-scale uses also do not offer a permanent storage solution.

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[11] Olajire (2013)
[12] Zevenhoven et al (2014)
[13] IPCC (2014)
[14] IEA (2016a)

Emerging CO_2 utilisation opportunities such as mineral carbonation and CO_2 concrete curing have the potential to provide long-term storage in building materials. However, the potential contribution of these measures to climate change is likely to be limited as demand for these products becomes saturated. The proposed conversion of CO_2 to liquid fuels could potentially displace fossil fuel use (thereby reducing emissions) but requires extensive energy use and would not deliver the same net climate benefit as geological storage because in such conversion the CO_2 is ultimately re-released.

It is important to note that not all CO_2 utilisation options will necessarily contribute to longer term climate change mitigation. The impact on climate mitigation will depend on the fate of the utilised CO_2: for example, CO_2 used in the food and beverage industry has a CO_2 storage lifetime counted in 'days to years' as opposed to 'centuries'. When used for urea and methanol production enhancement, the CO_2 storage lifetime can be counted as 'less than a decade'. Nevertheless, there is scope for the re-use of CO_2 to reduce the environmental footprint of existing chemical processes (for example, efficiency gains in plastics manufacture by displacing a less efficient process).

5. **Policies and Regulations:**

Policies and measures that enable advancement of CCS and CCUS are developed in two tiers – in global/regional forums and in national context. Since CO_2emissions reductions link clear energy and climate change discourses – global, regional and national climate policies are also strongly linked in advancement of CCS and CCUS.

Global CCS Institute compares and reports on levels of national policy support to drive domestic action on CCS through its CCS Policy Indicator (CCS-PI) which provides a ranked assessment of policy support for CCS within countries with most promising conditions.

The most recent summary of national policy and regulations which was for 2017 includes: Norway is taking concrete steps towards CCS deployment in the form of concept and FEED studies on industrial facilities, and continues a consistent policy narrative about the need for CCS to achieve climate goals, which are set in legislation. The United Kingdom continues to provide the strongest policy leadership in encouraging CCS; Canada and the United States also rank highly and have improved in standing since 2013; China has a strong inherent interest in setting favourable policies towards CCS and has implemented a range of positive measures since 2013; India, Russia and Indonesia also have a strong inherent interest in promoting CCS and would benefit from stronger policy support[15],[16].

While implementing stronger policies to support CCS deployment in this environment may seem difficult however, analysis by IPCC, IEA and other leading bodies around the world reflects the realisation that CCS must play a role in addressing climate change at least cost.

The following **Table 1** provides relevant policies focusing on CCS and CCUS at the global and the Arab regional level.

[15] GCCSI (2015a)
[16] GCCSI (2017a)

Table 1: CCS policy relevance in global and regional level

Organizations	Policy context	Remarks
Paris Agreement 2015	CCS and CCUS as mitigation measures in submitted Intended Nationally Determined Contribution (INDC)	Strong focus on CCS and CCUS in several Arab countries: Bahrain, Egypt, Saudi Arabia, United Arab Emirates (UAE).
UNFCCC	CCS and CCUS as mitigation measures in submitted National Communication to UNFCCC	Strong focus on CCS and CCUS from Arab countries: Egypt, Iraq, Kuwait, Qatar, Saudi Arabia, United Arab Emirates.
CDM under the Kyoto Protocol of UNFCCC	2005-2011 Eligibility for CCS projects under CDM of the Kyoto Protocol The Subsidiary Body of Scientific and Technological Advice (SBSTA), which is the technical subsidiary body of the UNFCCC, discussed CCS in CDM in several meetings during 2009 (FCCC/SBSTA/2009/MISC and FCCC/SBSTA/2009/8.)	Only three methodologies submitted to CDM EB for approval as following. However, no methodology has been approved by CDM Executive Board (EB) , hence no CCS projects under CDM till to date.
IPCC[17]	2005 – Special Report on CCS 2014 – 5th Assessment Report (the availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets as mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters[18]) 2018 – SR1.5 (First Order Draft) (deployment of CCS plays a very important role in CO_2 emission reductions in mitigation pathways consistent with 1.5°C. The carbon budget limitation requires a rapid implementation of CCS, soon after 2020)	CCS has been a strong focus as a technological solution to mitigating CO_2 emissions from fossil-energy systems based on scientific evidence (peer-reviewed literatures).
G20 Leaders' Declaration 2017[19]	Mitigate greenhouse gas emissions through, among others, increased innovation on sustainable and clean energies and energy efficiency, and work towards low greenhouse-gas emission energy systems.	CCS as low greenhouse-gas emission energy systems
Carbon Sequestration Leadership Forum (CSLF) [20]	Assert and advocate for clean energy policies that support CCS alongside other clean energy technologies, such as renewable energy and efficiency measures.	Main focus is CCS. 6th Meeting of CSLF Communique 2015 (before Paris)

[17] IPCC (2014)
[18] IPCC (2014), p25
[19] G20: https://www.g20.org/Webs/G20/EN/Home/home_node.html
[20] CSLF: https://www.cslforum.org/cslf/

	Give CCS fair consideration in clean energy policies and resource commitments, while also supporting development of comprehensive CCS policy frameworks.	7th Meeting of CSLF in 2017 (December) 26 members (25 countries + EU)
Mission-Innovation[21]	Mission Innovation aims to reinvigorate and accelerate global clean energy innovation with the objective to make clean energy widely affordable. Carbon Capture Innovation Challenge – To enable near-zero CO_2 emissions from power plants and carbon intensive industries. CCUS as Mission Innovation Clean Energy R&D Focus Area	22 member countries + EU 18 CSLF members are also members of Mission Innovation
Clean Energy Ministerial (CEM)[22]	The CCUS Action Group was conceived as a time-limited group. Having fulfilled its mandate, in 2014, the Action Group undertook a process of consultation with members on how to best communicate CCS reporting to the CEM	In 2014 reporting on CCS to the CEM has been transferred from the Action Group to CSLF. The CCUS Action Group, formed in 2010, includes governments of 13 CEM countries. These are: Australia, Canada, China, France, Germany, Japan, Korea, Mexico, Norway, South Africa, United Arab Emirates, United Kingdom and the United States.
Carbon Pricing Leadership Coalition[23]	The Carbon Pricing Leadership Coalition is a voluntary partnership of national and sub-national governments, businesses, and civil society organizations that agree to advance the carbon pricing agenda by working with each other towards the long-term objective of a carbon price applied throughout the global economy by: • strengthening carbon pricing policies to redirect investment commensurate with the scale of the climate challenge; • bringing forward and strengthening the implementation of existing carbon pricing policies to better manage investment risks and opportunities; and	Carbon price on CCS to make CCS competitive in meeting Paris Agreement climate ambition

[21] Mission-Innovation: http://mission-innovation.net/
[22] CEM: http://www.cleanenergyministerial.org/Our-Work/Initiatives/Carbon-Capture
[23] Carbon Pricing Leadership Coalition: https://www.carbonpricingleadership.org/

	• enhancing cooperation to share information, expertise and lessons learned on developing and implementing carbon pricing through various "readiness" platforms	
4 Kingdom Initiative on CCS[24]	This four-country initiative aims to explore the potential for collaboration on CCS between countries committed to its development and deployment	Saudi Arabia, Norway, the Netherlands and the United Kingdom have established the 4-Kingdom Initiative
North Sea Basin Task Force[25]	On 30 November 2005, Minister Enoksen of Norway and Minister Wicks of the United Kingdom agreed to establish a North Sea Basin Task Force, composed of public and private bodies from countries on the rim of the North Sea	Norway and the United Kingdom
OSPAR Convention[26]	Convention for the Protection of the Marine Environment of the North East Atlantic, 1992 Key Legal Issues Concerning CCS as per OSPAR Convention	Contracting Parties: Belgium, Denmark, European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom
IMO London Protocol[27]	The Protocol aims to create a more modern and comprehensive waste management system for the seas than the one established under the 1972 London Convention with a heightened emphasis upon the protection of the environment. Key Legal Issues Concerning CCS	

A more coordinated policy approach is suggested for example, with regard to the energy-water-food nexus and other un-tackled vulnerabilities. Also, policy comparison between different solutions as well as a focus on clean technology in accord with the Paris Agreement goals on economic development, energy security and emissions reductions are aligned.
However, other drivers are necessary beyond the drivers of climate policy to create a value and market for carbon[28]. While relevant CCS and CCUS policies vary in several jurisdictions, there is no clearly consistent approach being taken by the bodies regulating CCS development across jurisdictions, overall an evolutionary pattern of law and policy is discernible[29].

