ERIA Research Project Report 2024, No. 16

Comprehensive CCUS Research Report: Storage, Value Chain, Policy & Regulation and Financing

Prepared by

Global CCS Institute (GCCSI)

With Support of

ERIA (Economic Research Institute for ASEAN and East Asia)

Comprehensive CCUS Research Report: Storage, Value Chain, Policy & Regulation and Financing

Economic Research Institute for ASEAN and East Asia (ERIA)
Sentral Senayan II 6th Floor
Jalan Asia Afrika No. 8, Gelora Bung Karno
Senayan, Jakarta Pusat 10270
Indonesia

ERIA Research Project FY2024 No. 16
Published in September 2024

Preface

In alignment with the Asia CCUS Network's (ACN) vision, which aims to contribute to decarbonisation in the Asian region through the development and deployment of Carbon Capture, Utilisation, and Storage (CCUS), the roadmap emphasises initiating a basin-scale CCS pilot project around 2025 and transitioning CCUS business to a commercial basis after 2030. ACN has taken a comprehensive approach to address key CCUS issues, including:

a. Assessing CO_2 storage potential in the ASEAN region. b. Establishing the policy and legal framework for CCUS business. c. Developing financing mechanisms to secure substantial investments for CCS business. d. Examining the CO_2 value chain, particularly cross-border CO_2 transportation in the Asian region.

In pursuit of these goals, ACN received a research proposal from the Global CCS Institute (GCCSI) to conduct studies on these four crucial points. ACN carefully reviewed the proposal, sought feedback from the ACN Advisory Group members, and forwarded comments to GCCSI. GCCSI revised the proposal based on ACN's feedback, finalising it for implementation.

Following the initiation of the study, lasting approximately one year, GCCSI compiled the results into a comprehensive report, including an executive summary. Upon receiving the report, ACN scrutinised it and provided feedback with several comments to GCCSI. The report was finalised after incorporating ACN's comments.

The key findings of the report include:

a. Identification of substantial CO_2 storage capacity in the ASEAN region, with a notable emphasis on Indonesia. b. Recognition of the indispensability of an appropriate policy and legal framework for successful CCS/CCUS implementation, especially in monitoring CO_2 leakage during specific periods. c. Emphasis on incorporating a financing scheme that includes establishing a suitable carbon price market and carbon credit mechanisms, such as the Joint Credit Mechanism (JCM). d. The necessity of establishing institutions to support CO_2 trade between CO_2 emitting countries and CO_2 storing countries, applying market mechanisms.

In light of these study results, ACN is poised to contribute to the initiation of a CCS pilot project in the ASEAN region.

Shigeru Kimura
Special Advisor to the President on Energy Affairs
Economic Research Institute for ASEAN and East Asia.

Acknowledgements

This report was collaboratively developed by researchers from the Global CCS Institute (GCCSI), each contributing expertise in specific areas:

Dr Christopher Consoli focused on assessing the geological storage potential of CO_2 in Southeast Asia.

Mr Ian Havercroft concentrated on the legal and policy framework for the deployment of CCUS in the Asia region, with a specific focus on ASEAN.

Mr Eric Williams contributed to the study on the financial framework for the deployment of CCUS in the Asia Region, including ASEAN.

Mr Alex Zapantis played a crucial role in establishing the Asia CCS/CCUS value chain as a collective framework in the Asia region.

Additionally, other researchers from GCCSI were actively involved in the preparation of this report. I take this opportunity to express my gratitude to GCCSI for its valuable contributions that significantly contributed to the success of this project.

Shigeru Kimura
Special Advisor to the President on Energy Affairs,
Economic Research Institute for ASEAN and East Asia

List of Project Members

GCCSI

Hugh Barlow

Selim Cevikel

Christopher Consoli

Aishah Hatta

Ian Havercroft

Matthew Loughrey

Joey Minervini

Errol Pinto

Nabeela Raji

Mojtaba Seyyedi

Shahrzad Shahi

Bernardene Smith

Eric Williams

Alex Zapantis

ERIA

Shigeru Kimura
Special Advisor on Energy Affairs

Han Phoumin
Senior Energy Economist

I Gusti Suarnaya Sidemen
CCUS Fellow, ERIA

Ryan Wiratama Bhaskara
Research Associate

Citra Endah Nur Setyawati
Research Associate

Table of Contents

List of Figures

List of Tables

List of Abbreviations/Acronyms

ACCU	Australia Carbon Credit Units
ACE	ASEAN Centre for Energy
ACR	American Carbon Registry
ADB	Asia Development Bank
AEMO	Australian Energy Market Operator
AEOS	Alberta Emission Offset Scheme
AETI	Asia Energy Transition Initiative
ANGEA	Asia Natural Gas and Energy Association
APAC	Asia-Pacific
APEC	Asia-Pacific Economic Cooperation
ASEAN	Association of South-East Asian Nations
AUD	Australian Dollar
AZEC	Asia Zero Emission Community
BCG	Boston Consulting Group
BECCS	Bioenergy with Carbon Capture and Storage
BIGST	Bujang, Inas, Guling, Sepat, and Tujoh
BNCCP	Brunei Darussalam National Climate Change Policy
BP	British Petroleum
BPMA	Badan Pengelola Migas Aceh
BRGM	Bureau des Recherches Géologiques et Minières
BSP	Brunei Shell Petroleum
CAPEX	Capital Expenditure
CARB	California Air Resources Board
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation, and Storage
CDM	Clean Development Mechanism

CDR	Carbon Dioxide Removal
CEQ	Council on Environmental Quality
CER	Clean Energy Regulator
CFPP	Coal-Fired Power Plant
CH4	Methane
CIPP	Comprehensive Investment and Policy Plan
CIX	Climate Impact X
CNOOC	China National Offshore Oil Corporation
CO	Carbon Monoxide
CO2	Carbon Dioxide
CO2Stop	Assessment of the CO2 Storage Potential in Europe
COP	Conference of the Parties
CRF	Capital Recovery Factor
CRRU	Carbon Reduction/Removal Unit
CSEM	Controlled Source Electro-Magnetic
CSU	Carbon Storage Unit
DAC	Direct Air Capture
DACCS	Directdirect Air Capture and Storage
DOE	Department of Energy
EC	European Comission
EDX	Energy Data Exchange
EEA	European Economic Area
EIA	Environmental Impact Assessments
ELD	Environmental Liability Directive
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Authority
ERF	Emissions Reduction Fund
ERIA	Economic Research Institute for ASEAN and East Asia
ESG	Environmental, Social and Governance
ESMAP	Energy Sector Management Assistance Program
ETS	Emission Trading System

EU	European Union
EUR	Euro
EV	Electric Vehicle
FEED	Front End Engineering Design
FID	Final Investment Decision
GBP	Great Britain Poundterling
GCCSI	Global CCS Institute
GD2	Guidance Document
GDP	Gross Domestic Product
GENZO	Global Economic Net Zero Optimization
GHG	Greenhouse Gas
GHGRP	Greenhouse Gas Reporting Program
H2	Hydrogen
IBRD	International Bank for Reconstruction and Development
IDA	The International Development Association
IDB	Inter-American Development Bank
IEA	International Energy Agency
IEAGHG	The IEA Greenhouse Gas R&D Programme
IED	Industrial Emissions Directive
IEG	Information Exchange Group
IETA	International Emissions Trading Association
IFC	International Finance Corporation
IIJA	Infrastructure Investment and Jobs Act (
IMF	International Monetary Fund
IMO	International Maritime Organization
IOGP	International Association of Oil and Gas Producers
IPCC	Intergovernmental Panel on Climate Change
IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
JBIC	Japan Bank of International Cooperation
JETP	Just Energy Transition Partnership

JOGMEC	Japan Organization for Metals and Energy Security
JSA	Joint Study Agreement
LCER	Low-Carbon Energy Research
LCFS	Low Carbon Fuel Standard
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LPO	Loan Programs Office
MARPOL	International Convention for the Prevention of Pollution from Ships
MCMPR	Ministerial Council on Mineral and Petroleum Resources
MCO_2	Estimated CO_2 Storage Resources
MDB	Multilateral Development Banks
MEMR	Ministry of Energy and Mineral Resources
METI	Ministry of Economy, Trade, and Industry
MFO	Marine Fuel Oil
MGO	Marine Gas Oil
MMP	Minimum Miscibility Pressure
MOU	Memorandum of Understanding
MRV	Measurement, Reporting and Verification
MW	Mega Watt
NCCAP	National Climate Change Action Plan
NCCS	National Climate Change Secretariat
NCOC	North Caspian Operating Company
NDC	Nationally Determined Contributions
NEATS	National Electronic Approvals System
NEMP	National Energy Master Plan
NEP	National Energy Policy
NETL	National Energy Technology Laboratory
NETR	National Energy Transition Roadmap
NG	Natural Gas
NGER	National Greenhouse and Energy

NGO	Non-Governmental Organization
NOC	National Oil Company
NOK	Norwegian Krone
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
NOPTA	National Offshore Petroleum Titles Administrator
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
OJK	Otoritas Jasa Keuangan
ONGC	Oil and Natural Gas Corporation
OPEX	Operation Expenditure
PDR	People's Democratic Republic
PEP	Philippine Energy Plan
PETRONAS	Petroliam Nasional Berhad
PSC	Production Sharing Contract
PTTEP	PTT Exploration and Production Public Company Limited
PV	Photovoltaics
RCAL	Routine Core Analysis Laboratory
RF	Recovery Factor
ROZ	Residual Oil Zones
SCAL	Special Core Analysis
SEA	South-East Asia
SEACA	South-East Asia CCS Accelerator
SOCAR	State Owned Company of Azerbaijan
SPE	Society of Petroleum Engineer
SRSAI	Significant Risk of a Significant Adverse Impact
TASR	Technically Accessible CO_2 Storage Resource
TBT	Technical Barriers to Trade
TCF	Trillion Cubic Feet
TDS	Total Dissolved Solids
TFEU	Treaty on the Functioning of the European Union

TVD	True Vertical Depth
UIC	Underground Injection Control
UK	United Kingdom
UN	United Nations
UNCLOS	The United Nations Convention on the Law of the Sea
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	United States Dollar
USDW	Underground Sources of Drinking Water
VCC	Value Chain Centre
VCM	Voluntary Carbon Market
VCS	Verified Carbon Standard
WACC	Weighted Average Cost of Capital
WEF	World Economic Forum
WRI	World Resources Institute
XRD	X-Ray Diffraction

Executive Summary

This report presents four separate studies completed by the Global CCS Institute for the Economic Research Institute for ASEAN and East Asia. Collectively, these studies assess the role of Carbon Capture and Storage (CCS) in southeast Asia to support the achievement of net-zero emissions targets, review the policy and legal frameworks necessary to enable CCS to play that role, examine the need for collaboration between southeast Asian nations including institutional frameworks and discuss options to facilitate the financing of CCS in the region. Each study contains recommendations.

The studies are:

1. CO_2 Storage Potential in Southeast Asia
2. Establishment of Asia CCS/CCUS Value Chain as a Collective Framework in the Asia Pacific Region
3. Legal and Policy Framework for Deployment of CCUS in Asia Region, focused on ASEAN
4. Study on Financial Framework for Deployment of CCUS in the Asian Region, including ASEAN

Key findings and recommendations from each study are summarised below.

Geological Storage Potential of CO_2 in Southeast Asia

This study investigates the potential of carbon capture and storage (CCS) to decarbonise industrial emissions in Southeast Asia, leveraging the region's numerous suitable storage basins and abundant CO_2 storage resources. The study evaluates emissions and basins across Southeast Asian nations, identifying 13 industrial emission clusters that could form CCS networks matched to storage basins. Networks can lower the cost and commercial risk of CCS deployment through shared infrastructure and knowledge inherent to their part of the CCS technical chain. Key findings and insights from the study include:

Key Findings

The suitability of basins for storage varies across countries as each nation is in a different state of storage resource development:

- Indonesia, Malaysia and Thailand are the most advanced, with suitable and highly suitable offshore and onshore basins, gigatonne storage resources, and active CCS facilities. However, only Indonesia has a national regulatory framework to enable CCS.
- Brunei Darussalam has a suitable offshore basin with gigatonne storage resources. However, storage development and CCS deployment have not commenced, and the nation lacks a dedicated regulatory environment for CO_2 storage exploration.

- Viet Nam and the Philippines host potential storage basins, but there is no storage development in key areas near strategic industrial emission clusters.
- Lao, Myanmar, and Cambodia were not assessed due to a lack of data, and the storage potential of those countries has never been reviewed.
- Singapore does not have a storage basin within its borders.

An estimated 200 gigatons (Gt) of storage resources confirm that the six Southeast Asian countries assessed for storage have sufficient resources to enable CCS in the region. On the estimated storage resource, around 98% is in saline formations. This estimate is remarkable as only nine saline formations in nine basins were reviewed. However, this estimate carries large uncertainty since the storage resources for saline formations are for theoretical storage, whereas the hydrocarbon field storage estimate uses field data.

Table S.1. Estimated Storage Resources in ASEAN Countries

Country	Saline Formation- P50 net storage resources ($MtCO_2$)	Depleted Field- P50 net storage resources ($MtCO_2$) and Number of Fields	CO_2 stored through EOR- P50 ($MtCO_2$) and Number of Fields
Indonesia	49,000	2,275 / 42 fields	153/ 6 fields
Malaysia	127,000	1,773 / 41 fields	105/ 9 fields
Brunei	18,000	579 / 7 fields	200/ 1 field
Thailand	15,000	1,024 / 27 fields	0
Viet Nam	5,000	303 / 9 fields	56/ 3 fields
Philippines	n/a	67 / 1 field	0
Total	**214,000**	**6,021 / 127 fields**	**514/ 19 fields**

Source: GCCSI.

There are limited to moderate opportunities for CO_2 EOR storage in the region, with Brunei, Indonesia, and Malaysia presenting the highest potential in that order.

International import of CO_2 is a very likely option for several basins across Southeast Asia, including Sabah - Baram Delta (Brunei), Sarawak and Malay (Malaysia) and Kutei (Indonesia).

There are significant information gaps related to geological storage resources in the region:

Gap 1: Characterisation of non-hydrocarbon-producing basins is lacking.

Gap 2: Basic basin-scale storage characterisations are lacking for Lao, Cambodia, Myanmar, and the Philippines

Gap 3: Limited characterisation of saline formations in the region.

Gap 4: Basin-wide, site-scale characterisation and appraisal have not been completed in any basin in the region.

Recommendations

- Develop a regional storage atlas led by advanced Southeast Asian nations and international experts using a standardised methodology.
- Create an online database of the atlas to facilitate further storage development and CCS infrastructure planning.
- Conduct detailed site-scale storage analysis, including characterising priority basins (Malay (Malaysia/Thailand), Northwest Java (Indonesia), Cuu Long (Viet Nam), and Pattani (Thailand).

Establishment of Asia CCS/CCUS Value Chain as a Collective Framework in the Asia Pacific Region

Key Findings

The development of CCS hubs and clusters, bringing together a number of different CO_2 emissions sources and/or storage sites in a connected network, offers participants several advantages over vertically integrated CCS projects. Benefits include reduced costs and risk, enabling more cost-effective transport and storage from small volume sources, and maintaining investment and jobs in high-emitting industrial regions.

Large-scale deployment of CCS in the region will require a coordinated effort between countries in Southeast Asia, to develop frameworks and platforms for successful and timely project delivery. Integrated upstream policy and robust institutional frameworks will be key to underpin regional project implementation. In addition, coordinated institutional frameworks, including coherent decarbonisation strategies, project approval and procurement strategies, and investment plans, will reduce project risk and enable capital investment.

The establishment of a centralised body, such as a CCS Value Chain Centre (VCC), to coordinate and administer regional efforts, could accelerate CCS deployment in the region.

The VCC, as a coordinating body, could review and make recommendations on how existing national policies, legislation and regulatory frameworks could be adapted to accommodate and enable regional CCS activities, including identification of near- and mid-term activities to support national regulators and policymakers to align national CCS policies to enable collaboration in the region. In collaboration with national policymakers and regulators, the VCC could implement the ASEAN CCS Roadmap currently under development by the ASEAN Center for Energy. As a regional body, the VCC could act as an advisory body, tasked with monitoring national CCS legislation and regulation development in the region, in line with the ASEAN CCS Roadmap and make recommendations to regulators as appropriate.

In addition, the VCC could coordinate the development of an ASEAN CCS Regulatory Principles guideline, based on the existing 'ASEAN Guidelines on Good Regulatory Practice' to provide guidance on the approach to developing CCS-specific regulation for the region.

The VCC could also play a role in the standardisation of CCS, based on international standards and global best practice and through collaboration with other associations in the climate change space. It could also become the official custodian of an ASEAN geological storage calculation engine and database, accessible to project proponents in the region and coordinate the development of a regional framework for risk assessment and management of CO_2 storage in geological formations.

To support investment in CCS projects in the region and to provide certainty to project sponsors and financiers, the VCC could act as a representative body for ASEAN countries, seeking foreign direct investment and other forms of climate finance. A coordinated multi-national approach will enhance negotiation power and reduce counterparty risk for investors.

Recommendations

Actions that should be considered by project proponents and governments to facilitate the development of CCS hub and cluster networks include:

- Identification of emissions clusters and storage resources that could support the development of CCS networks in each country and regionally. This provides the initial starting point for strategically developing CCS networks.
- Support with resources and funding for the appraisal of CO_2 storage resources in a given country or region. Locally available storage resources will always be more cost-effective than leveraging regional storage resources. Identifying surplus storage resources for the needs of the current emission sources allows for opportunities for low-emissions industry growth and provides storage resources to neighbouring countries with limited or no locally available storage.
- Identify avenues for incorporating new industries (i.e. clean hydrogen or ammonia) with existing emissions clusters early in developing CCS networks.
- Regional CCS networks will in most cases be more complex with the transboundary movement of CO_2. Early identification of these CCS networks will enable project proponents and governments to work through the necessary steps to facilitate their development.
- Identify opportunities to fast-track the development of first-mover CCS networks to expedite knowledge growth and accelerate the development of further CCS networks.

- Well-planned, early engagement with stakeholders and the community in the vicinity of emissions clusters and potential CCS networks.
- Governments should investigate the establishment of CCS Value Chain Centre (VCC) to coordinate and administer regional efforts to accelerate CCS deployment in the region.

Legal and Policy Framework for Deployment of CCUS in Asia Region, focused on ASEAN

Key Findings

The approach to regulating CCS activities is an important preliminary consideration for governments seeking to develop a CCS-specific legal framework. Regulators and policymakers have historically demonstrated a preference for one of two pathways; a stand-alone regulatory framework or enhancing existing oil and gas legislation to regulate CCS activities.

Regulators and policymakers may decide to expand the focus of regulatory frameworks to include the broad suite of applications that constitute CCS technologies across the industrial and power sectors. The inclusion of various applications will depend on the objectives underpinning the legislative framework for the technology, which may relate to the nation's climate change mitigation, energy transition and economic development priorities.

Permitting approaches may differ for various applications and separate permitting pathways may be established for specific applications. In some countries, certain enhanced hydrocarbon recovery applications, such as Enhanced Oil Recovery (CO_2-EOR), have been excluded entirely from the scope of CCS-specific frameworks.

Learning from the experiences of early-mover nations and engaging with international stakeholders provides valuable insights and expertise in the development of regulatory frameworks for CCS. Policymakers and regulators can benefit from established international forums and engagement in formal and informal dialogues to inform their decision-making processes regarding CCS-specific legislation.

Within the region, the experiences of the governments of Indonesia and Thailand offer tangible examples of the processes involved in developing regulatory frameworks for CCS. Both countries have undertaken collaborative, iterative processes, that have engaged a diverse group of stakeholders across various levels of government.

CCS-specific frameworks may build upon existing licensing regimes and in some instances rely upon established pathways to regulate discrete aspects of the CCS process. The resulting regulatory frameworks will therefore require the involvement of numerous regulatory authorities and/or agencies, as permits and licenses are sought for capture, transport, and storage activities.

Many of the government departments and authorities likely to assume roles and responsibilities in the regulation of the technology, throughout the project lifecycle, will be unfamiliar with the technology. There is a risk of delay or a disconnect within the regulatory process, where these stakeholders take time to familiarise themselves with the technology and new regimes.

Activities involving the transport of CO_2 across international maritime zones and marine areas have implications under a broad range of international agreements, including those relating to the pollution of the marine environment, the safety of maritime transport, the transport of dangerous goods and the carriage of compressed gases.

The London Protocol removed barriers to the technology's deployment and provided a basis under the Protocol's mechanisms for the regulation of CO_2 sequestration in sub-seabed geological formations. Recent amendments to this agreement offer an important pathway for facilitating the transboundary transportation of CO_2 for geological storage.

A substantial body of domestic legislation will ultimately apply to the entirety of a CCS project. For many nations within the ASEAN region, existing oil and gas operations will provide a good analogue for the various regimes that may also apply to CCS activities.

Compliance with CCS-specific legal and regulatory regimes is an important feature of many carbon crediting schemes that offer support for CCS activities.

The detailed reporting and accounting of stored CO_2, as part of geological storage operations, is an important aspect of ensuring compliance with CCS-specific legislation and for ensuring the wider integrity of CCS operations.

The 2006 IPCC Guidelines offer an important indication as to how national accounting schemes may manage the reporting of transboundary CCS operations.

Legal and regulatory issues will arise in the context of transboundary project models, which will trigger obligations under international, regional, and national regimes. The absence of clear legal and regulatory frameworks for these operations, within international and national law, suggests this issue is addressed in the pre-injection phase and prior to operation.

Examples from current regulatory frameworks demonstrate that countries have chosen to adapt or enhance a variety of existing regulatory regimes to regulate these activities. Legislation governing oil and gas and resources operations, environmental protection, property, planning, health and safety, and pollution control, may all have an impact upon CCS operations.

Existing regulatory frameworks, predominantly those facilitating other industrial activities, may serve as the basis for CCS regulation in the ASEAN region. Further amendment of these frameworks will be necessary to fully address the regulatory issues posed by CCS activities.

The responsible and safe closure of a CO_2 storage site are the focus of regulatory requirements during the closure phase. Legislation will require project operators to seek authorisation to close a CO_2 storage site upon the fulfilment of prescribed criteria and may include well decommissioning and plugging requirements.

Regulatory obligations during the post-closure phase will include long-term monitoring and responsible site care, to ensure the safety and security of CO_2 storage sites. Regulatory frameworks may oblige project operators to provide post-closure monitoring plans to address potential risks, including leakage and site integrity concerns.

Liability for stored CO_2 is a key issue that regulators and policymakers have attempted to address within early CCS-specific legal and regulatory frameworks.

Regulatory provisions enabling the transfer of liability for a storage site or stored CO_2, from an operator to a state's competent authority, following the closure of the storage site is a key mechanism adopted across various regulatory frameworks.

Regulatory frameworks also mandate financial security provisions to address the long-term liabilities associated with the closed CO_2 storage site, by requiring financial guarantees to cover closure, post-closure, and potential CO_2 leakage liabilities, to reduce the burden on public funds.

Recommendations

- Evaluate national policy priorities relating to climate change mitigation, energy security and economic development to evaluate the objectives that will underpin CCS-specific legislation and the preferred pathway for regulating the technology.
- Engage the wider public to better understand public sentiment towards CCS, and to gauge the public's level of knowledge and awareness of the technology's role in reducing greenhouse gas emissions.
- Review existing legal and regulatory frameworks relating to resources, energy, environment, property and planning, the adequacy of these regimes in regulating the novel aspects of CCS and the possibility of amending or adapting these frameworks to regulate CCS activities throughout the project lifecycle.
- Identify the specific applications to be covered by the scope of domestic regulatory frameworks.
- Review the extent to which existing regulatory frameworks, relating to resources, environment, property, and planning, may support dedicated geological storage and enhanced hydrocarbon recovery projects.
- Ensure CCS-specific regulatory frameworks remain future focused and are adaptable to reflect the technological advances associated with various applications and emerging technologies.
- Establish dedicated processes, that engage all relevant stakeholders within government, to examine and consider the relevant policy, legal and regulatory issues.

Activities may include the conducting studies to obtain an understanding of the nuances required in regulating CCS technologies.

- Engage a diverse range of expert stakeholders from across industry, academia, research institutions and civil society, to gather expert perspectives on the regulation of the technology.
- Leverage international expertise through dialogue with international stakeholders experienced in addressing CCS regulatory challenges. Engage in formal discussions or collaborations through established platforms to benefit from international insights and experiences.
- Government should identify and formally designate a lead government department or regulatory authority, to promote the development and implementation of a CCS-specific regulatory regime.
- The lead authority or department may then act as a coordinator to ensure that all relevant policy and regulatory entities are engaged and familiar with their roles and responsibilities, as part of the regulatory process.
- Governments may wish to consider developing an education and capacity development programme, aimed at familiarising the relevant policy and regulatory stakeholders with the technology and their roles and responsibilities within the regulatory process.
- Government, through the lead regulatory authority, may undertake a formal process of public consultation to ensure interested parties are afforded the opportunity to provide their feedback and that this information is formally captured.
- A formal information programme, delivered by government and/or third-party expert organisations, may be delivered in-tandem with the public consultation effort. A programme of this nature could seek to clarify the role of CCS in addressing domestic climate change commitments or address any misconceptions surrounding the technology.
- Undertake a detailed review of national commitments under wider international law, to determine their impact upon CCS operations.
- Investigate the implications of exporting/importing CO_2 from those countries which are Parties or non-Parties to the London Protocol.
- Develop secondary guidance to support project developers when advancing projects that feature the transboundary movement of CO_2.
- Undertake a detailed review of national legislation to determine key legal instruments applicable to CCS operations.
- As part of this review, policymakers and regulators should identify the wider approvals pathways for CCS projects, to reflect all necessary national and sub-

national legislation. The review should also seek to clarify obligations for project proponents and determine responsibilities between various national and sub-national regulatory authorities.

- Identify overlapping permitting responsibilities between national and sub-national regulatory authorities and identify any potential challenges.
- The development of secondary guidance may assist project proponents in navigating the requirements of wider legal and regulatory regimes.
- Timely engagement with project proponents to understand project proposals in development.
- Ensure that the development of any subsequent CCS-specific legislation adequately manages these new and emerging project models.
- Undertake a formal review of the inclusion of CCS activities within any existing or proposed domestic carbon crediting scheme or mechanism.
- Examine the legal and regulatory implications of formally recognising the geological storage of CO_2 within any existing or proposed scheme or mechanism.
- Review current emissions reporting and accounting frameworks to determine the extent to which CCS operations may be addressed.
- Ensure clarity within domestic emissions accounting frameworks of the treatment of CO_2 subject to transboundary movement.
- Review existing national protocols and guidance that may support the development and interpretation of future CCS-specific legislation.
- Where legislation is being proposed or implemented, policymakers and regulators may consider the development secondary guidance to support project developers in complying with the new legislative requirements.
- Determine how captured CO_2 is to be treated within domestic legal frameworks. Consider the necessity of excluding it from the scope of current waste management legislation.
- Establish guidelines or standards regarding the purity and composition of CO_2 streams.
- Clarify and define ownership rights over subsurface geological formations and the pore space, potentially through legislation or regulatory amendments.
- Develop site selection and characterisation requirements to ensure that CO_2 storage sites are suitable for the safe and permanent containment of CO_2. Consider the need for secondary guidance to assist project developers in their interpretation of these requirements.

- Engage with regulators and policymakers in the region to support the development of a consistent approach to the transboundary movement of CO_2.
- Ensure that these activities and requirements are adequately captured within a domestic permitting framework.
- Develop a regulatory regime aimed at facilitating the operational phase of a CCS project, including technical requirements that ensure the safe operation of capture, transport and storage activities.
- Review existing regulatory frameworks and the extent to which they accommodate the regulatory issues associated with the technology and ensure that CCS activities are sufficiently integrated within wider legal frameworks that may also be applicable.
- Develop adequate risk mitigation measures that incorporate strategies and contingency plans to address potential CO_2 leakage during the operational phase and after the closure of a project.
- Clarify project operators' responsibilities during operation and ensure clarity as to the allocation of liabilities during this phase in instances of non-compliance with regulatory obligations or in the event of any accident or leakage.
- Establish adequate monitoring and reporting procedures to ensure robust accounting verification of the stored CO_2.
- Ensure there are adequate, formal opportunities for regulators to monitor activities and ensure compliance with the regulatory framework.
- Develop a procedure within the regulatory framework to formally authorise site closure.
- Review existing legislation relating to oil and gas exploration and production for the purpose of enhancing or adapting provisions relating to well abandonment and site closure.
- Develop regulatory provisions addressing long-term monitoring after site closure and require approval of these plans to ensure adherence to safety and reporting provisions.
- Consider how long-term liabilities are to be managed within a domestic regime and, in particular, whether a transfer mechanism would be an option.
- Introduce provisions requiring operators to provide financial security to cover potential long-term liabilities arising from CCS activities.

