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Study on the Potential for the Promotion of Carbon Dioxide Capture, Utilisation, and Storage in ASEAN Countries

Current Situation and Future Perspectives

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Study on the Potential for the Promotion of Carbon Dioxide Capture, Utilisation, and Storage in ASEAN Countries: Current Situation and Future Perspectives

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Preface

The total primary energy supply of the Association of Southeast Asian Nations (ASEAN) will increase by 2.8 times from 2017 to 2050, and its share of fossil fuels in 2050 will be just less than 90% in the business-as-usual case and 80% in the Alternative Policy Scenario (APS) case, which will include ambitious targets for promoting energy efficiency and conservation (EEC) activities and the deployment of variable renewable energy (VRE), such as solar photovoltaics. The main use of coal and gas will be as fuels for power generation, and the share of power generation for both will be 80% for the BAU and 70% for the APS. On the other hand, oil is and will be consumed mainly for road transport activities, such as vehicles. Consequently, carbon dioxide (CO_2) emissions will increase by 3.2 times (1.2 billion tonnes of carbon in 2050) from 2017 to 2050 under the BAU. If ASEAN can achieve EEC and VRE aggressively, CO_2 emissions will decrease to 0.9 billion tonnes of carbon in 2050 and this could be significant (a 28% reduction) but will not be sustainable compared to the current levels (0.4 billion tonnes of carbon in 2017). Many of the ASEAN Member States will need to accomplish higher economic growth in order to catch up with developed countries, and, thus, they will surely need electricity to accelerate their economic growth. Considering these matters, one of the solutions for ASEAN will be the application of carbon capture, utilisation, and storage (CCUS).

ASEAN will continue to consume coal and gas for its power generation but will be able to reduce CO_2 emissions from coal and gas combustion with CCUS in future. However, CCUS is not currently available as an energy technology in terms of the economic aspect (cost). Thus, ASEAN has to start collaborating and cooperating with Organisation for Economic Co-operation and Development (OECD) countries and joining discussions on CCUS. In addition, ASEAN has to seek CCUS value chains covering the capture of CO_2, the application of technology for reducing CO_2, and the storage of CO_2 in ASEAN or the East Asian Summit region. I hope this report encourages ASEAN Member States to work towards the implementation of CCUS.

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This project received tremendous support from the Ministry of Economy, Trade and Industry (METI) of Japan. Most of the findings on the current state of CCUS included in the report are based on a METI-commissioned research project from 2019. The invaluable advice received from METI throughout the planning stage of the 3rd East Asia Energy Forum enabled fruitful discussion on the topic of creating a cooperative network in Asia for CCUS. The Global Carbon Capture Storage Institute also provided insightful information in terms of the technical and economic aspects of this project. The project members would also like to extend their appreciation to all speakers and organiser team members for the successful implementation of the 3rd East Asia Energy Forum, which provided valuable inputs for the report.

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Abbreviations and Acronyms

APS	Alternative Policy Scenario
ASEAN	Association of Southeast Asian Nations
BAU	Business as Usual
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation, and Storage
CEM	Clean Energy Ministerial
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSLF	Carbon Sequestration Leadership Forum
DAC	Direct Air Capture
EAEF	East Asia Energy Forum
EEC	Energy Efficiency and Conservation
EOR	Enhanced Oil Recovery
EU	European Union
F	Fluorine
GCCSI	Global CCS Institute
Gt	Gigatonnes
H_2S	Hydrogen Sulphide
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
JCM	Joint Crediting Mechanism
METI	Ministry of Economy, Trade and Industry
Mt	Megatonne
Mtoe	Million Tonnes of Oil Equivalent
NDC	Nationally Determined Contribution
NOx	Nitrogen Oxides
NZE2050	Net-zero Scenario

SDS	Sustainable Development Scenario
SOx	Sulphur Oxides
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
US NETL	United States National Energy Technology Laboratory

Executive Summary

Growing importance of carbon capture, utilisation, and storage in the transition to decarbonisation.

The development of carbon capture, utilisation, and storage (CCUS) has always been closely aligned with the energy and environment circumstances of the time. Since the adoption of the Paris Agreement in 2015, many have come to realise that we need to rely on CCUS technology to achieve the 1.5-degree scenario or even the 2-degree scenario. This is not only true for the major world economies and corporations that began to announce 'net-zero' ambitions as early as 2050 but also for Association of Southeast Asian Nations (ASEAN) countries. At the 3rd East Asia Energy Forum (EAEF), it was pointed out that CCUS is 'particularly crucial' as it is a technology that can contribute to the energy transition of ASEAN countries in meeting the goals of the Paris Agreement whilst allowing for a supply of affordable energy to meet the growing energy demand (ERIA, 2020).

CCUS has become something that attracts not only policy importance but also commercial interest. Whilst some predicted that the coronavirus disease (COVID-19) will shift the policy focus away from the climate change agenda, it has, in fact, played a role of reinforcing climate change response measures. Numerous developed countries have pledged substantial budget for economic stimulus through 'green recovery' and significant investment in CCUS technology development with the view towards commercialisation and international cooperation. As also discussed at the 3rd EAEF, there is also growing interest from the private sector for deploying CCUS in the ASEAN region.

CCUS technology is well proven in most cases, whilst further enhancement for carbon removal technology is needed to bring down its cost and create a sustainable value chain.

Carbon capture from industrial sources with high carbon dioxide (CO_2) concentrations, such as power plants, chemical plants, oil refineries, and steel plants, is an already proven technology, and, in most cases, its implementation is dependent upon not on its technical feasibility its but policy and/or financial capabilities. The transport and storage of CO_2, likewise, also have good track records even though the long-term storage of CO_2 for the purpose of containment and the accounting of quantity of CO_2 stored for the purpose of meeting emissions reduction targets are still limited. CO_2 removable from low-concentration sources, such as direct air capture from the atmosphere, requires more pilot cases to prove its effectiveness and cost performance. In terms of utilisation, utilising the captured CO_2 to create value-added products, such as hydrogen and synthetic fuel, is being planned and demonstrated around the world. In addition, the creation of a value chain of the captured CO_2 is likely to greatly contribute to the commercialisation of CCUS activities through the generation of profits, which will, in turn, lead to further technological development.

Hub and cluster business models with an industrial development approach to match national policies.

A hub and cluster model is said to be a type of business model that can solve the problems of the high-risk and high-cost nature of CCUS by allocating the risks amongst various parties and reducing costs via shared infrastructure. Additionally, as already seen in some countries, a hub and cluster model can also play a role in new industrial development, such as CO_2 storage services for several emitting industrial facilities in Norway, the hydrogen economy for industrial hubs planned in the United Kingdom, and synthetic fuel production in the Netherlands, etc. Whilst many countries in Asia are also planning for COVID-19 recovery plans as well as second nationally determined contributions, engaging with the hub and cluster model of CCUS and involving the industrial sector may contribute to both economic and climate goals.

The creation of a hub and cluster model in ASEAN and East Asia needs extensive collaboration and capacity building through a regional platform.

ASEAN and East Asia comprise a diverse area with some common issues. Most countries are highly vulnerable to climate change and need immediate action but lack capacity. At the same time, there are government institutions as well as the private sector with applicable technologies. As seen in European case studies, the hub and cluster model is most effectively done through international collaboration. Through the creation of a common platform, efforts can be aggregated to explore potential storage sites as well as providing fora to discuss practical issues through capacity building, such as legal and policy frameworks, technology applicability, and business model, as well as financing options most relevant to the region.

Introduction

The report consists of four chapters. Chapter 1 covers global policy development with an emphasis on climate change. It discusses the historical trend where CCUS first started as a measure to boost oil production in the time of an oil crisis and is now being increasingly promoted as a measure to tackle climate change issues. It also covers the trend in increasing investment by governments as CCUS is often promoted as an economic development vehicle.

Chapter 2 discusses the technologies required for CCUS for each segment: the separation and capture of CO_2, transport, utilisation, and storage. It introduces and explains the technical outline and discusses their application in ASEAN and the East Asia region. Chapter 2 reveals that most technologies involved in CCUS are proven and can be applied to ASEAN and East Asia even though consideration must be made to account for the long-time storage of CO_2 if CCUS is implemented as part of a carbon credit scheme. It also covers new technologies that have attracted attention, such as direct air capture which removes CO_2 from the atmosphere, leading to negative emissions.

Chapter 3 describes business model case studies of some early-start projects with a focus on the hub and cluster model. It introduces the advantages of such a business model and some of the pre-existing conditions that have contributed to the early-start projects. It also discusses its development potential in ASEAN and East Asia.

Chapter 4 explores the view towards creating a regional CCUS network in ASEAN and East Asia and its expected function for further promoting CCUS development in the region. It introduces discussions held at the CCUS panel session at the 3rd EAEF by key stakeholders comprising representatives from ASEAN governments, academia, multilateral development banks, the private sector, international organisations, and financial institutions, and the outputs referring to the need for a regional platform to further facilitate regional collaboration and capacity building to develop a workable CCUS business case in ASEAN.

Chapter 1

Global State of Affairs for Carbon Capture, Utilisation, and Storage

1. Historical development

Carbon capture, utilisation, and storage (CCUS) has been adopted for almost half a century to address important economic and environmental issues. A classic type of CCUS can be found in enhanced oil recovery (EOR), which involves the capturing of carbon dioxide (CO_2) from fossil fuel production or industrial plants and injecting the captured CO_2 into oil wells. EOR leads to improved oil production and was favoured by oil companies that wanted to prolong the longevity of oil wells. It was adopted by many oil companies in the United States amidst the oil crises in the 1970s. EOR eventually spread to other oil-producing countries, such as China, Saudi Arabia, and Brazil, over the 2000s and 2010s. In China, in particular, the dependence on fossil fuels by the energy and petrochemical industries, as well as the resulting CO_2 emissions in these sectors, has prompted them to explore EOR. Climate change is another issue that has given renewed focus to CCUS. Pioneered by Norway since the 1990s, CCUS for the purpose of CO_2 sequestration is being considered, tested, and implemented by countries with high goals for climate mitigation and is especially active amongst European countries. Table 1.1 lists commercial CCUS projects by country.

Table 1.1. Commercial CCUS Projects by Country

	EOR	Onshore CCS	Offshore CCS
Australia		1	
Brazil	1		
Canada	3	1	
China	2		
Norway			2
Qatar	1		
Saudi Arabia	1		
United Arab Emirates	1		
United States	12	2	

CCUS = carbon capture, utilisation, and storage, EOR = enhanced oil recovery.
Note: The Boundary Dam project in Canada involves both EOR and CCS. The utilisation targeted in this classification is EOR.
Source: Created by Mitsubishi Research Institute based on GGCSI (2020b).

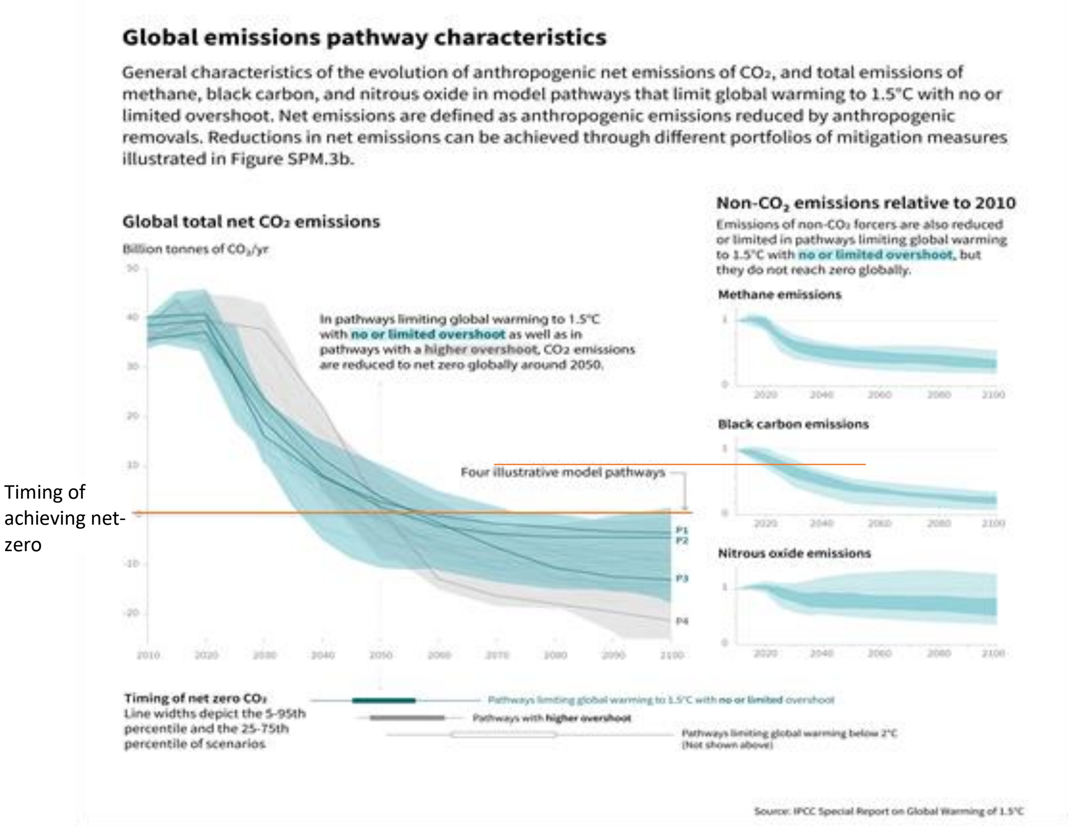
2. Global policy agenda

2.1. Paris Agreement

As previously stated, climate change issues have led to the renewed rise of CCUS in recent years. Global demand for the mitigation of climate change culminated in the Paris Agreement, which was agreed upon by participating parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. The Paris Agreement set the goal of limiting global warming to well below 2-degrees Celsius, and preferably below 1.5-degrees Celsius, compared to pre-industrial levels.