[24] 4 Kingdom Initiative on CCS: http://www.zeroco2.no/projects/countries/the-netherlands
[25] North Seas Basin Task Force: https://hub.globalccsinstitute.com/category/organisation/north-sea-basin-task-force
[26] OSPAR Convention https://hub.globalccsinstitute.com/publications/offshore-co2-storage-legal-resources/ospar-convention
[27] IMO London Protocol: https://hub.globalccsinstitute.com/publications/offshore-co2-storage-legal-resources/london-protocol
[28] Burton, E., et al., (2013)
[29] Baker & McKenzie, (2012)

Rapid expansion of CCS and CCUS requires appropriate policy frameworks to both promote demonstration and deployment of CCS and ensure it is undertaken in a safe and environmentally responsible manner[30] . Policies in dealing with valuing off-set CO_2 and the role of financing institutions such as the Green Climate Fund (GCF) should be aligned with CCS and CCUS development and linking adaptation benefits with mitigation activities.

6. **Financing CCS and CCUS Projects:**

Worldwide, around US$2.5 trillion has been invested in clean energy technologies during the last ten years, of which US$1.8 trillion has been on wind and solar technologies. This investment activity has been driven by strong and sustained policy support. In comparison, investment in CCS during the same timeframe amounts to around US$20 billion (or the amount invested in other clean energy technologies has been 120 times greater than that for CCS) [31]. According to the IEA, only US$10 billion has been invested in large-scale CCUS compared to US$4,850 billion in low carbon energy during 2016[32].This indicates that current opportunities for commercial investment in CCUS are limited and/or policies and programs that have been successful in supporting low carbon energy investments have not been tailored and applied to CCUS.

A growing body of literature is examining various support models that could incentivise CCS. Concepts such as 'splitting the chain', or tailoring transportation and storage infrastructure development to help de-risk carbon capture projects, have emerged, along with consideration of various public/private shared investment models. The following Table provides strategic options for attracting investment.

Table 2: Strategic options for attracting investment in CCS and CCUS development

Strategic Options	Relevance to CCS/CCUS facilities
Carbon regulation	Applying CCS to clusters of major industrial or other sources of CO_2 can protect regions against future forms of carbon regulation; establishment of 'low-carbon industrial zones' could also bring significant advantages in the race to attract and maintain investment.
Integrated industrial facilities	Development of strategically sized, shared transport and storage infrastructure can facilitate the efficient aggregation of smaller volumes of CO_2 from industrial sources.
Value-added by-product	For a number of industrial processes, CO_2 emissions are not a product of the combustion of substitutable fossil fuels, but rather an unavoidable by-product of an inherent chemical process. Captured CO_2 could be used for other chemical processes.
High value product	For EOR to offset the CCS cost by using CO_2 as a product to increase oil production
Public-private partnerships	Joint venture, Joint Ownerships

[30] IEA (2016a)
[31] GCCSI (2016)
[32] IEA (2017)

Transitional government support	Direct support to facilitate development of CCS facilities

While direct financing of CCS and CCU projects have been primarily sourced from several national agencies, innovative financing such as via market mechanism could potentially attract investments in CCS and CCU – especially in developing countries. Following sections focus on innovative financing mechanisms.

CCS and Market Mechanism:

The inclusion of CCS in geological formations as Clean Development Mechanism (CDM) project activities has been considered in different instances including the CMP, the SBSTA and the CDM Executive Board, dating back as early as November 2005.

The SBSTA, which is the technical subsidiary body of the UNFCCC, discussed CCS in Conference of the Parties serving as the Meeting of the Parties (CDM) in several meetings during 2009 (FCCC/SBSTA/2009/MISC and FCCC/SBSTA/2009/8). At its 50th meeting (October 2009) the CDM Executive Board agreed to present a summary of possible consequences of the inclusion of CCS in geological formations as CDM project activities. This has contributed to the CMP7 in Durban recommendations for adoption of modalities and procedures for CCS in geological formations as CDM project activities (10/CMP.7) including associated requirements were made. However, to date no CCS projects under CDM have been developed.

With regard to monitoring and reporting of captured and stored CO_2, there have been submitted to CDM Executive Board (EB) for approval. However, no methodology has been approved by CDM EB. The following new methodologies considered for developing CCS:

- Recovery of anthropogenic CO_2 from large industrial greenhouse gas (GHG) emission sources (this could include but is not limited to: fossil fuel fired power plants, natural gas/oil processing plants, chemical manufacturers, etc.) and its storage in an oil reservoir in relation to the Project Activity. The White Tiger Oil Field Carbon Capture and Storage (CCS) project in Vietnam (submitted in 2005)

- The capture of CO_2 from natural gas processing plants and liquefied natural gas (LNG) plants and its storage in underground aquifers or abandoned oil/gas reservoirs in relation to the Project Activity The capture of the CO_2 from the LNG complex and its geological storage in the aquifer located in Malaysia (submitted in 2006)

- The capture of CO_2 from the front-end of integrated Gas-to-Liquid (GTL) plants, transport via pipeline and long-term containment in appropriately selected and well-managed geological storage complexes (submitted in 2010) (UNFCCC CDM methodologies website does not provide any details of this methodology).

In addition, a few other initiatives have been taken regarding developing CCS methodologies. Two such examples are as following:

- Draft Carbon Capture and Storage (CCS) Emission Reduction Quantification Methodology, 2009 developed by Blue Source Canada (not under UNFCCC CDM scheme)

- Draft Quantification Protocol for the Capture of CO_2 from Steam Methane Reforming and Permanent Storage in Deep Saline Geological Formation (not under UNFCCC CDM scheme).

These methodologies, however, have adopted components from industry standards, for example, International Petroleum Industry Environmental Conservation Association (IPIECA) Guideline on Oil and Natural Gas Industry Guidelines for Greenhouse Gas Reduction Projects. Part II: Carbon Capture and Geological Storage Emission Reduction Family and ISO Standard 14064: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements.

Oil and Gas Climate Initiative (OGCI):
OGCI is a voluntary CEO-led initiative which aims to lead industry response to climate change. Launched in 2014, OGCI is currently made up of ten oil and gas companies that pool expert knowledge and collaborate on action to reduce GHG emissions. OGCI Climate Investments is US$1 billion investment fund and invests in promising technologies including CCUS and business models that have the potential to significantly reduce GHG emissions[33].

Green Climate Fund (GCF):
The GCF is the main compensating measure under the current climate regime. Discussed and approved during COP16 in Cancun in 2010 and officially launched the following year at COP17, the GCF is defined as an operating entity under the financial mechanism of the UNFCCC. The purpose of the GCF is to 'promote the paradigm shift towards low-emission and climate-resilient development pathways by providing support to developing countries to limit or reduce their greenhouse gas emissions and to adapt to the impacts of climate change, taking into account the needs of those developing countries particularly vulnerable to the adverse effects of climate change.