Study on Financial Framework for Deployment of CCUS in the Asian Region, including ASEAN

Key Findings

CCS and other climate mitigating technologies deliver a public good; a stable climate. The value they create for society is far greater than the value that can be captured by a private sector investor in an individual project. Thus, any consideration of the financing of CCS, or any climate mitigation technology, necessarily requires a consideration of public policy to ensure that investment is sufficient to meet the needs of society. Public policy must create additional incentives for private sector investment beyond those that naturally exist in the market to secure the investment necessary to meet broader societal objectives (stable climate) that would otherwise not be made. These policies will generally require the allocation of public and private resources by governments on behalf of the communities they represent.

All ASEAN Member States have made commitments to achieve net zero emissions by 2050 or 2060. Having set the achievement of net-zero emissions as one of many priorities or commitments, governments need to find the lowest cost solution. This can only be defined through the use of an appropriate model, such as the Global CCS Institute's Global Economic Net Zero Optimization (GENZO) model.

Assuming the central scenario modelled in this report (Accelerated Storage Scenario), 2Gtpa CO_2 must be captured in southeast Asia by 2060 to support net zero commitments. This will require almost US$880 billion to invested in CCS between now and 2065 across southeast Asia, peaking at over USD40 billion per year, on average, in the 2040s. However, this investment will reduce the overall cost to the region of meeting net zero commitments by more than US$20 trillion over the same period.

Mobilising this quantum of capital for CCS will require both public and private finance. The private sector has enormous financial resources, human capital and capabilities necessary for the development and operation of CCS projects. However, the private sector can only invest where there is an appropriate risk weighted return on that investment. Current experience from around the world demonstrates that significant public finance is necessary to leverage the private finance required to accelerate CCS investment.

Policies are required that align private investment incentives with public good investment incentives. This can be done through any combination of:

- Increasing the cost of emitting CO_2 (e.g. carbon taxes or emissions trading)
- Command and control mechanisms (e.g or prohibition or mandates through regulation)
- Reducing the cost to private sector investors of CCS (e.g. through capital grants or concessional finance)

- Increasing the revenue created through CCS (e.g. through payments per tonne of CO_2 stored or operational subsidies)

Of the 376 commercial CCS facilities in development, construction or operation in the Global CCS Institute's database, 254 are in the USA, Europe, the United Kingdom or Japan. A common factor across these leading jurisdictions is that public finance, whether through capital grants or operational subsidies or tax credits, is a critical enabler of the rapid growth in the CCS project pipeline. Even in Europe where carbon prices have approached and even exceeded Euro100 per tonne, CCS has required significant policy support including public financing to attract private sector investment.

In summary, the role of public finance in this phase of CCS deployment, where there is a requirement to accelerate investment well beyond what the market would deliver without intervention, is to de-risk private investment in CCS.

However, ASEAN countries' economic and political structure differs significantly from the US and the EU. ASEAN Member States, perhaps with the exception of Singapore, have far fewer resources available to allocate to climate change mitigation. Potential sources of external finance for CCS include multilateral development banks (World Bank Group, Asian Development Bank), international climate related funds and foreign direct investment from the governments of developed countries with climate related aid or investments in the region.

ASEAN members benefit from the considerable resources, experience and expertise of national and international oil companies that are active in the region. This industry has some of the lowest cost opportunities for very significant emissions reductions in their production value chain. For example, reservoir CO_2 which is currently vented to atmosphere, may instead be compressed ready for transport and geological storage after minimal clean up (e.g. dehydration).

The oil and gas industry also holds subsurface data from oil or gas exploration and production necessary to identify, appraise and develop pore space for the geological storage of CO_2 and has the technical expertise and knowledge necessary to establish and operate CO_2 transport and injection infrastructure. In some cases, existing infrastructure such as pipelines or offshore platforms may be utilised or re-tasked to support CCS operations, very significantly reducing the necessary capital investment.

These first projects, being developed in the 2020s, are likely to be the lowest cost opportunities for CCS projects and may also be the anchor projects for the establishment of CCS networks that will serve the broader needs of industry in the region seeking a carbon management solution. In the absence of a material carbon price, these first CCS projects in the region will likely require capital investment support to reach FID.

Investment in CCS in the 2030s must ramp up significantly to stay on track to achieve net-zero emissions targets, reaching an average of USD15.6 billion per year (Accelerated Storage Scenario) during this decade in southeast Asia. By this time, the global CCS industry will have accrued another decade of operational and commercial experience.

Business models, risk mitigation strategies, and commercial confidence will have matured. More providers of CCS technologies and services will have entered the market and the policy and regulatory environments in developed economies will probably have strengthened the business case for CCS. The European Carbon Border Adjustment Mechanism will be in force, effectively exposing exports to Europe to the ETS carbon price. Private sector finance will likely be more accessible and attract a much lower risk premium (if any) as the finance sector becomes familiar with CCS. The first CCS projects in southeast Asia will have commenced operations.

The top three sectors which must host capture projects in the 2030s include, in decreasing order of investment, bioenergy with CCS in industry, electricity generation, and refining. These capture projects will require access to CO_2 transport and storage infrastructure which will likely be provided, in the majority of cases through networks. The importance of investment in networks this decade is clear from the GENZO model (Accelerated Storage Scenario). From GENZO, of the USD155 billion required to be invested in CCS in the region in the 2030s, over USD73 billion is required for CO_2 transport and storage including shipping, pipelines and geological storage development. This infrastructure is essential to enable the region to reach its net zero targets.

In the 2040s, as operational experience accumulates and networks are established in the region, government can shift from a capital subsidy policy model toward supplemental loan guarantees to lower the cost of private finance as the private sector takes a more active role. Government can gradually remove loan guarantees as the private sector gains confidence in lending for CCS projects and as the CO_2 price signal goes higher, making CCS projects more and more cost-effective.

Recommendations

A phased approach to driving investment in CCS is recommended.

<u>Phase 1 – First Projects; 2020s</u>

- The oil and gas industry is studying several CCS projects in the ASEAN region that share a common strategy; establish CCS infrastructure to enable the reinjection of their own reservoir CO_2, and explore opportunities to receive third party CO_2 for storage for a fee. Establishing the first CCS projects and their infrastructure to kickstart CCS deployment in the region this decade and lay the foundations for broader CCS deployment should be a priority for government climate policy in the region.
- Where the developer of a CCS project is a National Oil Company, government should consider supporting the financing of the CCS project off the company's balance sheet. This will necessarily require government to accept a reduced return from the NOC for a period. This represents, in effect, government investment in the establishment of CCS infrastructure that will deliver a return in the future.

- Government should put in place a proactive strategy to identify and obtain sources of external finance that could support these first CCS projects. This could be provided in the form of grants or concessional loans or loan guarantees. Sources to consider include the World Bank Group, the Asian Development Bank, the Green Climate Fund and developed countries with climate aid programmes or climate - related investments in the ASEAN region such as Japan, Australia, and the USA. Multilateral initiatives focused on CCS such as the Carbon Management Challenge which has an explicit objective of supporting carbon management efforts in the Global South (Clean Air Taskforce, 2023) should also be actively engaged.

- Government should consider the provision of targeted low-cost loans, capital grants or operational subsidies to CCS projects to bridge any remaining finance gap and allow developers to reach FID. Public finance could be awarded on a competitive basis to ensure funds are allocated and utilised efficiently.

- Governments should commence the development and implementation of carbon pricing schemes, starting at low prices for the least developed ASEAN economies, but with announced plans to increase the price in the future. Even at low prices of a few dollars per tonne of CO_2, carbon pricing, if applied broadly across the economy, could generate hundreds of millions of dollars of revenue for each government which could then be used to support climate mitigation initiatives, including CCS. These schemes will also set a clear expectation in the market of more stringent future climate policies and higher carbon prices that will incentivise increased analysis of CCS opportunities, entrepreneurial activity and CCS project development.

Phase 2 – CCS Network Establishment and Deployment Ramp-up; 2030s

- In the 2030s, Governments should aim to facilitate investment in the next wave of CCS projects especially where they leverage the infrastructure developed by the first wave of CCS projects.

- Governments should prioritise investment in additional CO_2 transport and storage infrastructure, including shipping necessary to establish CCS networks that will reduce the overall cost of CCS, and emissions mitigation, in the region. This will require continued development of carbon pricing programs (carbon price should continue to rise), continued engagement with multilateral development banks and other potential sources of external finance, and continued provision of targeted capital support.

- Governments should increase international collaboration and regional cooperation and proactively seek to facilitate investment in geological storage resource development and CCS networks.

- In addition to leveraging CO_2 transport and storage infrastructure that has been constructed in the 2020s to service the first CCS projects, Governments should deliberately target specific opportunities to create CO_2 collection hubs to service regions with significant emissions intense industry, to support the next wave of investment in CO_2 capture projects.

Phase 3 – CCS Industry Maturity; 2040s and beyond

- During this decade, governments should achieve material carbon prices that are sufficient to drive investment in CCS, and all other climate mitigating technologies, with little or in some cases no public finance or policy support. The capital investment required for CCS in the region peaks in the 2040s at an average on over USD40 billion per year. Investment at this scale will only be possible with full private sector engagement.
- In the 2040s Governments should look for opportunities to facilitate private sector investment in CCS investments that are commercially viable without significant public finance. One potential opportunity will likely be the production of low carbon hydrogen and its derivatives.

Chapter 1

Geological Storage Potential of CO_2 in Southeast Asia

Chris Consoli, Matthew Loughrey, Joey Minervini, Motjaba Seyyedi, Aishah Hatta, Errol Pinto, and Alex Zapantis

1.1. Southeast Asian CO_2 Storage Resource Development

Storage assessments in Southeast Asia have been limited, with most assessments focusing only on oil and gas fields and lacking supporting data. The last regional study of Southeast Asia was the Asia Development Bank's (ADB) *'Prospects for CCS In Southeast Asia*' report from 2013 (ADB, 2013). The techno-economic report was comprehensive but only focused on four countries: Viet Nam, Thailand, Metro Manila (Philippines), and South Sumatra in Indonesia. The report detailed a roadmap for deployment, focusing initially on pilot plants that could be upscaled to commercial facilities, finding natural gas processing and power plants had the best chances of successful commercialisation.

The ADB (2013) report found that the storage resource estimate for the four nations was 54 $GtCO_2$, with the vast majority (88%) of resources held in saline formations. Hydrocarbon fields were also assessed, with only 3.5 $GtCO_2$ storage resources across 143 fields. Unfortunately, the saline formations, fields, or the data behind the methodology and calculation were not provided, meaning no further progress could be made. Since the 2013 ADB study, no regional studies have characterised saline formations, hydrocarbon fields or completed source-sink matching exercises. These types of analysis are critical for ongoing storage resource development.

This current analysis aims to identify strategic storage resources in saline formations and hydrocarbon fields adjacent to clusters of industries where CCS can be applied. These emission-intensive clusters include power generation, chemical, cement and steel production, gas processing, and oil refining. A process known as source (industrial emissions sources)-sink (storage resources) matching. Source-sink matching identifies early mover opportunities for CCS development.

1.1.1. Current CCS Deployment Status

Despite Southeast Asia being a focus for CCS for over a decade, CCS facility deployment is very low compared to other parts of the world. indicates the current CCS facilities at various stages of development in the region. There are no operational facilities, with Petronas currently building the Kasawari CCS facility in the Sarawak Basin, Malaysia. Petronas and PTTEP also plan a second facility, Lang Lebah, in the same basin. That project is currently suspended, citing an unclear regulatory framework. Petronas and J.X. Nippon are planning the BIGST Project, a joint plan to explore opportunities for gas potential and CCS in the Bujang, Inas, Guling, Sepat, and Tujoh (BIGST) fields, situated offshore in Kerteh, Terengganu.

Indonesia hosts eight vertically integrated CCS facilities from various industries, but all are led by the oil and gas sector, focusing on gas processing, hydrogen/ammonia production and oil refining (Table 1.1). The Arun CCS Hub in Aceh is planned to be a multi-user storage site. In addition, the pilot Gundih Project plans to start injecting in 2024.

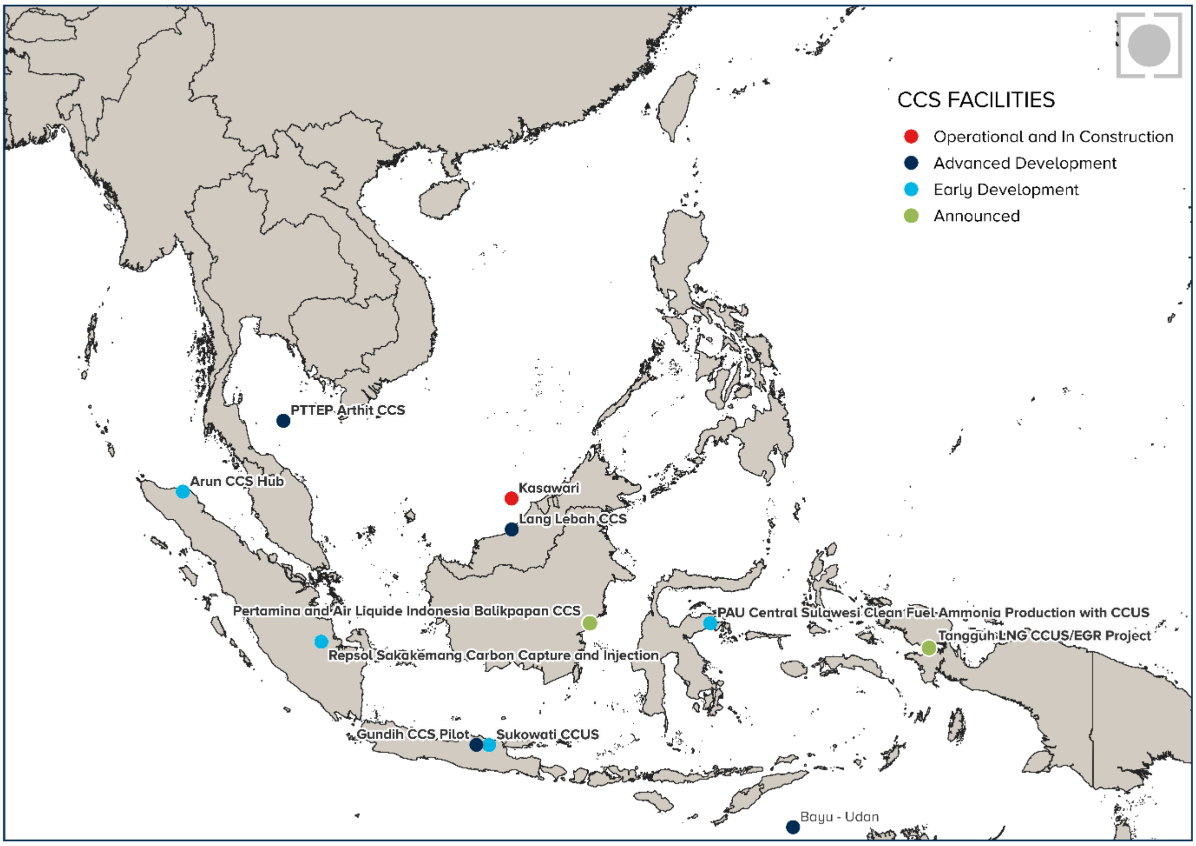
In Thailand, PTTEP is planning the Arthit facility in the Pattani Basin offshore Thailand (Figure 1.1).

Table 1.1. Commercial CCS Facilities in Indonesia

Commercial Facility	Status	Planned Operational Date	Industry
BP Tangguh LNG	Advanced Development	2026	Natural Gas Processing
Carbone Aceh Arun Hub	Early Development	2029	CO_2 Transport / Storage
ExxonMobil Indonesia Regional Storage Hub	Early Development	Under Evaluation	CO_2 Transport / Storage
PAU Central Sulawesi Clean Fuel Ammonia	Early Development	2025	Hydrogen / Ammonia / Fertiliser
Pertamina and Air Liquide Indonesia Balikpapan	Announced	Under Evaluation	Hydrogen / Ammonia / Fertiliser
Pertamina Jatibarang	Advanced Development	Under Evaluation	Natural Gas Processing
Pertamina Sukowati	Early Development	2028	Oil Refining
Repsol Sakakemang	Advanced Development	2026	Natural Gas Processing

Source: GCCSI.

Figure 1.1. CCS Facilities in Southeast Asia



Note: the locations of Jatibarang and the ExxonMobil Regional Storage Hub were unknown at the time of map production.
Source: CO2RE, 2023

1.2. Methodology

The methodology for completing source-sink matching requires two steps. First, a basin suitability assessment is conducted to identify potential basins for CO2 storage. Potential basins near industrial emission clusters are then prioritised. Second, the CO2 storage resources in hydrocarbon fields and saline formations are estimated within those storage basins and the CO2 EOR-storage potential is calculated.

The analysis incorporates only selected Southeast Asian nations with suitable storage and data. Importantly, not all emission clusters and storage basins were detailed across Southeast Asia, which means that the CCS networks presented below should be viewed as a preliminary guide for future studies.

1.2.1. Basin Suitability Assessment and Source Sink Matching

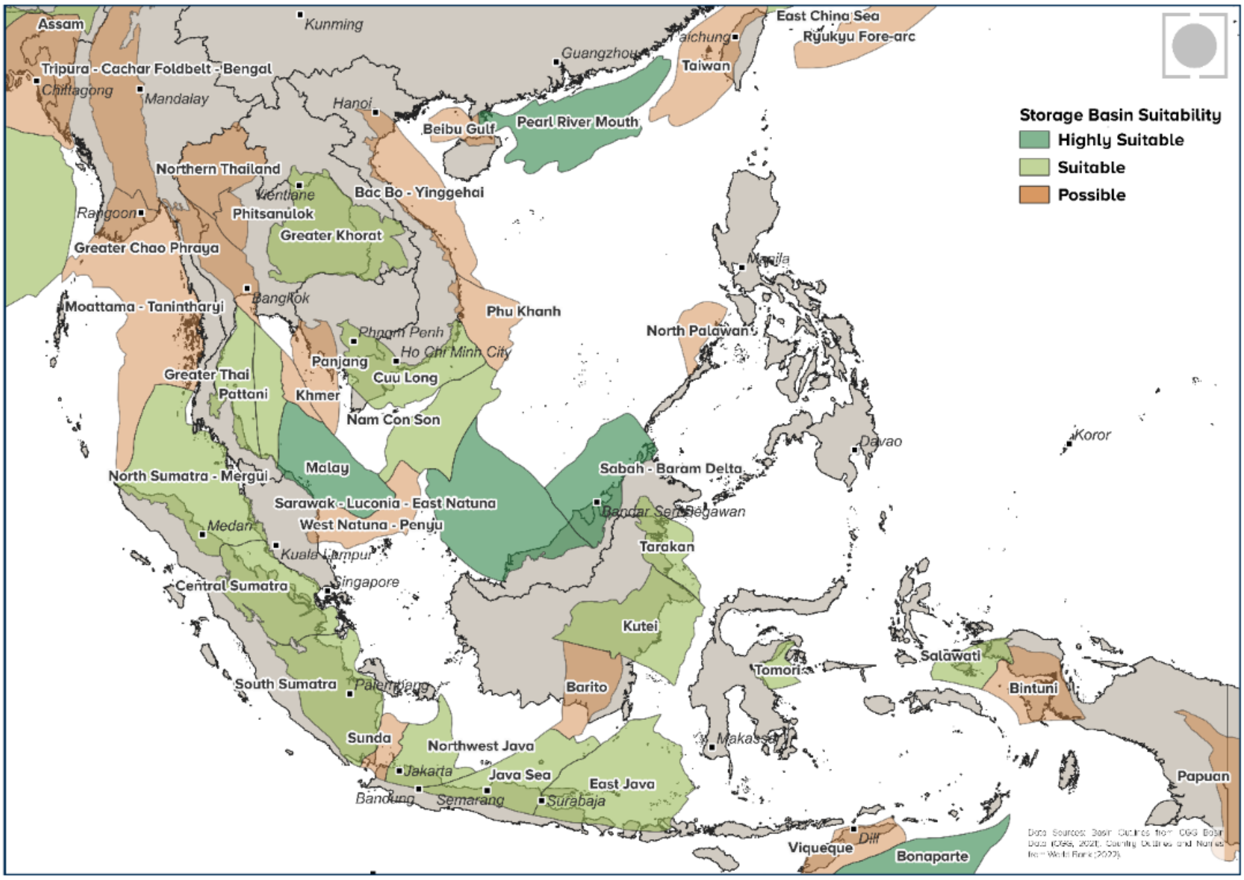
The following steps were completed to identify focus areas for CO_2 storage development in Southeast Asia proximate to CO_2 source clusters:

1. The Institute's storage basin assessment tool was used to assess every Southeast Asian basin (Figure 1.2); more information on the assessment methodology can be

found in Appendix A. The outcome of the basin assessment tool was to categorise each basin as either:

- ✓ Highly suitable (dark green in maps). These basins have most, if not all, the following characteristics:
  - Optimal geology for storage
  - Completed multiple detailed assessments of its storage characterisation and resource estimates by multiple parties with consensus on results
  - In most instances, the injectivity and storage of CO_2 have been tested, undertaken (pilot/EOR) or modelled.
  - The basin hosts a commercial-scale storage operation or advanced planning
  - The basin is (or has been) a mature and major oil and gas producer
  - The basin is accessible to CO_2 storage operations
- ✓ Suitable (light green). These basins meet many properties of a highly suitable basin, but generally:
  - Optimal geology for storage
  - Storage assessments have been more localised on particular parts of the basin
  - Do not host active or completed storage operations (commercial or pilot)
  - CO_2 storage operations may have accessibility issues
- ✓ Possible (orange). These basins have the following:
  - Prominent indicators of viable storage geology, such as oil and gas operations suggesting viable reservoirs and seals for CO_2
  - Storage analysis is limited to only broad, regional assessments, generally focusing on the oil and gas fields
  - Can have significant accessibility issues for CO_2 storage operations
- ✓ Unlikely (red). These basins generally have either:
  - Obstructing accessibility issues for CO_2 storage operations
  - The geology is currently defined as unsuitable for CO_2 storage. For example, a shallow (<800 m) basin means that CO_2 would not be stored in a supercritical phase, decreasing storage efficiency and increasing plume movement.

Figure 1.2. Southeast Asia Basin Suitability Assessment



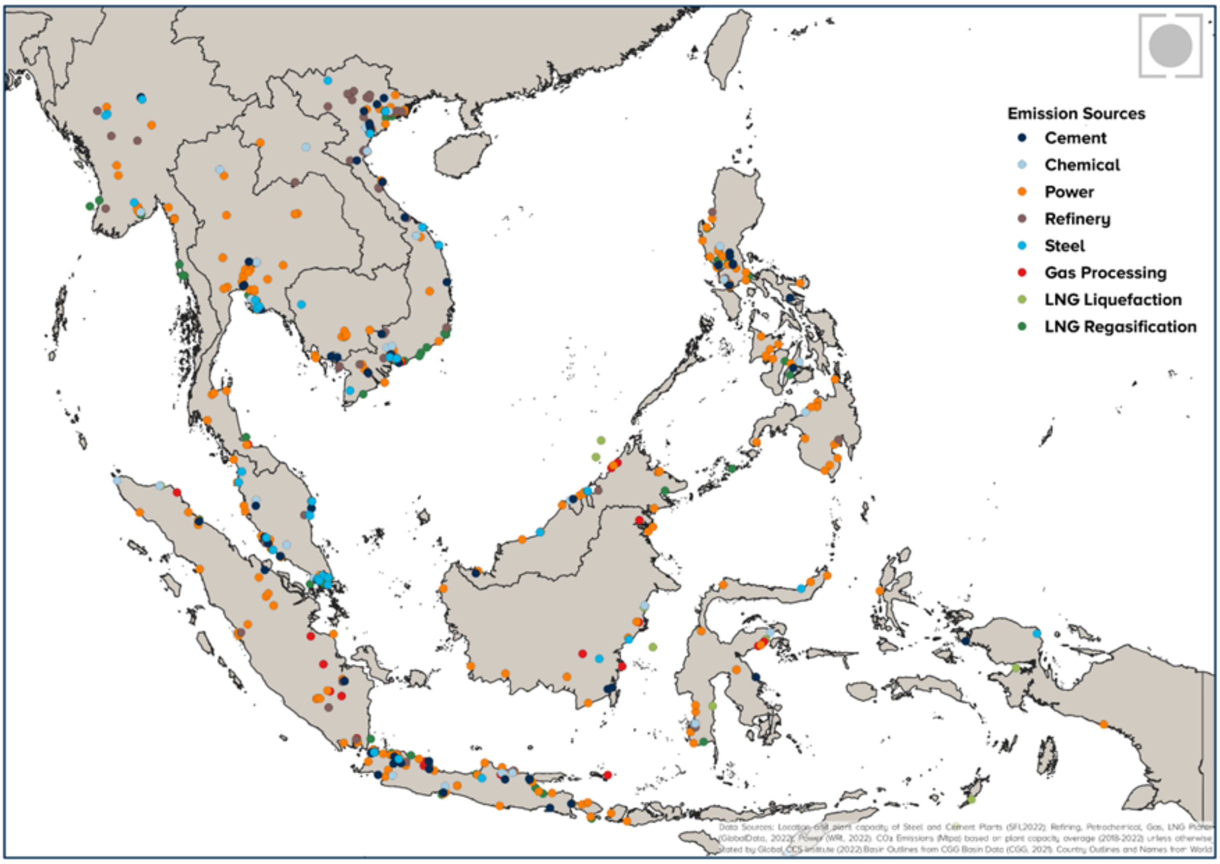
Note: This figure does not show basins categorised as 'Unlikely'.
Source: GCCSI.

2. The second step was to identify industrial emission clusters.
   - ✓ All industrial plants where CCS could be applied were identified in the region (Figure 1.3). The sector, the number of plants and sources of data are presented in Table 1.2.
   - ✓ The assumption for these plants is that each plant is operational and that the CO_2 emitted from the plants could be captured and transported for storage.
3. Grouping plants within 100 km of each other that could theoretically form clusters of emissions for a CCS network were identified. A distance of 100 km is arbitrary. However, techno-economic studies have found that pipelines greater than 100 km between capture plants or capture and storage sites become uneconomic because they require booster stations for compression.
   - ✓ The clusters are presented in the individual country maps (Figure 1.5; Figure 1.8; Figure 1.12; Figure 1.15; Figure 1.18).
4. Emission clusters were matched to their nearest storage basin.

   Note: A matching exercise comparing the cumulative emission rates of each cluster with their matching maximum cumulative injection rates and corresponding cumulative storage resources was outside the scope of this analysis.

5. Resource calculations for each suitable basin near an emissions cluster were the final step in this analysis. The resource calculation methodology is detailed in Section 1.2.2.

Figure 1.3. Emission Sources: Industrial Plants with the Potential to Host a Capture Unit Across Southeast Asia



Source: GCCSI

Table 1.2. Emissions Sources: Industrial Plant Data

Sector	Count of Plants	Source of Data
Power Generation	331	Byers, 2022
Cement	76	McCarten, 2022
Chemical	46	GlobalData, 2022
Refining	91	GlobalData, 2022
Steel	41	(Global Energy Monitor, 2022)
Gas Processing	41	GlobalData, 2022
LNG Liquefaction and Regasification	90	GlobalData, 2022

Source: GCCSI

1.2.2. Resource Calculation

1.2.2.1. Depleting and Depleted Hydrocarbon Fields

This analysis considered depleting and depleted fields. In a depleted hydrocarbon field, the majority of the economically recoverable oil or gas has already been extracted, leaving behind a relatively small amount of hydrocarbons that are uneconomical to produce using conventional drilling and extraction methods. Depleted fields may still contain some residual hydrocarbons, but the cost of extracting them may outweigh the potential profits. Depleting fields means the field is in production and still has economically recoverable oil or gas. This study did not have any metrics to distinguish between depleted and depleting fields, as the ultimate aim was to estimate available, remaining, and net CO_2 storage resources.