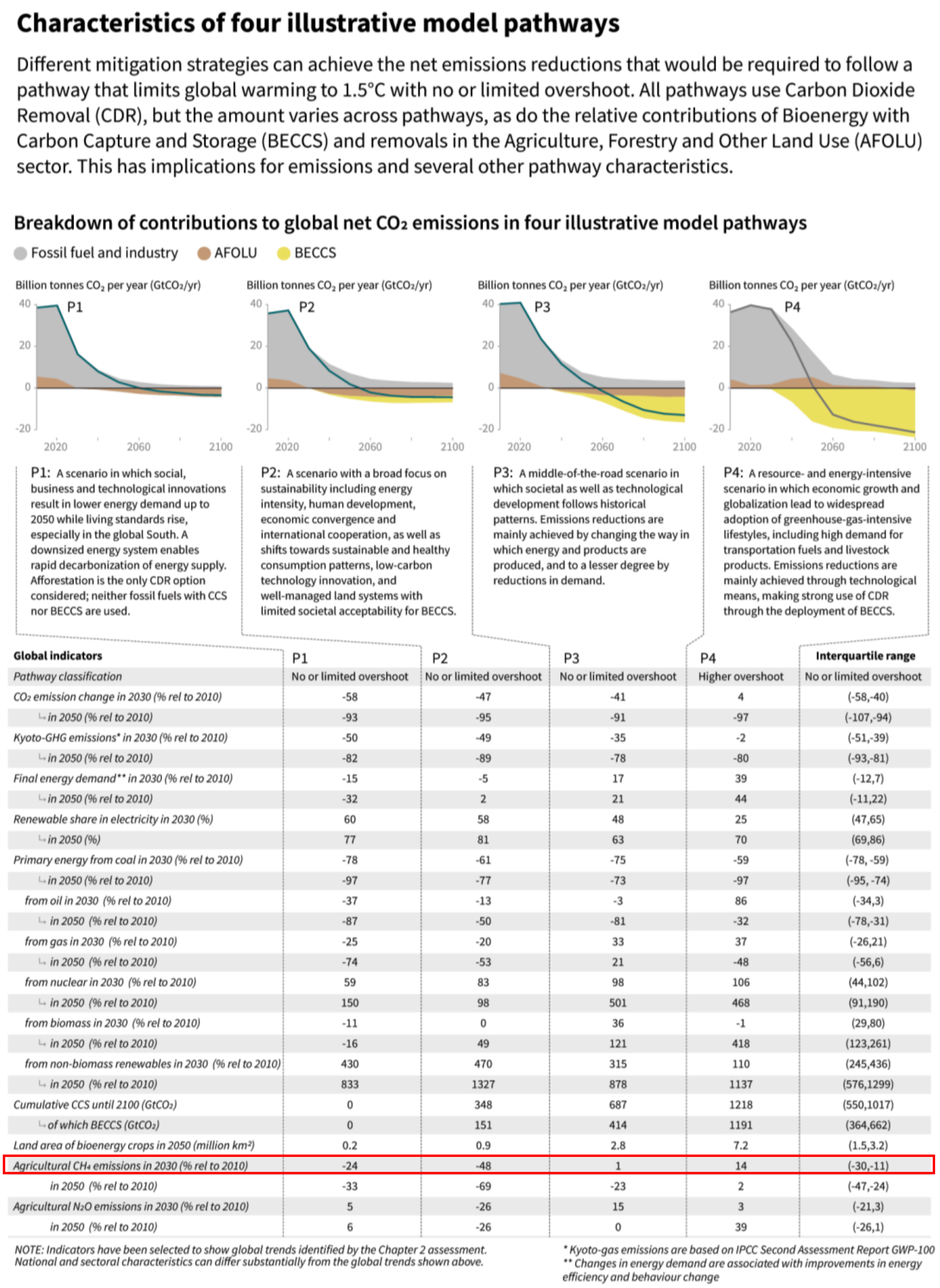
Whilst CCUS was rarely identified as a climate change mitigation measure in the nationally determined contributions (NDCs) submitted by the parties following the ratification of the Paris Agreement, the Intergovernmental Panel on Climate Change (IPCC) recognised the significant role of CCUS in achieving the 1.5-degree target in its 'Special Report: Global Warming of 1.5℃'. The report, in developing the four pathways towards achieving the 1.5-degree target, includes CCUS technology in three out of the four pathways. As described in Figure 1.1, the amount of accumulative CO_2 removal by CCUS for Pathway 2, Pathway 3, Pathway 4 is 348 gigatonnes (Gt) of CO_2, 687 Gt of CO_2, and 1,218 Gt of CO_2, respectively. As demonstrated in Figure 1.2., analysis by the IPCC reveals that the sooner the expected achievement of net-zero, the greater the dependence on CO_2 removal by CCUS (IPCC, 2018).

Figure 1.1. Characteristics of Global Emissions Pathways



Note: Author added the red line describing the timing of achieving net-zero.
Source: IPCC (2018).

Figure 1.2. Four Illustrative Model Pathways and the Role of CCUS



Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limits global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways

P1: A scenario in which social, business and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A downsized energy system enables rapid decarbonization of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource- and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas-intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or limited overshoot	No or limited overshoot	No or limited overshoot	Higher overshoot	No or limited overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-58,-40)
↳ in 2050 (% rel to 2010)	-93	-95	-91	-97	(-107,-94)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-51,-39)
↳ in 2050 (% rel to 2010)	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12,7)
↳ in 2050 (% rel to 2010)	-32	2	21	44	(-11,22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47,65)
↳ in 2050 (%)	77	81	63	70	(69,86)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
↳ in 2050 (% rel to 2010)	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
↳ in 2050 (% rel to 2010)	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
↳ in 2050 (% rel to 2010)	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
↳ in 2050 (% rel to 2010)	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
↳ in 2050 (% rel to 2010)	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(245,436)
↳ in 2050 (% rel to 2010)	833	1327	878	1137	(576,1299)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550,1017)
↳ of which BECCS ($GtCO_2$)	0	151	414	1191	(364,662)
Land area of bioenergy crops in 2050 (million km²)	0.2	0.9	2.8	7.2	(1.5,3.2)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-47,-24)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,3)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

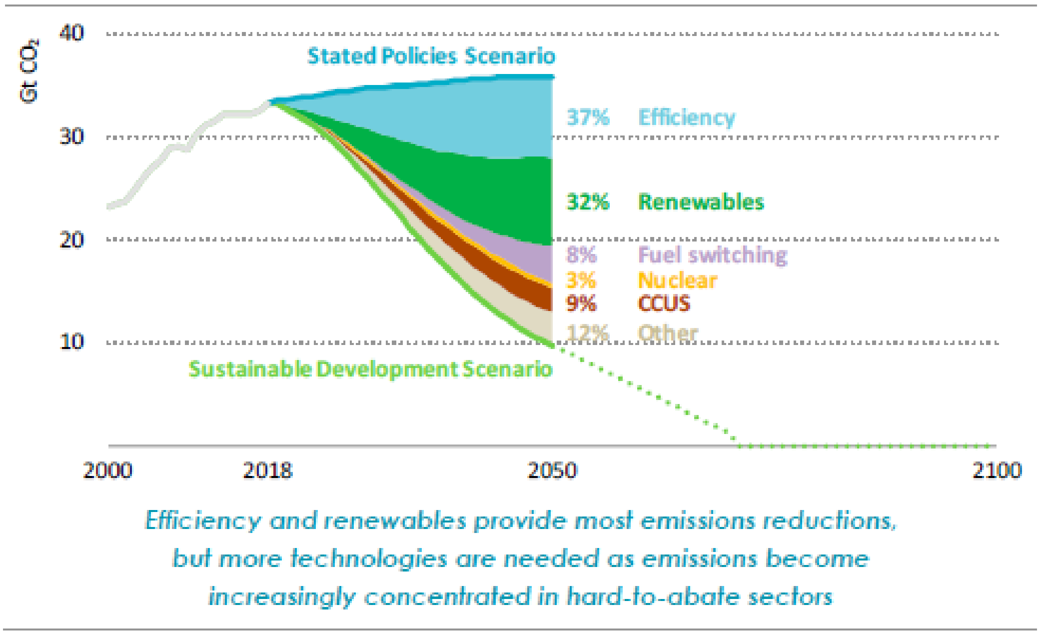
NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on IPCC Second Assessment Report GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

CCS = carbon capture and storage, CO_2 = carbon dioxide, GHG = greenhouse gas, Gt = gigatonne.
Note: The author added the red box describing the emissions removal contribution by CCS.
Source: IPCC (2018).

The International Energy Agency (IEA) estimated that in order to deliver its Sustainable Development Scenario (SDS), which is in line with Paris Agreement's goals and expects to achieve net-zero by 2070, 9% of its cumulative energy-related emissions reduction is to be provided by CCUS as described in Figure 1.3. The mass of CO_2 captured annually in energy-related emissions using CCUS is expected to go up from 38 megatonnes (Mt) of CO_2 in 2018 to about 763 Mt in 2030 and 2,776 Mt in 2050 (IEA, 2019).

Figure 1.3. CCUS in Energy-related Emissions Reduction in the International Energy Agency's Sustainable Development Scenario



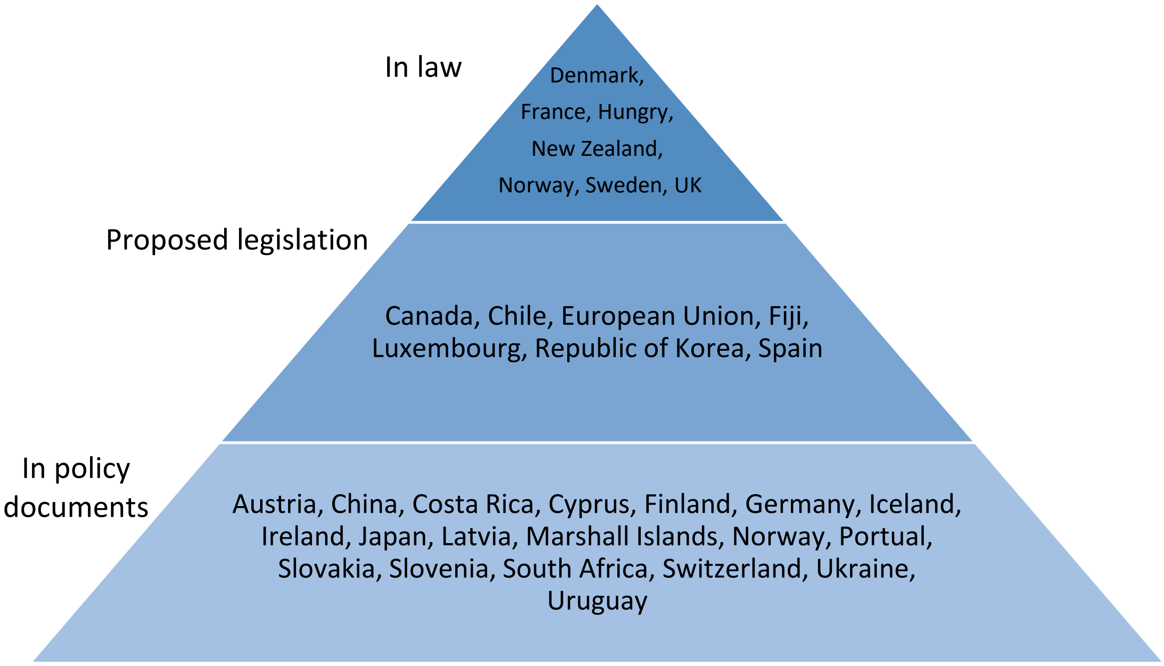
CCUS = carbon capture, utilisation, and storage, CO_2 = carbon dioxide, Gt = gigatonne.
Source: IEA (2019).

With the onset of many governments and multinational companies announcing net-zero goals by 2050, in 2020, the IEA developed a new 'net-zero scenario' (NZE2050), in which the IEA emphasises that CCUS needs to be deployed more and faster, including equipping CCUS with existing facilities, whilst estimating the shift from net-zero achievement year from 2070 to 2050 means approximately 50% more CCUS deployment (IEA, 2020a). The IEA states that CCUS will be used to capture emissions from around 270 million tonnes of oil equivalent (Mtoe), or 3.5 % of the total fossil fuel consumption in NEZ2050 in 2030. This translates into 1.15 billion tonnes of energy and industrial sector CO_2 emissions being captured (IEA, 2020b).

2.2. 'Net-zero' goals by governments and corporations

As indicated as a background to developing the IEA's NZE2050, there has been a recent surge in the announcement of 'net-zero' ambitions by governments, notably by industrial countries in Asia. China announced its 2060 net-zero goal in September 2020, whilst Japan and the Republic of Korea (henceforth, Korea) both made their 2050 net-zero announcements in December 2020. Figure 1.4 shows the countries with net-zero announcements in accordance with the level of policy enforcement. These announcements by governments are accompanied by plans to vigorously support the introduction of measures through CCUS.

Figure 1.4. Net-zero Commitments by Legal Status



UK = United Kingdom.
Note: Japan is reported to be in the process of drafting new legislation for its net-zero target as discussed at the Ministry of Environment working group on an institutional framework to promote global warming countermeasures, held on 21 December 2020 (MOE, 2020).
Source: Created by project members based on IEA (2020b) and Energy and Climate Intelligence Unit (2020). When the two sources conflicted, the author prioritised the latter due to its more recent publication.

Preceding many governments’ announcements were pledges of net-zero by corporations around the world. The UNFCCC reported in September 2020 that the commitments of non-state actors (such as regional and local governments, private corporations, and citizens’ groups) to net-zero doubled in less than a year. 1,101 businesses participate in the United Nations’ Race to Zero campaign, most of whom pledge net-zero by 2050. Some ASEAN companies are also participants in this campaign as follows (UNFCCC, 2020):

- C.P. Group, Thailand
- Charoen Pokphand Group Co., Ltd., Thailand
- City Developments Limited (CDL), Singapore
- Sarawak Energy Berhad, Malaysia
- The Lux Collective Ltd, Singapore
- Tai Wah Garment Industry Sdn. Bhd., Malaysia

In addition, Petronas became the first oil and gas company in Asia to declare its ambition to reach net-zero by 2050. As described, there is a clear momentum of increased ambition both on the government and corporate sides that would give a strong foundation for policies and promotion measures specified for CCUS as a climate change mitigation measure.

2.3. CCUS in COVID-19 related economic recovery plans

The year 2020 saw a big boost to budgetary commitments to CCUS by some governments around the world. This movement was spurred by the need for package programmes to stimulate economies ailing from the effects of pandemic and the implications CCUS has on industrial development, which in turn lead to growth in income and employment. Figure 1.5 shows examples of governments’ strong intentions to increase their support for CCUS with not only the aim of achieving the climate goals but also to impact economic growth through technology development and create new industrial activities coupled with employment, such as the hydrogen economy in conjunction with CCUS and CO_2 storage service. Although most of these announcements have been made by developed nations, they have repercussions on the developing countries in ASEAN as technology deployment is likely to go beyond borders.