Since inception, GCF has funded 54 projects comprising 40% mitigation and the rest focused on adaptation and cross-cutting objectives[34]. However, no CCS or CCU projects have been financed until today.

A way forward could be seeking CCUS financing through GCF's new initiative as reported during COP23 in Bonn. In line with paragraph 38 of the Governing Instrument, and in response to guidance from the COP relating to decision 7/CP.21, paragraph 22, the GCF considered options to support technology collaborative research and development at B.18. There are two approaches to support collaborative research, development and demonstration in developing countries as noted by the GCF Board, namely: 1) climate technology innovation systems; and 2) targeted climate technology research, development and demonstration support[35].

While these innovative financing mechanisms are shaping, there are number of factors that hinder CCUS investment:

- Higher investment costs – this is due to higher cost of CO_2 capture compared to transport and storage. Transport costs increase with the volume transported and the distance of the plants to the storage facilities.

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[33] http://www.oilandgasclimateinitiative.com/portfolio/#ccus
[34] http://www.greenclimate.fund/what-we-do/portfolio-dashboard)
[35] UNESCWA (2017a)

Storage, costs are higher for offshore than for onshore locations, and higher for saline aquifers than for depleted oil and gas fields.

- Levelized cost of electricity (LCOE) increases when CCS is integrated with coal- and gas-fired power plants. Studies suggests that levelized costs are generally higher for CCS than for onshore wind and nuclear power, but can be lower or of the same order of magnitude as offshore wind.
- For those sectors in which CCS applications are relatively cheap, especially when CO_2 capture is already part of the production process and/or it is highly concentrated in flue gases, investment in CCS can be more appealing than in the power generation sector.
- There is investment challenge specific to power generation sector where captured CO_2 does not bring any economic value, for instance when captured CO_2 are not been used other than EOR or EGR.
- Unlike fossil-fuel based power generation facilities, industrial sectors exposed to international trade face additional strains on costs due to competitiveness issues. One important implication is that CCS costs cannot be passed easily on to customers, as this would affect their competitiveness, unless a border tariff was applied on the basis of embedded carbon dioxide.
- The long-lived nature of manufacturing infrastructure and the slow turnover of stock mean that large-scale commercial deployment of CCS technology in the industrial sector could take several years over and above the power sector. A large number of cement and steel plants, for instance, usually only undergo major refurbishment in line with the lifetimes of key pieces of equipment, often around twenty years.
- It is also challenging to integrate CCS while also optimising manufacturing processes and meeting production specifications, especially when installations are part of supply chains that are already highly integrated and specialized.
- In addition, current overcapacity in some sectors, such as steel, leads to low profit margins, leaving little capital available for long-term technology development. This, together with a lack of clear first-mover advantage, reduces firms' appetite for large investments in new CCS equipment.

In order to unlock CCUS investment the following are recommended five keys[36]:

- Harvest 'low hanging fruit' to build CCUS deployment and experience from the ground up
- Tailor policies to shepherd CCUS through the early deployment phase and to address the unique integration challenges for these facilities
- Target multiple pathways to reduce costs from technology innovation in carbon capture and CO_2 utilization to progressive financing arrangements
- Build CO_2 networks and accelerate CO_2 storage assessment in key regions
- Strengthen partnerships and cooperation between industry and governments

However, it's yet to see deployment of CCS projects beyond currently operating 17 projects around the world and specially in the regions where introducing CCS into fossil-fuel based power generation could potentially facilitate multiplier effects such as economic development and electricity access.

A way forward could be valuing captured CO_2 such as a signal on price of carbon[37] and streamlining with internationally recognised standard monitoring and reporting of captured CO_2. **Box 1** provides two case studies on CCU and CCS. These case studies show how private sectors collaborated in developing and implementing emerging CCU and CCS technologies.

[36] IEA (2017)
[37] Uddin and Barretto (2007)

Box 1:
Solidia Technologies:
Solidia Technologies is a cement and concrete technology company that makes it easy and profitable to use CO_2 to create superior and sustainable building materials. Solidia's patented processes produce sustainable cement and concrete that cures using CO_2. Combined, these technologies reduce carbon emissions by up to 70% and recycle 60-80% of the water used in the production of concrete. Based in Piscataway, N.J. (USA), Solidia's investors include Kleiner Perkins Caufield & Byers, Bright Capital, BASF, BP, LafargeHolcim, Total Energy Ventures, Bill Joy and other private investors. [38]

Boundary Dam carbon capture project:
Unit 3 at the Boundary Dam coal–fired power station in Saskatchewan, Canada, completed a refurbishment program in October 2014 that included retrofitting CO_2 capture facilities with a capture capacity of approximately 1 million tons per annum (Mtpa) of CO_2 . The majority of the captured CO_2 is transported via pipeline and used for enhanced oil recovery at the Weyburn Oil Unit, also in Saskatchewan. A portion of the captured CO_2 is transported via pipeline to the nearby Aquistore Project for dedicated geological storage. In the fall of 2014, Boundary Dam Power Station became the first power station in the world to successfully use Carbon Capture and Storage (CCS) technology. The initiative:
- Produces 115 MW of power – enough to power about 100,000 Saskatchewan homes.
- Captures up to 1.3 million tons of CO_2, the equivalent of taking more than 300,000 cars off our roads.
- Reduces sulfur dioxide (SO_2) emissions from its coal process by up to 100% and CO_2 by up to 90%.

The total cost of the project is US$1.5 billion, an increase of US$200 million from the original cost estimate. Of the original cost estimate US$800 million was for the CCS process and the remainder for retrofit costs. SaskPower feels that the next unit could cost 20-30% less compared to this one. The Boundary Dam project received US$240 million from the Federal Government. Beside the Federal Government support, the provincial government also supported the project. In addition to electricity, revenue will be generated from sale of CO_2, sulphuric acid and fly ash[39].

7. CCS and CCUS: Actions by the Arab countries

While climate change has never played a significant role in Arab countries' discourse on energy use, the Arab region is one of the most vulnerable to climate change. Water shortages and hazards to food security posed by climate change jeopardize the livelihoods of large segments of the population.[40] The publication of the Stern Review in 2006,[41] the IPCC report of 2007[42] and the World Development Report of 2010[43] have left little doubt as to the urgency of climate action needed today. The Arabian Peninsula is already one of the most water-

[38] http://www.lafarge.com/en/04282015-Lafarge-Solidia-commercialize-new-low-carbon-solution-for-construction-sector
[39] http://www.saskpower.com/our-power-future/carbon-capture-and-storage/boundary-dam-carbon-capture-project/ , http://sequestration.mit.edu/tools/projects/index_capture.html
[40] FAO (2014d), p. 122
[41] Stern (2006)
[42] IPCC (2007a, b)
[43] World Bank (2010)

stressed regions in the world, making its long-term water and food security highly vulnerable to climate change.[44]

Many Arab countries, have undertaken ambitious climate actions based on each country's national circumstances. For instance, economic diversification with mitigation co-benefit (Decision 24/CP.18) is the central pillar of climate actions by several Arab countries and climate actions such as carbon management with an emphasis on financial, technology transfer and capacity building or are in the process of doing so.

A review of Arab countries national communications (NCs) reports and Intended Nationally Determined Contributions (INDCs) to the UNFCCC shows that Arab countries are in fact implementing various climate friendly policies and measures in order to reduce anthropogenic GHG emissions as well as to enhance carbon sinks. One of the key aspects of climate actions is focusing on CCS and CCUS as a technology-based solution to combat GHG emissions. Among other green technologies (for example, renewables, energy efficiency and savings), CCS could assist mitigation of climate change impacts in the region and globally via reducing GHGs emissions[45].