CO_2 storage resource estimates for depleting and depleted conventional oil and gas fields were calculated using the approach published by the United States Geological Survey (Brennan et al., 2010). This method assumes that some portion of the reservoir pore volume originally occupied by hydrocarbons produced from that reservoir can be replaced with injected CO_2. As such, the estimated CO_2 storage resources (MCO_2) of the hydrocarbon fields can be calculated using Equations 1-3:

Equation 1

$$M_{CO2\ availbale} = (N_{o-produced}.B_o + N_{g-produced}.B_g).E.\rho_{CO2} \quad (1)$$

Equation 2

$$M_{CO2\ remaining} = (N_{o-remaining}.B_o + N_{g-remaining}.B_g).E.\rho_{CO2} \quad (2)$$

Equation 3

$$M_{CO2\ net} = M_{CO2\ availbale} + M_{CO2\ remaining} \quad (3)$$

Where:

- E refers to storage efficiency, which is ''site-specific'' and can be determined via reservoir simulations. The commonly used value for E in oil and gas fields is between 0.2 to 0.4.
- B_o and B_g stand for the formation volume factors of the oil and gas, respectively, dependent on oil and gas properties and current reservoir conditions.
- ρ_{CO2} represents the CO_2 density at reservoir conditions, a function of reservoir pressure and temperature.
- $N_{o-produced}$ and $N_{g-produced}$ refers to the produced volume of the oil and gas in a field.
- $N_{o-remaining}$ and $N_{g-remaining}$ refers to the remaining volume of oil and gas in a field.
- $M_{CO2\ avaibale}$ refers to the storage resources currently available due to hydrocarbons that have been produced.
- $M_{CO2\ remaining}$ refers to remaining storage resources in a field that can become available upon production of the hydrocarbons (the field becomes depleted).
- $M_{CO2\ net}$ refers to the net CO_2 storage resources of a field.

Hydrocarbon Fields: Assumptions and Limitations

Recovered resource volumes for hydrocarbon fields were obtained from the hydrocarbon reserves database compiled by Global Data. In many instances, essential field data, such as average depth, temperature, and pressure, were unavailable. To address the missing data issue, the depth was estimated using a well's True Vertical Depth (TVD) within the field, or an arbitrary depth of 1200 m was assumed.

The acquired depth data were then employed to calculate the average field pressures, utilising a hydrostatic pressure gradient of 1.45 psi/m.

The depth data was also used to determine the average field temperatures using a Gaussian probability distribution (Monte Carlo) defining the geothermal gradient's minimum, maximum, and standard deviation values, as presented in Table 1.3.

Utilising the calculated pressure and temperature data, densities of CO_2 and CH_4 were calculated for each field. Assuming that natural gas within each field, if present, is completely made of CH_4 and utilising the CH_4 specific gravity of 0.554, the gas formation volume factor (B_g) for each field was computed.

Regarding the oil formation volume factor (B_o), due to data limitations, minimum, maximum, and standard deviation values reported in Table 1.3 were defined. These values were used to calculate the oil formation volume factor for each field using a Gaussian probability distribution. Table 1.3 also presents the values used in calculating storage efficiency for each field using the Gaussian probability distribution. A Monte Carlo simulation was employed to estimate resources, conducting one thousand simulations with a sample size of five for each parameter in every simulation.

This study only examined producing and abandoned conventional oil and gas fields. Currently discovered or planned-to-be-produced fields were not assessed due to data limitations. More importantly, these fields would not be ready for CO_2 storage until they become depleted, or in the case of oil fields, until their primary production recovery rate becomes so low that it justifies CO_2 EOR storage. Furthermore, the fields were screened based on their depth and P50-net CO_2 storage resources, and only fields with a depth equal to or higher than 800 m and net storage resources greater than 5 $MtCO_2$ are reported here. The depth criterion is crucial because CO_2 would not be in a supercritical phase in shallow fields. The 5 $MtCO_2$ screening criterion is applied because fields with smaller volumes would not offer economically viable CCS project opportunities.

It should be noted that the calculated average pore pressure, temperature, gas formation volume factor, and estimated oil formation volume factor values for each field obtained through the above methodology may not precisely represent the actual values in each field. However, the utilised methodology is the most reliable approach to understanding the storage resources of the fields. A detailed analysis of each field is essential to acquire accurate information regarding its storage resources.

Additionally, water and gas production during primary production, as well as water flooding or any other secondary injection techniques that may have been applied to some fields, are beyond the scope of this study. The equations used account only for the physical trapping of CO_2 and do not consider solubility trapping.

Understanding the local geological conditions is out of the scope of this analysis. Hydrocarbon fields are assumed to have a viable reservoir(s) and overlying seal(s). Furthermore, the calculation does not consider pore-space connectivity and assumes all pore spaces are available to CO_2. Compartmentalisation can negatively impact CO_2 storage resources.

Table 1.3. Parameters Used in the Monte Carlo Simulation to Estimate Storage Resources per Field

	Average	Min	Max	Standard Deviation
Geothermal gradient (°C/km)	33	23	40	6
B_o	1.5	1.1	2	0.2
E	0.3	0.2	0.4	0.04

Source: GCCSI

1.2.2.2. Saline Formations

Saline formations are deep (>800 m) geological bodies saturated with brine with a high total dissolved solids (TDS) concentration. According to underground drinking water sources (USDW) in the United States, those formations with TDS exceeding 10,000 mg/L can be targeted for CO_2 storage (US EPA, 40 CFR § 144.3, 2010). Since TSD data for formations were unavailable for this report, it is assumed the formations assessed herein could be potential targets for CO_2 storage.

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

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

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

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

Saline Formations: Assumptions and Limitations

Understanding the local geological conditions is out of the scope of this analysis. It is assumed there is a viable reservoir(s) and overlying seal(s) for saline formations. The analysis doesn't consider reservoir properties, such as porosity, permeability, pressure or temperature variations, or faulting. In addition, in the resource assessment, the calculation assumes that the pore space will be available for CO_2. The calculation does not consider pore-space connectivity. Saline formations could be heterogeneous or compartmentalised due to faulting, impacting storage resource estimates. This approach accounts only for the physical trapping of CO_2 and does not consider solubility trapping. Finally, the approach assumes that the saline formation has open boundaries, which may not be true for all formations. Therefore, the results may be overly optimistic.

1.2.2.3. *CO_2 EOR-Storage (CCUS)*

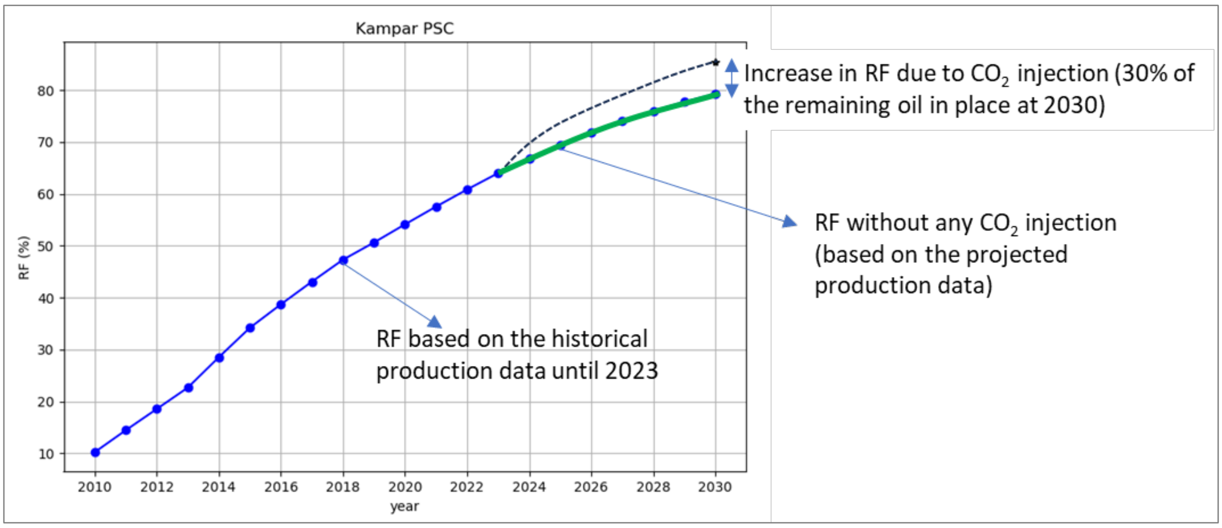
CO_2 EOR is a well-established oil and gas industry technique designed to enhance oil recovery. With a track record spanning over three decades of global operational experience, this technique has consistently demonstrated its effectiveness. The primary mechanisms driving oil recovery in CO_2 EOR are well-documented and extensively studied by many researchers. These mechanisms include oil swelling, oil viscosity reduction, and achieving miscible conditions when the reservoir pressure is higher than the minimum miscibility pressure (MMP).

The quantity of additional oil recovered through this technique depends on various parameters. These factors encompass the type of oil, the purity of the injected CO_2, the attainment of miscibility or near-miscible conditions, reservoir heterogeneities, the quantity and spatial distribution of residual oil in place, injection and production strategies and placement.

As such, a comprehensive analysis involving experimental and numerical studies for each field is essential to accurately determine a realistic recovery factor (RF), but this is beyond the scope of the present study. Therefore, a range of recovery factor values, spanning from as low as 5% to as high as 30% of the remaining oil in place, has been considered for this study.

By analysing oil production history data of oil fields from 2010 to 2023 and incorporating projected oil production rates until 2030 (sourced from GlobalData), each field's projected remaining oil in place by 2030 has been calculated. It is assumed that a reduction of 5%, 10%, 15%, 20%, 25%, or 30% in remaining oil in place by 2030 could be achieved through CO_2 EOR, thereby enabling the calculation of the additional oil that could be extracted by 2030 using CO_2 injection. For simplicity, only 5% and 30% results are reported here.

Figure 1.4. Recovery Factors (RF)



Note: the blue line indicates the primary recovery factor until 2023, the green line indicates the projected recovery factor from primary production until 2030, and the black dashed line shows the secondary recovery factor by CO_2 injection.
Source: GCCSI

During the CO_2 injection process, some injected CO_2 can become trapped within the reservoir through residual trapping, structural trapping, and solubility trapping. Solubility trapping encompasses the dissolution of CO_2 in the formation brine and within the residual oil. The solubility of CO_2 in oil depends on reservoir conditions and the specific type of oil. Nevertheless, this solubility can often be multiple times greater than the amount of CO_2 that can dissolve in the formation brine. Consequently, CO_2-EOR is also recognised as a CO_2 storage and utilisation technique (CCUS). The estimated CO_2 storage resources of the studied oil fields are calculated using equations 1 and 2 presented earlier.

CO_2 EOR-Storage: Assumptions and Limitations

It is assumed that oil field candidates for CO_2 EOR storage are those with a depth higher than 800 m, a storage resource exceeding 5 $MtCO_2$, a current recovery factor (RF) of less than 90%, and a projected primary remaining oil in place in 2030 greater than zero.

Note that, using equations 1-3, the consideration of the amount of CO_2 that can be stored through the displacement and production of water during CO_2 injection is omitted. High water cuts are expected during CO_2 EOR, and the pore space made available by such production provides additional CO_2 storage resources. Additionally, there is a high possibility of CO_2 breakthrough (i.e. injected CO_2 arriving at and being produced at production wells) and surface production during the injection. The breakthrough time varies depending on the injection, production strategy/design, and reservoir characteristics. It is assumed in this study that the produced CO_2 is separated and treated at the surface before being re-injected into the reservoir.

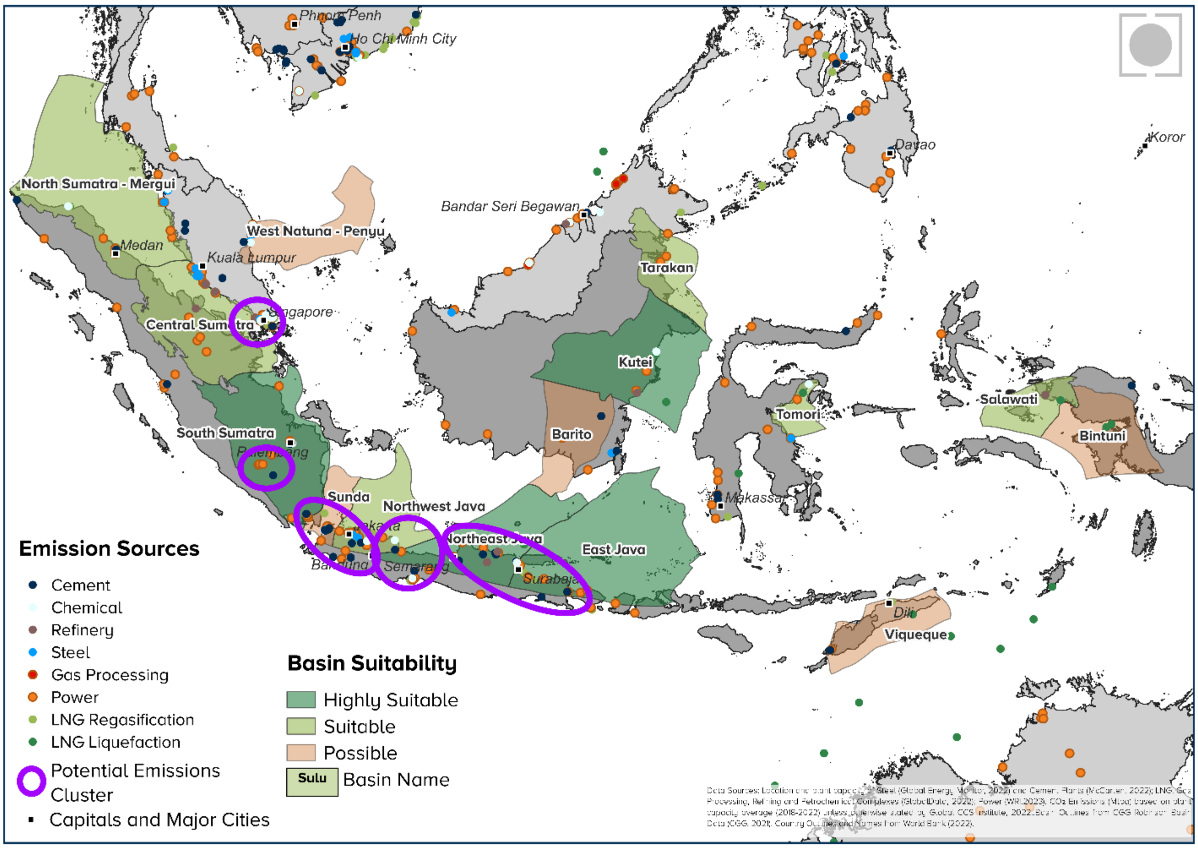
1.3. Results and Discussion

The outcomes of the source-sink matching exercise and the resource calculations are presented below. This analysis is supported by existing published literature where required.

1.3.1. Indonesia

Indonesia has a high overall CO_2 storage potential with abundant resources enabling a CCS Industry. Across Indonesia, four major emission clusters have been identified (Figure 1.5). There is the potential for numerous networks across Indonesia. In addition, the Singapore cluster is shown in Figure 1.5.

Figure 1.5. Indonesian and Singaporean Emission Clusters and Storage Basins



Source: GCCSI.

There is a major industry-led drive for CO_2 storage development in Indonesia, with support from international bodies (World Bank, 2015) to support CCS. Indonesia hosts the most CCS facilities in the region, with eight commercial facilities and one pilot (Gundih) distributed across the country (Figure 1.1). Six of the eight CCS facilities (PAU Central Sulawesi, Sakakemang, Tangguh LNG, Sukowati, Balikpapan, Jatibarang) are vertically integrated, with a capture plant having its own dedicated downstream transport and storage component. This reduces emissions from planned plants. None of these facilities has discussed broader access to their sites. However, the Arun CCS Hub in Aceh will be designed as a multi-user storage site. According to internal and external storage resource estimates, the depleted gas field has between 500 Mt - 1 $GtCO_2$ storage resources available (D. Lim pers. comm.).

1.3.1.1. CO_2 Storage Resources Summary

The estimated CO_2 storage resources of oil and gas fields (Table 1.4; Figure 1,6; Figure 1.7), CO_2-EOR Table 1.5, and saline formations (Table 1.6) are summarised below. Table1.6 shows the median (P50) cumulative net CO_2 storage resources ($\boldsymbol{M_{CO2\,net}}$) across studied conventional oil and gas fields per basin. As observed in the figure, the majority of storage resources are provided by gas fields, with the Kutei Basin having the highest net storage resources. The Kutei Basin also boasts the highest available storage resources (Table 1.4). Figure 1.6 displays the P50 net and available storage resources in the examined oil and gas fields. The figure reveals that many fields are relatively small, offering less than 20 MtCO2 net storage resources. This size constraint might render them unsuitable for average-sized, long-term commercial-scale CCS facilities, around 0.8 Mtpa over 20-40 years, according to capture rate data of the Global CCS Institute's CO2RE database (Global CCS Institute, 2023a). However, a more in-depth field assessment is necessary before making definitive conclusions.

Table 1.4. Indonesia: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50- Storage Available ($MtCO_2$)	P50- Storage Remaining ($MtCO_2$)	P50- Storage Net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
Banggai-Sula Basin	23.4	25.3	48.7	2	0
East Java Basin	100.8	29.3	130.2	3	2
Kutei Basin	598.8	99.3	698.1	6	2
North East Java Basin	78.1	60.0	138.1	6	2
North Sumatra Basin	506.0	0.3	506.3	1	0
North West Java Basin	65.3	36.6	101.9	2	0
Sengkang Basin	5.3	0.0	5.3	1	0
South Sumatra Basin	281.9	143.7	425.6	6	3
Sunda Basin	44.3	1.8	46.1	0	1
Tarakan Basin	5.2	1.0	6.2	0	1
West Java Basin	4.2	2.1	6.3	0	1

Basin	P50- Storage Available ($MtCO_2$)	P50- Storage Remaining ($MtCO_2$)	P50- Storage Net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
West Natuna Basin	137.8	24.4	162.3	2	1
Total	**1,851**	**424**	**2,275**	**29**	**13**

Note: Central Sumatra Basin is missing because all the studied fields are too shallow (<800 m depth).
Source: GCCSI

Table 1.5. Indonesia: Estimated CO_2 Storage Resources in Oil Fields Assessed for CO_2 EOR-Storage

Basin	P50- Storage Available	P50- Storage Remaining	P50- Storage Net	Extra Oil Recovery (MMbbl) @RF5%	Extra Oil Recovery (MMbbl) - @RF30%
East Java Basin	88.82	7.95	96.85	7.7	46.3
Kutei Basin	5.31	1.80	7.10	1.0	5.7
North East Java Basin	17.14	20.56	37.70	11.2	67.3
South Sumatra Basin	1.52	4.11	5.63	0.4	2.6
Tarakan Basin	5.23	0.98	6.21	0.6	3.8
Total	**118**	**35**	**153**	**21**	**126**

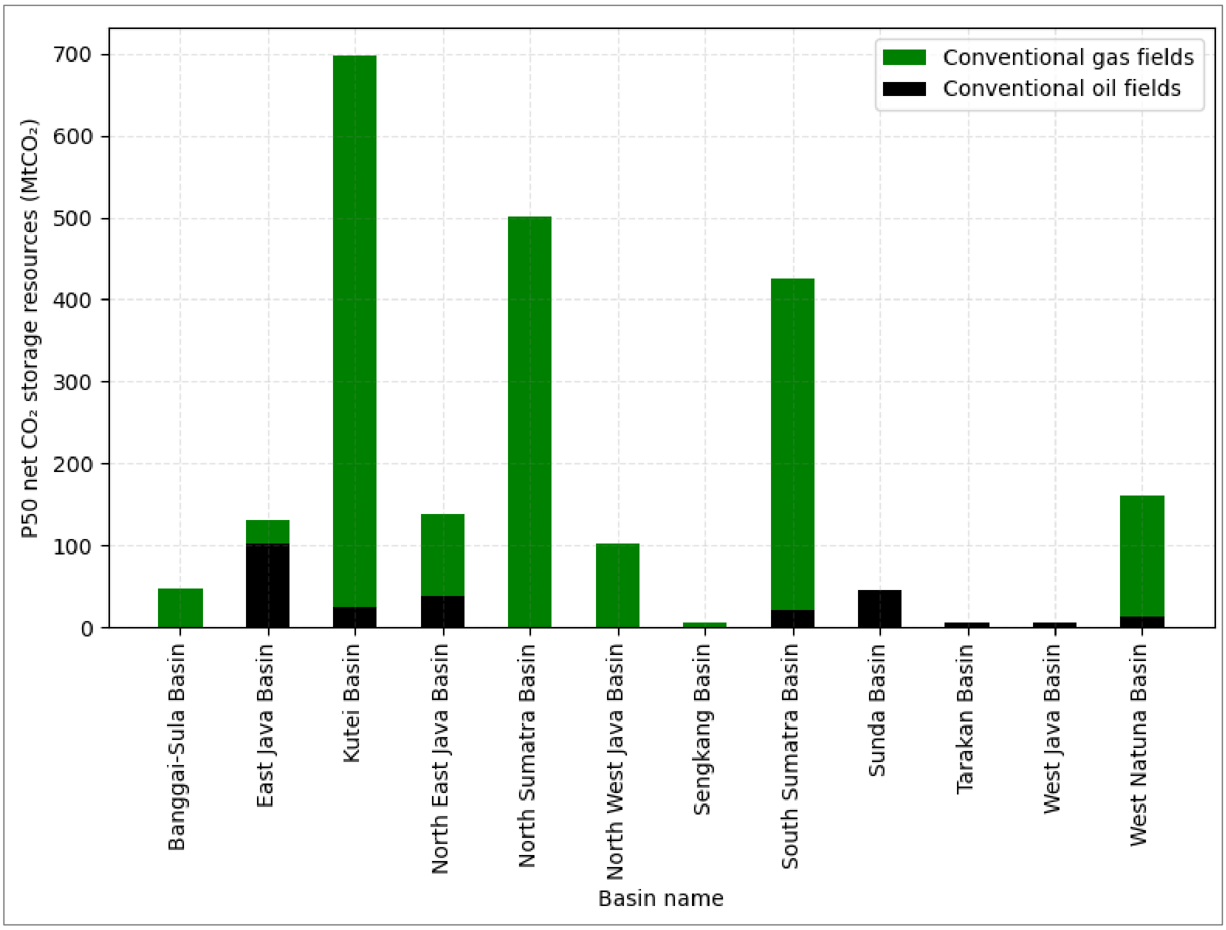
Source: GCCSI

Table 1.6. Indonesia: Estimated CO_2 Storage Resources in Saline Formations

Basin	Formation(s)	P10 ($GtCO_2$)	P50 ($GtCO_2$)	P90 ($GtCO_2$)
Kutei	Balikpapan Group	23	35	53
East Java	Kujung	4	8	13
Central Sumatra	Bekasap and Duri (Sihapas Group)	5	6	9
Total		**32**	**49**	**75**

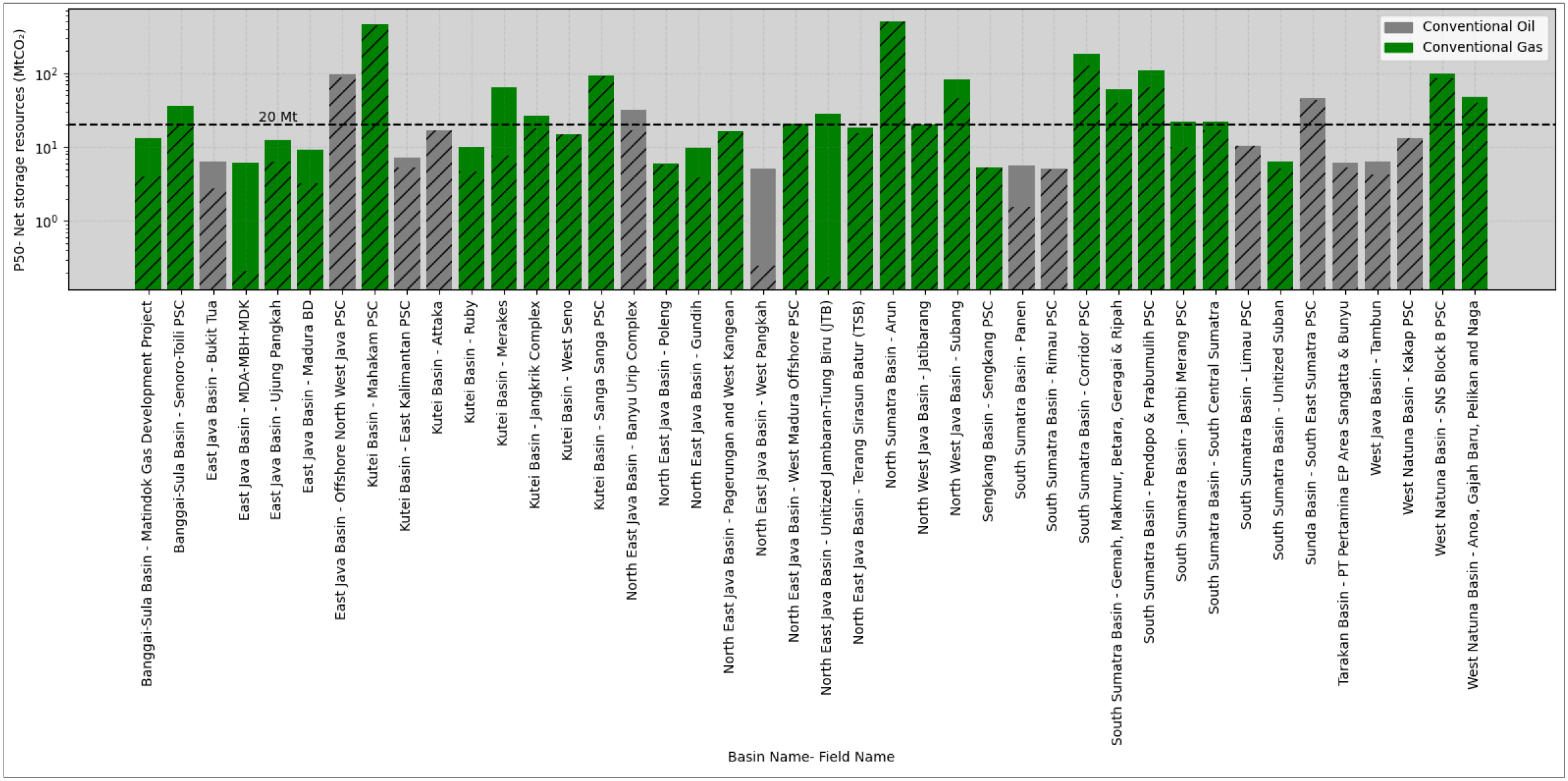
Source: GCCSI

Figure 1.6. Cumulative P50 CO_2 Storage Resources in Studied Oil and Gas Fields per Basin Across Indonesia



Source: GCCSI

Figure 1.7. P50- Net CO_2 Storage Resources of the Studied Oil and Gas Fields in the Indonesian Basins



Note: the available CO_2 storage resources are shown as a texture on the bars.
Source: GCCSI

1.3.1.2. Prospective Basins with Potential Clusters

According to the basin suitability analysis, Indonesia hosts 10 suitable basins (Figure 1.5) distributed across most of the islands of Indonesia. Unique to Indonesia, many of these basins extend from onshore to offshore. All these basins are oil and gas producers with proven reservoir-seal pairs and data availability. However, the subsurface data (such as well log and seismic data) is not publicly available.

The abundance of emission sources across Indonesia means five potential industrial clusters were identified (Figure 1.5). The optimal source-sink matching and potential networks are located in the following basins:

1. Central Sumatra Basin
2. South Sumatra Basin
3. Northwest Java Basin
4. Northeast Java
5. East Java Basin

1.3.1.2.1. Central Sumatra

The Central Sumatra Basin has comparatively few domestic emissions and is predominantly onshore (Figure 1.5). The most prospective area of the basin is in the centre, near the hydrocarbon fields.