Figure 1.5. Examples of Government Announcements for Increased Funding for CCUS Activities

European Union

- €1 billion addition to Horizon 2020 for the research and development of CCUS.
- Horizon Europe (€84.9 billion) to succeed Horizon 2020.

United Kingdom

- US$1.3 billion (£1 billion) as part of the “10 point plan” announced in November 2020.
- Capture 10 megatonnes of carbon dioxide by 2030.
- Establish two CCUS clusters in the 2020s and four by 2030.
- Create 50,000 jobs by 2030.

United States

- President Joe Biden pledges to “double down on federal investments” as part of the Green New Deal.
- Department of Energy announces series of grants for CCUS in 2020, totaling more than US$300 million.

Asia

- Japan announced in December 2020 the establishment of US$19 billion (¥2 trillion) fund for technologies required to reach carbon neutrality by 2050, including CCUS, as part of the economic stimulus package.
- Republic of Korea announced to spend US$7.1 billion (W8 trillion) on the Green New Deal.

CCUS = carbon capture, utilisation, and storage.
Sources: European Union: European Commission (2020a), European Commission (2020b); United Kingdom; Prime Minister’s Office (2020); United States: Department of Energy (2020); Japan: Cabinet Office (2020); Republic of Korea: Korean JongAn Daily (2020).

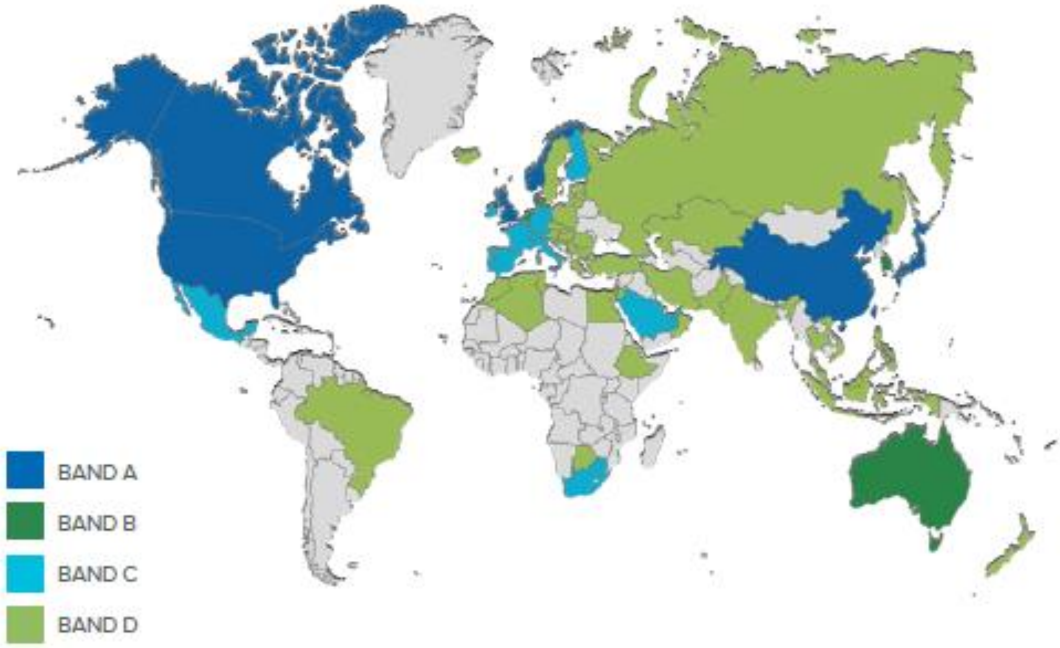
3. Policy and legal framework development

3.1. Global status of legal framework development

Even with strong commitments from governments backed by budgetary measures and the ambitions of the private sector, CCUS will not fully be realised in a commercial sense without a robust legal framework, which is essential in mitigating risks and securing finance.

The Global CCS Institute (GCCSI) studies the state of legal framework development around the world and provides a ranking of countries through its 'CCS Policy Indicator'. In the 2018 report, 68 countries were ranked based on government commitments to and interest in CCS, the provision of public assistance and incentives, capabilities, information sharing and collaboration with other countries, international assistance, market mechanisms, and organisational capacity, etc. as well as the development of policies and regulations by their respective governments. Figure 1.6 describes the classification of the countries into four bands, with Band A signifying most advanced favourable legal systems (GCCSI, 2018). Table 1.2 shows the global top three countries plus Asian countries in the top 10 in the 2018 Global CCS Institute Policy Report.

Figure 1.6. Global CCS Institute Global Legislation Rankings



Note: Band A = Score ≥ 27/100 ('clear leaders'), Band B = Score 23/100 to 26/100 ('sound foundation for policy development'), Band C = Score 11/100 to 22/100 ('very immersion'), Band D = Score ≤ 10/100 ('very immersion').

Source: GCCSI (2018).

Table 1.2. Top Three Countries Plus Asian Countries in Top 10 in the 2018 Global CCS Institute Policy Report

Ranking	Country	Overall Score (value out of 100)	Change from 2015 Reports	Notable Points
1	Norway	56 (Band A)	▲	・ Norway's score increased in 2018 because the government decided to support Front End Engineering and Design (FEED) costs for two large CCS facilities (the previous score in 2015 was 40).
2	United Kingdom	46 (Band A)	▼	・ The Government of the United Kingdom expressed its long-term commitment to CCS in its 'Clean Growth Strategy' published in 2017. ・ GCCSI took the establishment of the 'CCUS Cost Challenge Taskforce' positively.
3	United States	41 (Band A)	▼	・ The United States' score dropped significantly after announcing its withdrawal from the Paris Agreement. ・ The Global CCS Institute took the expansion of the CCUS/CCS eligible for the 45Q tax credit positively.
5	China	40 (Band A)	▲	・ The Chinese government continues to provide various support for CCUS/CCS projects. ・ China's state-owned oil company had its first large-scale CCS project in 2018, and two other state-owned companies plan to begin construction of large-scale CCS facilities.
6	Japan	39 (Band A)	▲	・ Since the Japanese government is providing support for the demonstration project, the score increased from the previous time.

CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage.
Source: Created by project members based on METI (2020) and GCCSI (2018).

3.2. Implications for ASEAN and East Asia

The GCCSI observes that there are mainly two types of legal framework development in some early mover countries. One type is the CCUS-specific model of legislation to regulate the entire process of CCUS. A typical case of this type is the European Union's (EU) CCS Directive. The other type is utilising existing regulations on oil and gas activities or environmental regulations. An example of this second type is the United States, where Underground Injection Control regulations established for the purpose of safeguarding drinking water are used to govern CCUS activities. Table 1.3 summarises the key issues in establishing CCUS-related legal frameworks identified through MRI's previous research based on interviews with government and industry stakeholders in key countries.

Table 1.3. Key Issues in Establishing CCUS/CCS Laws and Regulations

Importance	Number	Items	Points of Contention
Medium	1	Comprehensive regulations on CCUS/CCS	・Control CCUS/CCS within the framework of existing oil and gas industry and environmental laws and regulations ・Introduction of new regulations specific to CCUS/CCS
High	2	Classification of CO_2	・Pollutants, waste (whether injection into geological formations is considered an act of disposal), etc. ・Commodities (CO_2 trading)
High	3	Land use, ownership, and permits	・Ownership and use rights of land and underground (including the pore space) under existing domestic laws
Medium	4	London Convention, London Protocol (sub-seabed injection)	・Response to treatment under the London Protocol to the London Convention (limited to projects involving transport by vessels and sub-seabed injection)
High	5	Legal liability and how to handle damages	・Rules for the allocation of liabilities after the closure of the CCS-EOR site, the applicable period, the liability transfer, etc.
High	6	Financial security	・Conditions for obtaining permission related to CCUS/CCS include the existence and severity of financial security requirements
High	7	Monitoring technique	・Existence of explicit monitoring methods
Medium	8	Handling of CO_2 transboundary movement	・Presence of laws and regulations on transboundary movements of CO_2 (only sites where transboundary CO_2 migration may occur)
Low	9	Site selection method and exploration method	・Requirement of specific technologies to be applied to site selection and exploration methods

CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, CO_2 = carbon dioxide, EOR = enhanced oil recovery.

Note: 'High' means important items. 'Medium' means important items but limited to related projects. 'Low' indicates items that are often referred to as laws and regulations but are low in priority from the viewpoint of the development of laws and regulations as they can be integrated into guidelines, etc.

Source: Created by project members based on METI (2020).

As ASEAN countries embark on developing legal frameworks for CCUS, the GCCSI indicates that the following are important points of consideration (GCCSI, 2020a):

- Whether to develop CCUS-specific legislation and the time needed to develop such legislation;
- Whether to regulate across the full chain of storage aspects or focus on discrete aspects;
- Addressing novel aspects and risks unique to CCUS, such as the classification of CO_2 for the purpose of permanent storage, temporal aspects of technology deployment, and arrangements for the long-term management of CO_2 storage and the related liability; and
- Administrative implications and arrangements for the regulatory framework to be considered.

Box 1. Examples of Different Types of Legal Framework

Case 1: Comprehensive CCS regulation in the European Union (EU CCS Directive)

- Regulates site selection and exploration, storage permits, carbon dioxide (CO_2) stream composition, monitoring and reporting, closure and post-closure obligations, transfer of responsibility, financial security, and financial contributions.
- Incentives are provided through various funding schemes and the EU emissions trading scheme.

Case 2: Utilisation of existing legal framework in the United States (Underground Injection Control Program)

- Regulation was originally developed to control underground activities for the safeguarding of drinking water.
- Regulated depending on Class II (CCS-EOR) and Class IV (Storage).
- Incentive is provided by Section 45Q of the Internal Revenue Code that stipulates CO_2 pricing to rise to US$50 for storage projects and US$26 for CCS-EOR projects.
- The guidance on 45Q also clarifies some of the liability issues, such as the recapture requirement of CO_2 in the event of leakage (GCCSI, 2020c).

4. Potential for developing CCUS projects

4.1. CO_2 storage demand and storage potential

As stated in Section 2, the amount of CO_2 to be stored globally is expected to reach around 5.6 Gt of CO_2 in 2050. On the question of whether this is enough storage capacity to accommodate the demand, GCCSI estimates there is plenty. According to GCCSI findings, the total amount of CO_2 storage resources in major oil and gas fields in selected countries alone amounts to approximately 310 Gt. In addition to these sites, the amount of CO_2 storage availability in saline formations is estimated to be 10 times that of oil and gas fields.

4.2. Assessment of storage capacity in key ASEAN countries

Although a global-scale study on CO_2 storage capacity has been conducted by international organisations, such as GCCSI, there is limited information on the storage capacity in individual ASEAN countries. METI conducted a study on storage potential and assessed the potential for its utilisation in Indonesia, Thailand, and Viet Nam based on existing information from GCCSI and other international and national sources in 2019–2020 (METI, 2020). Table 1.4 demonstrates the findings from the storage potential assessment for these three countries. Figures 1.7-1.9 show maps of the identified storage potential.

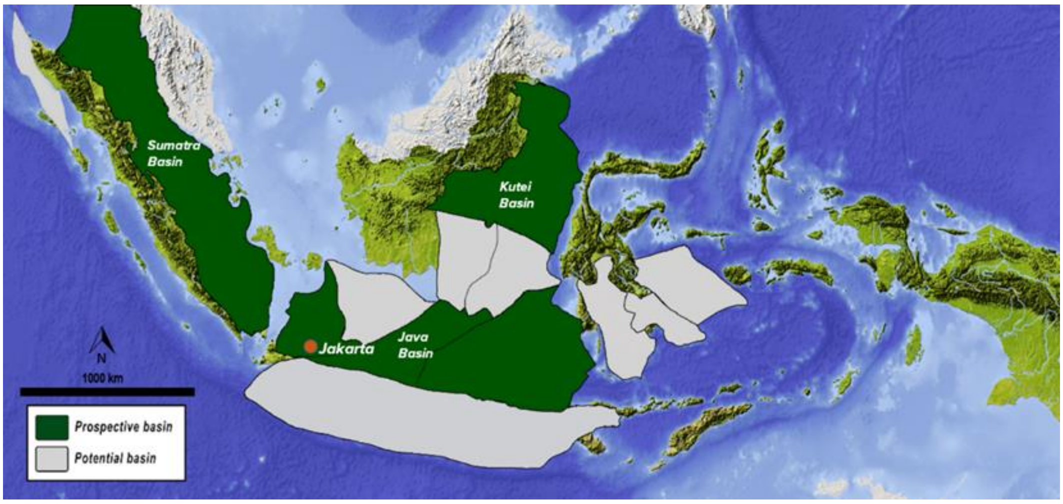
Table 1.4. Summary of CO_2 Storage Assessment in Indonesia, Thailand, and Viet Nam

Country	Identified Potential CO_2 Sources	Development Potential
Indonesia	● South Sumatra Basin: 7.65 $GtCO_2$ (Hedriana et al.) ● Java Basin (deep saline layers): 386 $MtCO_2$ (World Bank) ● Tarakan Basin: 130 MtCO2 (CCOP) ● Central Sumatra Basin: 229 $MtCO_2$ (CCOP)	Relatively high for enhanced oil recovery (EOR)-type projects. Reservoirs are located near developed or already depleted gas and oil fields. Access to mining plants and oil refineries, which are major sources of emissions in the country, would be a key factor.
Thailand	● Saline formation in the Greater Thai Basin and Pattani Basin: 8.9 $GtCO_2$ (ADB) ● Gas and oil fields: 1.4 $GtCO_2$ (ADB)	Demand for EOR is expected to be high as both Thailand's gas and oil fields are on the verge of exhaustion.
Viet Nam	● Deep saline reservoirs: 10.4 $GtCO_2$ ● Depleted oil and gas fields: 1.4 $GtCO_2$	Limited information.

$GtCO_2$ = gigatonnes of carbon dioxide, $MtCO_2$ = megatonnes of carbon dioxide.