Actions on CCS and CCUS in several Arab countries span from research, demonstration to project implementation and cover a range of industries including oil, gas and petrochemicals. **Table 3** summarises current CCS and CCUS activities in the Arab region countries.

Table 3: CCS, CCUS in INDCs and NCs – Actions by Arab region countries[46]

Countries	NDCs	NCs	Energy	Oil & Gas	Other Industries
Bahrain	CCUS				Refinery, Petrochemical
Egypt	CCS	CCS	CCS	EOR	
Iraq		CCS	CCS		Cement, Ammonia, Iron
Kuwait		CCS	CCS	EOR	Desalinated water generation
Qatar		CCS			Research Project on CCS technologies
Saudi Arabia	CCUS	CCUS		EOR	Research Projects; Petrochemical
United Arab Emirates	CCUS	CCUS		EOR	Masdar CCS Network, Steel and Oil Field

Moreover, many countries in the Arab region started focusing on management of carbon from their energy intensive sectors. While some of the countries have implemented CCS and/or CCU – as carbon management strategies, a number of countries have implemented several measures from policy approach to designing early ground work favorable for carbon management.

Some oil and gas countries in the Arab region have developed carbon atlases as a major step forward to support their decarbonization. For example, Kuwait in 2017 developed a first carbon atlas for the country[47]. Sustainability of Saudi energy generation sector is planned to be met by integration of CCS and other technologies[48]. Both Saudi Arabia and UAE are in

[44] Odhiambo (2016); UNDP (2013a)
[45] UN (2013)
[46] IGES (NDC database); UNFCCC (INDCs Interim Registry)
[47] Al-Mutairi et al (2017)
[48] Alshammari and Sarathy (2017)

advance stages of CCS implementation and have greater understanding of CO_2 storage in oil and gas fields[49].

7.1. Technology transfer:

Development and transfer of low emission technologies is one of the key components to enhance mitigation actions in countries that lack such capacities and capabilities. CCS is the critical enabling technology in reducing CO_2 emissions significantly. Although the developed countries lead the CCS effort, there is an urgent need to spread CCS in the developing countries including countries in the Arab region.

There are many possible barriers to technology transfer for CCS and CCU as being comparatively new technology in developing countries including high tariffs, investment risk, high interest rates and others. Most of these barriers are linked with financing. Most channels of technology transfer also require appropriate financing – either in the form of direct purchasing or co-financing. This is particularly important for countries that lack financing and relevant infrastructure as well as lack of experience in adopting technologies such as CCS and CCU. Hence, financing in the form of direct cost compensation to capacity building, could enhance countries capacity and capability in implementing CCS and CCU technologies.

Technology transfer has been a continuous concern since the establishment of UNFCCC. Given technologies for reducing GHG emissions originate mainly in developed countries, technology transfer, as an important feature emphasized by both the UNFCCC, the Kyoto Protocol and the Paris Agreement, therefore has a key role to play in bridging a gap between developed and developing countries[50]. The 2007 Bali Action Plan under UNFCCC renewed interest in technology transfer. In order to facilitate climate technology development and transfer, the UNFCCC has established two organizations, the Technology Executive Committee (TEC) and the Climate Technology Centre and Network (CTCN) as well as CCS and technology transfer under Clean Development Mechanism (CDM) of the Kyoto Protocol. However, technology transfers under CDM of the Kyoto Protocol has been a mixed success although initiatives on CCS under CDM did not materialise till to date.

Technology transfers has also been heavily emphasised in the 2015 Paris Agreement as it calls for developed countries to provide transfer of technologies among others to developing countries (Art. 13 of the Paris Agreement).

While TEC, CTCN, NCs and NDCs are the UNFCCC's 'vehicles' that assist technology transfer facilitation (i.e. reporting, review, discussion platforms, cooperative approaches, planning tools and strategies), there are other vehicles which could facilitate CCS and technology transfer. The following **Table 4** provides 'vehicles' of the UNFCCC relevant to the Arab region and how they link with CCS and technology transfer.

[49] Liu et al (2012)
[50] Liu and Liang (2011)

Table 4: UNFCCC 'vehicles' with relevance to Arab region countries[51]

UNFCCC 'vehicles'	Relevance to CCS	Relevance to Technology Transfer
Technology Executive Committee (TEC)	Yes	Possible
Climate Technology Centre and Network (CTCN)	Yes	Possible
Clean Development Mechanism (CDM)	Yes	Possible
National Communications (NCs)	Yes	
Nationally Determined Contributions (NDCs)	Yes	
Biennial Update Reports	Yes	
International Assessment Reviews		
International Consultation Analysis		
Nationally Appropriate Mitigation Actions (NAMAs)	Yes	Potential
Monitoring, Reporting and Verification (MRV)	Yes	
Low Emissions Development Strategies (LEDS)	Yes	
Technology Needs Assessments (TNAs)	Yes	Possible
Technology Action Plans (TAPs)	Yes	Possible
Technical Examination Process (TEP) and Technical Expert Meetings (TEMs)		
Sustainable Development Goals (SDGs)		Potential
Country driven applications for Global Environment Facility (GEF)		Possible (Finance)
Country driven applications for Green Climate Fund (GCF)		Possible (Finance)

While most of other vehicles were established prior to the Paris Agreement (2015), they all remain relevant to current national climate action efforts, and are linked and highly complementary in supporting the climate actions of both developed and developing countries.

A number of Arab countries are involved in technology transfer in the form of know-how, joint collaborative research and development. The following describes current programs, collaborative approaches for CCS and CCUS technology transfer and sector-specific research and development (**Box 2**).

Box 2:
Saudi Arabia:
Several institutions in Saudi Arabia are engaged in CCS research including: the King Abdulaziz City for Science and Technology (KACST), the King Fahd University of Petroleum & Minerals (KFUPM), the King Abdullah University of Science and Technology (KAUST), Saudi Aramco, and King Abdullah Petroleum Studies and Research Centre (KAPSARC).

The Saudi universities and research centres, including KACST, KFUPM, KAUST, and KAPSARC are conducting basic technical research on CCS. For example, the Technology Innovation Centre for CCS (KACST-TIC CCS) at KFUPM has been awarded KACST baseline funding of SAR10 M/year (US$ 2.7 M/year) for a 5-year period (2011–2015). The ongoing research of the KACST-TIC CCS has

[51] Adapted from GCCSI 2017b, Author's analysis

been focusing on oxy-fuel combustion, mobile capture, site assessment and measurement, monitoring and verification (MMV) of CO_2 storage. KACST-TIC CCS has extensive collaboration with private sectors (Saudi Aramco, Aker Solutions) and institutions (TNO – the Netherlands, MIT – USA, Carnegie Mellon – USA).

Saudi Aramco established: a joint research collaborative research centre with the Korea Advanced Institute of Science and Technology (KAIST) in 2013; a MIT-Saudi Aramco cooperation on carbon management and energy in 2012; and trilateral cooperation with Stanford University and KFUPM.

The World Bank selected King Abdulaziz University (KAU), as represented by its Centre of Excellence for Climate Change Research (CECCR), to lead an Arab research team for a study on climate change in the Arab region. The CEECR was established in 2009. It is working on collecting and compiling relevant climate data for the Kingdom which can be used for policy development (KSA 3rd National Communication to UNFCCC 2016).

United Arab Emirates:
The effect of the CCS technology in large scale deployment on the natural gas market in UAE has been researched technology with regard to captured CO_2 being used for enhancing EOR, a benefit to the natural gas market due to freeing up natural gas used in oil wellbores by the Masdar Institute of Science and Technology[52] .