Suitability

The Central Sumatra Basin is categorised as 'suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A moderate-sized (25,000-50000 km^2) basin with viable reservoir-seal pairs inferred from oil and gas fields.
- Published basin-scale storage assessments with resource estimates of hydrocarbon fields only. Field or data were not provided.
- Moderate exploration and development of hydrocarbon fields mean the subsurface geology is well-characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- Indonesia does not host a public system to access subsurface data. However, data is accessible for approved users with nominal fees per data set.
- Indonesia has a regulatory framework to enable CCS.

Negative characteristics include:

- A convergent tectonic environment can increase the likelihood of major faulting, seismicity, and high geothermal gradient and pressure issues.
- Moderate exploration and development of hydrocarbon fields restricts assessments to producing areas.
- Assessed hydrocarbon fields are small size (<5 $MtCO_2$) or are shallow (<800 m)
- Published storage assessments have not reviewed saline formations.

Storage Resources

The basin is a mature hydrocarbon producer. According to the current analysis and data, all the studied fields are too shallow (<800 m) or had storage resource estimates of less than 5 $MtCO_2$. This finding varies from the 229 $MtCO_2$ estimated by Iskandar and Sofyan (2013), although the authors provided no information on the fields assessed and whether they used any screening criteria.

Due to the small and shallow hydrocarbon fields, CO_2 storage development in the basin will rely on saline formation storage. This analysis only acquired data for the Bekasap and Duri (Sihapas Group) with a P50 storage resource estimate of 6.4 $GtCO_2$. The formations are the major producing sandstones of the basins's oil fields. This infers viable reservoir-seal pairs. The Group extends across much of the basin, varying from 150-450 m thick (C. Caughey & T. C. Cavanagh, 1994).

The Central Sumatra Basin still requires the fundamental early stages of exploration and characterisation. Therefore, the basin presents a near to long-term (5+ years) opportunity for CO_2 storage in saline formations. As an onshore basin, the development of a site could have lower costs and be quicker to develop compared to an offshore Indonesian site.

Notably, the Central Sumatra Basin could potentially host international CO_2 from nearby sources in Singapore and the west coast of Malaysia. These are discussed below in the relevant sections.

1.3.1.2.2. South Sumatra Basin

The South Sumatra Basin is located under Sumatra Island, underlying the major city of Palembang.

Suitability

The South Sumatra Basin is categorised as 'highly suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A moderate-sized (25,000-50000 km^2) basin with viable reservoir-seal pairs inferred from oil and gas fields.
- Published basin-scale storage assessments on oil and gas fields and saline formations with resource estimates, but field/formation or data were not provided.
- Prolific exploration and development of hydrocarbon fields mean the subsurface geology is well-characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc.
- Indonesia does not host a public system to access subsurface data. However, data is accessible for approved users with nominal fees per data set.
- Indonesia has a regulatory framework to enable CCS.
- The basin is host to the planned Repsol Sakakemong CCS Facility. Pursuing a CCS Facility in the basin strongly indicates that an operator understands that the storage resources are available and commercially feasible.

Negative characteristics include:

- The basin is only moderately explored away from producing areas, reducing access to data and a complete understanding of the basin's storage potential.
- Published storage assessments have not reviewed saline formations in detail or provided data, including the formation name.

The basin is predominantly onshore, with a minor offshore component to the north of the island. The basin underlies a significant industrial emissions cluster. The basin's most prospective area is located in the onshore, central portion. The South Sumatra Basin has been thoroughly reviewed for CO_2 storage. The ADB (2013) assessed only this basin during their multi-national Southern East Asia study, finding it prospective for CO_2 storage.

Storage Resources

The basin is a mature oil and gas province. The basin hosts a few giant gas fields that could prove strong candidates for storage. The storage resources estimated in the hydrocarbon fields in this basin are the third highest in Indonesia, with a P50 total storage estimate of 426 $MtCO_2$. Over half of all storage is hosted in the gas fields of the Corridor PSC (184 $MtCO_2$) and Pendopo & Prabumulih PSC (107 $MtCO_2$). The total estimate is comparable to the 532 $MtCO_2$ estimate for hydrocarbon fields by the World Bank (World Bank, 2015) and 537 $MtCO_2$ by Hedriana et al. (2017). All authors noted that most fields could not host a commercial-scale

CCS facility due to their small size[1]. Based on the current analysis and data, there are limited CO_2 EOR-storage opportunities in the conventional oil fields of the South Sumatra Basin, with an additional oil recovery ranging from 0.4 to 2.6 MMbbl and net CO_2 storage resources of approximately 5.6 $MtCO_2$. This limitation is attributed to the small size of the oil fields.

The current analysis could not derive data for the saline formations of the South Sumatra Basin. The Batu Raja (Carbonate) and the Talang Akar (Sandstone) formations underlie much of the basin and are the reservoirs for hydrocarbon fields. The World Bank estimated a storage resource for unnamed saline formations in the South Sumatra Basin of 279-683 $MtCO_2$ (World Bank, 2015).

The basin represents early, near-term (5 years +) opportunities for storage. The significant industrial emissions would likely exhaust short-term prospects such as depleted hydrocarbon fields. More analysis of saline formations is required. The subsurface geology around the oil and gas fields is well-characterised in the onshore part of the basin. Subsurface data reduces uncertainty in storage assessments and improves the confidence of storage resource estimates.

1.3.1.2.3. Java Island

The island of Java represents an almost continuous collection of industrial emission clusters stretching west to east across the island.

Suitability

Three basins were identified on Java Island: Northeast Java and East Java were categorised as 'highly suitable' for CO2 storage, and Northwest Java was categorised as 'suitable' according to the Institute's storage basin assessment tool (). These basins present a robust source-sink matching across Java. The following positive factors include:

- Northwest and East Java basins are moderate-sized (25,000-50000 km^2) basins with viable reservoir-seal pairs inferred from oil and gas fields; the Northeast Java Basin is classified as large (over 50,000 km^2).
- Published basin-scale storage assessments with resource estimates of hydrocarbon fields only. Field or data were not provided.
- A comprehensive site scale analysis for the Northeast Java Basin is associated with the Gundih Pilot Project.

[1] Although there are no official standards on categorising a CO_2 storage site by its resource estimate (comparable to AAPG's Super Giant and Giant oil fields), generally, a storage site should host 20-40 years of a commercial CCS facility's CO_2 emissions. Therefore, at a minimum, a small site would have a total storage capacity of less than 20 $MtCO_2$, whereas a large site would be above 100 $MtCO_2$.

- Prolific exploration and development of hydrocarbon fields mean the subsurface geology is well-characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables detailed assessments of storage resources. In this case, it is limited to the resources of the oil and gas fields within the basins, apart from the East Java Basin, which has saline formation data.
- Indonesia does not host a public system to access subsurface data. However, data is accessible for approved users with nominal fees per data set.
- Indonesia has a regulatory framework to enable CCS.
- The Northeast Java Basin has two CCS facilities planned by Pertamina – Jatibarang and Sukowati. In addition, the basin hosts the Gundih Pilot Plant. Pursuing a CCS Facility in the basin provides a strong indication that an operator understands that the storage resources are available and commercially feasible.

Negative characteristics include:

- The Northeast Java basin is a convergent tectonic environment that can increase the likelihood of major faulting, seismicity, and high geothermal gradient and pressure issues.
- The basins are only moderately explored away from producing areas, reducing access to data and a complete understanding of the basin's storage potential.
- Published storage assessments have not reviewed saline formations.

Storage Resources

North East Java Basin has an estimated P50 storage resource totalling 138 MtCO_2 across eight hydrocarbon fields, with 78 MtCO_2 storage resources available. This resource estimate of East Java and North West Java totals around 130 and 102 MtCO_2, respectively (Table 1.4). However, as seen in Figure 1.7, the storage potential in most of the Javanese basins' fields is less than 20 Mt CO_2, with some exceptions:

- North West Java hosts the two large gas fields in Jatibarang (P50- $M_{CO2\,net}$ ≅ 20 MtCO_2) and Subang (P50- $M_{CO2\,net}$ ≅ 82 MtCO_2).
- North East Java basin with three fields above 20 MtCO_2.
- East Java Basin has a field of around 96 MtCO_2.

East Java and North East Java have the highest CO_2 EOR-storage potentials amongst the studied Basins.

Comparable to other Indonesian basins, there is very little data on the saline formations of Java Island. This analysis found data on the Kujung Formation within the onshore East Java

Basin. The storage resource estimate is 8 $GtCO_2$ (P50) (Table 1.6). This formation is the main reservoir for a host of fields in the basin. The carbonate extends across much of the basin and is fair to good quality reservoir (porosity 7-32, permeability 1-1400 mD). The heterogeneous nature of carbonate reservoirs and the variation in reservoir data across different fields means there is low confidence in a cumulative resource estimate for Saline Formations in the Kujung Formation.

The small to moderate size of the hydrocarbon fields across Java Islands means saline formation represents the best opportunity to develop large CCS networks. Unfortunately, there is limited information on the saline formations of these basins. The existence of major oil and gas-producing fields across all basins infers that there are viable reservoir seal pairs across several different formations. The saline formations associated with these fields need to be explored further.

1.3.1.2.4. Kutei

The Kutei Basin was not selected in the source-sink matching exercise because the area hosts significantly fewer industrial emissions. However, this analysis shows the basin hosts the largest total hydrocarbon field potential of 698 $MtCO_2$ (Figure 1.6) and saline formation of 32 $GtCO_2$ (Table 1.6). Despite the area having comparatively fewer industrial sources than other places across Indonesia, several sources of CO_2 emissions are still associated with natural gas and petrochemical refining. The basin is planned to host the Pertamina Balikpapan CCS Facility.

1.3.1.3. Summary of storage deployment prospects, barriers, and issues

Indonesia is in the execution phase of the deployment of CCS, with multiple hydrocarbon companies progressing CCS facilities associated with natural gas development and hydrocarbon/ammonia production. The country now has a comprehensive national regulatory framework for CCS projects. The introduction of these regulations provides a strong indication that the government is supportive of CCS.

A unique challenge to central Sumatran and Java's industrial emission clusters is access to sufficient storage resources. According to the Institute's internal analysis, these clusters require gigatonne annual injection and storage rate. This rate of storage means significant investment and acceleration of storage development. Yet, Indonesia's storage potential remains largely unknown. For example, there are no public assessments of saline formations, and published analysis of hydrocarbon fields has no accompanying data. These two factors represent a significant barrier to developing storage resources and wider CCS deployment.

1.3.2. Malaysia

Malaysia has high prospects for multiple CCS networks, focussing on the offshore Malay-Tho Cho (herein 'Malay' and Sarawak basins. Malaysia's storage potential has been reviewed consistently for at least two decades. An extensive and mature oil and gas industry has enabled the characterisation of the subsurface geology in oil and gas basins.

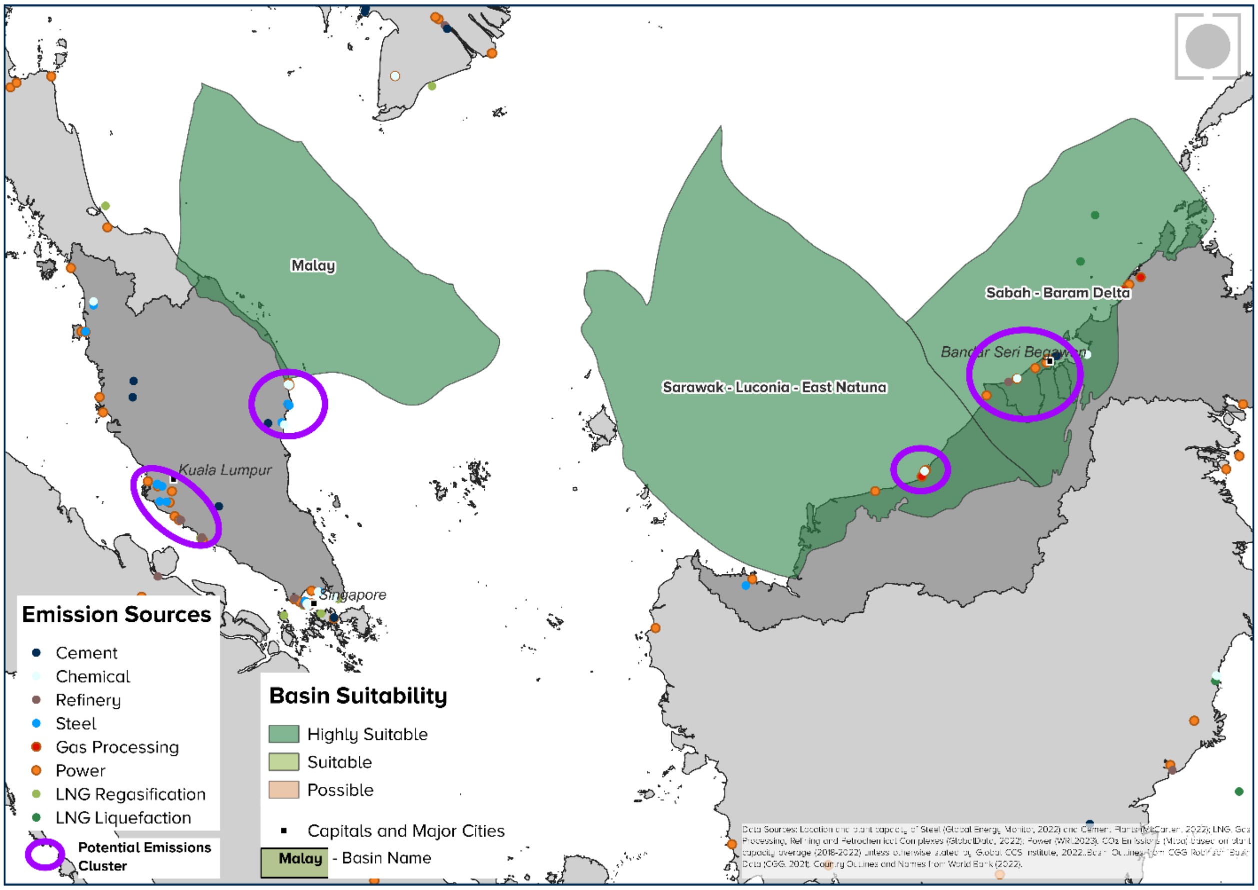
Petronas is building the Kasawari CCS Facility in the Sarawak Basin (Figure 1.1). Reservoir CO_2 from a high CO_2 (up to 25 mol%) gas field will be separated using membrane separation technology. CO_2 will be transported via a 138 km long subsea pipeline to a fixed offshore platform for injection into a depleted gas reservoir at the M1 field. Given the volume of CO_2 from the existing operation, other emission sources beyond Petronas' gas fields are unlikely to use the services of the Kasawari CCS.

Petronas is planning a second CCS operation in the Sarawak Basin, called Lang Lebah. Here, CO_2 from a high CO_2 field will be processed onshore and piped for offshore injection into a depleted gas field.

In addition, Petronas seeks agreements from third parties from dedicated CO_2 transport and storage networks. One such example is the Korean Sheperd CCS. The Korean consortium plans to capture CO_2 from industrial emissions in Korea for storage in Malaysian waters through Petronas.

In Malaysia, three emission clusters have been identified (Figure 1.8). In addition, there is the Singapore cluster (See Singapore below).

Figure 1.8. Emission Clusters and Storage Basins in Malaysia and Brunei



Note: This analysis categorises the Brunei part of the Sabah-Baram Delta Basin as 'Suitable'.
Source: GCCSI.

1.3.3. CO_2 Storage Resource Summary

The estimated CO_2 storage resources of oil and gas fields (Table 1.7; Figure 1.9; Figure 1.10), CO_2-EOR (Table 1.8), and saline formations (Table 1.9) are summarised below. Figure 1.9 shows the median (P50) cumulative net CO2 storage resources ($\boldsymbol{M_{CO2\ net}}$) across studied conventional oil and gas fields per basin. As observed in the figure, the majority of storage resources are provided by gas fields, with the Sarawak Basin having the highest net storage resources ($\boldsymbol{M_{CO2\ net}}$). Notably, the Sarawak Basin also boasts the highest available storage resources (Figure 1.9). Figure 1.10 displays the P50-net storage resources in the examined oil and gas fields. The figure reveals that half of the fields are relatively small, offering storage resources of less than 20 $MtCO_2$. This size constraint might render them unsuitable for average-sized, long-term commercial-scale CCS facilities. However, a more in-depth assessment of each field is necessary before making definitive conclusions.

Table 1.7. Malaysia: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50-Storage Available ($MtCO_2$)	P50-Storage Remaining ($MtCO_2$)	P50-Storage Net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
Malay Basin	421.6	147.9	569.5	8	9
Sabah Basin	84.8	97.9	182.7	2	5
Sarawak Basin	783.9	236.6	1020.5	13	4
Total	**1290**	**482**	**1773**	**23**	**18**

Source: GCCSI.

Table 1.8. Malaysia: Estimated CO_2 Storage Resources in Oil Fields Assessed for CO_2 EOR-Storage

Basin	P50-Storage Available	P50-Storage Remaining	P50-Storage Net	Extra Oil Recovery (MMbbl) @RF5%	Extra Oil Recovery (MMbbl)-@RF30%
Malay Basin	14.88	4.86	19.74	3.4	20.3
Sabah Basin	30.37	17.46	47.84	6.4	38.1
Sarawak Basin	22.69	14.93	37.61	6.6	39.6
Total	**68**	**37**	**105**	**16**	**98**

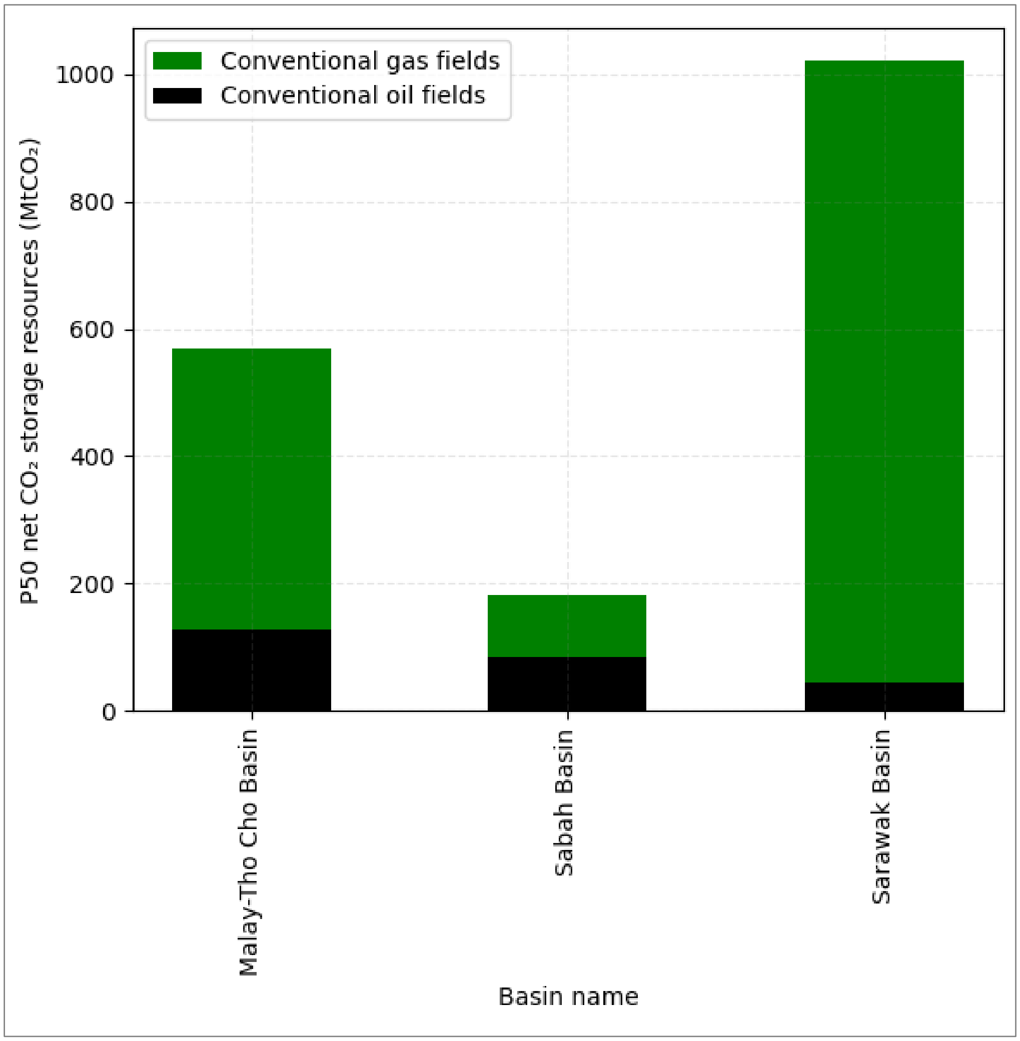
Source: GCCSI.

Table 1.9. Malaysia: Estimated CO_2 Storage Resources in Saline Formations

Basin	Formation(s)	P90 ($GtCO_2$)	P50 ($GtCO_2$)	P10 ($GtCO_2$)
Malay (Malaysia)	Sandstone below Upper Miocene intraformational seal	48	83	136
Sarawak	Carbonate below Middle-Upper Miocene regional marine shales	31	44	61
Total		**80**	**127**	**197**

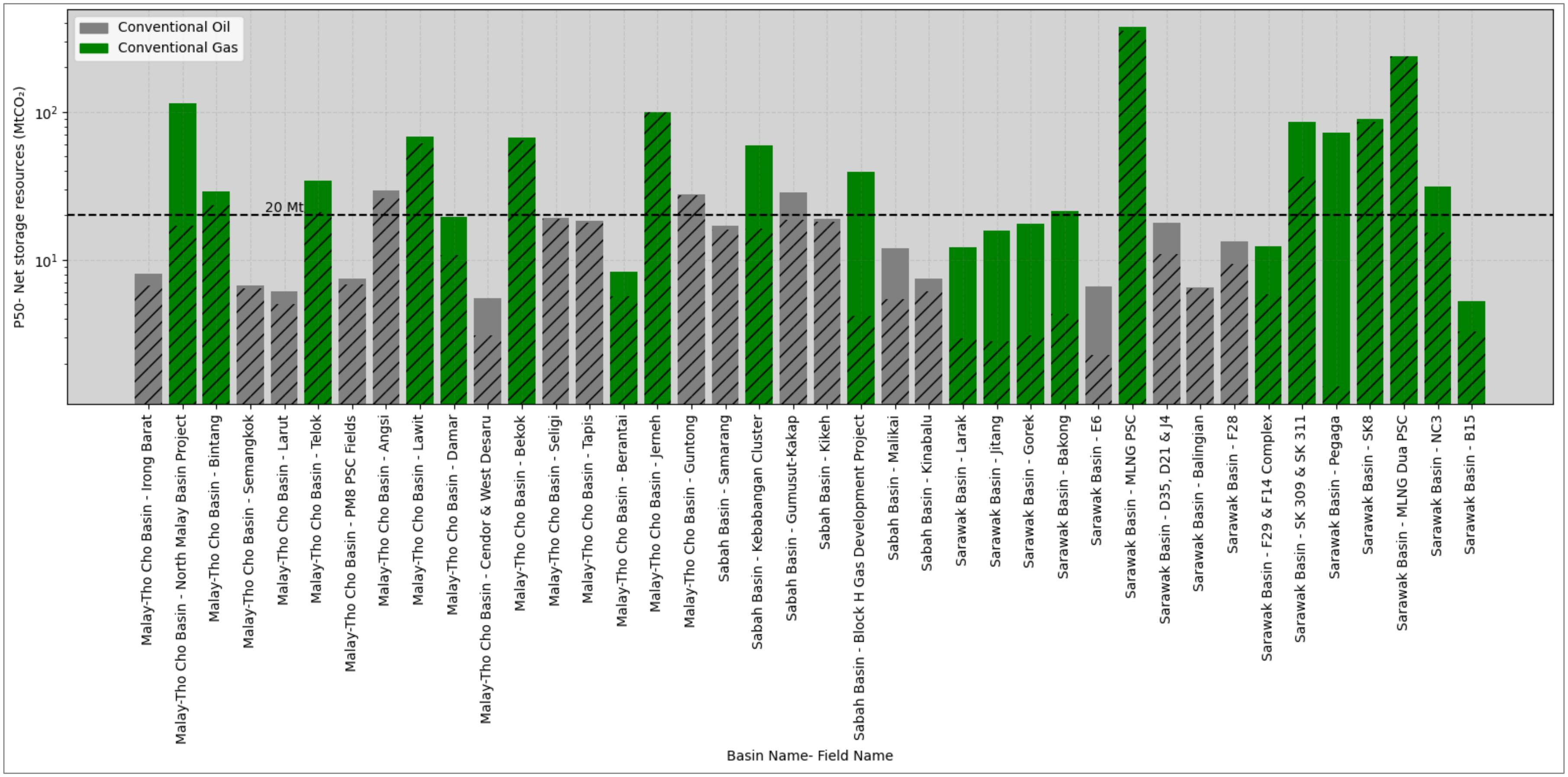
Note: the resources of the Malaysian part of the Sabah Basin were not completed due to a lack of data.
Source: GCCSI.

Figure 1.9. Cumulative P50 Net CO_2 Storage Resources in Studied Oil and Gas Fields per Basin Across Malaysia



Source: GCCSI.

Figure 1.10. P50 Net CO_2 Storage Resources of the Studied Oil and Gas Fields in the Malaysian Basins



Note: the available CO_2 storage resources are shown as a texture on the bars.
Source: GCCSI.

1.3.3.1. Prospective Basins with Potential Clusters

Malaysia has three key storage basins with a cluster of industrial emissions adjacent to a suitable storage basin (Figure 1.8) and significant storage resources in hydrocarbon fields and/or saline formations. The basins include:

1. Malay Basin
2. Sarawak Basin
3. Sabah Basin

1.3.3.1.1. Malay Basin (Thailand and Malaysian Waters)

The Malay Basin is located in the South China Sea, adjacent to Malaysia and Thailand. The basin is entirely offshore, in around 90-130 m water depths. There are two prospective areas in the basin: Thailand's portion in the north and the southeast of the basin in Malaysian waters. These areas are mature hydrocarbon-producing areas, predominantly gas and oil in the north and mainly oil in the southeast.

Suitability

The basin is categorised as 'highly suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A large (>50000 km^2) basin with viable reservoir-seal pairs inferred from multiple hydrocarbon fields.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- Published basin-scale storage assessments with resource estimates. Most studies focus on oil and gas fields, but some analyses also studied saline formations. Data on fields and formation in these studies was not provided or was very limited. A dynamic model with some limited injection data was also published.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.
- The Thai part of the basin is the target of the PTTEP Arthit CCS Facility. Pursuing a CCS Facility in the basin provides a strong indication that an operator understands that the storage resources are available and commercially feasible.

Negative characteristics include:

- An offshore basin can increase an operation's costs and complexity.
- The high CO_2 content of gas fields (up to 70 mol%; Raza et al., 2018, and references therein) can compete for pore space with other industrial sources onshore.
- Malaysia has no national regulatory regime, with a regulatory framework limited to Sarawak.
- Malaysia does not host a public system to access subsurface data.

Storage Resources

The Malay Basin (Thai and Malay parts) is highly suitable; this conclusion is based on a mature hydrocarbon industry and published storage analysis associated with developing hydrocarbon fields. The Malay Basin hosts 570 $MtCO_2$ in hydrocarbon fields, with the majority available (422 $MtCO_2$) due to the region's long production history. Figure 1.10 shows two large gas fields (Jerneh and North Malay) in the basin that offer P50-net CO_2 storage resources higher than 100 $MtCO_2$. However, the Jerneh gas field is largely depleted out of these two and could host a significant CCS network. The Jerneh gas field has a water depth of approximately 60 m and was discovered in 1969 (Fahmi, 2007). The field comprises coastal plain to tidal/shallow marine sandstones of the Upper Miocene seismic group D and E reservoirs (Bintang and Jerneh Formations, respectively) in the Malay Basin (Madon & Council, 2016). Porosity ranges from 10 to 25 %, and permeability can be up to 1000 mD in Jerneh Field sandstones (Bishop, 2002; Madon & Council, 2016).