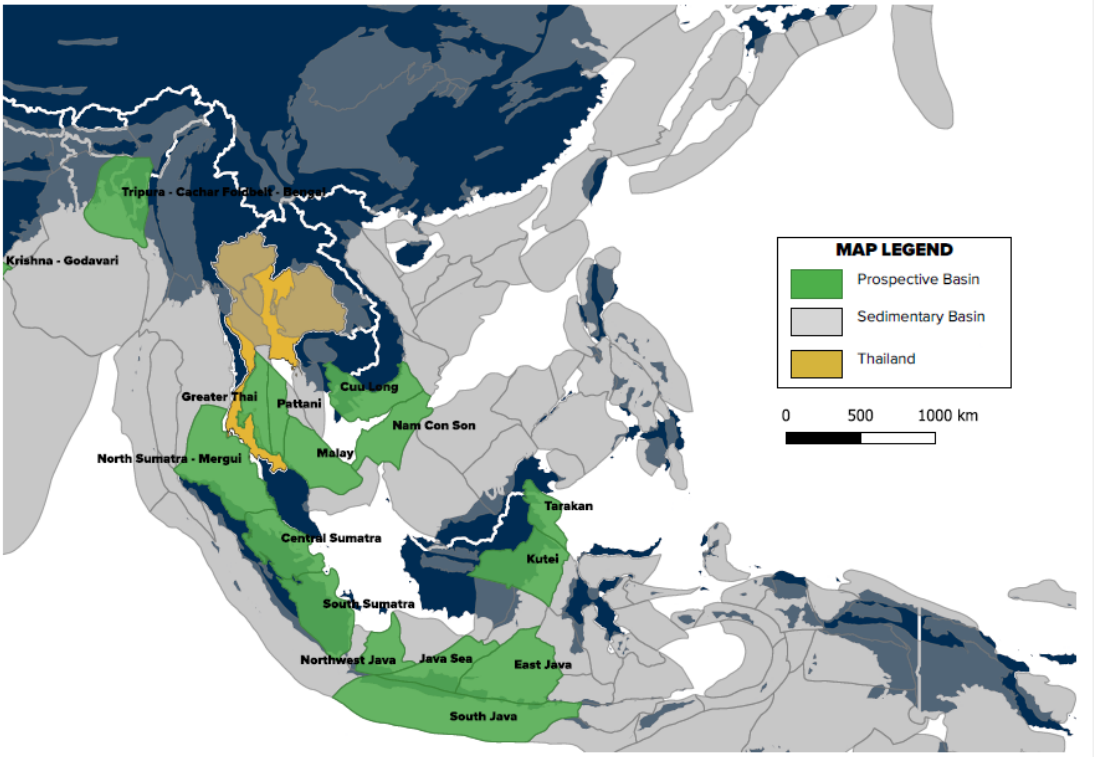
Source: Created by project members based on METI (2020).

Figure 1.7. Underground Deep Strata with Potential for CO_2 Storage Around Indonesia



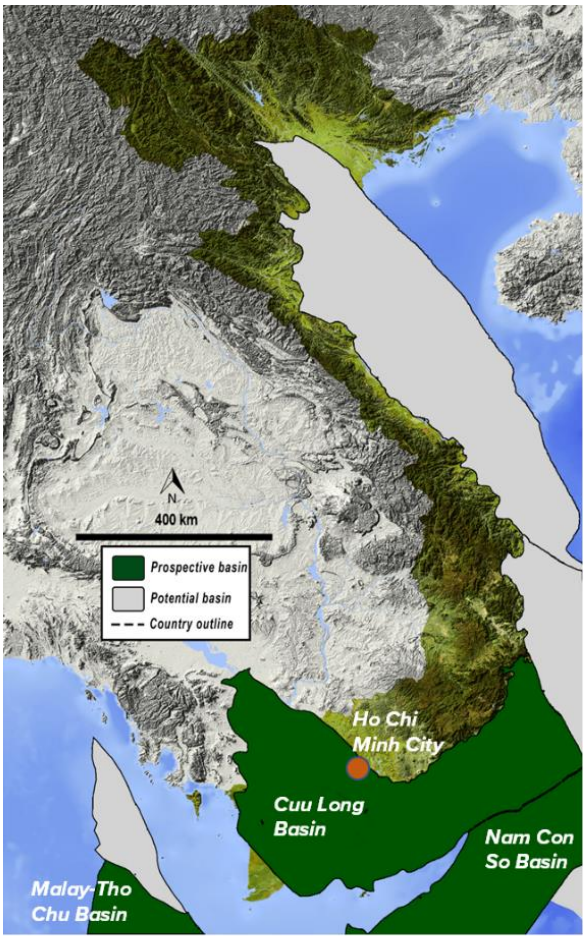
Note: Deep underground strata with particularly high storage potential (green); deep underground strata with some storage potential (grey).
Source: METI (2020), prepared by GCCSI.

Figure 1.8. Underground Deep Stata with Possibility of CO_2 Storage Around Thailand



Note: Deep underground strata with particularly high storage potential (green); deep underground strata with some storage potential (grey).
Source: METI (2020), prepared by GCCSI.

Figure 1.9. Underground Deep Strata with Possibility of CO_2 Storage Around Viet Nam



Note: Deep underground strata with particularly high storage potential (green); deep underground strata with some storage potential (grey).
Source: METI (2020), prepared by GCCSI.

It should be noted that apart from oil and natural gas reservoirs in the South Sumatra Region of Indonesia, no deep underground geological survey has been conducted. There is room for further surveys to conduct a more accurate analysis of the storage potential, which would be a big push for project development to achieve deep decarbonisation in the region.

4.3. Summary

As stated, the needs and potential of CCUS globally are evident. In order to translate this into reality and deploy CCUS in ASEAN and East Asia, more awareness-raising is required both at the policy and commercial levels. Governments need to make a stronger commitment to decarbonisation with CCUS as a technology option, and there needs to be an environment to attract private sector involvement. The following chapters elaborate on the technological and commercial considerations and the ramifications on ASEAN and East Asia.

Chapter 2

Overview of Carbon Capture, Utilisation, and Storage Technology

1. Capture

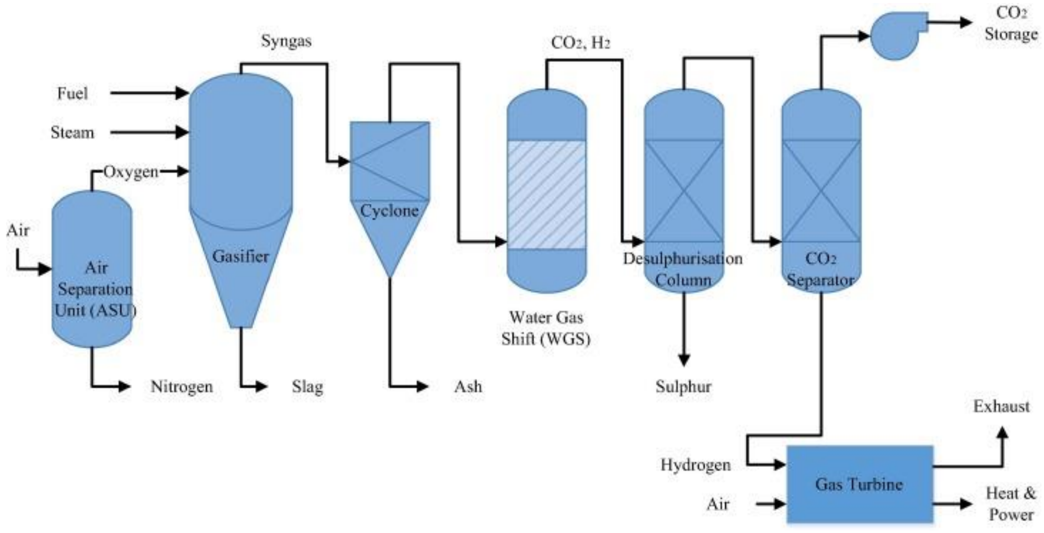
1.1 Technology overview

There are four main types of capture process. Depending on the industrial process, the type of power plant, or the geographical conditions, pre-combustion capture, post-combustion capture, oxy-fuel combustion, or direct air capture is applied. For each type, there are multiple technological approaches, which will be explained in the following sections.

1.1.1. Pre-combustion capture:

Pre-combustion capture is a process in which carbon is extracted from a fossil fuel (i.e., gas, oil, or coal) before it is burnt. This is done by a pre-treatment process called 'gasification', in which the fuel is heated under low pressure with a limited amount of oxygen. The product is called 'synthesis gas', or just 'syngas', and is used in gas turbine generators at power plants. It primarily consists of carbon monoxide (CO) and hydrogen. In the next stage, steam is added to the syngas. This converts the carbon monoxide to carbon dioxide (CO_2) and separates the hydrogen, which can also be used as a fuel. Pre-combustion recovery is mainly used in industrial facilities, such as natural gas processing, whilst the application to power plants is still limited to a few integrated gasification combined cycle (IGCC) coal plants. The process scheme of pre-combustion capture is described in Figure 2.1.

Figure 2.1. Process Scheme of Pre-combustion CO_2 Capture



CO_2 = carbon dioxide.
Source: Theo et al. (2016).

Research efforts are being made in several fields to improve the efficiency and commerciality of the pre-combustion process, including for membrane systems and solvent- or sorbent-based capture methods.

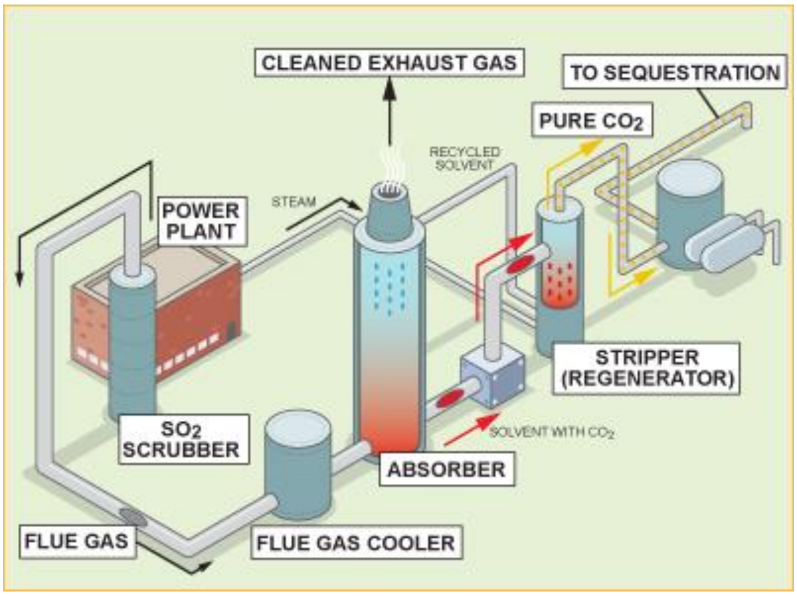
1.1.2. Post-combustion capture

Post-combustion carbon capture removes CO_2 after the fossil fuel has been burned. The CO_2 is separated from the exhaust flue gas before it is released to the atmosphere. The CO_2 can be recovered using several different methods. One option is to use liquid solvents, which can absorb CO_2 from flue gas. The absorption liquid is heated to produce high-purity CO_2. This technology is suited to retrofit application and is, therefore, widely used at a variety of industrial facilities, such as iron and steel plants using blast furnaces, refining plants using process heaters, and cement plants using rotary kilns. However, it is a highly energy-intensive method. Further options are sorbent-based and membrane-based capture methods.

Sorbent-based technology follows a similar concept to the solvent-based method. The sorbent-based method is expected to be less energy-intensive, but at this stage, the technology is considered less developed than solvents.

The membrane-based process offers numerous potential advantages, such as 'no hazardous chemical storage, handling, disposal or emissions issues, simple passive operation, tolerance to high SO_x and NO_x content, a reduced plant footprint, efficient partial CO_2 capture, and diminished need for modifications to the existing power plant steam cycle' (US NETL, 2020). The cost-efficiency and durability of the membranes (important for application at large-scale facilities), as well as the relatively low purity of the captured CO_2, are challenges for further development. The process scheme of post-combustion capture is described in Figure 2.2.

Figure 2.2. Process Scheme of Post-combustion CO_2 Capture



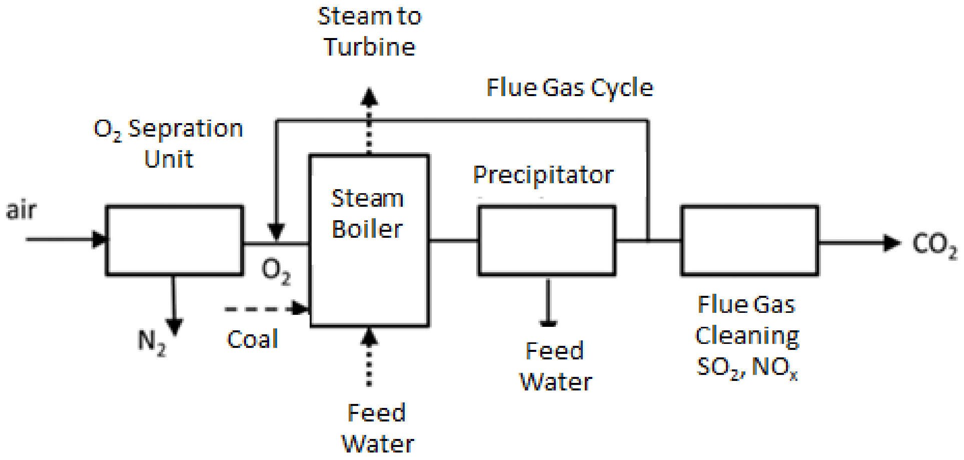
CO_2 = carbon dioxide.

Source: Clean Air Task Force (2020).

1.1.3. Oxy-fuel combustion

Oxy-fuel combustion, as described in Figure 2.3, uses almost pure oxygen instead of air to burn a fossil fuel. This produces an exhaust gas consisting of water vapour and CO_2, which can be easily separated, after being dried and compressed, to produce high-purity CO_2. It is a relatively cost-intensive technology that requires large-scale equipment to be installed. However, it can be used in combination with other separation/recovery technologies.

Figure 2.3. Process Scheme of Oxy-fuel CO_2 Capture



CO_2 = carbon dioxide, N_2 = nitrogen, NO_x = nitrogen oxides, O_2 = oxygen, SO_2 = sulphur dioxide.
Source: Markewitz et al. (2012).

Since the construction is such that an oxygen separation unit and a flue gas recycle device are added to the conventional power plant configuration, it can not only be applied to new power plants but can also be applied to retrofit existing power plants.

1.1.4. Direct air capture

Direct air capture (DAC) technologies extract CO_2 directly from the atmosphere, making it a unique example under the four carbon capture processes explained in this section. Compared to the other three technologies, DAC is still in the early stages of development. There are currently two major technology approaches. One is a liquid system, in which a hydroxide solution reacts with CO_2 to remove it from the air. Another approach is based on solid sorbents, similar to the post-combustion capture process. Solid sorbent filters chemically bind with CO_2. When the filters are heated, they release the concentrated CO_2 (IEA, 2020c).