Qatar[53]

The Qatar Carbonates and Carbon Storage Research Centre (QCCSRC), is the result of a 10-year, $70 million strategic collaboration between Imperial College London, Qatar Petroleum (QP), Shell and the Qatar Science and Technology Park (part of Qatar Foundation). Objectives of QCCSRC are:

- Conducting novel geoscience research to better understand Qatari carbonate reservoirs.
- Supporting the deployment of carbon sequestration in carbonates by improving the underlying science and engineering.
- Developing local talent in Qatar through higher education and research training in geosciences and engineering capacity building and knowledge transfer.

Qatar University's Gas Processing Centre (GPC) released a Carbon Capture and Management Roadmap in 2012 and is conducting a CO_2 capture research project which will evaluate the performance of different chemical solvents in capturing CO_2 from the flue gas of a simulated natural gas-fired power plant.

Transfer and diffusion of existing technologies such as CCS and CCU are essential to enhance mitigation actions and thus could give more flexibility for future innovation. However, as well as technology transfer, the flexibility and the efficiency of emissions reduction from CO_2 sources (both process CO_2 emissions – specially from chemical industries and combustion CO_2

[52] Ustadi et al (2017)
[53] http://www.imperial.ac.uk/qatar-carbonates-and-carbon-storage/

emissions from energy industries[54]) needs to be addressed taking into consideration in the context of an integrated system for the power and industrial sector in a CO_2 circular economy[55].

Knowledge and greater understanding of CO_2 storage, particularly in oil and gas fields in some countries in Arab region could also be transferred into the region/countries that are in need.

Joint Industry Projects (JIPs):

Joint Industry Project (JIP) in the form of collaborative research, development, and demonstration on CCS technologies would enable technology transfer and to share costs, risks and gain knowledge. JIPs could cover full value-chain of CCS and CCU projects in the form of collaboration by several countries and relevant industries. JIPs enable to develop new solutions, standards and practices that add value by solving industry challenges and adopting a new technology such as CCS and CCU in country specific conditions. A number of JIPs have been initiated in several Arab countries on CCS and CCUS and are provided in **Box 3** below:

Box 3:

Algeria:

In Salah Gas (ISG) is a Joint Venture (JV) Project between BP (33%), Sonatrach (35%) and Statoil (32%), which comprises seven gas fields located in the Central Algerian Sahara. The CO_2content in the natural gas produced from the In Salah project ranges between 1 to 10%, which is above the export (market) gas specifications of 0.3% and therefore require CO_2 removal facilities. Rather than venting CO_2, ISG compresses and re-injects the produced CO_2 stream (up to 70 MMscf/d or 1.2 million tonnes per year) back into the underground at 1,800 meters depth, within the water leg of the gas reservoir.

Qatar:

In commissioning the Carbon Dioxide Recovery (CDR) plant in 2014, The Qatar Fuel Additives Company (QAFAC) has demonstrated a world-class example of achieving sustainable growth of production, i.e. utilizing production resources for maximum efficiency whilst simultaneously avoiding significant emissions of greenhouse gas CO_2 into the atmosphere. With the installation of the CDR plant, QAFAC became self-sufficient in generating CO_2 gas, which is used as input material for methanol production. Replacing purchased CO_2 with its internally generated gas. In addition to increasing methanol production by 250 MT/day and reducing CO_2 emission by 500 MT/day CDR plant also reduces water consumption by 10% by recycling recovered water vapor from flue gases and reduces nitrogen oxide (NOx) emissions[56].

[54] Bains et al (2017)

[55] Koytsoumpa et al (2017)

[56] https://www.qafac.com.qa/environmental-stewardship accessed on 31 Oct 2017

7.2. Policies and measures

All Arab countries are signatories to the UNFCCC. Also most Arab countries identified adaptation and mitigation actions in their nationally determined contributions and submitted them to UNFCCC in 2015, with emission reduction targets subject to available financial resources and appropriate technologies[57].

Several policy and support measures are presently adopted in a number of countries that enables advancement of CCS and CCUS. The following **Table 5** provides an overview of CCS and CCUS policies in national context – GCC countries.

Table 5: CCUS Regulatory Gaps[58]

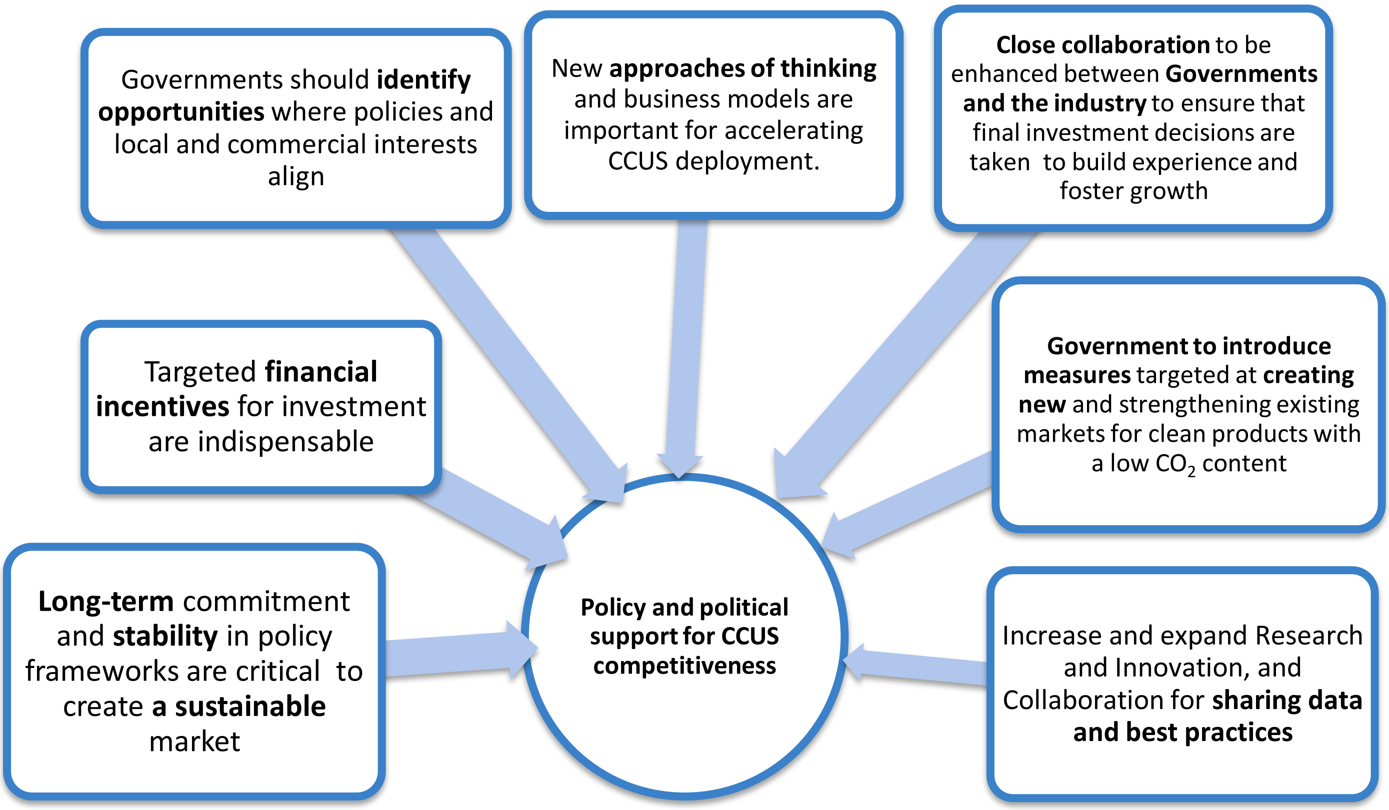
Regulatory Domain	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE
CO_2 classification	X	X	X	X	X	X
Ownership of surface facility		X		X	X	
Transboundary CO_2	X	X	X	X	X	X
CO_2 impurity	X	X	X	X	X	X
CO_2 capture regulation		X		X	X	
CO_2 transportation regulation		X		X	X	
CO_2 storage regulation	X	X	X	X	X	X
Liability during post-closure period	X	X	X	X	X	X
Regulation for CCS with EOR	X	X	X	X	X	X
Incentives			X			

Note: "X" indicates a lack of both the implicit regulation and the explicit regulation; blank indicates close-to-no or no inadequacy.