A multi-nation, regional analysis of CO_2 storage associated with gas fields found an estimated storage potential of 602 $MtCO_2$ in the Malay Basin (CO2CRC, 2010). This estimate is comparable to the current assessment. Furthermore, a subsequent review of Thailand's oil and gas fields in the Malay Basin estimated a storage resource of 601 $MtCO_2$ (Choomkong et al., 2017).

Based on the current analysis and data, there are limited CO_2 EOR-storage opportunities in the studied conventional oil fields of the Malay Basin, with an additional oil recovery ranging from 3.4 to 20.3 MMbbl and P50 net CO_2 storage resources of approximately 19.7 $MtCO_2$.

A total storage potential of 83 $GtCO_2$ (P50) was estimated for a saline formation in the Malay Basin. The sandstones below the Upper Miocene intraformational seal in the Malay Basin (Groups D and E) belong to the Bekok and Tapis formations, where the data was derived. The deposits are coastal plains and shallow marine sandstones (Ramli, 1988). Tapis Formation porosity ranges from 10 to 30%, and permeability ranges from 1 to 1000 mD (Ramli, 1988), making it a suitable target for CO_2 storage.

Junin and Hasbollah (2016) estimated that the same saline formations (Groups D and E in their study) in the same area of the Malay Basin could host a total of 84 $GtCO_2$. Within

Thailand's part of the Malay Basin, a dynamic simulation on Pleistocene fluvial sandstones that dominate much of the region found an injection rate of 0.3-1.3 Mtpa CO_2.

The Malay Basin still requires the fundamental early stages of exploration and characterisation. Therefore, the basin presents a near-term (5 years +) opportunity for CO_2 storage. However, Thailand and Malaysia's national oil companies are pursuing CCS operations in the basin and incorporating CCS networks into their long-term plans.

1.3.3.1.2. Sarawak

The Sarawak Basin is west of Malaysian Borneo in the South China Sea. The basin is predominantly offshore, with water depths ranging from very shallow (50 m) to 500 m. This large basin's most prospective storage area is where previous studies focused on the re-injection of CO_2 from gas fields. That area is in the centre of the SW Luconia Sub-province, around 300 km from the Sarawak region.

Suitability

The basin is categorised as 'highly suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A large (>5,0000 km^2) basin with viable reservoir-seal pairs inferred from multiple hydrocarbon fields.
- Published basin-scale storage assessments with resource estimates. Most studies focus on oil and gas fields, but few focus on saline formations. Data on fields and formation in these studies was not provided or was very limited. Several site-scale studies evaluating the potential for storage in depleted fields adjacent to planned high CO_2 gas field developments were also completed.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates, as hydrocarbon data enables detailed assessments of storage resources, such as numerical studies, in the oil and gas fields within the basins.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.
- The basin will host two planned CCS Facilities, Petronas Kasawari and PTTEP Lang Lebah. Pursuing a CCS Facility in the basin provides a strong indication that an operator understands that the storage resources are available and commercially feasible.
- A regulatory framework is limited to Sarawak.

Negative characteristics include:

- An offshore basin can increase an operation's costs and complexity.
- The high CO_2 content of gas fields (up to 70 mol%; Raza et al., 2018, and references therein) can compete for pore space with other industrial sources onshore.
- Malaysia does not host a public system to access subsurface data

Storage Resources

The Sarawak Basin is highly suitable; this conclusion is based on a mature hydrocarbon industry and published storage analysis associated with developing hydrocarbon fields. The basin hosts a total of 1 $GtCO_2$ in hydrocarbon fields, with the majority available (784 $MtCO_2$) due to the long production history of the region (Table 1.7). The field with the largest CO_2 storage resources in the basin is the MLNG PSC (Figure 1.10), which comprises five gas fields totalling 374 $MtCO_2$. The data for this assessment did not separate the five fields individually.

The Sarawak Basin offers the highest CO_2 EOR-storage opportunities between the studied basins, with an additional oil recovery ranging from 7 to 40 MMbbl and P50 net CO_2 storage resources of approximately 38 $MtCO_2$.

This analysis has found the saline formations in the Sarawak Basin are Middle-Upper Miocene carbonates and sandstones (Cycles IV, V) with a storage resource estimate of 44 $GtCO_2$ (P50) (Table 1.6). These formations are around 1-1.5 km in depth, with an average porosity of 20% and total thicknesses above 900 m, extending for over 150 km (Junin & Hasbollah, 2016). Junin and Hasbollah (2016) found a storage resource of between 56 $GtCO_2$ in the same formations of this analysis using the same methodology.

Other published studies have identified multiple reservoir-seal pairs, the primary target being carbonate reefs sealed by regional Middle-Upper Miocene regional marine shales. Several studies have focused on storage in carbonate reefs in the Sarawak Basin. These studies' primary driver is the development of high CO_2 (up to 70 mole%) gas fields in the same basin (Raza et al., 2017). A second set of studies recently focused on the Tangga Barat cluster of fields. Presently operated by Petronas, the fields have high CO_2 content (40 mole%) (Sukor et al., 2020). The storage operation would focus on the same formation as the gas field, with injection down-dip from the field.

When considering CCS network development opportunities, the Sarawak Basin still requires the characterisation of storage sites, mainly focussing on saline formations. Hence, the basins present a near-term (5-10 years) opportunity for CO_2 storage. However, developing a CCS facility associated with high CO_2 gas field development could be the anchor facility for a wider CCS network of emission sources, potentially importing from international sources due to the high resource estimate versus local emissions.

1.3.3.1.3. Sabah - Baram Delta

The Sabah - Baram Delta has a single industrial emissions cluster of natural gas processing (including LNG), petrochemical and power generation (Figure 1.8). In addition, the gas content of the basin's fields contains up to 80 mol% CO_2 (CO2CRC, 2010). Therefore, the reservoir CO_2 produced from those fields could be the main focus of domestic CO_2 storage operations in Malaysia.

Suitability

The Malaysian part of the basin is categorised as 'highly suitable' for CO_2 storage in the Malaysian portion, according to the Institute's storage basin assessment tool. This assessment is based on:

- A large (>50,000 km^2) basin with viable reservoir-seal pairs inferred from multiple hydrocarbon fields.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.
- A regulatory framework is limited to Sarawak.

Negative characteristics include:

- An offshore basin can increase an operation's costs and complexity.
- The high CO_2 content of gas fields (up to 70 mol%; Raza et al., 2018, and references therein) can compete for pore space with other industrial sources onshore.
- Malaysia does not host a public system to access subsurface data

The Malay portion of the basin is categorised higher than the Brunei portion because of its:

- Greater size
- Previous published storage studies and resource estimates
- Accessibility (regulations in place)

Storage Resources

The Malaysia part of the Sabah - Baram Delta Basin's hydrocarbon fields is estimated at 182

$MtCO_2$ (Total), with 84 $MtCO_2$ available now (Table 1.7). Only one field exceeds 20 $MtCO_2$, the Kebabangan Field (Figure 1.10).

1.3.3.2. Summary of Storage Deployment Prospects, Barriers, and Issues

- Malaysia hosts three highly suitable basins (including the Sabah Basin, which is both Malaysia and Brunei) in the region, with significant resources in hydrocarbon fields and saline formations with limited adjacent domestic emissions, even if considering the emissions of the Kuala Lumpur cluster.
- Malaysia lacks a comprehensive national CO_2 storage resource atlas, with limited information on saline formations.
- The development of high CO_2 content gas fields in offshore Malaysia enables the development of CCS networks with natural gas processing as the anchor facility.
- While Malaysia features several basins highly suitable for CO_2 storage (Malay, Sarawak, Sabah), only one state (Sarawak) has a CCS-specific legal and regulatory framework.
- Beyond the offshore potential of the Sabah, Sarawak and Malay basins, there is limited opportunity for the cluster of emissions near Kuala Lumpur. The nation will unlikely seek storage in Indonesia even though storage exists adjacent to the emissions sources. Accessing the Malay Basin's resources is the only likely potential for the KL cluster.

1.3.4. Brunei

Brunei has one basin for storage characterisation, the Sabah-Baram Delta Basin Malaysian Borneo in the South China Sea (Figure 1.8). The basin is predominantly offshore, with water depths ranging from very shallow (50 m) to 2,000 m. The prospective area is the nearshore portion of the basin, which hosts a significant hydrocarbon production along the length of Brunei and Malaysian Borneo.

1.3.4.1. CO_2 Storage Resource Summary

The estimated CO_2 storage resources of oil and gas fields (Table 1.10; Figure 1.11), CO_2-EOR (Table 1.11) and saline formations (Table 1.12) are summarised below. Figure 1.11 displays the P50-net storage resources in the examined oil and gas fields.

Table 1.10. Brunei: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50-Storage Available ($MtCO_2$)	P50-Storage Remaining ($MtCO_2$)	P50- Storage Net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
Baram Delta	560.7	18.6	579.3	4	3

Source: GCCSI.

Table 1.11. Brunei: Estimated CO_2 Storage Resources in Oil Fields Assessed for CO_2 EOR Storage

Basin	P50-Storage Available	P50-Storage Remaining	P50-Storage Net	Extra Oil Recovery (MMbbl) @RF5%	Extra Oil Recovery (MMbbl) - @RF30%
Baram Delta	186.35	13.52	199.81	13.6	81.7

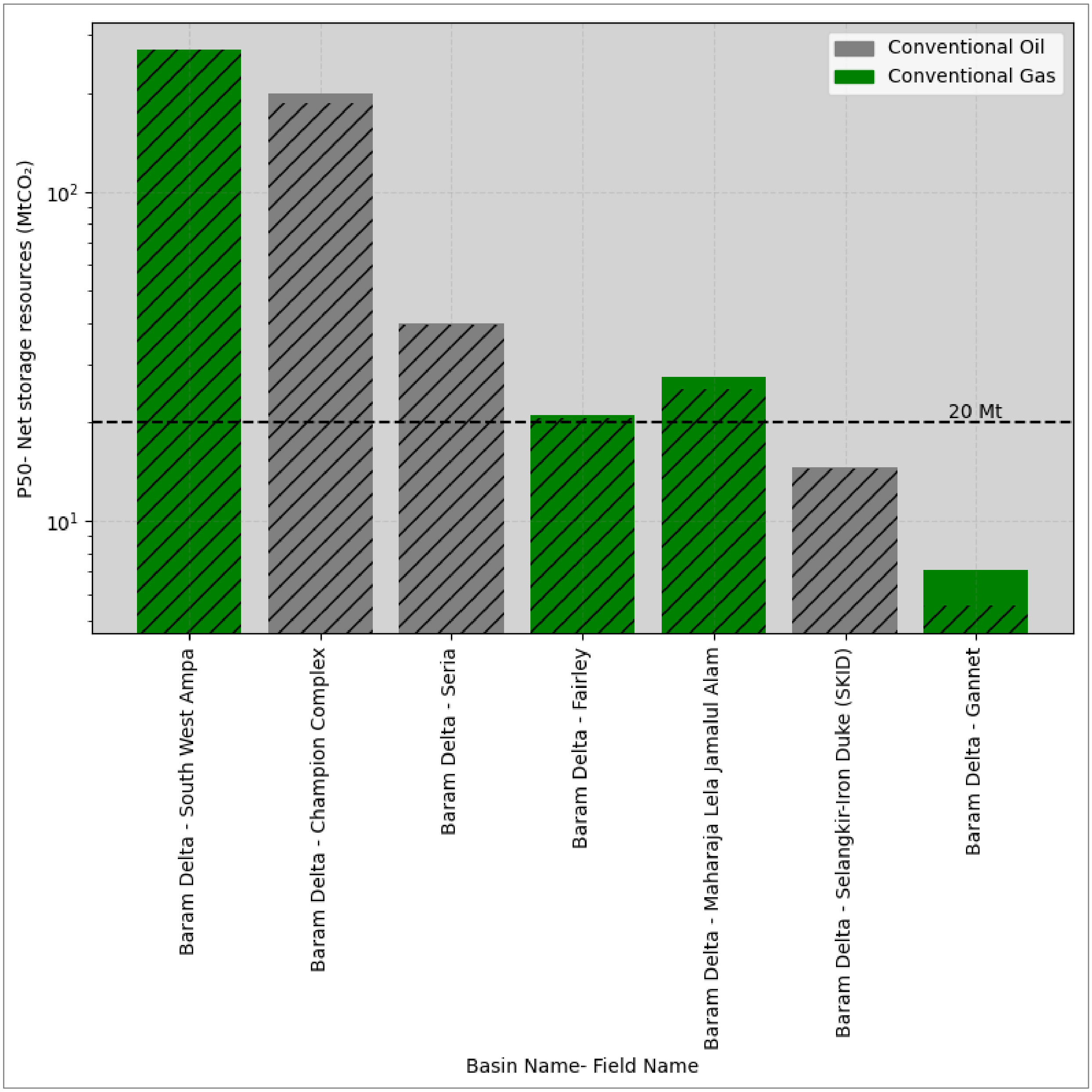
Source: GCCSI.

Table 1.12. Brunei: Estimated CO_2 Storage Resources in Saline Formations

Basin	Formation(s)	P90 ($GtCO_2$)	P50 ($GtCO_2$)	P10 ($GtCO_2$)
Sabah - Baram Delta	Baram Fluvial-Deltaic System sands	13	18	25

Source: GCCSI.

Figure 1.11. P50- Net CO_2 Storage Resources of Brunei's Studied Oil and Gas Fields



Note: The available CO2 storage resources are shown as a texture on the bars.
Source: GCCSI

1.3.4.2. Prospective Basins with Potential Clusters

1.3.4.2.1. Sabah - Baram Delta

The Sabah - Baram Delta has a single industrial emissions cluster of natural gas processing (including LNG), petrochemical and power generation (Figure 1.8). In addition, the gas content of the basin's fields contains up to 80 mol% CO_2 (CO2CRC, 2010). Therefore, the reservoir CO_2 produced from those fields could be the focus of domestic CO_2 storage operations in Brunei.

Suitability

The Brunei part of the basin is categorised as 'suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A moderate-sized (25,000-50000 km^2) basin with viable reservoir-seal pairs inferred from oil and gas fields.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.

Negative characteristics include:

- An offshore basin can increase an operation's costs and complexity.
- The high CO_2 content of gas fields (up to 80 mol%; (CO2CRC, 2010) can compete for pore space with other industrial sources onshore.
- Brunei does not host a public system to access subsurface data
- No Brunei-specific published storage assessments with resource estimates. Brunei has only been included in global analyses of oil and gas fields.
- Brunei has no national regulatory regime.

Storage Resources

The Bruneian part of the Sabah - Baram Delta Basin's hydrocarbon fields is estimated at 579 $MtCO_2$ (Total), with 560 $MtCO_2$ available now (Table 1.10). The South West Ampa gas field is situated in less than 60 m of water depth and was discovered in 1963. The South West Ampa Field is assessed to possess 269.9 Mt of available CO_2 storage resources and 0.26 Mt of remaining CO_2 storage resources, resulting in a total CO_2 storage resource base of 270.16 Mt (Figure 1.11). These data indicate a significant level of depletion in the field, making it a potential strong candidate for average-sized, long-term commercial-scale CCS facilities in Brunei and the broader region. Nevertheless, a thorough field analysis is imperative to evaluate the impacts of geological complexities, such as reservoir compartmentalisation, on storage resources and injectivity. Following the South West Ampa Field, the Champion Complex offers the second-largest storage resources in the country, with net storage resources of around 200 $MtCO_2$, out of which 186 $MtCO_2$ is already available for storage

(Figure 1.11).

Regarding CO_2-EOR, there is a potential opportunity in the Champion Complex, presenting a range of additional oil recovery from approximately 6.4 to 38.1MMbbl, coupled with P50 net CO_2 storage resources of around 47.8 $MtCO_2$ (Table 1.8). Further detailed analysis of the fields is essential before making definitive conclusions.

The CO_2 storage resources of saline formations of Baram Fluvial-Deltaic System sands are estimated to be around 18 $GtCO_2$ (P50) (Table 1.12). The Baram Fluvial-Deltaic System comprises several sequences of Neogene clastic deposits ranging in thickness from 1,000 to 3,000 m offshore Brunei (Rijks, 2014). The Baram Fluvial-Deltaic System sands (Cycle V) feature porosities averaging 20 % and permeabilities averaging 980 mD, making it a suitable target for CO_2 storage (CO2CRC, 2010).

1.3.4.3. Summary of Storage Deployment Prospects, Barriers, and Issues

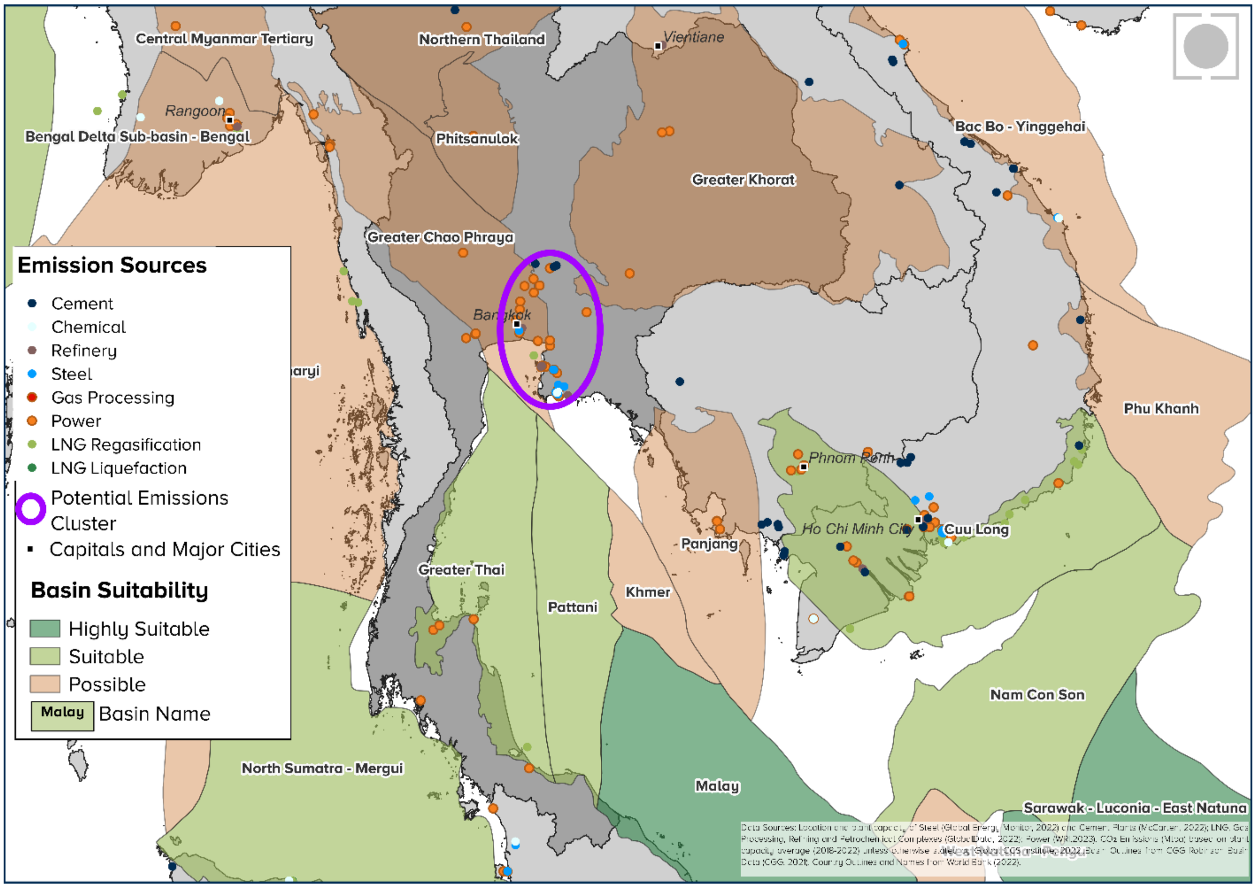
- Brunei hosts significant resources in hydrocarbon fields and saline formations in a highly suitable basin with limited domestic emissions.
- Detailed analysis of the South West Ampa Field and Champion Complex is essential for unlocking their CO_2 storage resources.
- Brunei could rapidly deploy CO_2 storage operations to enable a domestic CCS industry and the international import of CO_2. A CCS roadmap with CO_2 storage characterisation and detailed site scale assessment would support these opportunities.
- Brunei lacks a CCS-specific legal and regulatory framework and CCS-specific domestic policies or incentives.

1.3.5. Thailand

Thailand has high prospects for multiple CCS networks, with CO_2 transport and storage operations focussing on the offshore basins in the Gulf of Thailand. The CO_2 storage potential in Thailand has been reviewed in the literature over the past two decades. Subsequently, there is a moderate understanding of Thailand's storage potential.

PTTEP is developing the Arthit CCS Facility near the boundary of the Malay and Pattani basins. This facility, currently under development, will reduce emissions from gas fields with high CO_2 concentrations. There is no indication of expanding this facility beyond the reservoir CO_2. Also, PTTEP is exploring opportunities to build a CCS Network for industries in Rayong and Chonburi provinces. However, there is no public information on the storage portion of this network. One significant emission cluster in Thailand covers several hundreds of kilometres and incorporates Bangkok, south of the Gulf of Thailand (Figure 1.12).

Figure 1.12. Thailand's Emission Clusters and Storage Basins



Source: GCCSI.

1.3.5.1. CO_2 Storage Resource Summary

The estimated CO_2 storage resources of oil and gas fields (Table 1.13; Figure 1.13; Figure 1.14) and saline formations (Table 1.14) are summarised below. No suitable oil fields meeting the defined criteria for CO_2 EOR storage were identified in this study. This is attributed to the small size of the studied fields. Figure 1.13 shows the median (P50) cumulative net CO_2 storage resources ($M_{CO2\ net}$) across studied conventional oil and gas fields per basin. As observed in the figure, the majority of storage resources are provided by gas fields, with the Pattani Basin having the highest net storage resources ($\boldsymbol{M_{CO2\ net}}$). Notably, the Pattani Basin also boasts the highest available storage resources (Table 1.13; Table 1.14). Figure 1.14 displays the P50-net storage resources in the examined oil and gas fields. The figure reveals that half of the fields are relatively small, offering storage resources of less than 20 $MtCO_2$. This size constraint might render them unsuitable for average-sized, long-term commercial-scale CCS facilities. However, a more in-depth assessment of each field is necessary before making definitive conclusions.

Table 1.13. Thailand: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50- Storage available ($MtCO_2$)	P50- Storage remaining ($MtCO_2$)	P50- Storage net ($MtCO_2$)	Number of gas fields	Number of oil fields
Khorat Plateau Basin	16.9	8.0	24.9	2	0
Malay Basin	211.2	160.3	371.5	3	0
Pattani Basin	414.3	182.8	597.0	19	2
Phitsanulok Basin	26.9	3.3	30.2	0	1
Total	**669**	**354**	**1024**	**24**	**3**

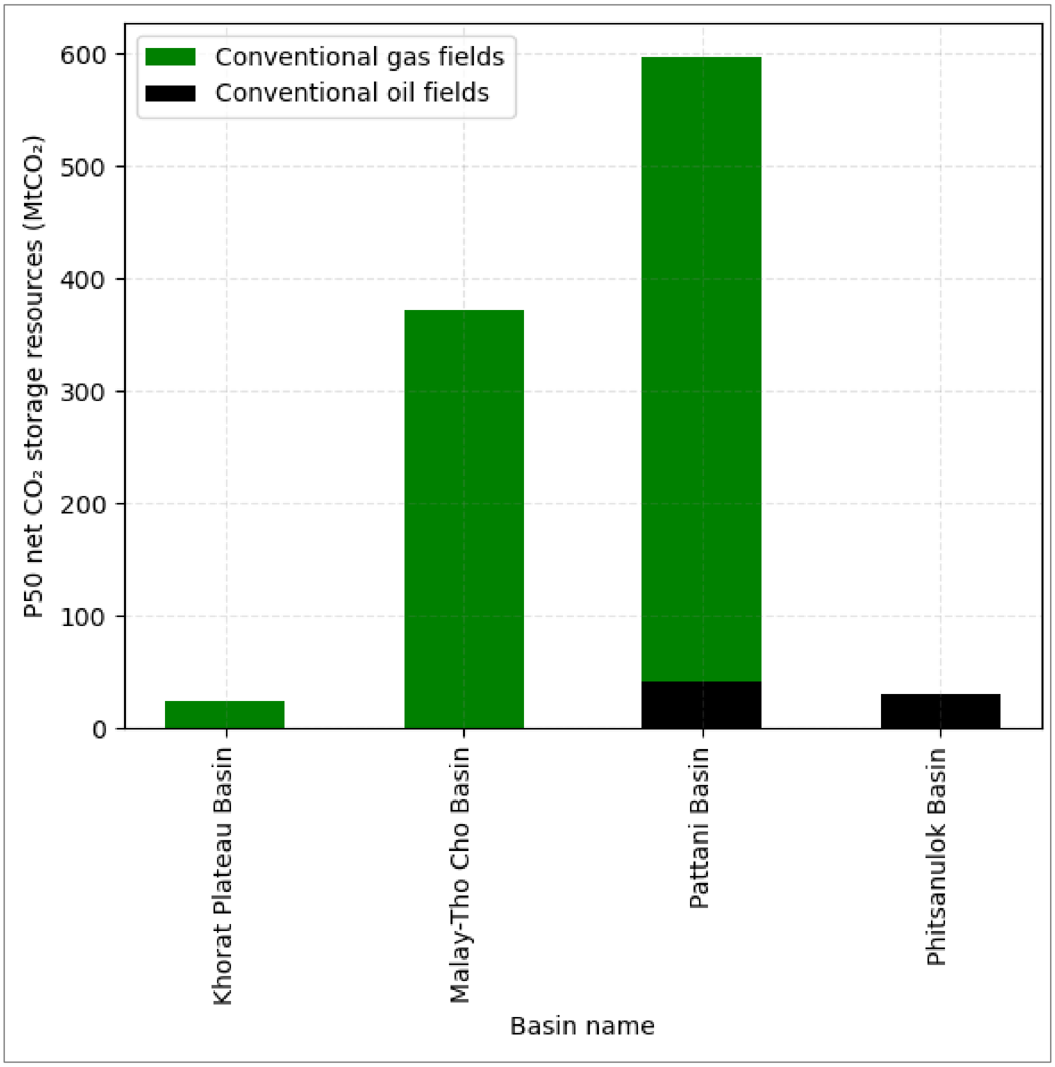
Source: GCCSI.