Both are technically feasible but are highly energy- and cost-intensive. Compared to the flue gas at fixed point capturing, the CO_2 intensity in the atmosphere is 200–300 times more dilute. This results in low capturing efficiency and is, therefore, more expensive.

It is, however, the only technology that can capture CO_2 already released into the atmosphere. This makes DAC not only a potential carbon-neutral technology but even a potential carbon-negative technology; but only potentially, because the technology consumes a lot of energy. To make DAC truly carbon-negative, it needs access to enough 'green' electricity.

Another advantage of DAC is the possibility to cover CO_2-intensive areas that cannot be covered by fixed point capturing. DAC offers the possibility to capture emissions from traffic at ports, airports, or even large intersections.

2. Transport

There are two major methods of transporting captured CO_2 to storage locations or utilisation sites, shipping and pipelines. CO_2 is typically compressed to a pressure of about 8 megapascals, reducing the transportation cost. CO_2 pipelines are already in use for the transport of CO_2 to enhanced oil recovery sites, but there are also efforts to utilise existing natural gas pipelines. Other feasible options for rather limited volumes of CO_2 are trains and roads.

3. Utilisation

An essential part of making CCUS an economically sustainable concept is the utilisation of CO_2. Changing CO_2 from an environmental burden that has to be disposed of somewhere to an economical asset that can be traded as any other resource, would create a new value cycle. This value cycle would offer a positive incentive for emitters to invest in CO_2 capturing and makes CCUS less dependent on public funding.

There are multiple approaches to utilising CO_2 as a resource. The food and beverage industry, fuel industry, construction industry, and agriculture are four sectors spearheading the research and development to find feasible applications. Products from these sectors are all essential on a global scale. This means that if CO_2-utilising products can be made for these sectors, the market will automatically be huge and the products will not require long-distance transportation.

3.1. Food and beverages

A popular example of CO_2 utilisation in the food and beverage industry is beverage carbonation. In this process, CO_2 is added to a beverage to impart sparkle. Conventional bottling plants obtain the required CO_2 from industrial gas companies or they have their own on-site CO_2-generating plant that combusts fossil fuel for the purpose of producing CO_2.

Several beverage and bottling companies are already using CO_2 captured from power plants to create sparkling drinks. Some are even more ambitious and have installed DAC-facilities on their plants. In both cases, the CO_2 must be purified to meet the strictest requirements for food and beverage purposes.

Another approach in the food and beverage industry is the production of protein, which can be used to make alternative meat products. Start-ups in Finland and the United States are developing a method to convert CO_2 into a protein powder. This approach still needs further development for commercial-scale production. It is, however, an environmental innovation in more ways than one. In addition to the utilisation of CO_2, it has the potential to reduce the environmental footprint of the livestock industry.

3.2. Fuel

Petrochemical fuels, such as gasoline or diesel, have always been at the centre of the discussion on greenhouse emissions and air pollution. Even though electric mobility is becoming more popular and more common, the fact is that the demand for fossil fuels is still huge.

CO_2 can be used as a raw material to produce fuels, for example through Fischer–Tropsch synthesis. In this chemical process, captured CO_2 is usually combined with hydrogen. It is a very energy-consuming process, but, nevertheless, there are multiple projects in this field around the world.

There are also approaches to combine CO_2 with hydrogen that is generated from non-fossil fuels to produce low-carbon synthetic fuels. The main target for this synthetic biogas is in many cases jet fuel, but it can also be used to produce gasoline.

Both approaches are highly energy-intensive. To make the fuel low carbon, the processes require a stable and large-scale supply of renewable energy. At this point, the financial feasibility for commercial scale production of the fuels is still very difficult to guarantee.

3.3. Agriculture

The carbon footprint of the agriculture sector is one of the biggest. This of course is understandable as it supplies food to the global population, feeds livestock, and produces cotton for the apparel industry. There are, nevertheless, some attempts to reduce the carbon footprint.

Utilising CO_2 for the production of fertilisers is one of them. India, amongst other countries, is actively promoting technology to separate CO_2 from the exhaust gases that arise during ammonia production and use the separated CO_2 as a raw material to produce urea. Urea in turn is used to produce nitrogen-release fertiliser.

The second attempt has a symbiotic effect on agriculture and the environment. To increase the yield of plants, the air in greenhouses gets enriched with CO_2. Additional CO_2 in the atmosphere accelerates photosynthesis and provides a greater rate of growth. It also protects the plants from drought and certain diseases. Conventionally, this happens using CO_2 generators that combust natural gas for the purpose of producing CO_2, in a similar manner to the previously described bottling plants. There are now attempts to reuse the captured CO_2 from power plants or industrial sites. Additionally, these sites can also supply the waste heat to the greenhouses.

It is important to mention that even though these processes have indeed the potential to utilise CO_2 on a larger scale, they do not offer a final solution regarding CO_2 reduction. Most of the CO_2 injected into greenhouses or used for fertilisers is ultimately released back into the atmosphere. The measures are, nevertheless, important for marketising CO_2 as a tradable resource.

3.4. Construction

Large utilisation potential is also expected from the construction industry. Cement, a major construction material and a huge source of CO_2 emissions, could become a gamechanger in this aspect.

One approach is the mineralisation of CO_2. Here, CO_2 is converted to calcium carbonate, which is the main component of cement's raw material, limestone. Another one is to infuse CO_2 during concrete production to make high-strength concrete. A number of large projects for both approaches are underway, whilst multiple start-ups are coming up with new CO_2-utilising materials that offer an alternative or might even replace conventional cement.

In contrast to CO_2-utilising products such as food and beverages, synthetic fuels, or fertilisers, these processes could theoretically be able to store CO_2 for longer periods of time.

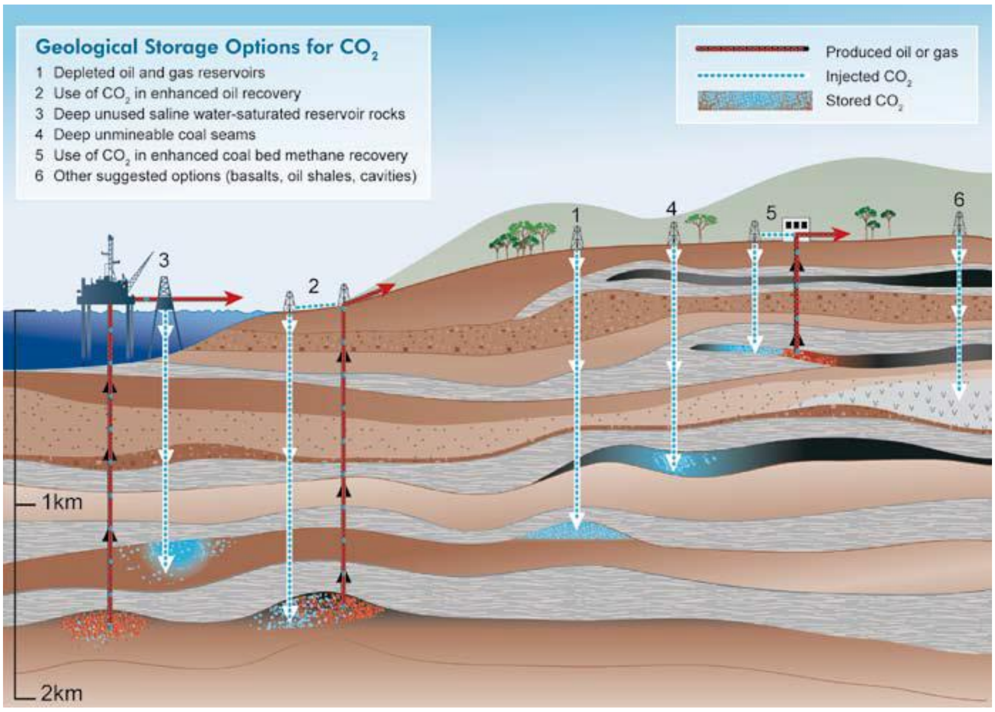
4. Storage

4.1. Technology overview

Storing CO_2 involves the injection of captured CO_2 into a deep underground geological reservoir of porous rock overlaid by an impermeable layer of rocks, which seals the reservoir and prevents the upward migration of CO_2 and its escape into the atmosphere.

There are several types of reservoir suitable for CO_2 storage. Figure 2.4 is a famous diagram contained in the IPCC Special Report on Carbon Dioxide Capture and Storage (Metz et al., 2005) showing options for a CO_2 reservoir, namely (1) depleted oil and gas fields, (2) enhanced oil recovery, (3) deep unused saline water-saturated reservoir rocks, (4) deep un-mineable coal seams, and (5) enhanced coal bed methane recovery.

Figure 2.4. Options for Storing CO_2 in Deep Underground Geological Formations



CO_2 = carbon dioxide, km = kilometre.
Source: Metz et al. (2005).

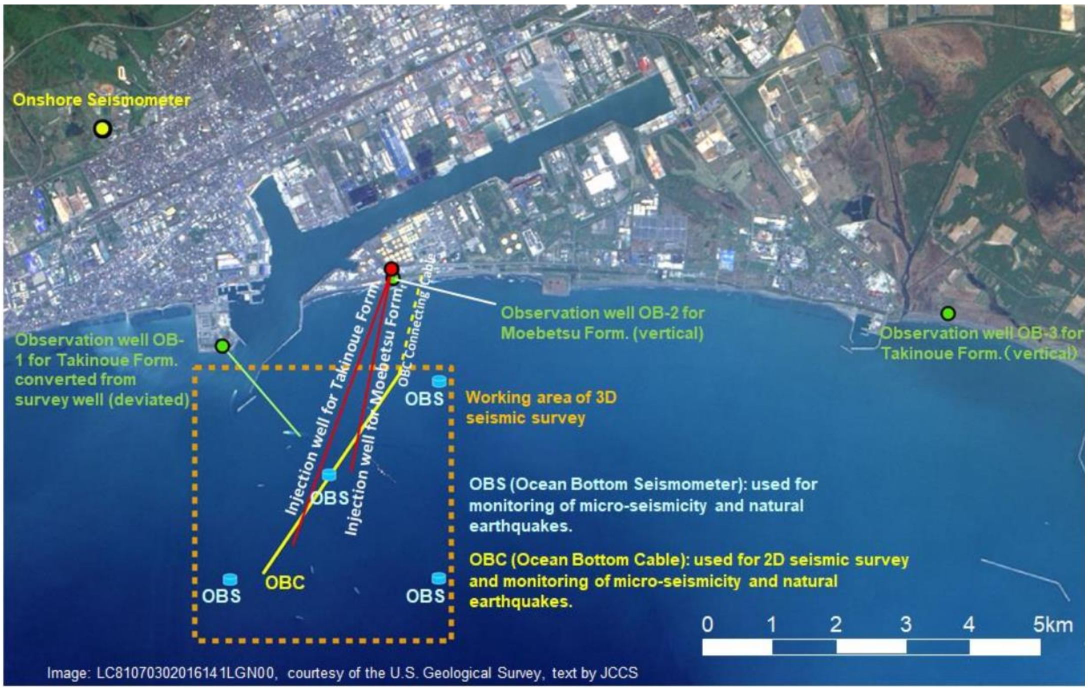
To geologically store CO_2, CO_2 must first be compressed, usually to a dense supercritical fluid. The reservoir must be at a depth of 800 metres or greater to retain the CO_2, where the injected CO_2 will be in a dense supercritical state. According to Metz et al. (2005), with this aspect, potential CO_2 reservoirs can be categorised into three types as follows:

- Deep saline formations: Layers of porous and permeable rocks saturated with salty water (brine), which are widespread in both onshore and offshore sedimentary basins.
- Depleted oil and gas reservoirs: Porous rock formations that have trapped crude oil or gas for millions of years before being extracted and which can similarly trap injected CO_2.
- Deep coal seams: Solid coal has a very large number of micropores into which gas molecules can diffuse and be tightly adsorbed. Adsorption is the main storage mechanism in coal seams at high pressure.

After injection, the CO_2 is permanently trapped in the reservoir through several mechanisms: structural trapping by the seal, solubility trapping in pore space water, residual trapping in individual or groups of pores, and mineral trapping by reacting with the reservoir rocks to form carbonate minerals. The nature and the type of the trapping mechanisms for reliable and effective CO_2 storage, which vary within and across the life of a site depending on the geological conditions, are well understood thanks to decades of experience in injecting CO_2 for enhanced oil recovery (EOR) and dedicated storage (IEA, 2020a).

There are a number of experiences in Asia as well, including EOR projects and dedicated storage projects in China and research and development activities in the Republic of Korea. Japan has also experienced geological storage since 2003 and commissioned the northern Tomakomai CCS facility in 2016, which was the world’s first offshore CCS project in a populated area (GCCSI, 2020d; Massachusetts Institute of Technology, 2016). The outline of the Tomakomai CCS Project is described in Figure 2.5.

Figure 2.5. CO_2 Storage Site of the Tomakomai CCS Project



Source: METI, NEDO, and JCCS (2020).

4.2. Key technologies for carbon storage

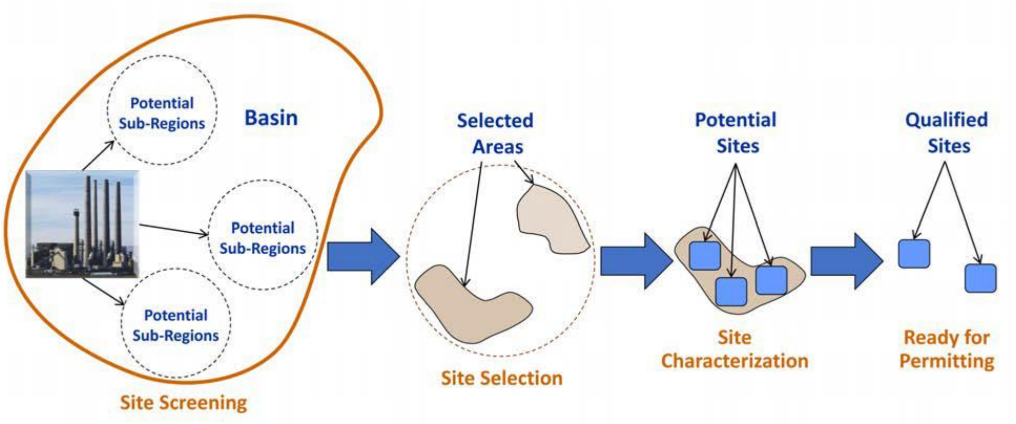
4.2.1. Geologic storage analysis

Before setting up a geological CO_2 storing project, it is necessary to appropriately select a site and characterise the geologic storage formation before site qualification. According to the Best Practices Manual of Site Screening, Site Selection, and Site Characterization for Geologic Storage Projects by US NETL (2017a), the following should be considered in the site development and evaluation process:

- Establish that the site has the resources to accept and safely store the anticipated quantity of CO_2 at the desired injection rate for the storage project.
- Provide input data to models required to predict site performance in terms of pressure change and CO_2 plume evolution.
- Minimise the probability of adverse effects on the environment.
- Identify and address any potential regulatory, subsurface ownership, site access, and pipeline issues.
- Ensure the site has the capability to meet the performance standards established for the project, such as operational efficiency, reliability, and safety.
- Ensure alignment of national, regional, and local social, economic, and environmental interests.