[57] UNESCWA (2017a)
[58] Tsai, I-T (2017)

Although commendable, CCS and CCUS projects remain dispersed and separate in most of the Arab member states. An overarching policy is needed at national and regional levels in order to achieve optimal results for mitigation efforts. CCUS can be beneficiary for Arab's economy diversification strategy if carefully structured and adequate policy is in place. **Figure 1** presents the key enabling factors for wide deployment of CCUS within the Arab region. [59]

Figure 1: Key enabling factors for wide deployment of CCUS within the Arab region. [60]



7.3. Analysis of financial gap:

Costs of a CCS technology at individual sites depend on a range of sector- and site-specific factors, including: CO_2 concentration; CO_2 partial pressure; CO_2 volumes; ease of industrial integration; and location. Hence, a significant amount of pre-investment work that needs to be undertaken before a CCS project is implemented. The pre-investment phase includes –

[59] Sedaoui, R., 2017, "CCUS challenges within the Arab Region: Policy Aspects for inclusive sustainable future", Middle East and South Africa CSLF Regional Stakeholder Engagement Workshop, SABIC HQ - RIYADH KSA, October 25 to 26, 2017

[60] Sedaoui, R., 2017, "CCUS challenges within the Arab Region: Policy Aspects for inclusive sustainable future", Middle East and South Africa CSLF Regional Stakeholder Engagement Workshop, SABIC HQ - RIYADH KSA, October 25 to 26, 2017

from theoretical to site-specific characterization, pre-feasibility/feasibility studies, geological storage assessments as well as FEED studies specific to the CCS aspects of the project. There is a lack of commercial or market-based incentives to justify extra costs and risks of CCS due to market failure. Other market failure is due to imbalance between 'risks and reward' for the first movers.

To date, an estimated US$ 10 billion in capital investment has been made in large-scale CCS projects that are operating or under construction globally, most of it this decade and predominantly private capital. However, leveraging private capital through government support would facilitate future CCS projects.

The availability of a revenue stream from CCS-EOR has supported investment decisions in three-quarters of CCS projects to date. For some early projects, the revenue from CCS-EOR was sufficient for commercial CCS operation, while more recently EOR revenue combined with capital grants has helped to close the commercial gap and support investment in CCS applied to coal-fired power generation.

Commercial interest in CO_2-EOR continues to expand and is expected to remain a major factor in supporting early CCS investment notwithstanding. However, these opportunities will be limited by region and geology, and accordingly CO_2-EOR will not be an alternative to developing dedicated CO_2 storage sites. Hence, new and innovative financial initiatives are required for implementation of CCS projects other than integrated with EOR.

While there is relatively weak business case for CCS in most developing countries including countries in Arab region, narrowing financial gap and building bridge would help facilitate CCS and CCUS. In fact, CCS integrated projects with power generation and industrial facilities are particular interesting especially in the Arab countries.

7.4. Commercialization:

Out of the 17 CCS projects operating globally to date, there are two CCS-EOR projects operating in Arab countries. Additional infrastructure investments would also be necessary for increasing the deployment and use of CCS in these countries. Recent international trends suggest that a large-scale utilization of CCS as decarbonisation technology for the electricity sector is unlikely, as the combination of renewables with storage and demand-side technologies provides the cheaper alternative[61]. Nevertheless, large-scale power storage technologies to match demand – supply mismatches are still a technological challenge and requires additional research[62].

Among the Arab countries, several GCC countries are committing funds for research and development on CCS (principally on carbon capture and geological storage) and approving deployment of carbon capture technology integration either for retrofitting operational industrial plants or in new plants.

[61] Breyer et al. (2017); Löffler et al. (2017)
[62] Annaluru and Garg (2017); Park and Lappas (2017)

While EOR will utilize CCS to boost oil production and release injected natural gas, deploying CCS on a large scale requires policy actions to help it overcome market barriers. The implication is that contribution of public funds is needed until CCS sustainability is achieved or as long as such public financing is justified through positively imparts to other sectors and balance of benefit vs. cost.

The following provides example projects in the Arab region countries (**Box 4**).

Box 4:
Bahrain:
BAPCO Project:
CO_2Recovery Plant Bapco and Yateem Oxygen, a Bahrain-based industrial gases company, signed a renewable 15-year technical and commercial contract for a CO_2 Recovery Plant. The plant, which will provide an environmentally-friendly alternative for CO_2 extraction at Bapco[63].

Gulf Petrochemical Industries Companies (GPIC):
GPIC installed a Carbon Dioxide Recovery (CDR) Unit to recover $CO_2$from Methanol reformer flue gas. It was among the first companies across the Middle East to launch a project to recover $CO_2$and turn it into useful economic products. In other words, CDR minimized greenhouse emissions and also augmented Methanol production capacity to 120 tonnes per day and also enhanced Urea production capacity in the company's complex located in the island of Sitra[64].

Saudi Arabia:
The Linde Group was awarded a contract to build the world's largest CO_2 purification and liquefaction plant for Jubail United Petrochemical Company (UNITED), a manufacturing affiliate of SABIC (Saudi Basic Industries Corporation). The plant will be designed to compress and purify around 1,500 tonnes per day of raw CO_2 coming from two nearby ethylene glycol plants. The purified gaseous CO_2 will be pipelined through the piping corridor of the Royal Commission of Jubail to three SABIC-affiliated companies for enhanced methanol and urea production. An estimated 500,000 tonnes of CO_2 emissions will be saved each year. The plant will also be capable of producing 200 tonnes per day of liquid CO_2 with food grade quality which will be stored and thereafter supplied by truck to the beverage and food industry. Completion was achieved in 2015 and was the first CCU project of this size to be realised in Saudi Arabia. The reduction of CO_2 emissions was an important aim in both SABIC's and Linde's sustainability strategy.

United Arab Emirates:
Al Reyadah:
The CCUS project of Emirates Steel (ES) is the first project under Al Reyadah, a joint venture between Masdar and Abu Dhabi National Oil Company (ADNOC). Al Reyadah is the Middle East's first specialised company focused on exploring and developing commercial-scale CCUS projects. It consists of three elements: industrial capture of the

[63] Source: http://www.bapco.net/Docs/publication.pdf
[64] http://www.sce.gov.bh/en/PartnershipwiththePrivateSector?cms=iQRpheuphYtJ6pyXUGiNqkweoImOYSRY
http://www.gpic.com/responcibility/CDRmoved/ImplementingCDRMilestones/ImplementingCDRMilestones.aspx

gas from the ES facilities; compression, dehydration at Al Reyadah carbon capture facility (CCF); and transportation of CO_2 gas for injection into ADNOC onshore oil fields for EOR. The project will save precious natural gas, traditionally used to maintain the pressure of oil reservoirs and aid in oil recovery, and free the available natural gas for traditional power generation and water desalination.

The facility captures CO_2 from the direct reduced iron process used at Emirates Steel plants 1 and 2. The captured CO_2 is diverted to the CCF, where the CO_2 is compressed to a supercritical state (dense phase) and dehydrated for delivery into an 8 inch CO_2 pipeline, from Mussafah to the ADNOC oil fields in Rumaitha and BAB, where the CO_2 is injected for EOR[65].

7.5. Role of the private sector:

Private sectors played a crucial role in early development of CCS projects across the globe. However, the role of the private sector could be enhanced through facilitating their engagement through value-chain of CCS by creating market-drivers and support mechanisms. One such example is valuing captured CO_2 or a carbon price indication.