Table 1.14. Thailand: Estimated CO_2 Storage Resources in Saline Formations

Basin	Formation(s)	P90 ($GtCO_2$)	P50 ($GtCO_2$)	P10 ($GtCO_2$)
Pattani	Bekok, Tapis, Pulai	9	13	18
Malay (Thailand)	Sandstone below Upper Miocene intraformational seal	1.5	2	4
Total		**11**	**15**	**22**

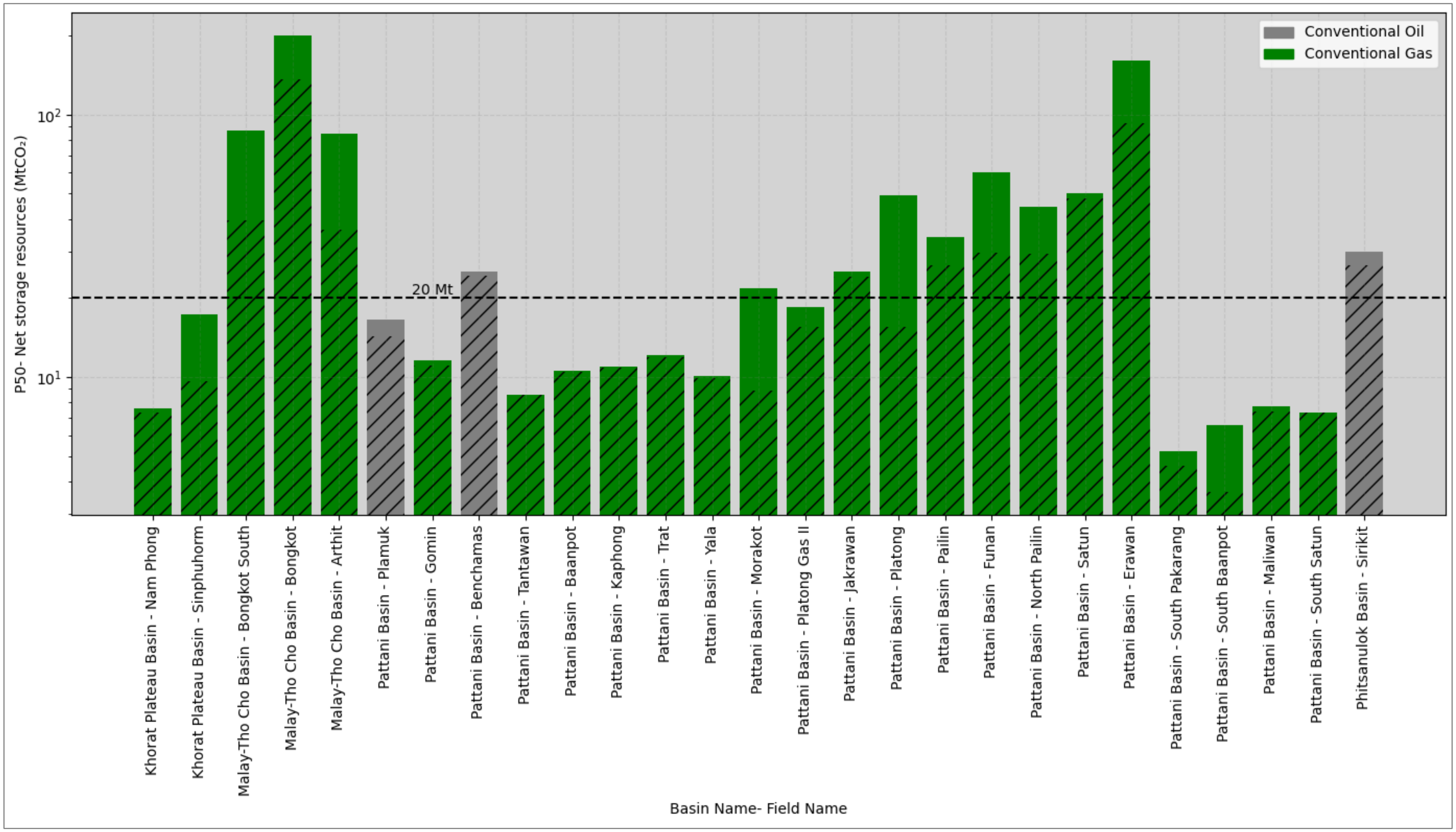
Source: GCCSI.

Figure 1.13. Cumulative P50 CO_2 Storage Resources in Studied Oil and Gas Fields per Basin Across Thailand



Source: GCCSI.

Figure 1.14. P50-Net CO_2 Storage Resources of the Studied Oil and Gas Fields in the Basins Across Thailand



Note: the available CO_2 storage resources are shown as a texture on the bars.
Source: GCCSI.

1.3.5.2. Prospective Basins with Potential Clusters

Thailand has two key storage basins with source-sink matching (Figure 1.12). The basins include:

- Malay
- Pattani

According to the Institute's Storage basin assessment tool, the Pattani Basin was assessed as 'suitable' for CO_2 storage. The suitability of the Malay Basin was previously discussed in the 'Malaysia' section; hence, it will not be repeated here.

1.3.5.2.1. Pattani

The Pattani Basin is in the Gulf of Thailand, adjacent to Thailand. The basin is entirely offshore in shallow water depths. The central portion of the basin is the most prospective, inferred from multiple hydrocarbon fields and the distribution of saline formations.

Suitability

The basin is categorised as 'suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A moderate-sized (25,000-50,000 km^2) basin with viable reservoir-seal pairs inferred from oil and gas fields.
- Published basin-scale storage assessments with resource estimates of hydrocarbon fields and saline formations. Field or data were not provided.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.
- PTTEP are planning a CCS network in Thailand with storage in the Pattani Basin. Pursuing a commercial CCS Facility in the basin is a strong indicator of a viable storage resource and commercial opportunity for CCS.

Negative characteristics include:

- An offshore basin can increase an operation's costs and complexity.
- Thailand has no national regulatory regime.
- Thailand does not host a public system to access subsurface data.

Storage Resources

The Pattani Basin hosts an estimated storage resource totalling 570 $MtCO_2$ in hydrocarbon fields, with the majority available (597 $MtCO_2$) due to the region's long production history. As seen in Figure 1.14, conventional gas fields offer the majority of the storage resources in the basin, and most of these resources are already available. The Erawan gas field offers the highest CO_2 storage resources amongst the fields in the basin. As discussed earlier, no suitable oil fields meeting the defined criteria for CO_2 EOR storage were identified in this study. This is attributed to the small size of the studied fields.

The ADB (2013) also assessed known hydrocarbon traps in 10 of 94 sedimentary basins of Thailand. The top three ranked oil and gas fields have a combined estimated storage resource of 350 $MtCO_2$ ADB. The report also identified (but did not specifically name) two EOR prospects.

The Pattani Basin has CO_2 storage potential in Cenozoic sediments for saline formation storage, including multiple reservoirs and intraformational seals. The Miocene-aged Bekok, Tapis, and Pulai formations were estimated to host storage resources of 13 $GtCO_2$ (P50). This estimate is comparable to the ADB's multi-national assessment that estimated a total theoretical storage potential of around 10 $GtCO_2$ storage resource (ADB, 2013). However, the basin is geologically complex. Accumulations of the oil and gas fields in the basin are known to be volumetrically small as individual reservoirs due to the fluvial depositional nature of the reservoirs and intense faulting.

1.3.5.2.2. Khorat, Greater Choa Phraya and Phitsanulok basins

The onshore basins of Thailand, the Khorat, Greater Choo Phraya and Phitsanulok basins, have not been reviewed in this analysis due to a lack of published studies on their CO_2 storage potential. All basins have been categorised as possible for storage. The P50 hydrocarbon resource estimates of the Khorat and Phitsanulok are 25 (2 gas fields) and 30 $MtCO_2$ (1 oil field) (Table 1.13). The Greater Choa Phraya Basin had no hydrocarbon fields for analysis. Therefore, storage deployment will focus on saline formations. A basic mapping and characterisation analysis of the saline formations of these basins is critical, given their proximity to emission sources in Bangkok and the surrounding areas. Critically, onshore CO_2 storage operations generally cost less and have less complexity than offshore operations.

1.3.5.3. Summary of storage deployment prospects, barriers, and issues

- Thailand lacks a modern, comprehensive national CO_2 storage resource atlas. A particular focus should be on the Khorat, Greater Choo Phraya and Phitsanulok basins onshore.
- The Malay and Pattani basins require targeted site-scale characterisation analysis to understand the hydrocarbon fields and associated saline formations. Hence, the basins present a near to long-term (5-10 years +) opportunity for CO_2 storage.
- Thailand lacks a CCS-specific legal and regulatory framework and CCS-specific domestic policies or incentives. However, the national oil company, PTTEP, are proactive in CO_2 storage deployment, which may drive changes in the regulatory and policy frameworks.

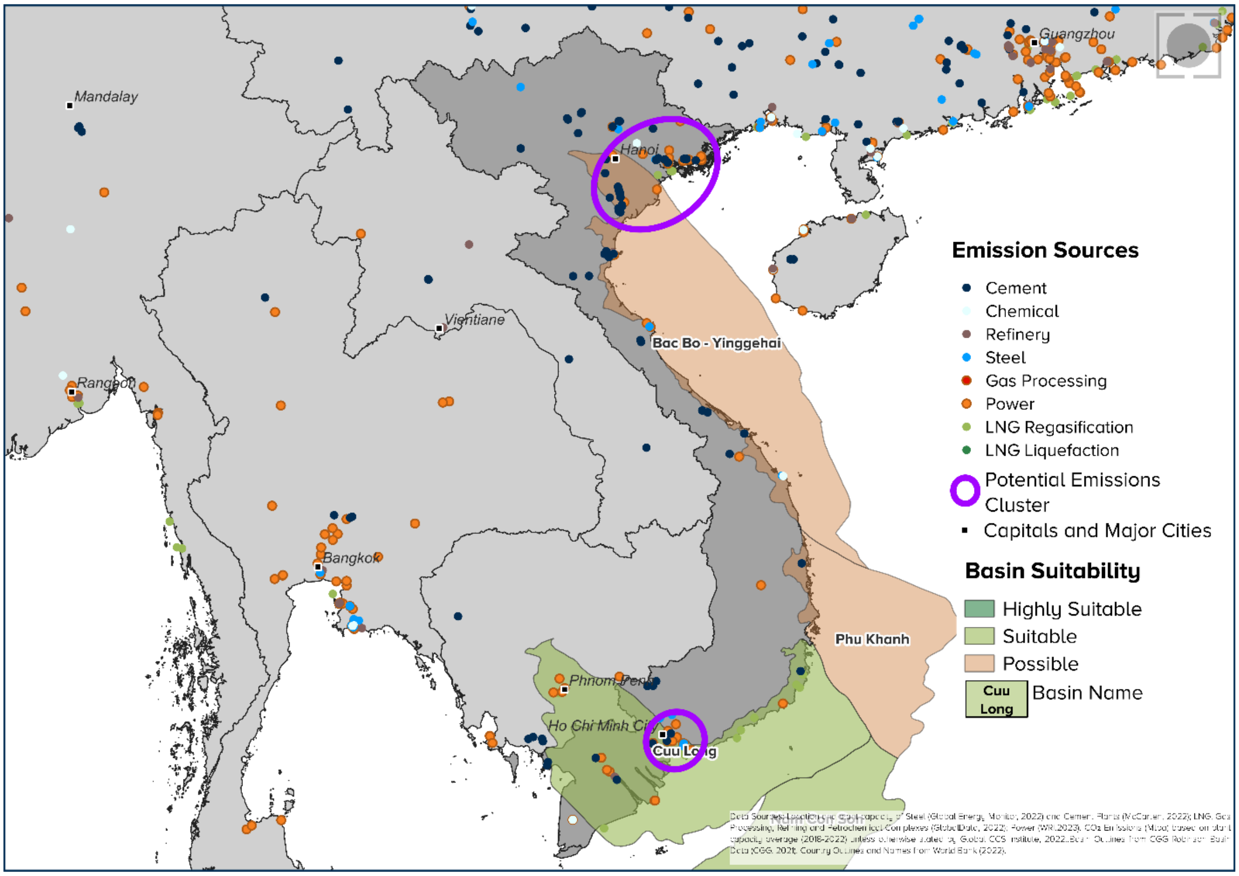
1.3.6. Viet Nam

Viet Nam has the geological potential to host a significant CCS industry. However, their lack of storage development means their prospects of hosting CCS networks in the short to medium term are unlikely.

Experience in CO_2 injection and storage includes two pilot CO_2-EOR operations, White Tiger (Bach Ho) and Aurora (Rang Dong). The White Tiger CO_2-EOR operation was the first pilot project in Southeast Asia and possibly the only CO_2 injection project to date. The details of the operation are unknown. However, according to Ha-Duong & Nguyen-Trinh (2017), a feasibility study by Petro Viet Nam in collaboration with Mitsubishi Heavy Industries estimated an injection rate of between 4.6 – 7.4 Mtpa. The timeframe for this injection rate and total storage capacity was not recorded.

The White Tiger CCS project applied for funding under the Clean Development Mechanism (CDM) of the UNFCCC. However, CCS projects were not included in the funding. Another small pilot CO_2 injection project is in the Song Hong Basin and has also been presented at forums (Hieu, 2016).

Figure 1.15. Viet Nam's Emission Clusters and Storage Basins



Source: GCCSI

1.3.6.1. *CO_2 Storage Resource Summary*

The estimated CO_2 storage resources of oil and gas fields (Table 1.15; Figure 1.16; Figure 1.17), CO_2-EOR (Table 1.16), and saline formations (Table 1.17) are summarised below. Figure 1.16 shows the median (P50) cumulative net CO_2 storage resources ($\boldsymbol{M_{CO2\ net}}$) across studied conventional oil and gas fields per basin. Figure 1.17 displays the P50-net storage resources in the examined oil and gas fields.

Table 1.15. Viet Nam: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50-Storage Available ($MtCO_2$)	P50-Storage Remaining ($MtCO_2$)	P50-Storage net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
Cuu Long Basin	138.9	22.0	161.0	0	4
Nam Con Son Basin	96.6	45.8	142.4	4	1
Total	235.5	67.8	303.4	4	5

Source: GCCSI.

Table 1.16. Viet Nam: Estimated CO_2 Storage Resources in Oil Fields Assessed for CO_2 EOR-Storage

Basin	P50-Storage Available	P50-Storage Remaining	P50-Storage Net	Extra Oil Recovery (MMbbl) @RF5%	Extra Oil Recovery (MMbbl) - @RF30%
Cuu Long Basin	39.52	16.35	55.86	7.6	45.7

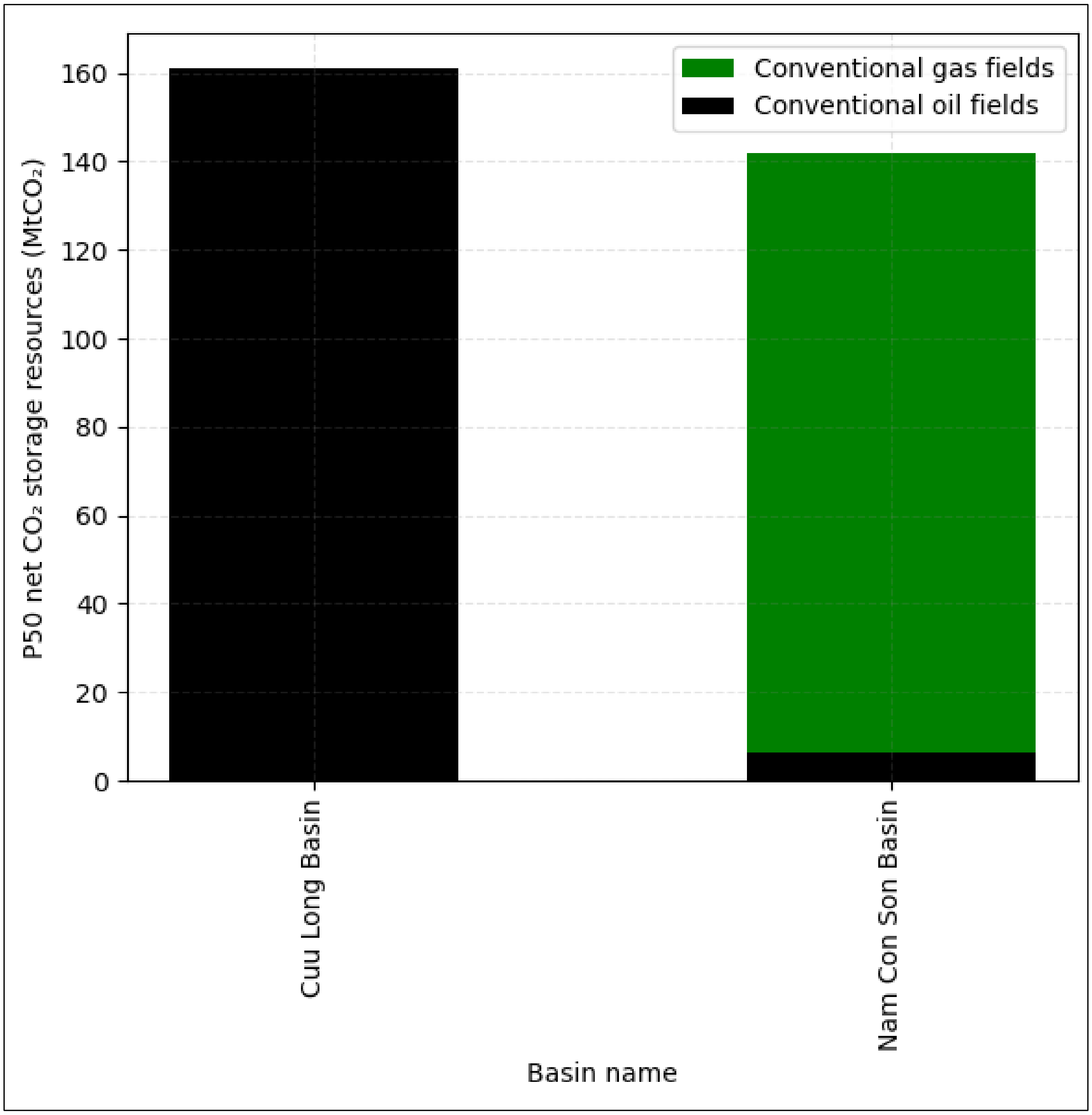
Source: GCCSI.

Table 1.17. Viet Nam: Estimated CO_2 Storage Resources in Saline Formations

Basin	Formation(s)	P90 ($GtCO_2$)	P50 ($GtCO_2$)	P10 ($GtCO_2$)
Cuu Long	Bach Ho	3	5	9

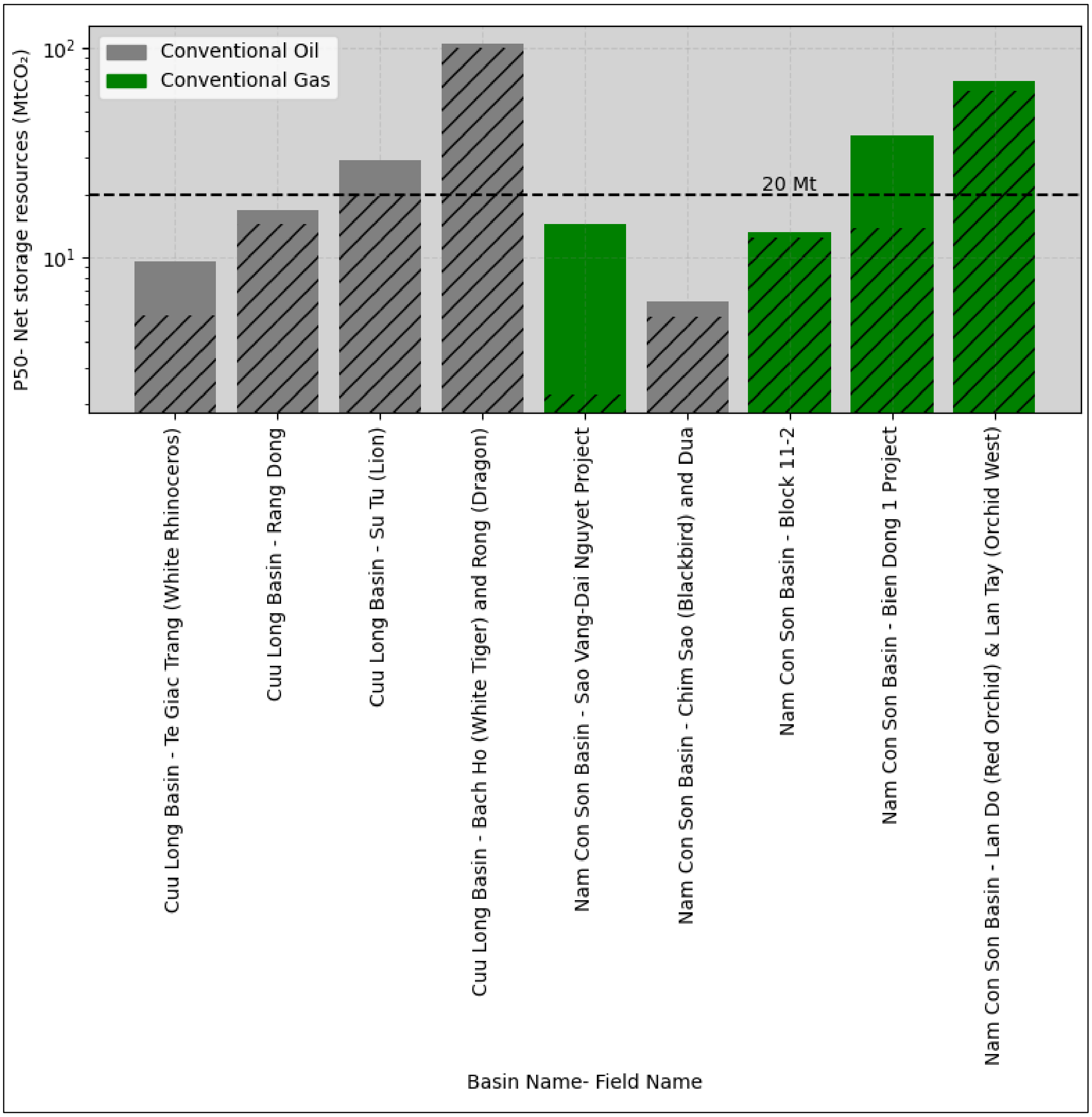
Source: GCCSI.

Figure 1.16. Cumulative P50 CO_2 Storage Resources in Studied Oil and Gas Fields per Basin Across Viet Nam



Source: GCCSI.

Figure 1.17. P50 Net CO_2 Storage Resources of Viet Nam's Studied Oil and Gas Fields



Note: the available CO_2 storage resources are shown as a texture on the bars.
Source: GCCSI.

1.3.6.2. Prospective Basins with Potential Clusters

Two significant clusters are present in Viet Nam, one surrounding Hanoi and the second in southwestern Viet Nam near Ho Chi Minh City (Figure 1.15). Viet Nam has two key storage basins (Nam Con Son and Cuu Long), but the only source-sink match is Ho Chi Minh City and the Cuu Long Basin.

1.3.6.2.1. Cuu Long Basin

The Cuu Long Basin is on the southern end of Viet Nam. The basin has an onshore and offshore component, although the offshore is the most prospective area inferred from the oil and gas fields.

Suitability

The basin is categorised as 'suitable' for CO_2 storage, according to the Institute's storage basin assessment tool. This assessment is based on:

- A moderate-sized (25,000-50000 km^2) basin with viable reservoir-seal pairs inferred from oil and gas fields.
- A single national published storage assessment with resource estimates. In addition, global or regional basin-scale storage assessments have been published with resource estimates of hydrocarbon fields and saline formations. Field/Formation or the data were not provided. Additional CO_2-EOR studies were also published, with only limited data provided.
- The extensive exploration and development of hydrocarbon fields mean the subsurface geology is well characterised.
- The legacy data associated with the mature hydrocarbon-producing basin reduces uncertainty in published resource estimates. Data associated with hydrocarbon exploration and production enables theoretical calculations of storage resources using real-world data.
- The mature hydrocarbon industry could provide access to legacy infrastructure such as pipelines, wells, platforms, etc., which could reduce timeframes to deployment and improve the economics of a CCS facility.
- Two pilot CO_2-EOR operations, White Tiger (Bach Ho) and Aurora (Rang Dong) were operational. A CCS Facility in a basin is a strong indicator of a viable storage resource and commercial opportunity for CCS, even as pilots.

Negative characteristics include:

- A convergent tectonic environment can increase the likelihood of major faulting, seismicity, and high geothermal gradient and pressure issues.
- The high CO_2 content of gas fields (many above 10% and some up to 80% (ADB, 2013) can compete for pore space with other industrial sources onshore.
- An offshore basin can increase an operation's costs and complexity.
- Viet Nam has no national regulatory regime.
- Viet Nam does not host a public system to access subsurface data.

The French Bureau des Recherches Géologiques et Minières (BRGM), in collaboration with Viet Namese counterpart KVN (Bureau des Recherches Géologiques et Minières, 2009), also identified the Cuu Long Basin as a priority basin in Viet Nam as part of a review of prospects for CO_2 storage of all basins across Viet Nam.

Storage Resources

The Cuu Long Basin is suitable due to the mature hydrocarbon industry and subsequent storage analysis associated with developing hydrocarbon fields. According to this analysis, this basin offers the highest CO_2 storage resources in hydrocarbon fields in Viet Nam, with P50-net CO_2 storage resources of around 161 $MtCO_2$ in four oil fields, most of which are available (139 $MtCO_2$) (Table 1.15).

The Bach Ho (White Tiger) and Rong (Dragon) offer the highest CO_2 storage resources amongst the studied fields. The field is estimated to hold 99 Mt of available CO_2 storage resources and 5.7 Mt of remaining CO_2 storage resources, for a total CO_2 storage resource base of around 105 Mt (Figure 1.17). The oil fields are approximately 60 m in water depth and were discovered in 1975 (Cuong & Warren, 2009). The fields comprise Mesozoic fractured 'basement' rocks (granites and volcanics) as well as overlying Oligocene fluvial-to-lacustrine clastic deposits of the Tra Tran Formation and Oligo/Miocene shallow marine-to-fluvial clastic deposits of the Bach Ho Formation – all of which serve as hydrocarbon reservoirs. Porosities in the Tra Tran Formation range from 9 to 15 % and from 12 to 25 % in the Bach Ho Formation (Cuong & Warren, 2009; Dien et al., 1997).

According to the analysis, three oil fields are suitable for CO_2 EOR storage; however, only one offers P50 Net storage resources higher than 20 $MtCO_2$, justifying averaged-sized, commercial-scale CCS facilities. Nonetheless, the cumulative extra oil that can be produced from these three fields in the basin ranges between 7.6 to 45.7 MMbbl, and the cumulative net CO_2 storage resources (P50) amount to around 56 $MtCO_2$ (Table 1.16).

The Bach Ho Formation is estimated to host 5 $GtCO_2$ (P50) storage resources and is the only studied saline formation in this analysis (table 1.17). The Bach Ho Formation comprises Late Oligocene to Early Miocene sandstones and mudstones in the Cuu Long Basin offshore Viet Nam. The sediments were deposited in shallow marine-to-fluvial environments, and sandstone thickness ranges from < 10 to 20 m. Bach Ho Formation's porosity ranges from 16 to 25 %, and permeability ranges from 1 to 5000 mD (Giao et al., 2016), making it a suitable target for CO_2 storage.

Beyond the Bach Ho Formation, the ADB (2013) assessed known hydrocarbon traps in six of eight basins of Viet Nam. The assessment indicates 300 $GtCO_2$ of storage basins across all storage basins and deep saline formations. The storage potential of fractured basement rock, which hosts some oil fields, is unknown. One detailed site scale analysis of the fractured basement rock using field data found the NV Gas Field could host between 7-99.5 $MtCO_2$

(Thanh et al., 2019).

The two clusters of emissions, north (Hanoi) and south (Ho Chi Minh), have very different prospects. The northern cluster would access the Song Hong Basin, which has almost no analysis of the storage potential. The Song Hong Basin is not a mature oil and gas province compared to other regional basins. For this reason, the basin is classified as 'possible' according to the Institute's storage basin assessment tool. Given that a significant portion of Viet Nam's emissions are proximal to this basin, extensive work is required on the basin's saline formation potential. Finally, the Nam Con Son Basin was omitted because it is not proximal to emissions sources.