US NETL (2017a) breaks down the process into phases as in Figure 2.6, and there are a number of data obtained from the technologies used in these processes.

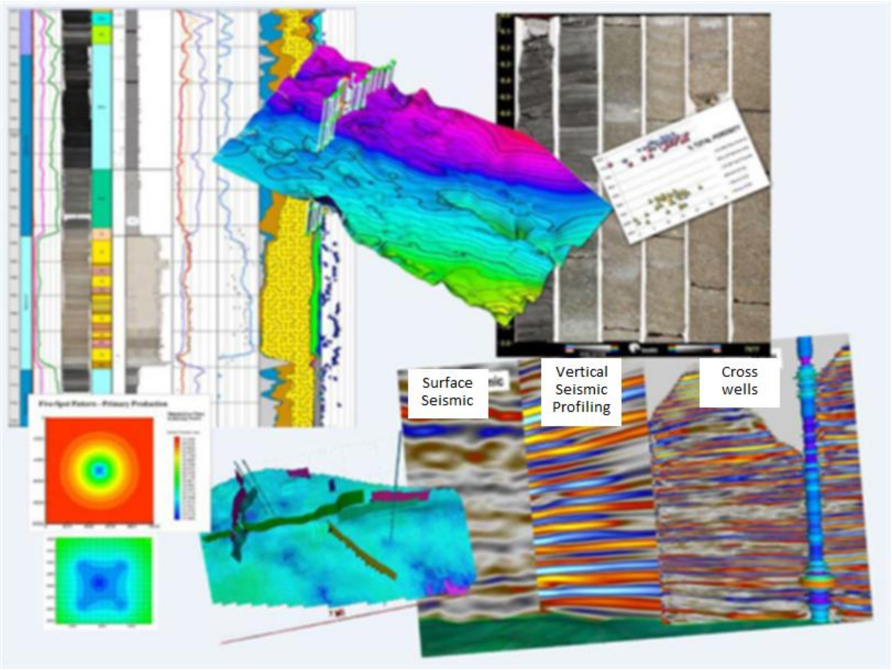
Figure 2.6. Analysis Procedure to Select an Appropriate Storage Site



Source: US NETL (2017a).

US NETL (2017a) describes examples of collected data for site characterisation as shown in Figure 2.7, namely physical core, core analysis data, log data, 2D and 3D seismic data, vertical seismic profiling (VSP) data, and reservoir simulations.

Figure 2.7. Examples of Collected Data in Site Characterisation



Source: US NETL (2017a).
Note: Author added site characterisation labels for clarification.

After site characterisation, it is necessary to conduct injected CO_2 behaviour simulation and risk assessment processes before the facility design and actual CO_2 injection. In simulating injected CO_2 behaviour, numeric simulation models (NSMs) are a key technology. Examples of NSMs and the outcome of the CO_2 behaviour analysis are depicted in Table 2.1 and Figure 2.8, respectively.

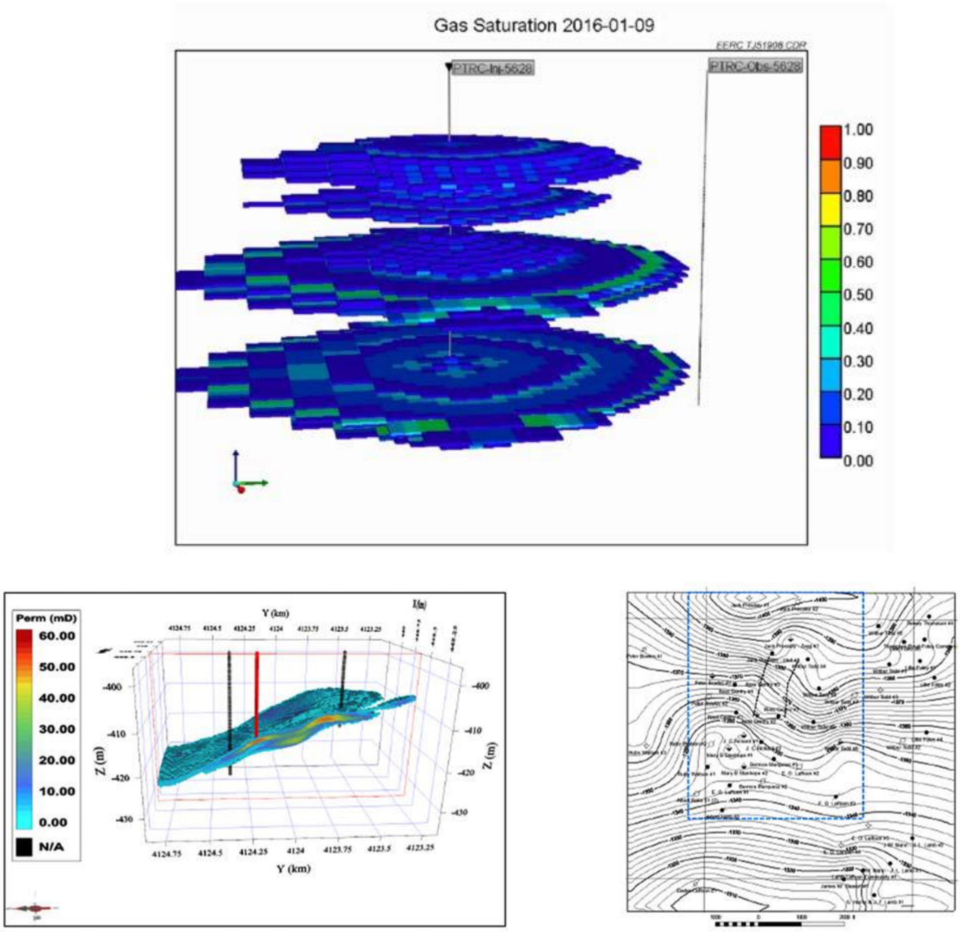
Table 2.1. Examples of Numeric Simulation Models for CO_2 Storage Simulation

Name of Code	Developer/ Supplier	Coupling	Processes Modeled
NFFlow-FRACGEN	NETL	H	Two-phase, multi-component flow in fractured media
Eclipse 100 Eclipse 300	Schlumberger	T,H	Non-isothermal black oil multiphase flow in porous media Non-isothermal compositional multiphase flow in porous media
MASTER	NETL	T,H	Black oil simulator, compositional multiphase flow
TOUGH2 (TOUGH+)	LBNL	T,H	Non-isothermal multiphase flow in unfractured and fractured media
Nexus (VIP) ® Reservoir Simulation Suite	Halliburton	T,H	Compositional simulator with dual porosity, sorption
PHREEQC	USGS	T,H	Speciation, batch-reaction, 1-D transport, and inverse geochemical calculations
Hydrotherm	USGS	T,H	2-phase groundwater flow and heat transport
General Purpose Research Simulator (GPRS)	Stanford University	T,H	Multiphase/compositional flow code
GMI – SFIB	Geomechanics International	M	3-D stress modeling for compressional (wellbore breakout) and tensional (tensile wall fractures) stress failure, fracture modeling

LBNL = Lawrence Berkley National Laboratory, GMI-SFIB = GeoMechanics International-Stress and Failure of Inclined Boreholes, NETL = National Energy Technology Laboratory, PHREEQC = PH REdox Equilibrium, USGS = United States Geological Survey.

Source: US NETL (2017b).

Figure 2.8. Example of CO_2 Storage Simulation Outcome Image



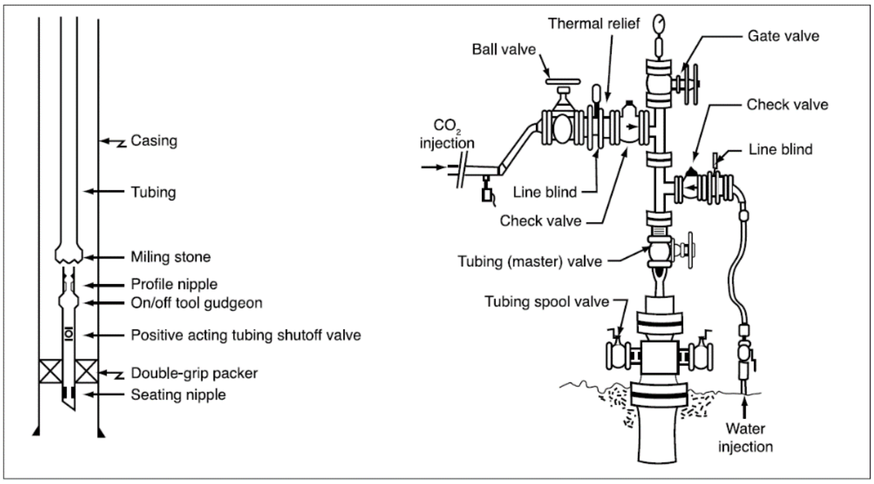
Source: US NETL (2017b).

4.2.2. Injection and field operation technology

After a suitable site is identified with the technology described in the previous section, one has to consider the way to inject large quantities of CO_2 into the subsurface and to operate the site effectively and safely.

The design of a CO_2 injection well is very similar to that of a gas injection well in an oil field or natural gas storage project. As shown in Figure 2.9, injection wells commonly are equipped with two valves for well control, one for regular use and one reserved for the safety shutoff. In acid gas injection wells, a downhole safety valve is incorporated in the tubing so that if equipment fails at the surface, the well is automatically shut down to prevent backflow.

Figure 2.9. Typical CO_2 Injection Well and Wellhead Configuration



CO_2 = carbon dioxide.
Source: Metz et al. (2005).

In addition, well abandonment technology is also important because the CO_2 could migrate up the well and into shallow drinking water aquifers from storage formation if a well remains open.

Overall, the tasks for injection and field operation as categorised as follows:

- Production systems: fluid separation, gas gathering, production satellite, liquid gathering, central battery, field compression, and emergency shutdown systems.
- Injection systems: gas re-pressurisation, water injection, and CO_2 distribution systems.
- Gas processing systems: gas processing plant, hydrogen sulphide removal systems, and sulphur recovery and disposal systems.

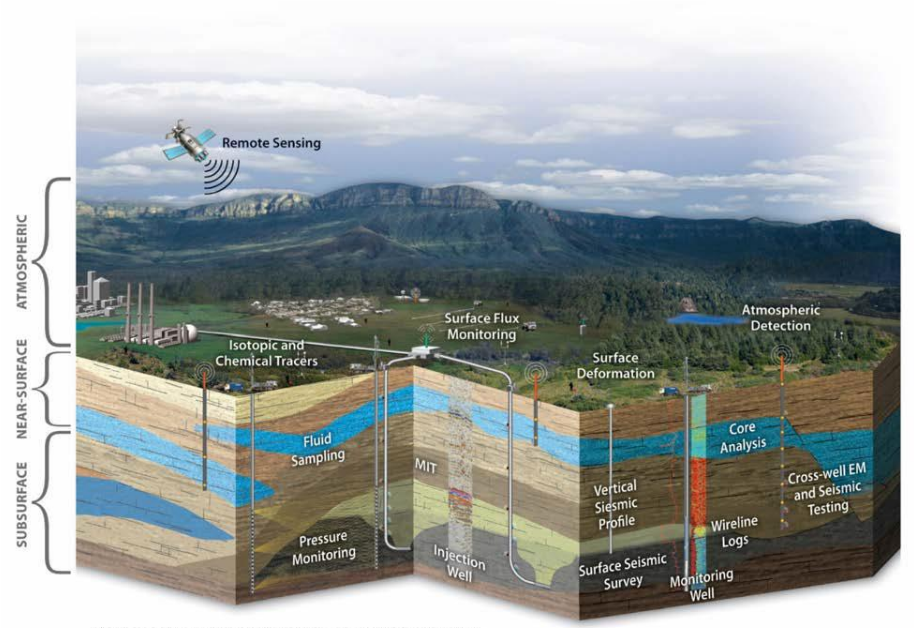
4.2.3. Monitoring and verification technology

Monitoring and verification technologies are necessary to prevent CO_2 leakages from the storage formation and to ensure CO_2 containment. There are three areas for monitoring and verification: atmospheric, near-surface, and subsurface monitoring as shown in Figure 2.10.

The purpose of atmospheric and near-surface monitoring is to detect manifestations of CO_2 potentially released from storage. The most common atmospheric monitoring techniques are optical CO_2 sensors, atmospheric tracers, and eddy covariance flux measurements. Near-surface monitoring techniques include geochemical monitoring in the soil and vadose zone, geochemical monitoring of the near-surface groundwater, surface displacement monitoring, and ecosystem stress monitoring.

Subsurface monitoring provides the information for storage operational control and the assessment of the performance of the storage formation. It includes monitoring the evolution of the dense-phase CO_2 plume, assessing the area of elevated pressure caused by the injection, and measuring to determine that both the pressure and CO_2 are within the expected and acceptable areas and migrating in a way that does not damage resources or the integrity of the storage.

Figure 2.10. Diagram of Atmospheric, Near-surface, and Subsurface Monitoring



Background Image Courtesy of Schlumberger Carbon Services

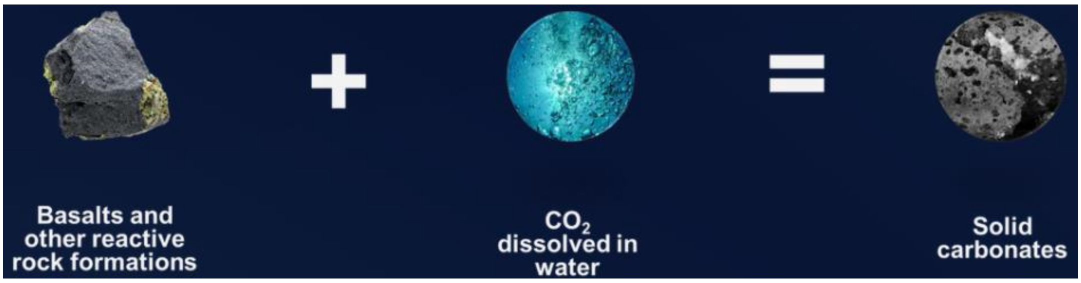
EM = electromagnetic, MIT = mechanical integrity testing.
Source: US NETL (2017b).