Examples of private sectors involvement are visible as several private sectors were engaged in developing CCS methodologies under CDM and initial development of CCS-CDM project ideas. The following CCUS projects that have been submitted for prior consideration to Designated National Authority (DNA) of Saudi Arabia and UNFCCC as per CDM Modalities and Procedures have been initiated by several private sectors as of today.

- CO_2Recovery Project in Saudi Arabia (Rabigh Refining and Petrochemical Company – Petro Rabigh)
- Construction of liquid-CO_2 plant in Saudi Arabia (Saudi Industrial Gas Company – a subsidiary of the Linde Group)
- SAFCO-V Project CO_2utilization at urea production facility (Saudi Arabian Fertilizer Company)

Similarly, the following two projects were submitted with prior consideration from UAE:

- ESI/ADCO Carbon Capture and Storage (CCS) Project by Abu Dhabi Future Energy Company PJSC (Masdar)
- RAK Power and Carbon Capture Project by Utico Fzc: Utico Middle East, a major private utility and solutions provider in the GCC, said it has joined hands with top coal power company Shanghai Electric to set up 'the world's greenest coal-fired power plant' at a cost of US$408 million in Ras Al Khaimah. The new plant on completion will generate 270 MW of power for UAE's industries in 2015 and will also capture 80 per cent of the carbon.

In order to attract more private sectors involvement in CCS projects, favourable policy framework, enabling institutional settings are crucial as initiation, development and operation of large-scale CCS projects are long-term in nature.

[65] http://www.masdar.ae/assets/downloads/content/268/al_reyadah_factsheet-final-jan_8,_2017.pdf

7.6. Knowledge platforms:

Knowledge platforms on CCS expand from lab-based research activities to experience from early project implementation, operation and maintenance – especially focusing on technology, financing and systems analysis.

There is a large literature on CCS sourced from research activities in this field worldwide. Initial research focused on modelling and systems analysis of CCS integrated with power generation and EOR. However, performance research based on real cases are scarce for point and mobile application of CCS.

The IPCC produced a special report on CO_2 capture and storage including a Summary for Policy Maker in 2005. In April 2013, the *Journal of CO_2 Utilization* was launched, providing multi-disciplinary platforms for the exchange of novel research in the field of CO_2 re-use pathways. In terms of industry best practices and managing risks associated with CO_2 capture, transportation and storage, a set of industry recommended practices has also been developed.

There are several university and research centres that focuses on CCS research, development and demonstration. These research centres are engaged on CCS research covering complete value-chain (technology, policy, regulation and risk assessment). The following are the research centres that are heavily involved in CCUS:

- European CCS Demonstration Project Network (knowledge sharing network) (Belgium)
- EU CCS Technology Centre Mongstad (TCM), in Norway
- Nottingham Centre for Carbon Capture and Storage (UK)
- Centre for Low Carbon Futures (consortium of five UK universities)
- CO_2CRC (Cooperative Research Centre) (Australia)
- DNV GL CCS Cluster (Partnered with Aker Solutions) – Recommended Practices for CO_2 pipeline transport and technology qualifications

Since know-how and technological learning assist in the form of soft 'technology transfer' as part of capacity building, it is therefore important for widening collaboration with active agencies and research centres around the world.

Besides these, there are global knowledge platforms on CCS, for example

- Global CCS Institute https://www.globalccsinstitute.com/
- International CCS Knowledge Centre https://ccsknowledge.com/
- The Carbon Capture and Sequestration Technologies Program at MIT http://sequestration.mit.edu/index.html
- The National Carbon Capture Center, a U.S. Department of Energy-sponsored research facility https://www.nationalcarboncapturecenter.com/

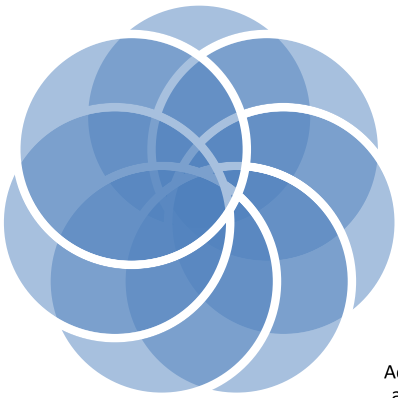
The following **Figure 2** provides an overview of the global and regional knowledge sharing platforms.

Bilateral CCS partnerships as platform for sharing technology developments and increasingly for direct collaboration on CCS projects: between the US and China in late 2014, Canada-US Clean Energy Dialogue, China –Europe - UK- Australia

Regional and Bilateral collaboration: contributing to development of regional strategies for CCS deployment: European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP), NA CCS Association (NACCSA), Coordinating Committee for Geoscience Programs in East and Southeast Asia (CCOP).

International CCS test centers:

Test and develop CCS solutions. Various test centers have recently established an International CCS Test Centre Network to share knowledge of the technological developments, construction and operational experience associated with CO_2 capture from flue gas. The network also intends to establish performance indicators and promote technology standardization.



IEA Greenhouse Gas R&D Program (IEAGHG):

Established in 1991 as a "Technology Collaboration Program" (TCP). IEAGHG studies and evaluates technologies to reduce GHG emissions from use of fossil fuels and much concentrated on CCS technology, economics and policy related matters.

Carbon Sequestration Leadership Forum (CSLF):

Established in 2004 to facilitate the development and deployment of CCUS technologies via collaborative efforts that address key technical, economic and environmental obstacles. The CSLF also promotes awareness and champions legal, regulatory, financial, and institutional environments that can be conducive to CCS. CSLF has a Ministerial Forum and Saudi and UAE are among its members

Global CCS Institute (GCCSI): founded in 2009,

Active in promoting the development, demonstration and deployment of CCS. The GCCSI gathers relevant groups of stakeholders from across the globe (government, industry, research community and civil society,.) to drive the adoption of CCS. The Institute performs analysis, shares expertise, builds capacity and provides advice to its members and more widely, on the potential and challenges of CCS.

Figure 2: "Expanding global, regional and bilateral CCS collaboration"[66]

7.7. Potential for regional cooperation and integration:

Among the Arab countries, GCC countries are in an advanced stage in demonstrating CCS and CCUS capabilities in terms of implementing first CCS-EOR and the world's largest CCUS projects. Application of CCS is also taking place in several industrial facilities for example, in UAE first's CCUS project of Emirates Steel developed by Masdar and ADNOC and Saudi Arabia's world largest CO_2 purification and liquefaction project initiated by SABIC. However, several countries in the Arab region has planned CCS and CCUS integrated with energy and other industries (other than oil and gas) as a key option in carbon management.

There are many factors that favour CCS in the GCC region. In fact, as all power generation plants in the Arab region are fossil-fuel based implies that significant proportions of carbon emissions are concentrated in large point sources. In addition, heavy industries in the GCC region are concentrated in a number of locations making them suitable for CCS integration in terms of carbon capture and optimal in transport infrastructure framework design. Also CO_2 storage sites in the region are widely available. The depleted oil and gas fields in the region are primary storage sites and naturally proven for their containment characteristics. They offer large reservoirs which can be used for storing many decades of carbon production in the

[66] R. Sedaoui, "Deployment of Carbon Capture, Use and Storage in the Arab Region: Challenges and Opportunities & linkage to NDCs projects on mitigation", Eighth Regional Training Workshop on Capacity Development for Climate Change Negotiations for the Arab Countries , Beirut, 10-13 April 2017

region. CCS activity in GCC region has two focuses: validation of large scale projects in local conditions and support for advanced R&D activities and collaboration.

However, further learning is needed on long-term CO_2 storage characteristics and safe extraction methods for oil and gas to maintain integrity for CO_2 storage without any leakage of carbon.