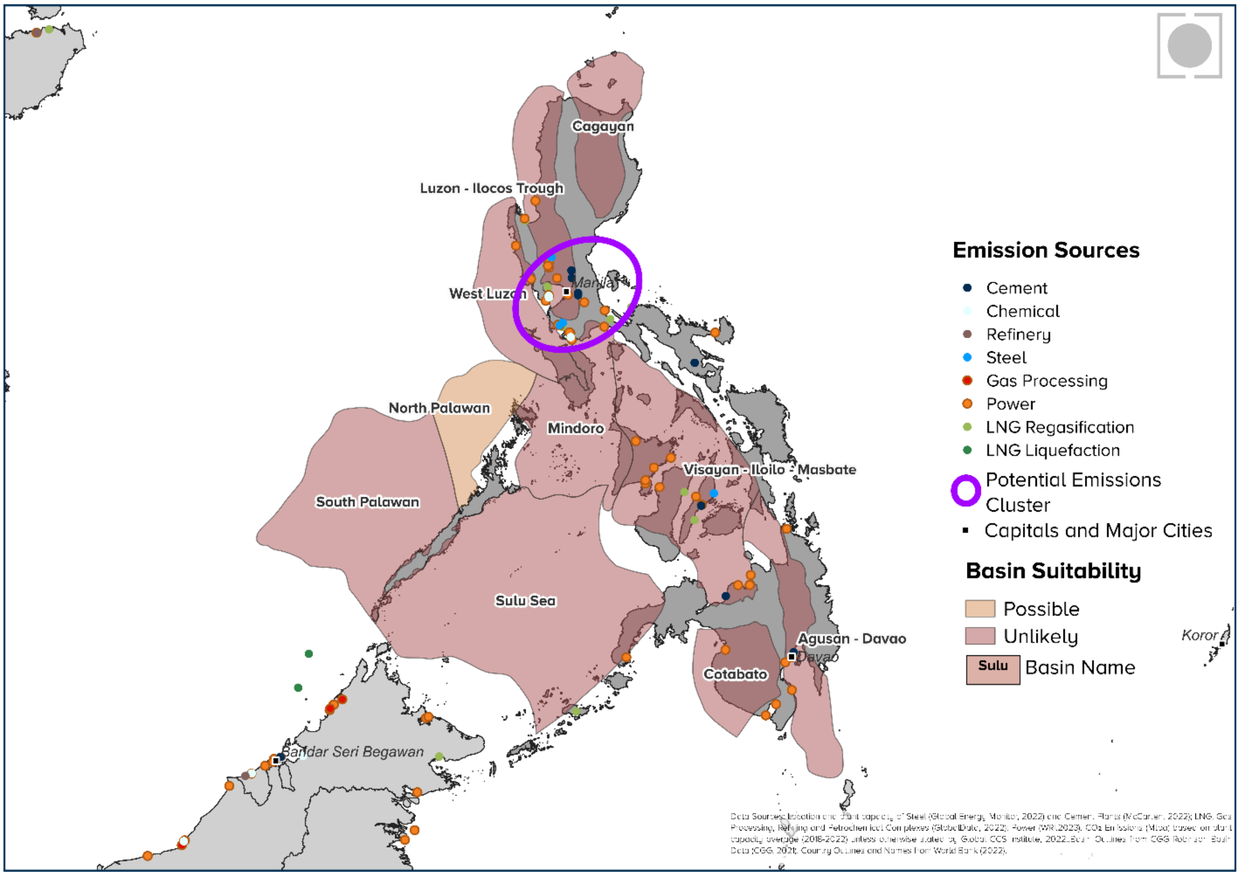
1.3.6.3. Summary of Storage Deployment Prospects, Barriers, and Issues

- Viet Nam lacks a modern, comprehensive national CO_2 storage resource atlas.
- The Cuu Long Basin requires a targeted characterisation study, focusing on saline formations and large depleted fields. Subsequently, the basin presents a moderate to long-term (<10 years) opportunity for CO_2 storage.
- The Song Hong Basin requires an extensive characterisation assessment, given a significant portion of Viet Nam's emissions are proximal to this basin.
- Viet Nam lacks a CCS-specific legal and regulatory framework and CCS-specific domestic policies or incentives.

1.3.7. Philippines

The storage potential of the Philippines is largely unknown and, therefore, has low prospects for hosting a large-scale CO_2 storage operation and CCS more generally in the near term. The Philippines' storage potential has been briefly reviewed as part of regional studies. No CCS facilities have been announced for the Philippines. One emission cluster in Luzon, near Manila, could form a CCS network (Figure 1.18).

Figure 1.18. Philippines Emission Clusters and Storage Basins



Source: GCCSI.

1.3.7.1. CO_2 Storage Resource Summary

Only one gas field passed the screening criteria used in this study (depth > 800 m and storage resources > 5 $MtCO_2$). Table 1.18 shows the storage resources of this field. No oil field could pass the criteria used for CO_2 EOR storage, mainly due to the small size of the fields. There was no data for saline formation resource estimates.

Table 1.18. Philippines: Estimated CO_2 Storage Resources in Hydrocarbon Fields

Basin	P50-Storage Available ($MtCO_2$)	P50-Storage Remaining ($MtCO_2$)	P50-Storage Net ($MtCO_2$)	Number of Gas Fields	Number of Oil Fields
North Palawan Basin	57.1	10.2	67.2	1	0

Source: GCCSI.

1.3.7.2. Prospective Basins with Potential Clusters

This analysis finds that the Philippines hosts only one basin with potential for CO_2 storage, albeit categorised as 'possible': the North Palawan Basin. The basin is entirely offshore, located off the island of Mindoro. The emissions cluster in Manila is a tenuous source-sink match as a ~500 km + pipeline from the Manila region to the North Palawan Basin would be required.

1.3.7.2.1. North Palawan Basin

The North Palawan Basin is classified as 'Possible' according to the Institute's storage basin assessment tool. The basin received this classification because it is hydrocarbon-producing, suggesting viable reservoirs and seals for CO_2 storage. However, overall, exploration and development in the basin are limited.

APEC (2005) and the ADB (2013) concluded that the prospects for storage in the Philippines were very low. Neither regional assessment provided extensive analysis or data to support their conclusions other than stating that the oil and gas fields in the North Palawan Basin did not present a significant opportunity based on field sizes. In addition, they noted the Luzon Basin, proximal to the emission sources of Manila, was of poor quality.

Storage Resources

The storage resource assessment of the Philippines is limited to a single gas field (Malampaya gas field) in the North Palawan Basin. The current study found that the Malampaya Gas Field had an estimated storage resource of 67.2 $MtCO_{2,}$ with 57.1 $MtCO_2$ available today (Table 1.18). The Malampaya gas field is situated at 850 water depth and was discovered in 1989. The field comprises Oligocene to Miocene carbonate build-ups (limestone) of the Nido Formation and sealed by mudstones of the overlying Pagasa Formation (Neuhaus, 2004). Porosity ranges from 5 to 30 %, and permeabilities range from 0.01 to 1,000 mD (Fournier & Borgomano, 2007).

The ADB (2013) also concluded that almost all hydrocarbon field resources were hosted in one unidentified field, 251 $MtCO_2$ (total of 307 $MtCO_2$).

The current analysis did not find sufficient data to complete a study of the saline formations of the Philippines. The ADB (2013) stated that Miocene to Pliocene shelfal sandstone has the best opportunity for further characterisation but noted that they were poor quality sandstones. According to the ADB, the storage resources in saline formations of the Luzon and Cagayan basins (both underlying Luzon Island) were estimated at around 32 Gt (ADB, 2013). Further analysis is required for the Sulu Sea, Cagayan, and Visayan basins if additional data can be identified or acquired.

Carbon Mineralisation

There are several notable mafic and ultramafic formations in the Philippines, each with unique characteristics and rock compositions. Some of these formations include:

- Zambales Ophiolite Complex: Located in Zambales Province, it is an extensive mafic and ultramafic rock formation. It comprises various rock units, including gabbros, basalts, and peridotites.
- Angat Ophiolites: Located in Luzon. It comprises layered and massive gabbros, diabase sheeted dikes, tonalites, and pillow basalts.
- Camarines Norte Ophiolite Complex: Located in Camarines Norte Province, it consists of harzburgites, gabbros, diabasic and basaltic dikes, and pillow lavas.
- Dinagat Ultramafic and Ophiolite Complex: Situated in the Dinagat Islands, this complex comprises ultramafic rocks such as dunites, peridotites, and serpentinites.
- Surigao Ophiolite Complex: Located in Surigao del Norte and Surigao del Sur provinces, this belt contains ultramafic rocks, including dunites, peridotites, and serpentinites.
- Leyte Ophiolite Complex: Located in Leyte province, this complex consists of ultramafic rocks such as peridotites and serpentinites.

The presence of ophiolites, dispersed across the Philippines in over 20 significant bodies, suggests a potential for carbon mineralisation in the country, provided they feature open, well-connected, and complex fracture networks.

A detailed evaluation is crucial to fully understand the potential and suitability of each formation for in-situ carbon mineralisation technology. Amongst the essential steps are precise quantification of their mineralogical composition, characterisation of their fracture networks and fluid flow properties, and comprehensive reactive transport modelling. With careful consideration of these factors, the Philippines can further explore the promising avenue of in-situ carbon mineralisation.

1.3.7.3. Summary of Storage Deployment Prospects, Barriers, and Issues

- The Philippines lacks a comprehensive national CO_2 storage resource atlas: the storage potential of onshore and offshore saline formations is unknown. A storage atlas mapping the formations is critical to advancing CO_2.
- A detailed evaluation is crucial to fully understand the feasibility and viability of the in-situ carbon mineralisation potential.
- The Philippines lacks a CCS-specific legal and regulatory framework and CCS-specific domestic policies or incentives.

1.3.8. Singapore

The geology of Singapore indicates there is no storage potential in that country. However, Singapore has significant emissions, primarily in the petrochemical and refining industries, requiring CCS for decarbonisation. Singapore, therefore, requires transboundary transport of CO_2.

The saline formations and/or hydrocarbon fields of Indonesia's Central Sumatra and North Sumatra basins are within 300 km of Singapore (Figure 1.5). However, Indonesia has significant domestic emissions in those regions that could result in competition for CO_2 storage resources. Alternatively, pipeline or shipping routes could export CO_2 to the Malay Basin in Malaysia. Competition for storage resources is less likely in the Malay Basin when compared to onshore Indonesian domestic CO_2 sources.

1.3.9. Cambodia, Lao PDR, and Myanmar

The storage potential of these nations is currently unknown as no analysis has been completed. Although they have comparatively minor emissions, CCS will eventually be required in each country.

The primary issue is a lack of CCS awareness and CO_2 storage expertise in these nations. They require the assistance of more advanced countries regionally (Thailand, Malaysia) and internationally.

It is recommended that these nations engage with the international storage community to progress CCS in each country. In addition, these nations currently do not have any CO_2 storage analysis, CCS-specific legal and regulatory frameworks or CCS-specific domestic policies or incentives.

1.4. Summary and Recommendations for Storage Development

This analysis confirms suitable storage basins across Southeast Asia with potentially gigatonnes of storage resources.

Overall

Most knowledge about the storage potential of the region's geology is derived from regional or global studies (ADB, 2013; CO2CRC, 2010; IEAGHG, 2009). Within those studies, resource estimates have focused on oil and gas fields but, in most cases, have not provided the data behind the estimates. Many of the basins in the region have not been reviewed for their storage potential. A limited number of basins have detailed site-specific studies published.

Despite over a decade of storage studies in Southeast Asia, a review of the countries above highlights three clear barriers to the development of CO_2 storage resources:

1) The storage resources of saline formations are largely unknown, and formations are uncharacterised.
2) Published storage resource estimates lack location, methodology, assumptions, limitations, or input data transparency. The raw data is unavailable in this current study due to copyright issues.
3) There is almost no access to subsurface data (such as geological data, well-log data, seismic reflection surveys, and core data).

These three barriers prevent the ongoing development of storage resources in Southeast Asia and restrict understanding of the applicability of CCS deployment in the region.

Each country is at a different stage of maturity in terms of CCS and storage development. A coordinated approach to storage resource development in Southeast Asia could accelerate the deployment of CCS in the region.

A series of public-private partnerships could sponsor the characterisation of storage basins in each nation. Each partnership would complete its assessment using a standardised approach to data collection, characterisation and resource calculations. The assessment results will be published in a public database of hydrocarbon fields and saline formations, showing the location, area extent, reservoir-seal properties, and resources, amongst other information critical for storage development.

As a public database, issues such as anti-trust or anti-competitive assertions can be avoided and enable industry to play a part. International experts and relevant experts in Indonesia, Malaysia, and Thailand could lead this programme to assist less advanced countries regarding CCS. The Southeast Asia CCS Accelerator (SEACA) initiative led by the Global CCS Institute laid the foundations of the above initiative by creating a storage working group in Jakarta in 2023.

The Jakarta SEACA Workshop was held physically on 20 and 21 November 2023 in Tangerang (near Jakarta), Indonesia and was co-organised by the Global CCS Institute, ASEAN Centre for Energy (ACE), and Asia Natural Gas and Energy Association (ANGEA). The Workshop was attended by representatives of six ASEAN Member States (Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, and Thailand) and Timor Leste. These representatives came from various sectors, including government, regulatory authorities, and state-owned companies. Additionally, invited participants from other government entities, industries, universities, consulting firms, etc., also participated.

The primary outcome of this meeting is to establish a Storage Working Group led by governments and supported by industry. The next steps of the Storage Working Group are now under consideration.

The specific recommendations for each county are detailed below. In addition, recommendations for each basin are described in Table 1.19. CCS policy is not discussed directly below. A general recommendation is to have supportive policies, such as carbon tax, that incentivise storage resource development, and CCS should be applied to every country.

Indonesia

Indonesia hosts multiple near-term opportunities to host significant CCS networks due to strong source-sink matching with sufficient onshore resources. With a regulatory framework in place, the development of storage resources relies on creating an environment for commercial success. Two key programmes can help create commercial success.

Firstly, producing a national storage atlas with public and open data (well, seismic, etc.) can bolster commercial success. An atlas identifies where storage resources are located and how much can be stored. An atlas also identifies data gaps and major risks. An atlas will also enable a comprehensive mapping and characterisation of saline formations, which has not been done in Indonesia.

Mapping these storage resources opens up a broader understanding of the overall CCS potential of Indonesia, rather than that knowledge (and data) being limited to only the oil and gas industry as it stands today. In addition, new storage operators could rapidly progress initial screening analysis by using the outcomes and data of the atlas. Finally, an atlas can enable the regulator to release storage leases in areas with the highest chance of uptake.

Based on the findings of the atlas, a government-led de-risking of storage resources through pre-competitive data acquisition can remove the initial cost barrier to storage exploration. The key focus should be areas with limited hydrocarbon exploration and production but likely have suitable saline formations. The acquisition could focus on filling data gaps, such as acquiring seismic over areas with no or limited seismic lines. The primary focus should be on those emission-intensive regions where data is limited.

For example, the Australian Government funded the national geological survey to complete several pre-competitive data acquisition programmes to support storage development. A CCS project has been announced in each area where data was acquired. (https://www.ga.gov.au/scientific-topics/energy/resources/carbon-capture-and-storage-ccs/geological-storage-studies).

Malaysia

The above strategies, a comprehensive atlas and a pre-competitive work programme for Indonesia, apply to Malaysia. Malaysia has multiple opportunities to host significant CCS networks with multiple emission clusters adjacent to suitable storage basins on the east coast of the Malay Peninsula and Sarawak. In the near term, the development would be restricted to the Sarawak region, which has a regulatory framework. Therefore, having national regulatory frameworks across Malaysia to support the exploration and development of storage is a priority.

The industrial emissions surrounding Kuala Lumpur present an interesting scenario. The closest storage options are in Indonesia's onshore basins. In contrast, the nearest known domestic storage options are in the Malay Basin, approximately 500 km away (direct), requiring shipping or a pipeline across the Malay Peninsula. The storage potential of the Strait of Malacca is currently unknown because there is no national atlas.

Finally, the 100 $GtCO_2$+ storage resources in Malay, Sabah, and Sarawak basins offshore Malaysian waters enable the opportunity to receive international CO_2 through shipping.

Thailand

Thailand does not have CCS-specific regulatory frameworks. A national regulatory framework to support the exploration and development of storage is a priority. Regarding storage development programmes, Thailand has the exact requirements as Malaysia and Indonesia - a national atlas mapping and characterising saline formations and hydrocarbon fields. This atlas can then be followed by a government-led pre-competitive data acquisition programme to de-risk sites and fill data gaps.

Given the storage resources are restricted to the offshore Gulf of Thailand, ~ 500 km from the major emission clusters around central and eastern Thailand, the exploration and appraisal of onshore basins is critical. Accessing onshore storage resources would significantly reduce transport and storage costs.

Other Southeast Asia Nations

Brunei, the Philippines and Viet Nam do not have regulatory frameworks, so that should be a priority for the government. Each country requires a national atlas of storage resources to identify potential storage sites within saline formations and to identify risks and barriers to deployment.

Brunei could potentially have the most rapid movement once regulations are in place. The country hosts a suitable basin for CO_2 storage and large, near-depleted oil and gas fields that could be converted to storage sites. Moreover, the limited domestic emissions compared to the overall storage resource of the Sabah-Baram Delta Basin means international import of CO_2 could be commercially viable.

In Viet Nam, the storage resources of the northern Song Hong Basin are unknown. This region would host the largest CCS Network in Viet Nam due to emissions clusters in and around

Hanoi. In southern Viet Nam, the emissions clusters around Ho Chi Minh City could access the resources of the offshore Cuu Long Basin. The storage potential of the saline formations of the offshore Cuu Long Basin is unknown and must be mapped and characterised.

The Philippines requires a fundamental analysis of its storage resources, focussing on the storage potential proximal to its emissions centres around Manila. This should include mineral carbonation evaluation.

Lao PDR, Cambodia, and Myanmar

Lao PDR, Cambodia, and Myanmar require a fundamental analysis of their storage resources. An international or fellow ASEAN nation should support this work to rapidly bring these three nations up to speed in understanding their CO_2 storage potential.

A summary of each basin and the required work programme is detailed in Table 1.19.

Table 1.19. Summary of the Storage Potential and Future Work Programmes of Southeast Asia Region

Country	Basin	Location	Basin Suitability	Emission Cluster Identified	Storage Resource Estimate Completed		Requirements for Accelerated Deployment
					Oil and Gas	Saline Formations	
Viet Nam	Song Hong	Offshore	🟠	P	X	X	1. Basic analysis of storage potential and resource calculations 2. Regulations to enable the exploration and storage of CO_2 storage
	Cuu Long	Offshore	🟢	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use 4. Regulations to enable the exploration and
	Nam Con	Offshore	🟢	X	P	X	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use 4. Regulations to enable the exploration and storage of CO_2 storage

Philippines	North Palawan	Offshore	●	X	P	X	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use 4. Regulations to enable the exploration and
	Luzon	Onshore	●	P	X	X	1. Basic analysis of storage potential and resource calculations 2. Basic mineral carbonation potential 3. Regulations to enable the exploration and storage of CO_2 storage
Thailand	Pattani	Offshore	●	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Regulations to enable the exploration and storage of CO_2 storage
Malaysia/ Thailand	Malay	Offshore	●	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use 4. Brunei to regulations to enable the exploration and storage of CO_2

Malaysia	Sarawak	Offshore	●	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use
Malaysia	Sabah-Baram	Offshore	●	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use
Brunei	Sabah-Baram	Offshore	●	P	P	P	1. Characterisation of saline formations and hydrocarbon fields with resource calculations 2. Regulations to enable exploration and storage of CO_2 storage
Myanmar	Central Myanmar	Onshore	●	P	X	X	• Basic analysis of storage potential and resource calculations
Cambodia	Panjang	Offshore	●	X	X	X	• Basic analysis of storage potential and resource calculations
Laos	Greater Korat	Onshore	●	X	X	X	• Basic analysis of storage potential and resource calculations
Indonesia	Central Sumatra	Onshore	●	P	P	P	• Characterisation of saline formations with resource calculations

	South Sumatra	Onshore	● (Highly Suitable)	P	P	X	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for re-use
	Northwest Java	Onshore	● (Suitable)	P	P	X	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for
	Northeast Java	On/Offshore	● (Highly Suitable)	P	P	X	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for
	East Java	Offshore	● (Highly Suitable)	P	P	P	1. Characterisation of saline formations with resource calculations 2. Detailed hydrocarbon field suitability and resource assessment 3. Infrastructure analysis to review potential for
	Kutei	Offshore	● (Highly Suitable)	P	P	P	• Detailed hydrocarbon field suitability and resource assessment • Infrastructure analysis to review potential for
SINGAPORE	No storage		● (Unlikely)	P	X	X	• Engage adjoining regions to support their storage development.
LEGEND	**Basin Suitability**		● Highly Suitable		● Suitable	● Possible	● Unlikely

Source: GCCSI.

Chapter 2

Establishment of Asia CCS/CCUS Value Chain as a Collective Framework in the Asia Pacific Region

Alex Zapantis, Eric Williams, Shahrzad Shahi, Matthew Loughrey, Joey Minervini, Ian Havercroft, and Errol Pinto

2.1. Introduction

CCS Networks can offer considerable benefit in supporting large scale and cost effective decarbonisation for industrial and power generation facilities globally. This section goes into detail to discuss these benefits including a demonstration through the development of a hypothetical CCS network design in Southeast Asia.

2.2. Understanding Clusters, Hubs, and Networks

2.2.1. Clusters

Many emissions-intensive industrial and power generation facilities globally are located in close proximity to one another. This is often for several reasons including energy supplies, power generation facilities, common feedstocks or common product distributions networks.

This provides the opportunity for CO_2 emitters in close proximity to each other to join together to form what is known as an emissions cluster. These emissions clusters can then be connected to large-scale CO_2 storage sites using strategically designed transport infrastructure for the total CO_2 produced from the emissions cluster.

The costs of a pipeline, possibly compression facilities, or ships and shipping infrastructure can be reduced on a cost per tonne of CO_2 basis if shared or only spent once rather than multiple times.

Like the physical infrastructure required, associated activities such as community consultation, government approvals, negotiations with property owners and so on, can be reduced on a cost per tonne basis.

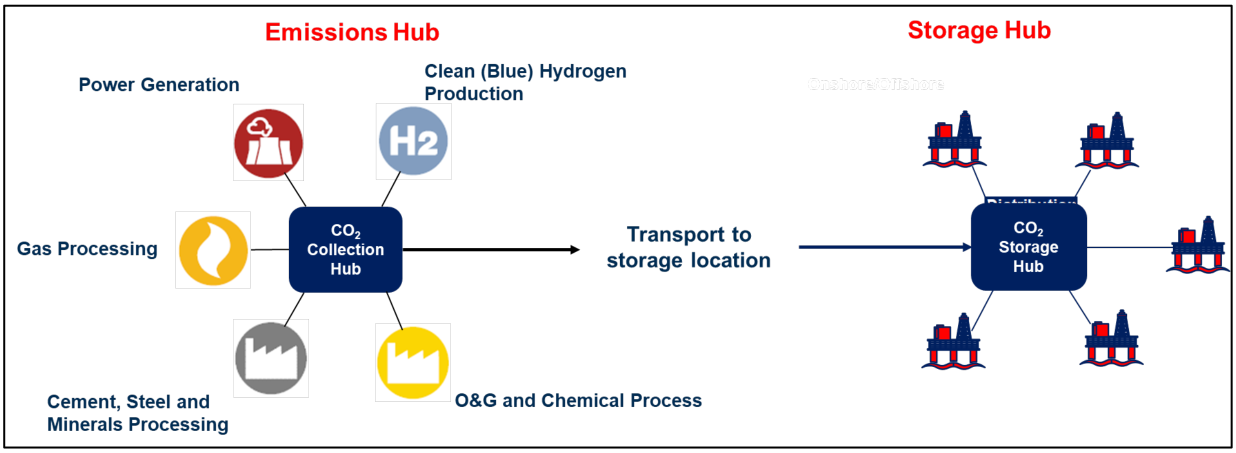
There can also be storage clusters, where CO_2 is distributed amongst a group of neighboring geological storage locations and/or oil fields suitable for enhanced oil recovery (EOR).

2.2.2. CCS Hubs

Hubs are very common in natural gas distribution systems globally, where pipeline networks bring together gas from many different production fields to distribute gas to dispersed markets.

CCS hubs work in a similar manner to natural gas distribution systems, acting as the central collection or distribution points for CO_2. One hub would service the collection of CO_2 from a emissions cluster or distribution of CO_2 to a storage cluster.

Figure 2.1. CCS Emissions and Storage Hubs



Source: GCCSI.

2.2.3. CCS Networks

A CCS network brings together all elements of the CCS value chain necessary to capture, transport, and store CO_2 for multiple emitting-intensive industries, including CCS hubs, emissions clusters, transport, injection, and storage.

As the network of emitters supplying CO_2 grows, the transport and storage infrastructure may increase to multiple transport pipelines, a greater number of ships with added port infrastructure, additional injection facilities, and storage locations.

Areas where there is a high density of CO_2 emitting industries and nearby suitable storage are considered excellent sites for hub and cluster developments supporting CCS network growth.

2.3. Strategic Benefit of CCS Networks

CCS networks are essential to secure the future of emissions-intensive industries and encourage future investments. This will be especially important as CO_2 emission reduction strategies become increasingly more necessary as a result of mechanisms such as climate protection policies or the introduction of a price on carbon emissions.

CCS networks offer several advantages for network participants, compared with vertically integrated CCS projects.

2.3.1. Cost Reductions through Shared Infrastructure

Industrial clusters create an opportunity to reduce cost by allowing multiple parties to share the often-expensive infrastructure for CCS. Larger capacity infrastructure also delivers economies of scale reducing the unit cost of CO_2 transport and storage.

Shared infrastructure with sufficient proven storage capacity can also allow facilities to separate their investment decisions from the development of the network. This is important to maximise the deployment and exploitation of CCS and its benefits at scale.

2.3.2. Enabling the Use of CCS for Smaller Emissions Sources

Many industrial facilities, including refineries, gas processing, hydrogen and fertiliser production and other chemicals generate CO_2 either through the conversion of feedstocks to products, or the use of high-temperature heat. However, compared to the typical emissions from large-scale emissions sources such as fossil fuel power stations, the volumes of emissions from these industrial processes can be small. Developing vertically integrated CCS projects at this small scale is often uneconomic. However, where they are located reasonably close to each other, the emissions from many small sources can be combined and can utilise shared CO_2 compression, transport and storage infrastructure accessing economies of scale that would not be available to any individual emission source.

It is important to understand that the number of smaller industrial facilities worldwide contribute significant cumulative CO_2 emissions that are unavoidable as long as the facilities continue to operate. The development of large-scale and strategically located infrastructure will enable the lower cost and full-scale deployment of CCS in industrial clusters, reducing cost and risk to smaller emissions sources.

2.3.3. Enabling CCS in Regions without Access to Suitable Local Storage

Networks offer an avenue for reducing emissions for industries in regions that do not have locally available storage. Regions with limited to no storage can leverage CCS networks to provide lower-cost transport either by pipeline or shipping to access storage in regions with abundant storage.

2.3.4. Enabling Low-Carbon Industrial Production

In many industries, such as steel, cement and chemicals, CCS is the only available technology capable of breaking the link between production and emissions of greenhouse gases. Operators able to connect their facilities to a CCS hub and cluster arrangement could effectively protect themselves and their investments against potential high future carbon prices, while regions that use CCS to establish themselves as 'low carbon industrial zones' could see significant advantages in the race to attract and maintain investment.

In an increasingly carbon-constrained world, the development of emissions clusters will attract investment, increase industry engagement, and encourage the development of further projects in each location, thereby accelerating the development of a broader CCS industry.

2.3.5. Reduced Exposure to Resource Constraints

Resource constraints can manifest in many different ways for CCS. The supply of raw materials for the CCS equipment, equipment manufacturing and the workforce resources required to build and operate the infrastructure necessary to transport and store CO_2 may all be constrained given the potential demand for CCS in meeting global net zero commitments.

CCS networks may require additional resources during development and construction due to their scale versus a single vertically integrated CCS project; however, the workforce resources and equipment on a total number basis will be less when compared to the number of vertically integrated CCS projects that would be required to transport and store CO_2 from each of the emissions sources that could contribute to a CCS network.

This benefit will also extend to land availability and managing congestion in existing or new pipeline or shipping corridors, which could be limited for some existing emissions clusters located in densely populated areas or a highly congested shipping region.

2.4. CCS transportation methods

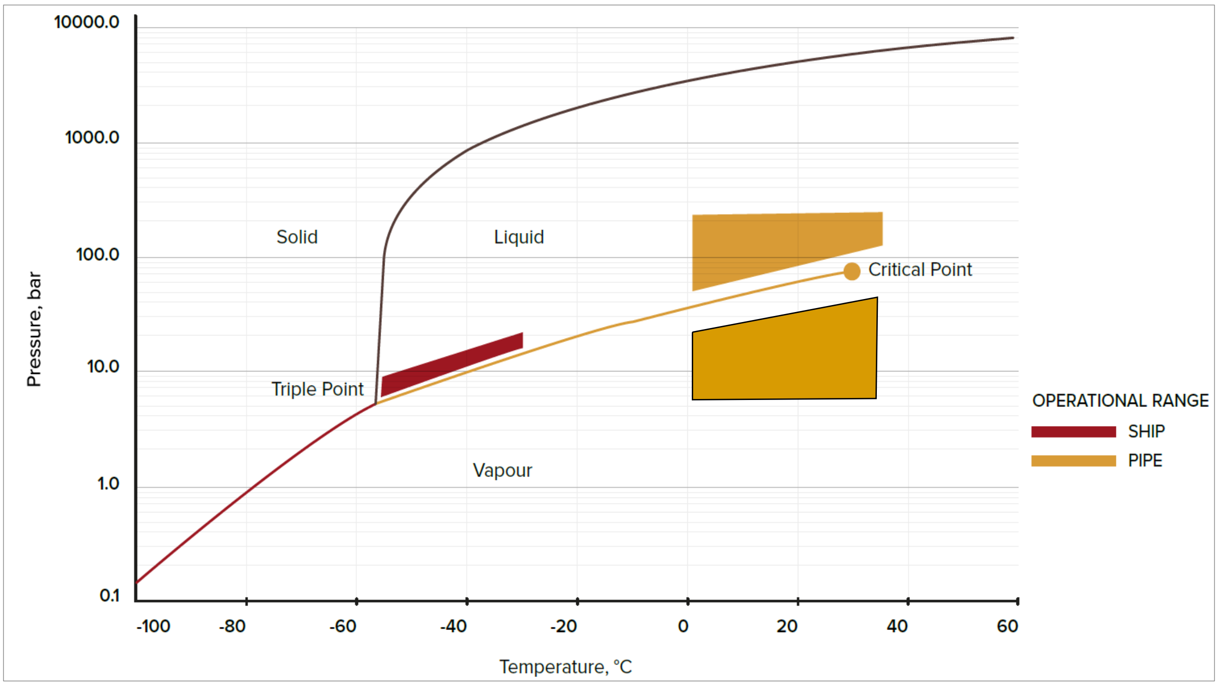
Several transport methods for transporting CO_2 from the emissions sources to a storage location for a CCS network include pipelines, ships, trucks, and rail.