4.3. New technology to fixate CO_2

As written in previous sections, injected CO_2 is fixed by structural trapping by the seal, solubility trapping in pore space water, residual trapping in individual or groups of pores, and mineral trapping by reacting with the reservoir rocks to form carbonate minerals, in general. In principle, it is necessary to separate CO_2 from other acid compounds like sulphur oxides (SO_x), nitrogen oxides (NO_x), hydrogen sulphide (H_2S) and fluorine (F) in captured gasses.

However, there is new technology to fix CO_2 without separation. The concept of the technology is shown in Figure 2.11.

Figure 2.11. Diagram of Atmospheric, Near-surface, and Subsurface Monitoring



CO_2 = carbon dioxide.
Source: Carbfix (2020).

The technology is called 'Carbfix' and demonstrated at a geothermal power plant operated by ON Power in Iceland. Carbfix, the company, is named the same as the technology. According to Carbfix's website, the technology has the following features (Carbfix, 2020):

- No chemicals used, other than water (or seawater).
- Co-capture of other soluble gases, such as SO_x, NO_x, H_2S, and fluorine. These polluting gases participate in reactions underground, forming minerals to various extents.
- Less-stringent requirements for pipes and casing materials than for purified CO_2.

There is also an advantage of Carbfix for storage formation restriction. It can be applied to mineral storage, which is different from the typical storage formations for conventional CCS technology. The Carbfix website says that about 5% of the continents are covered by favourable rocks for carbon mineralisation, and the global storage potential is greater than the emissions of the burning of all fossil fuels on Earth.

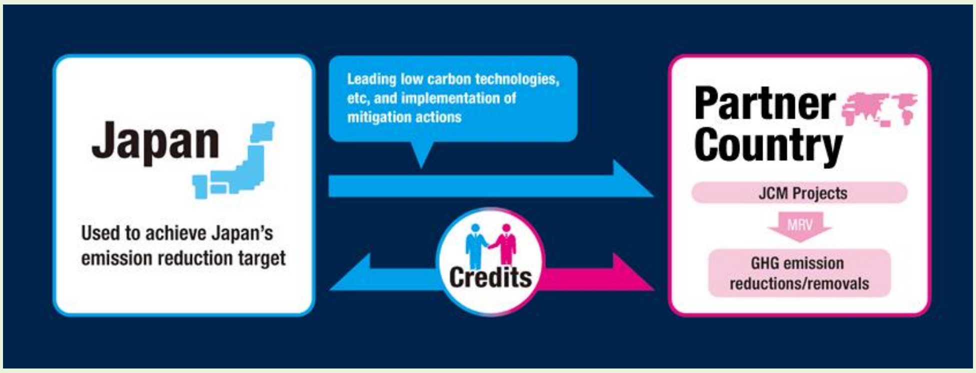
5. Summary

This chapter introduced the gist of technologies involved in CCUS and the key components. As described above, some of the technologies have a good track record, and there is significant progress in their demonstration in Asia as well.

Utilisation shows great potential as it entails the possibilities of creating value-added industrial products, such as cement, fertiliser, hydrogen, and so on. However, it is important to note that the carbon fixation aspect needs to be carefully considered if CO_2 utilisation is implemented for the purpose of carbon sequestration. The storage technology is described more in detail compared to other technologies also for the reason of its significance when CO_2 sequestration is taken into account. It is paramount for project developers to select appropriate sites, apply well treatment, conduct site operations, and ensure proper monitoring so there is no leakage of CO_2, especially when issuing carbon credits with a market mechanism, such as the Joint Crediting Mechanism. Accordingly, it will be vital to establish 'viable and affordable' monitoring methods applied to post-injection sites in pursuing CCUS dissemination in Asian countries.

Box 2. Joint Crediting Mechanism

The Joint Crediting Mechanism (JCM) is a mechanism initiated by the Government of Japan where mitigation actions implemented through cooperation with partner countries are measured, verified, and reported to produce emissions offsets that are shared amongst participating governments and the private sector and can be counted towards the emissions reduction targets of the participating countries.
It was first started with Mongolia in 2013 and now counts 17 participating countries. Included in the signatories are ASEAN countries, such as Cambodia, Indonesia, Lao PDR, the Philippines, Thailand, and Viet Nam.



Source: Carbon Markets Express (2020).

Chapter 3

Business Models

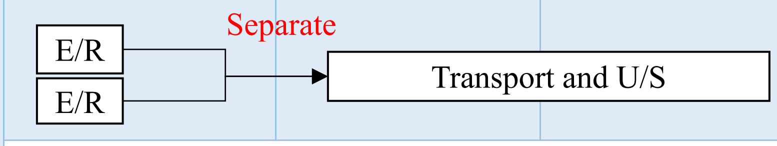
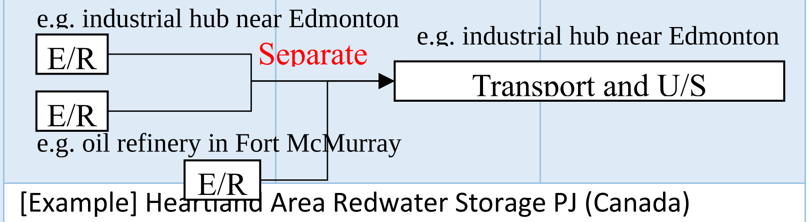
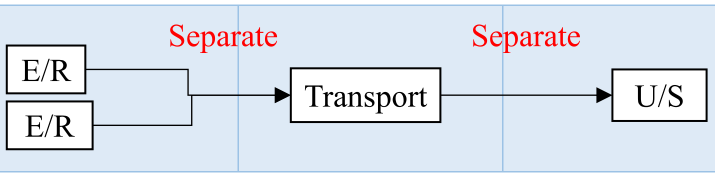
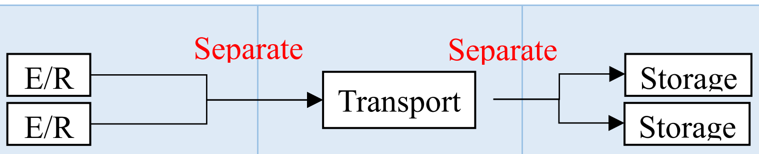
1. Case studies

As mentioned in the previous chapter, to ensure the longevity of carbon capture, utilisation, and storage (CCUS) projects, it is important to create financially healthy schemes covering each stage of the CCUS process. The financial hurdles already start at the beginning in capturing the carbon dioxide (CO_2). CCUS requires the emitters to install carbon capture equipment, which is still high in cost. There also needs to be feasible solutions to transport the captured CO_2. Then, the captured CO_2 has to be sequestrated at a safe location, if not used for other purposes. Finally, the sequestrated CO_2 is subject to monitoring over a year-long, or even decade-long, period of time to make sure there are no unforeseen or unwanted side effects or leakages. Each of these steps needs investment, and at a stage where there is no realistic chance for short-term profitability, private companies cannot cover all the investments on their own nor can financial institutions provide loans. Therefore, CCUS strongly relies on public funding.

The medium-term target should be to build up a new value chain for CO_2. This can only be realised by making CO_2 a marketable resource on a wider scale. Giving CO_2 a value and trading it like oil or other resources would make CCUS an autonomous scheme, reducing greenhouse gases in the atmosphere without being an economic burden. Although carbon trading schemes in Europe and carbon-based tax incentives in the United States give some incentives, we are not yet at the stage where financial institutions and the private sector see it as a promising business opportunity despite the existence of some encouraging projects. CCUS projects need to be not only ecologically but also economically attractive for widespread deployment.

A promising business structure that reduces both cost and risks whilst striving for economy of scale is a model that involves multiple stakeholders, such as CO_2 emitters and those involved in transport and storage. Such a business model would not only reduce costs by sharing some of the infrastructure, including CO_2 pipelines and storage sites, but also enable risk- and responsibility-sharing amongst the stakeholders. Several types of these so-called 'hub and cluster' models are shown in Figure 3.1. There are some promising projects taking place, as explored in detail in the subsequent sections.

Figure 3.1. Examples of Various Hub and Cluster models of CCUS

No.	Type	Emission/Recovery (E/R)	Transport	Utilisation/Storage (U/S)
1	Neighbouring emitters share transport/storage facility			
		[Comment] A typical hub and cluster model. Reduces risk/cost by separating E/R and U/S.		
2	Variation of Type 1 that includes distant emitter			
		[Example] Heartland Area Redwater Storage PJ (Canada) [Comment] Sharing of storage facility, high transport cost.		
3	Different ownership for transport and storage			
		[Example] Peterhead PJ (United Kingdom) [Comment] Improved flexibility of transport and storage facilities		
4	Multiple storage sites			
		[Example] Teesside Low Carbon PJ (United Kingdom) [Comment] Improved flexibility of transport and storage facilities. Possibility of improved profitability when tax rates differ based on storage type (enhanced oil recovery, storage).		

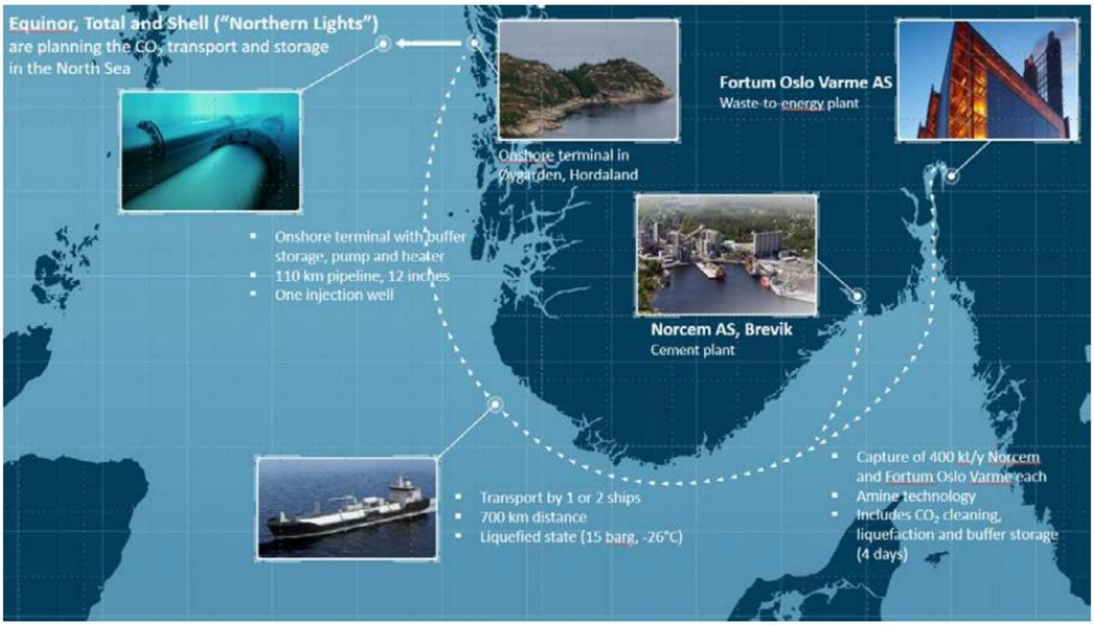
Source: Created by project members based on METI (2020).

1.1. CO_2 transport and storage service: Longship (Norway)

Norway is one of the most ambitious countries in the field of carbon capture and storage (CCS). It already recognised the necessity of capturing and permanently storing CO_2 in the early 1990s and has been actively engaged in CCS since that time. Norway has been attracting attention as one of the most ambitious countries in the field in recent years as a CCS pioneer. Norway's government is promoting the research and development of CCS technologies and large-scale demonstration projects towards commercial CCS as a national agenda.

'Longship', or 'Langskip' in the native language, is Norway's most recent and most ambitious initiative aiming to build up the first commercial CCS infrastructure. An important characteristic of Longship, and Norway's approach towards CCS, is its two-pillar structure. As demonstrated in Figure 3.2, the initiative contains three projects. Two of these projects, a cement plant and a waste treatment plant, are focusing mainly on the capturing process. The other one, Northern Lights, is responsible for the transport and storage. Each project is implemented individually by the responsible companies. Longship's main target is to prove the feasibility of full-scale CCS to show that the capture and storage of CO_2 can be executed on a large scale and pave the way for a wider contribution in the future. The two-pillar structure, which promotes the capturing sites and the transport-to-storage service individually, is a realistic approach for a potential business model. In future, CO_2 transport and storage companies could offer a similar service like conventional waste management companies, but for CO_2 emitters. Each emitter will only have to bring its 'CO_2 garbage bin' to a collecting hub like a harbour or train station. Separating the CO_2 transport and storage infrastructure from the CO_2 capture projects reduces the overall commercial risk and cost of the CCUS value chain.

Figure 3.2. Overview of the Longship Project



Source: Gassnova (2019).

1.2. Hub and cluster CCUS for the community: Net Zero Teesside and Zero Carbon Humber (United Kingdom)

The United Kingdom (UK) is promoting another approach to implementing CCUS. In 2018, the government announced an action plan for the social implementation of CCUS, which targets deploying CCUS at scale and in an economically feasible way by the 2030s. The government has made close cooperation between the public and private sectors a top priority in promoting CCUS (HM Government, 2018).

A decisive strategy is to facilitate CCUS deployment through the utilisation of existing infrastructure. Developing a viable business model, sharing transport and storage infrastructure, and strategically reusing existing oil and gas industry assets (pipelines and depleted oil fields, etc.) can significantly reduce the initial costs of building up a CCUS value chain.