Besides GCC's advancement of CCS and CCUS, there are a number of Global Networks on CCS:

- Carbon Sequestration Leadership Forum (CSLF) – the CSLF is a Ministerial-level international climate change initiative focused on development of technologies for capture and geologic storage of CO_2.
- IEA International CCS Regulatory Network
- 4-Kingdom Initiative on CCS
- Carbon Capture, Use and Storage (CCUS) Action Group under Clean Energy Ministerial (CEM)
- Carbon Capture and Storage Association

CCS initiatives such as regional CCS transportation network as well as a common reservoir, by CSLF could also be translated in developing countries for example, in the context of developing African countries. GCC is one of the example in the Arab region, which could foster cooperation with other countries beyond GCC member countries.

8. Conclusion and Recommendations

If the world is to develop sustainably, it is essential to secure access to affordable, reliable, sustainable, and modern energy, improve energy efficiency, and to improve the environmental footprint of the energy sector.

Despite the adoption of alternative energy sources and energy efficient systems to reduce the rate of CO_2 emissions, the cumulative amount of CO_2 in the atmosphere needs to be reduced to limit the detrimental impacts of climate change. Carbon Capture Utilization and Storage (CCS or CCUS) is a proven technology in meeting climate change mitigation and has been in safe and commercial operation for over four decades [67]. CCUS could contribute for achieving sustainable energy future where fossil fuels will continue to play a major role.

The CCUS technology is now proven in many applications and the portfolio of operating projects has grown and diversified. However, the availability of CCS in the future depends on investment today. An expanded project pipeline is needed to allow for more new projects to become operational in 2020 and beyond.

The CCUS can also be beneficiary for Oil and Gas Arab's economy diversification strategy if carefully structured (institutional alignment) and when proper policy is in place. However, the challenges facing CCS (including for the Arab countries) are well known and must now be addressed with a renewed sense of urgency if global climate goals are to be met.

Further government deliberations in support of CCS and other mitigation technologies will hopefully arise from the UNFCCC's "Facilitative Dialogue" and the IPCC's "Special Report" on

[67] GCCSI (2017b)

the impacts of limiting global warming to 1.5°C, both to be released in 2018. These are highly likely to reinforce the important role of CCS and potentially lead to enhanced awareness and pressure on governments to implement measures that will strengthen the business case for CCS.

The “Global Stocktake on Mitigation” in 2023 and the second round of Nationally Determined Contributions (NDCs) expected in 2025 are critical decision points for governments to review their commitments; however, waiting for these junctures to act on CCS will lock in a much higher level of emissions and make meeting the Paris climate targets prohibitively expensive.

From Arab region perspective, challenges and opportunities do exist to expand the deployment of CCUS technology to attract more investments and private sectors involvement in the development and operation of large-scale CCUS projects. The following are key recommendations and enabling factors for wide deployment of CCUS within the Arab region:

- Significant policy support is required to deploy CCUS at a scale that is commensurate with the level of GHG emission reductions required.
- Long-term commitment and stability in policy frameworks for CCUS deployment are required.
- Targeted policies which provide financial incentives for investment will be essential in the near term. New approaches and thinking can also help to drive CCUS forward.
- Governments and industry should explore novel ways of financing and need to work together to ensure that final investment decisions are taken.
- Governments and industry should exploit CCS retrofitting opportunities as CCS has the unique capacity to reverse the “lock-in” of emissions from existing infrastructure.
- Governments should identify opportunities where policies and local and commercial interests align to encourage CCS deployment, and introduce measures targeted at creating new and strengthening existing markets.
- Differentiated business models for CO_2 capture, transport and storage could address some of the challenges faced by integrated projects.
- Since know-how and technological learning assist in the form of soft ‘technology transfer’ as part of capacity building, it is therefore important for widening collaboration with active agencies and research centers around the world.

Annex 1: CCS projects

Facility name	Lifecycle stage	Country (State/District)	CO_2 (Mtpa)	Operation date	Industry	Capture type	Transport type	Transport length (km)	Primary storage type
Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants)	Operating	USA (Texas)	0.4-0.5	1972	Natural gas processing	Industrial separation	Pipeline	316	Enhanced oil recovery
Enid Fertilizer	Operating	USA (Oklahoma)	0.7	1982	Fertiliser production	Industrial separation	Pipeline	225	Enhanced oil recovery
Shute Creek Gas Processing Plant	Operating	USA (Wyoming)	7	1986	Natural gas processing	Industrial separation	Pipeline	Multiple, maximum of 460 km	Enhanced oil recovery
Great Plains Synfuel Plant and Weyburn-Midale	Operating	CANADA (Saskatchewan)	3	2000	Synthetic natural gas	Industrial separation	Pipeline	329	Enhanced oil recovery
Century Plant	Operating	USA (Texas)	8.4	2010	Natural gas processing	Industrial separation	Pipeline	64 to 240	Enhanced oil recovery
Air Products Steam Methane Reformer	Operating	USA (Texas)	1	2013	Hydrogen production	Industrial separation	Pipeline	158	Enhanced oil recovery
Coffeyville Gasification Plant	Operating	USA (Kansas)	1	2013	Fertiliser production	Industrial separation	Pipeline	112	Enhanced oil recovery
Lost Cabin Gas Plant	Operating	USA (Wyoming)	0.9	2013	Natural gas processing	Industrial separation	Pipeline	374	Enhanced oil recovery

Petrobras Santos Basin Pre-Salt Oil Field CCS	Operating	BRAZIL (Santos Basin)	Approx. 1.0	2013	Natural gas processing	Industrial separation	No transport required (direct injection)	Not applicable	Enhanced oil recovery
Boundary Dam Carbon Capture and Storage	Operating	CANADA (Saskatchewan)	1	2014	Power generation	Post-combustion capture	Pipeline	66	Enhanced oil recovery
Uthmaniyah CO2-EOR Demonstration	Operating	SAUDI ARABIA (Eastern Province)	0.8	2015	Natural gas processing	Industrial separation	Pipeline	85	Enhanced oil recovery
Abu Dhabi CCS Project (Phase 1 being Emirates Steel Industries)	Operating	UNITED ARAB EMIRATES (Abu Dhabi)	0.8	2016	Iron and steel production	Industrial separation	Pipeline	43	Enhanced oil recovery
Petra Nova Carbon Capture	Operating	USA (Texas)	1.4	2017	Power generation	Post-combustion capture	Pipeline	132	Enhanced oil recovery
Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream	In construction	CANADA	0.3-0.6	2018	Fertiliser production	Industrial separation	Pipeline	240	Enhanced oil recovery
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream	In construction	CANADA	1.2-1.4	2018	Oil refining	Industrial separation	Pipeline	240	Enhanced oil recovery

Yanchang Integrated Carbon Capture and Storage Demonstration	In construction	CHINA	0.41	2018-19	Chemical Production	Industrial separation	Pipeline	150	Enhanced oil recovery
Sinopec Qilu Petrochemical CCS	Advanced development	CHINA	0.5	2021	Chemical Production	Industrial separation	Pipeline	75	Enhanced oil recovery
Lake Charles Methanol	Advanced development	UNITED STATES	4.2	2022 (Institute estimate)	Chemical production	Industrial separation	Pipeline	244	Enhanced oil recovery
Texas Clean Energy Project	Advanced development	UNITED STATES	1.5-2.0	2022 (Institute estimate)	Chemical production	Industrial separation	Pipeline	Not specified	Enhanced oil recovery
Sinopec Eastern China CCS	Early development	CHINA	0.5	2020-2021	Fertiliser production	Industrial separation	Pipeline	200	Enhanced oil recovery
Sinopec Shengli Power Plant CCS	Early development	CHINA	1	2020's	Power generation	Post-combustion capture	Pipeline	80	Enhanced oil recovery

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