A second important strategy is to develop clusters as a regional group in which multiple CCUS facilities share information and infrastructure. This will lead to the promotion of CCUS cost reductions and is expected to enhance the regional economy. Revitalisation of the regional economy would again promote continuous technological innovation and create a virtuous cycle that accelerates innovation in the CCUS field. To promote and accelerate innovation that leads to cost savings across the sector, the UK is planning to develop at least two CCUS clusters that can be operated from the mid-2020s. These two projects are Net Zero Teesside and Zero Carbon Humber, as described in Figure 3.3. They are located in industrial areas off the North Sea in the north-eastern part of England, which have been a high-emission industrial cluster for many years with the steel and chemical industries. The projects were launched with the aim of completely decarbonising the region by 2030. Both projects will start the decarbonisation in stages from 2026. The concept combines CCUS with the utilisation of low-carbon hydrogen by large-scale offshore wind farms that will supply renewable energy to the clusters. The two industrial clusters will build up a CO_2 and hydrogen transportation network and share storage facilities. In future, they can become hubs for an international CO_2 and hydrogen transportation network. Sharing the North Sea with Norway and other nations, there is a possibility of bilateral or multilateral cooperation to form a North Sea CCS network. This would offer northern European countries an ideal platform for CO_2 trading and CCS-related services, stimulating the marketability of CO_2.

Figure 3.3. Overview of Net Zero Teesside and Zero Carbon Humber

Source: Net Zero Teesside (2020).

2. Ramifications for ASEAN and East Asia

The perceptions and acceptance of CCUS amongst ASEAN Member States and countries in East Asia countries are quite diverse. Some countries are already actively funding and promoting CCUS projects, from basic research projects to large-scale testing sites. Other countries are still observing the concept of CCUS and the related technology with caution. However, most of them agree that CCUS can play a vital role in the fight against climate change. It is, therefore, important to maintain close multilateral collaboration between the nations. CCUS is still a field where a lot of research and development happens. This includes technological achievements, geological requirements, risk assessment, law-making, and considerations about carbon pricing. The concept of CCUS aims to create a new economic structure for CO_2 by making it a marketable resource. Cautious observations from nations, companies, and individual experts are targeted at the environmental, geological, technological, and financial feasibility. So, sharing information about the newest achievements with a wide audience will be essential for including as many players as possible.

Even though the economic and environmental situation, as well as the industrial structure of each country, shows big differences, there are some key components that might help to paint a hypothetical picture of what a multilateral CCUS collaboration could look like. Countries like Norway, the Netherlands, and the UK are already taking the first steps towards building a CO_2 transportation network, and in future surely also a trading network. From these countries, the Netherlands and the UK are trying to restructure existing industrial clusters that are traditionally high-emitting areas into large-scale, low-carbon CCUS clusters. Those clusters have an oil or gas industry background with refineries, access to pipelines, and exploited gas fields. These are characteristics that many industrial port cities in the ASEAN region fulfil. Industrial port cities are, without exception, carbon-intensive areas and account for a big part of each country’s carbon footprint. At the same time, they are well-connected locations with maritime access to other countries. Most of the ASEAN Member States and countries in East Asia depend heavily on maritime traffic and, therefore, have relatively sophisticated ports. This offers the ideal requirements to strive for a CCUS hub and cluster network. Singapore, Japan, and the Port of Rotterdam Authority recently signed a memorandum of cooperation, seeking to collaborate for the development of a clean maritime fuels network. In future, this kind of network could be extended towards CO_2 and hydrogen trading. Countries with underground storage potential could offer storage services such as Northern Lights in Norway, offering high-emitting countries carbon solutions for reasonable prices. Costs for individual projects are still high and, as stated above, there is no existing CO_2 market yet that can immediately attract private companies to offer low-cost, low-carbon solutions. Therefore, it is vital for the further development of CCUS in the ASEAN region to further encourage information and knowledge sharing. Developing a model CCUS cluster as a multilateral joint project would not only help to collect essential experience but would also initiate participating countries to promote common regulations and standards for a regional CCUS network.

Chapter 4

Potential of Carbon Capture, Utilisation, and Storage Deployment in ASEAN and East Asia

1. Current issues with carbon capture, utilisation, and storage deployment in the Association of Southeast Asian Nations region

As part of this research project, a session entitled 'CCUS – Current Situation and Future Perspectives' was held as part of the ERIA-sponsored 3rd East Asia Energy Forum (EAEF) on 17 November 2020, where various issues including the legal framework required for CCUS and possible business models were introduced, and current interest and issues on commercialisation faced by governments, academia, and the private sector as well as financial institutions were discussed.

Box 3. Programme of Session 2, 3rd EAEF

Opening of the session – Objective, discussion topics, and the expected outcome

by Mr. Ulysses Coulmas, Researcher, Mitsubishi Research Institute

Keynote speech

1. 'CCUS promotion through policies'

Status of public policy and legal framework in CCUS-ready countries and ramifications for Asian countries

by Mr. Ian Havercroft, Senior Consultant - Legal & Regulatory, Global Carbon Capture and Storage Institute (GCCSI)

2. 'Global trend in CCUS business cases' – Introduction of advanced business models

by Ms. Kikuko Shinchi, Senior Researcher, Climate Change Solutions Group, Sustainability Division, Mitsubishi Research Institute (MRI)

Introduction of 'case studies in ASEAN and creating a successful business model through partnership'

1. Introduction of CCUS-EOR and CO_2 pipeline project development in Indonesia

   by Dr. Toshiyuki Anraku, Vice President of Technical Division, Japan Petroleum Exploration Co., Ltd.

2. Introduction of CCUS and power generation development project in Indonesia

   by Dr. Yucho Sadamichi, Consultant, Environmental Consulting Department, JAPAN NUS Co., Ltd.

Break
Panel discussion: ‘Towards acceleration of CCUS promotion in Asia/ASEAN through partnership’ 1. Mr. Hoang Van Tam, Deputy Head of Climate Change and Green Growth Office, Ministry of Industry and Trade, Viet Nam 2. Dr. Zhong Sheng, Research Fellow, Energy Studies Institute, National University of Singapore 3. Ms. Dewi Mersitarini, Advisor of CCUS Upstream Innovation, PT. Pertamina (Persero), Indonesia 4. Mr. Jinmiao Xu, Energy Specialist, Energy Sector Group, Department of Sustainable Development and Climate Change, Asian Development Bank (ADB) 5. Ms. Yukimi Shimura, Director, Sustainable Business Office, Solution Products Division, MUFG Bank 6. Mr. Juho Lipponen, Coordinator, Clean Energy Ministerial (CEM) 7. Mr. Yukihiro Kawaguchi, Director, Global Environmental Affairs Office, Ministry of Economy, Trade and Industry of Japan *(Moderator: Kikuko Shinchi, MRI)*
Closing remarks by Prof. Hidetoshi Nishimura, President, ERIA

According to the discussion, there are three pillars of issues with CCUS deployment in ASEAN and East Asia region:

a. Knowledge sharing and management promotion
b. Risk management approach (for technological and financial aspects)
c. Obtaining practical experience with concrete projects

For knowledge sharing and management promotion, there was an opinion in the session that technological experience is vital for CCUS dissemination, and regional and international collaboration is needed. In terms of technology, it was mentioned that there are diverse technological portfolios in each country in Asia. Therefore, it will be desirable to bridge the differences whilst being conscious of the differences in each technology experience.

Regulatory, institutional, and geological aspects of knowledge should also be shared in the region. For the geological aspect, CO_2 storage site mapping in Asia should be further explored and shared, for which it is necessary to consider the CO_2 storage projects described in the previous chapter.

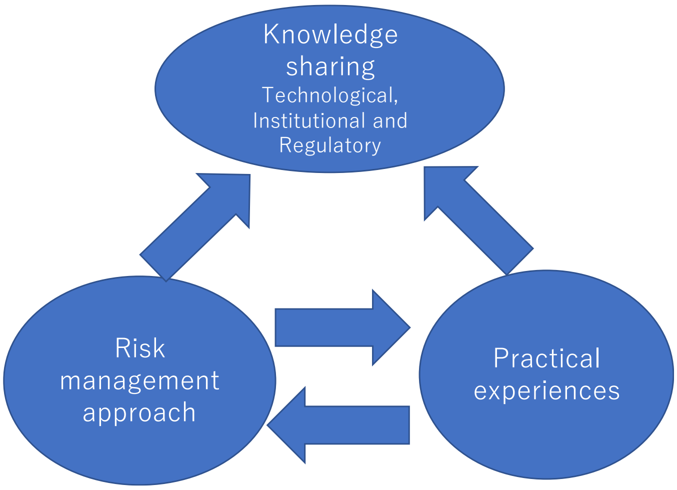
The second pillar discussed in the session was the risk management approach. On the technological aspect, there were plenty of discussions on risk management for addressing the CO_2 containment responsibility. As written in the previous chapter, it is necessary to address the risk of seepage from the storage formation for CO_2 storage projects, and this imposes correspondence of more than a couple of decades. It is necessary to mitigate the duty imposed on the project owner by risk-sharing and so on.

Risk management is a keyword also related to the financial aspect. It will be desirable to establish methods to assess the CCUS risks financially to make decisions for the financial sector.

The third pillar is related to obtaining practical experience with concrete projects. Concrete project development is vital to identify practical issues in implementing CCUS. As discussed in the symposium, a regulatory framework should be considered with a project-oriented manner in the beginning stages.

These three pillars and their mutual relationships are shown in Figure 4.1. In addition, business model development, cost reduction methods, and any approaches to implementing CCUS are thought to be derived from concrete projects. With this thought, it is desirable to set up diverse pilot projects suitable for the context in the Asian region.

Figure 4.1. Speculative Issue Structure for CCUS Deployment in the ASEAN Region



Source: Created by Mitsubishi Research Institute.

2. Prospectives based on partnerships – Outcome from the 3rd EAEF

The proposed Asian regional CCUS network is expected to complement existing international cooperation frameworks, such as the Carbon Sequestration Leadership Forum (CSLF) and Clean Energy Ministerial (CEM). The CSLF is technologically oriented, whilst the CEM is more focused on policy proposals and business model creation. Although both focus on international cooperation, of the ASEAN and East Asian countries, only China, Japan, and the Republic of Korea are members of the CSLF, whilst the same three countries plus Indonesia are members of the CEM. As raised in the EAEF session, even countries with little or no emphasis on CCUS seek knowledge sharing in their post-2030 consideration of their decarbonisation strategies. The proposed Asia CCUS network is expected to adopt a grassroots approach, involving countries that have yet to take an active stance on CCUS.

Bearing in mind the supplementation of the existing framework and issues identified in the previous section, three activities are identified as having the potential of promoting CCUS through the Asian regional network.

Open technological platform

Activities for the identification of technological issues and knowledge sharing are taking place to some extent through existing international initiatives. However, technological capacity development and dissemination takes time and requires intensive involvement. In this context, the Asian regional network may have the potential to supplement and accelerate existing technology cooperation. One example of CCUS technology capacity development would be the open source of technological knowledge and human resource exchange.

Policy suggestions and a problem-solving platform

In order to develop concrete CCUS projects, it is necessary to address the practical issues faced in individual countries. These could not be solved without intensive cooperation and information exchange to implement concrete policies and problem-solving in actual projects. The Asian regional network could offer an intensive cooperation platform amongst policymakers, project developers, technology providers, and financial institutions to exchange views to overcome practical issues. Working groups and meetings can be held to facilitate discussions on legal frameworks and policy development, risk mitigation, and bankability, etc.

Demonstrating concepts through pilot projects

Once the issues and their possible solutions are identified through working groups and meetings, they need to be tested to implement fine-tuning towards commercialisation. The proposed regional network can support such pilot projects through identifying storage sites and fostering collaboration amongst technology providers, policymakers, and financial institutions.

Drawing shared visions for CCUS in Asia

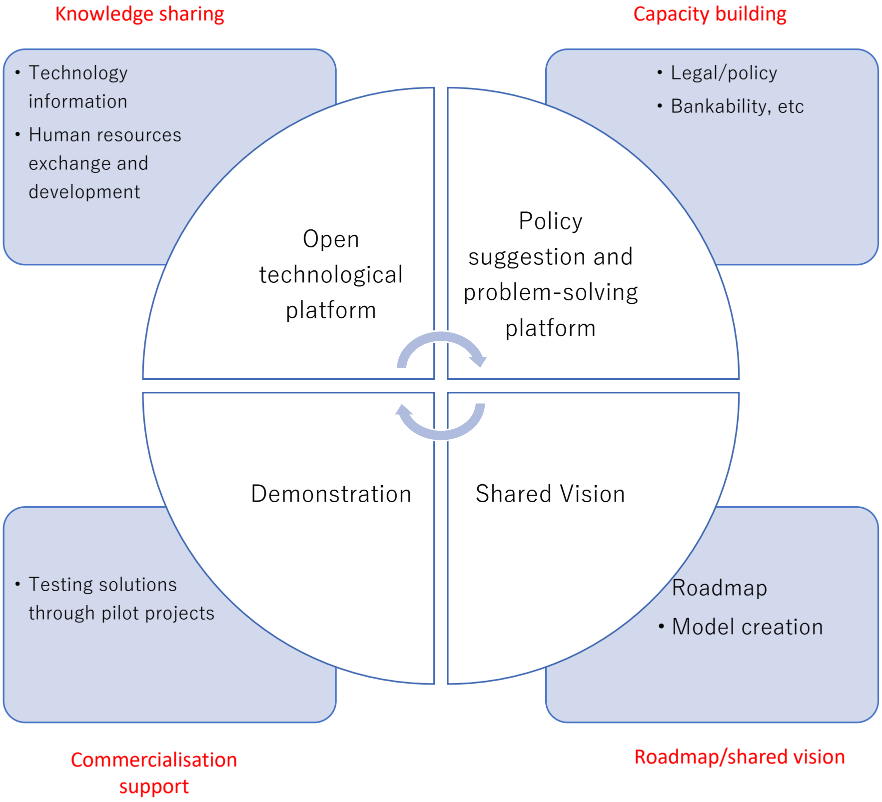
Last but not the least, it is important to have shared visions for such a large-scale technology as CCUS. Shared objectives and directions will facilitate swifter international understanding, cooperation, and communication.

One example of a shared vision could be to develop an industrial hub and cluster where the required technological and institutional knowledge components for CCUS are accumulated. Having a physical network of CO_2 collection, transport, and storage could be another example for a shared vision as seen in Norway’s Northern Lights project and the Northern Endurance Partnership of the United Kingdom in Europe. It is hoped that a roadmap for achieving the shared vision is designed and agreed at the launching of the Asia CCUS Network.

Progressive cycle of the Asia CCUS Network

In addition, actions should be implemented in a consistent manner. Work programmes under the Asia CCUS Network are best constructed being conscious of the progressive cycle as shown in Figure 4.2.

Figure 4.2. Conceptual Image of the Functions of the Asia CCUS Network



Source: Created by Mitsubishi Research Institute.

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