2.4.1. Pipeline

Pipeline transport is the most commonly used mode of transport for CO_2 and is likely to remain so for the foreseeable future. Globally, the Institute tracks over 9,600km of operating CO_2 pipelines, primarily in the United States, and many more are in various stages of development.

Pipeline transport requires the CO_2 once captured to be compressed in either its gaseous phase or to dense or supercritical conditions beyond the critical point for ongoing transport to the storage location. Gas phase compression typically consists of a multi-stage compressor to raise the CO_2 to the desired pressure for transport. To compress to dense phase conditions a multi-stage compressor brings the CO_2 to the critical pressure of 74 bara after which the CO_2 behaves similar to a liquid and dense phase pumping can be used to continue to raise the CO_2 to the desired pressure for transport.

Figure 2.2. Pressure and Temperature Status Diagram of CO_2. Note the Small Area for the Transport of CO_2 Near the CO_2 Triple Point



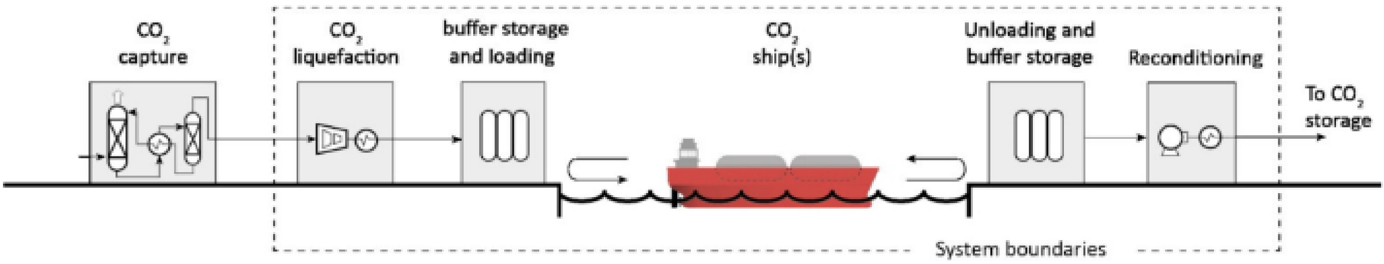
Source: GCCSI.

Water removal is essential to prevent corrosion of downstream pipeline infrastructure and enable the use of low-cost carbon steel versus higher metallurgical steel at a more significant cost. Water removal is often before, integrated with or following initial compression using dedicated drying equipment such as glycol dehydration or molecular sieves.

2.4.2. Shipping

The shipping supply chain for CCS consists of the following elements in Figure 2.3.

Figure 2.3. Main components for shipping logistics for CCS



Source: Roussanaly et al., 2021.

Liquefaction

Liquefaction involves the compression and liquifying of CO_2 prior to storage and transport by ship.

Liquefaction processes are typically divided into two methods:

- Internal cooling system ('open' system) where CO_2 is compressed to near the critical pressure before being decompressed to the transport pressure.
- External refrigeration system ('closed' system) where the CO_2 is compressed to the transport pressure and then liquified using an external refrigeration system.

Open systems are simpler in configuration but are typically less efficient.

The choice of liquefaction method depends on a number of factors (IEAGHG, 2020):

- The state of the CO_2 before liquefaction (either pressurised, at 70-100 bar abs, or at no or low pressure, at 1-2 bar abs source pressure).
- The required transport condition.
- The temperature of available cooling water.
- Availability/desirability of an external refrigeration system (e.g. using ammonia).

The liquefaction process is often the most energy intensive step in the ship transport value chain, requiring 11-14% more energy than the compression energy required for pipeline transport (IEAGHG, 2020).

The removal of water is essential at the conditions for liquefying CO_2 to prevent ice formation. Dehydration can occur through the compression and condensation steps of the liquefaction process. Alternatively, the CO_2 can be dehydrated prior to liquefaction using glycol dehydration or molecular sieve technology. Non-condensibles are typically removed through fractionation following liquefaction.

Buffer Storage

The flow of CO_2 from their sources and subsequent liquefaction of CO_2 is a continuous process. However, shipping operates discretely or in batches. To ensure that the flow of CO_2 remains continuous, buffer storage is required. Typical buffer storage consists of pressure vessels that are horizontal, vertical or spherical in shape. The shape considered is dictated by the area available for storage and costs.

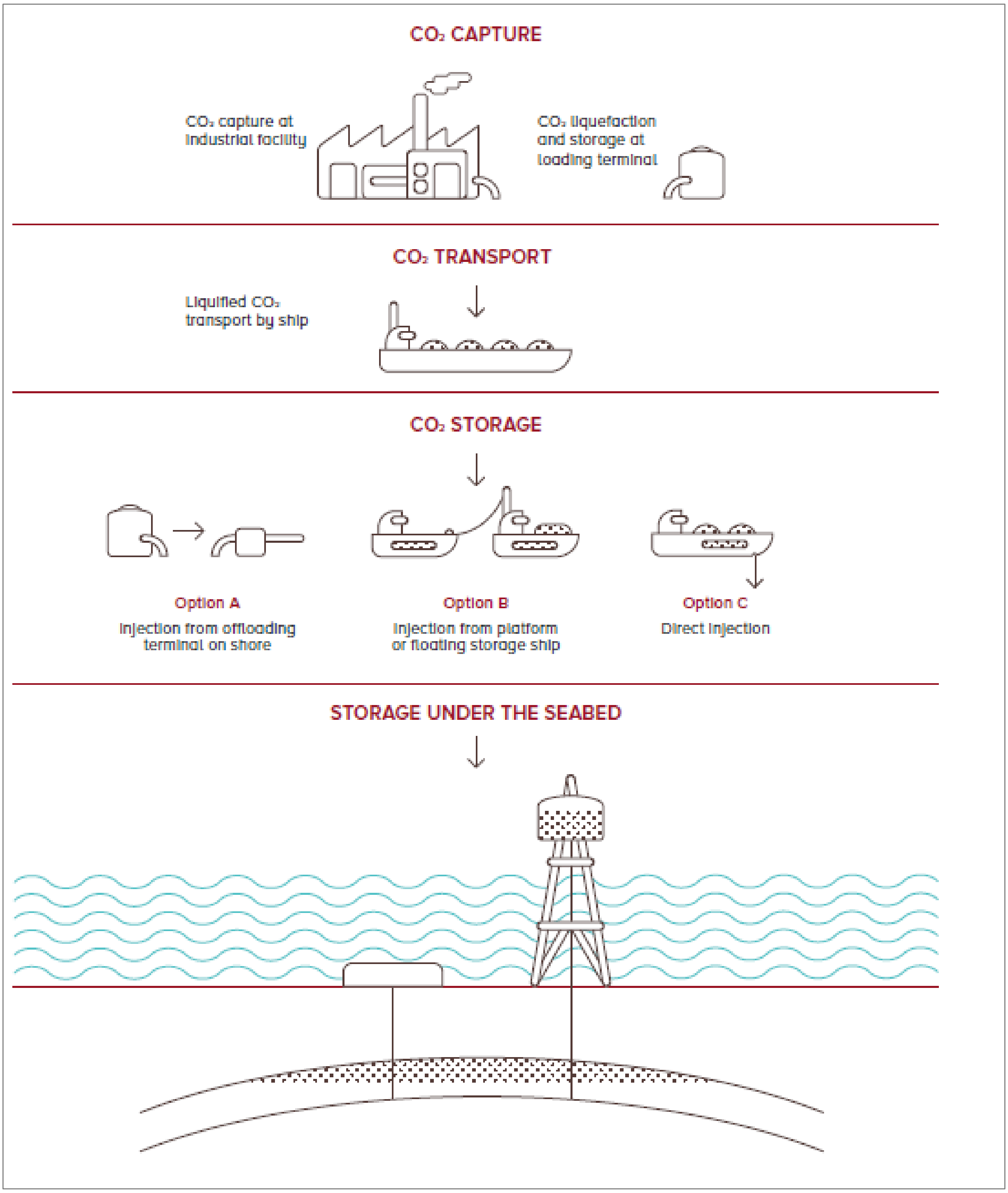
The capacity for buffer storage is important when designing shipping infrastructure. The capacity is based on factors including ship size and ship logistics. BEIS (2018) cites several literature sources that choose capacities between 100-150% of the ship capacity with 120% based on experience with LNG shipping balancing flexibility and cost being considered for the shipping cost study in the report.

Loading and Offloading Facilities

Loading of CO_2 from the onshore buffer storage to the CO_2 carrier can be performed using conventional articulated loading arms that are commonly used for cryogenic liquids like LPG or LNG.

The offloading scheme in Figure 2.4 illustrates the three basic options for offloading CO_2 from a ship to an injection site. If storage is onshore, the CO_2 is unloaded into an intermediate storage tank at the terminal (Option A) from where it can be piped to the onshore storage site. If the storage site is offshore, the ship could unload to an intermediate floating vessel, platform or buoy mooring anchor (Option B), or alternatively inject the CO_2 directly into the storage reservoir from the ship (Option C). Regarding Options B and C, the IEAGHG Shipping study identified that offshore unloading, although present in the literature, is largely unknown when compared to onshore unloading (IEAGHG, 2020). Also, the infrastructure and ship design vary significantly between Options B and C.

Figure 2.4. Offloading Options from Ship to Reservoir



Source: GCCSI.

CO_2 Ships

CO_2 is transported by ship in a liquid state at conditions near the triple point (Figure 2.2). Transporting near the triple point means the density of liquid CO_2 is much higher than in a gaseous state, enabling a larger amount of CO_2 transported per ship. Based on the density of CO_2, ships are categorised as low, medium and high pressure.

Ships used today for food-grade CO_2 transport are referred to as medium-pressure ships – they are designed to transport CO_2 as 'refrigerated liquid', at conditions in the range of 15-20 bar abs and -20 to -30°C, which is similar to liquefied petroleum gas (LPG) carriers. The existing size and number of these ships are limited. To date, there are only a few operational vessels specifically designed for the transport of CO_2, with a capacity in the range of 900-1,250 m^3 (Brownsort, 2015). Most of them were converted from LPG carriers.

For large-scale CCS applications, larger ships would be required than those available today. The majority would require more than one tank. For larger ships, CO_2 conditions of 5-9 bara and lower temperature -55°C are proposed and are categorised as low-pressure. The lower pressure is advantageous to reduce the thickness of the tank's walls, which helps lower the weight of the ship and reduces transport costs. Ships for the transport of CO_2 at low pressure would have a comparable design to typical LPG ships, with large, cylindrical tanks. This concept, however, requires the most energy for the liquefaction (cooling) of the gas.

Conditioning

Conditioning of the CO_2 corresponds to bringing the temperature and pressure of the liquified CO_2 to the desired conditions for further transport to the storage location. This process is fairly standard for cryogenic gases, with LNG regasification a good example. Heating is simple through cryogenic heat exchangers using air or seawater with compression handled by dense phase pumps.

2.4.3. Rail and Truck

Rail and trucks are an alternative means for connecting sources of CO_2 to CCS networks. Both transport CO_2 under cryogenic conditions, similar to shipping. Rail can enable large-scale transport but is typically only cost-effective if existing rail infrastructure can transport the CO_2 part or all of the desired distance to the storage location. If new rail infrastructure is required, pipelines typically offer a more cost-effective and flexible transport method. Trucking of CO_2 has been considered or employed for pilot or first-of-a-kind projects globally. Costs and logistics limit trucking for large-scale CCS projects; however, trucking can offer an opportunity to transport CO_2 from isolated industrial emitters to a CCS hub for further transport and storage.

2.5. CCS Transport Cost Trends

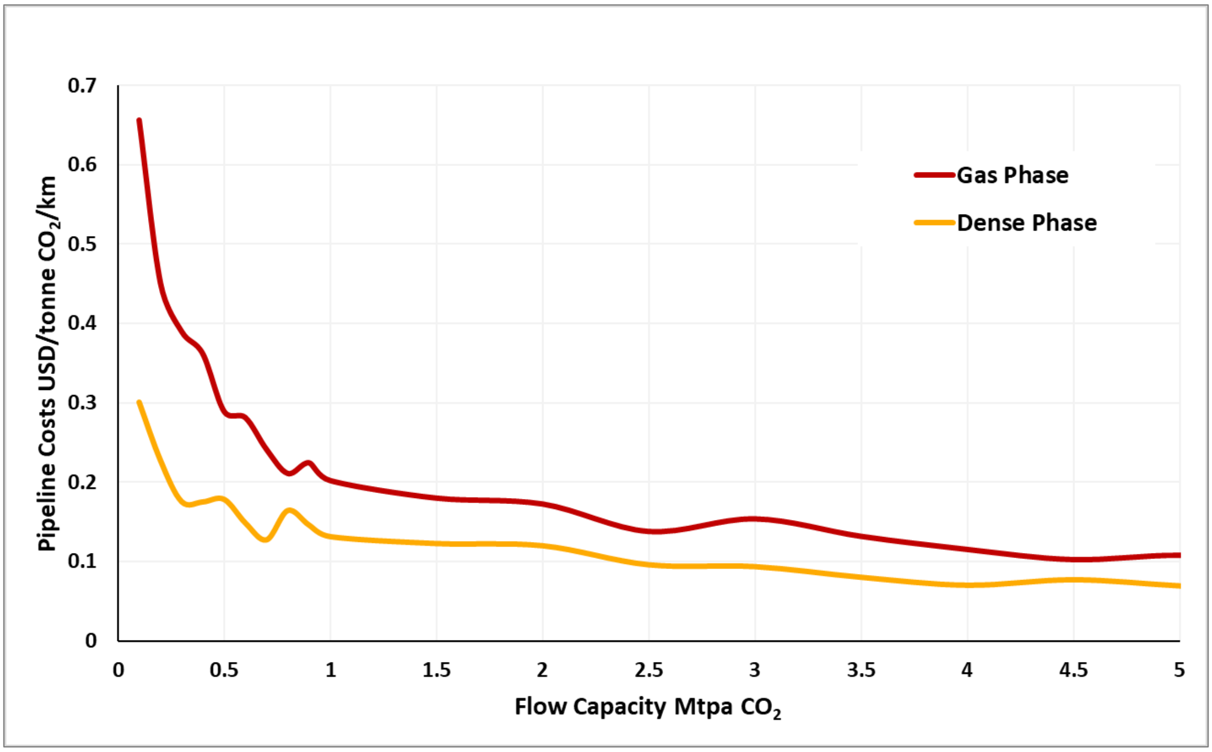
To understand how a network can support lowering costs for emissions sources, it is essential to outline the cost trends associated with key large-scale transport methods for CCS, including pipelines and shipping.

Pipelines

Pipeline transport network design is strongly influenced by cost trends for pipelines and CO_2 compression. An existing GCCSI report (GCCSI, 2021) highlighted the general trends for pipelines and CO_2 compression that should be considered when initially designing a CCS network:

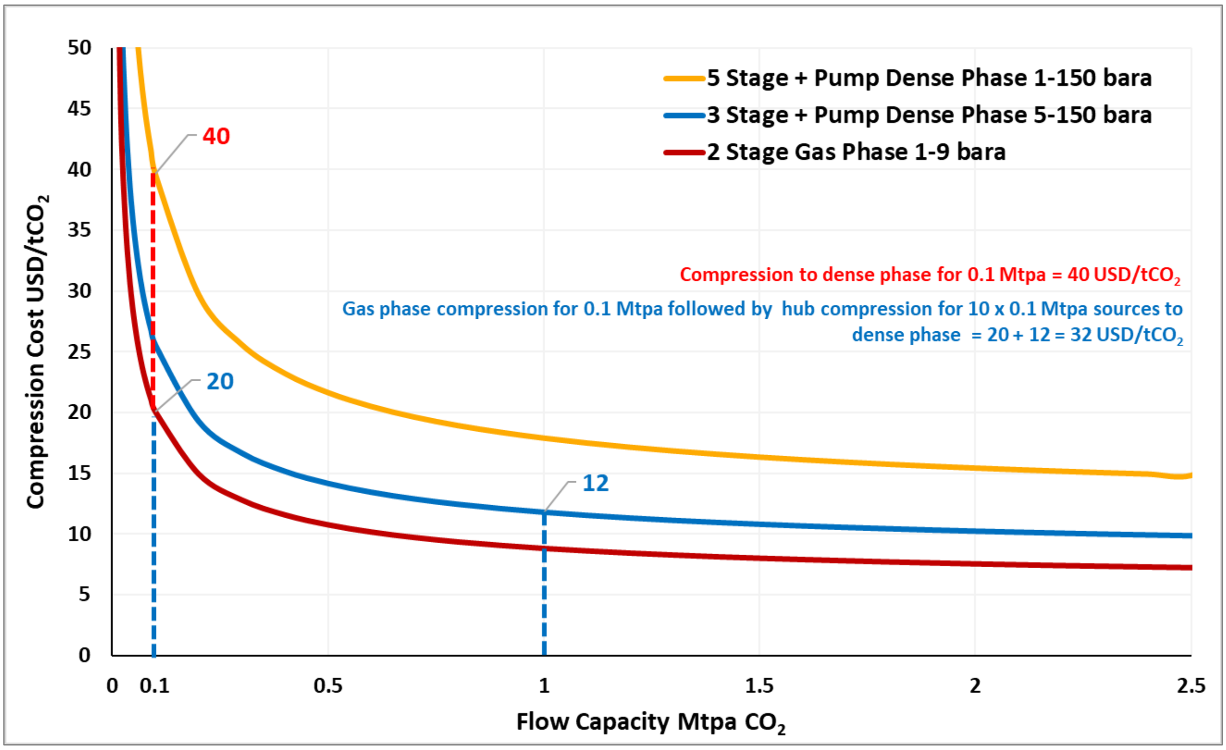
- Both pipelines and compression are strongly affected by economies of scale. Above a flow capacity of 1 Mtpa, further economies of scale offer a much smaller benefit.
- For short transport distances, gas phase transport is generally cheaper than dense phase transport due to lower initial compression costs and should be considered for transporting CO_2 sources to a CCS hub for further compression to dense phase conditions for ongoing transport.
- For long-distance pipelines, dense-phase transport is generally more cost-effective.

Figure 2.5. Indicative Costs of CO_2 Pipelines - Dense Phase (> 74 bara) and Gas Phase



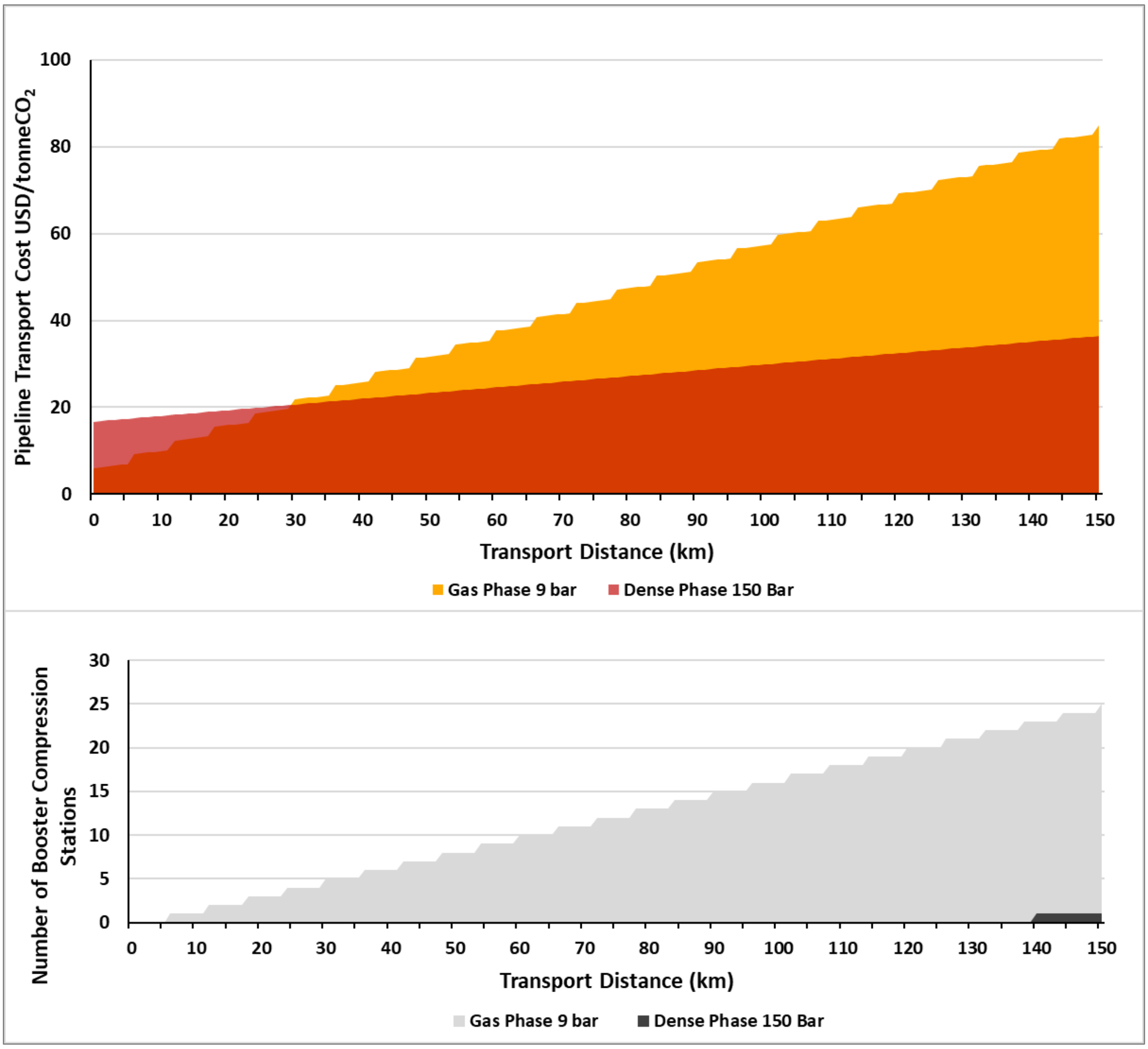
Source: GCCSI.

Figure 2.6. Costs of Gas Phase and Dense Phase Compression with Scenarios for Compressions Costs



Source: GCCSI.

Figure 2.7. Comparison between Gas Phase and Dense Phase Transport by Distance for a 1 Mtpa Flow Capacity Demonstrating the Benefit for Gas Phase Transport for Short Distance and Dense Phase Transport for Longer Distances



Note: Gas phase transport assumes pipeline operation between a maximum of 9 bara and minimum 5 bara. This results in gas booster compression required every 7km. Dense phase transport assumes pipeline operation between a maximum of 150 bara and minimum 100 bara, above the critical pressure. This results in dense phase booster pumping required every 140km.
Source: GCCSI.

Shipping

For ship-based transport, beyond economies of scale the design pressure of CO_2 ship storage and the size of the ship influence transport costs. The following table provides general factors that influence the costs for the two pressures proposed for ship-based transport for CCS. Generally, for large-scale transport of CO_2, low-pressure conditions are favoured; for small-scale transportation, either medium-pressure or low-pressure is considered.

Table 2.1. Positive and Negative Factors of Medium and Low-Pressure Ships

Factor	Medium Pressure	Low Pressure
CO_2 density	1 060 kg/m^3 Less CO_2 is transported per tank for a fixed volume, and larger volume capacity is required for a fixed mass	1 153 kg/m^3 More CO_2 is transported per tank for a fixed volume, and smaller tanks are required for a fixed mass
Liquefaction	Lower energy requirement for liquefaction (cooling and compression).	Greater energy requirement for liquefaction (around 10% higher).
Transport and storage tank design	Greater wall thickness is required, increasing weight and cost per volume stored and affecting workability. Storage tanks must be smaller, requiring more tanks and therefore higher capital and operational costs. Less expensive materials such as carbon steel may be used (depending on impurity levels, see next section).	Wall thickness can be lower, reducing weight and cost. Storage tanks can be larger, resulting in lower operational and investment cost. Higher quality material may be required to handle the lower temperature (close to -50°C), increasing material costs, but not the installation cost.
Ship design and operation	Greater number of tanks increases required ship size, increasing cost. Higher fuel consumption due to increased weight of tanks.	Lower number of tanks reduces required ship size, reducing cost. Lower operational and investment cost due to lower weight of tanks.
Heel	4%, greater impact on transport capacity.	1.6%, lower impact on transport capacity.
Water content limit	More strict requirements to avoid hydrate formation than Low P.	Less strict requirements – up to 100 ppmv.
Dry ice formation	Little dry ice formation in the event of a pressure drop.	As the condition is close to the triple point, the margins for formation of dry ice are smaller with implications for required control systems and relief valve streams.

Source: IEAGHG (2020).

Pipelines or Shipping

In some cases, there may be a choice between pipeline transport and shipping to manage costs of transport amongst several other factors. Existing studies have compared the two transport methods for large scale CO_2 transport and agree on the following conclusions:

- For an individual project, the choice between piped or shipped CO_2 will be mainly defined by cost optimisation.
- Generally, pipelines have lower costs than ships for transporting large quantities of CO_2 over short distances, while ships have lower costs over long distances.
- Pipeline costs are roughly proportional to distance, while shipping costs are only marginally influenced by distance.
- Costs of a pipeline generally consist for the most part of CAPEX (e.g. 75%–95%), while the costs of ships consist for the most part of OPEX (e.g. 60%–80%).
- A ship can be less costly than pipelines not only for single sources but also for CCS clusters during ramp up given the flexibility to adapt CO_2 shipping routes in contrast to pipelines.
- Due to the different CAPEX–OPEX structure, shipping might be used during the first-of-a-kind CCS deployment to limit investments upfront, reducing financial risk. Pipelines could be used in regions with well-established CCS infrastructure already available.

CO_2 shipping can also offer a more flexible alternative to pipelines for offshore storage and during the overseas movement of $CO_{2,}$ especially where there is variability in sources, demand, and storage sites. There are four major advantages of shipping over pipelines:

- Shipping enables the scale of a project to be rapidly increased if the market demands. Whilst additional or larger ships can be added to increasing CO_2 supply, the capacity of a pipelines needs to be defined from the initiation of the project. This presents an issue of over-engineering a pipeline anticipating greater demand or limiting the demand to pipeline design.
- Shipping enables a single ship, or shuttle shipping to load from multiple CO_2 sources and offload to a single storage site. From a storage perspective, this increases the economics of multi-user offtake agreements. From a capture perspective, this enables various-sized capture facilities, most likely industrial sources clustered in the same region to access transport and storage at a lower cost.
- Shipping routes can be changed, and new storage sites can be utilised if the original storage site becomes unusable. For example, if a storage site does not have the injection rates and total capacity required for the corresponding capture rates, the ship can be moved to another storage site. Re-routing a pipe or developing new pipelines would cost significantly more, or may not be feasible at all.

- Upon the closure of a CCS facility, a ship can be re-routed, sold, or reused, whereas a pipeline needs to be removed at a cost.

2.6. Hypothetical CCS Network Design and Costs

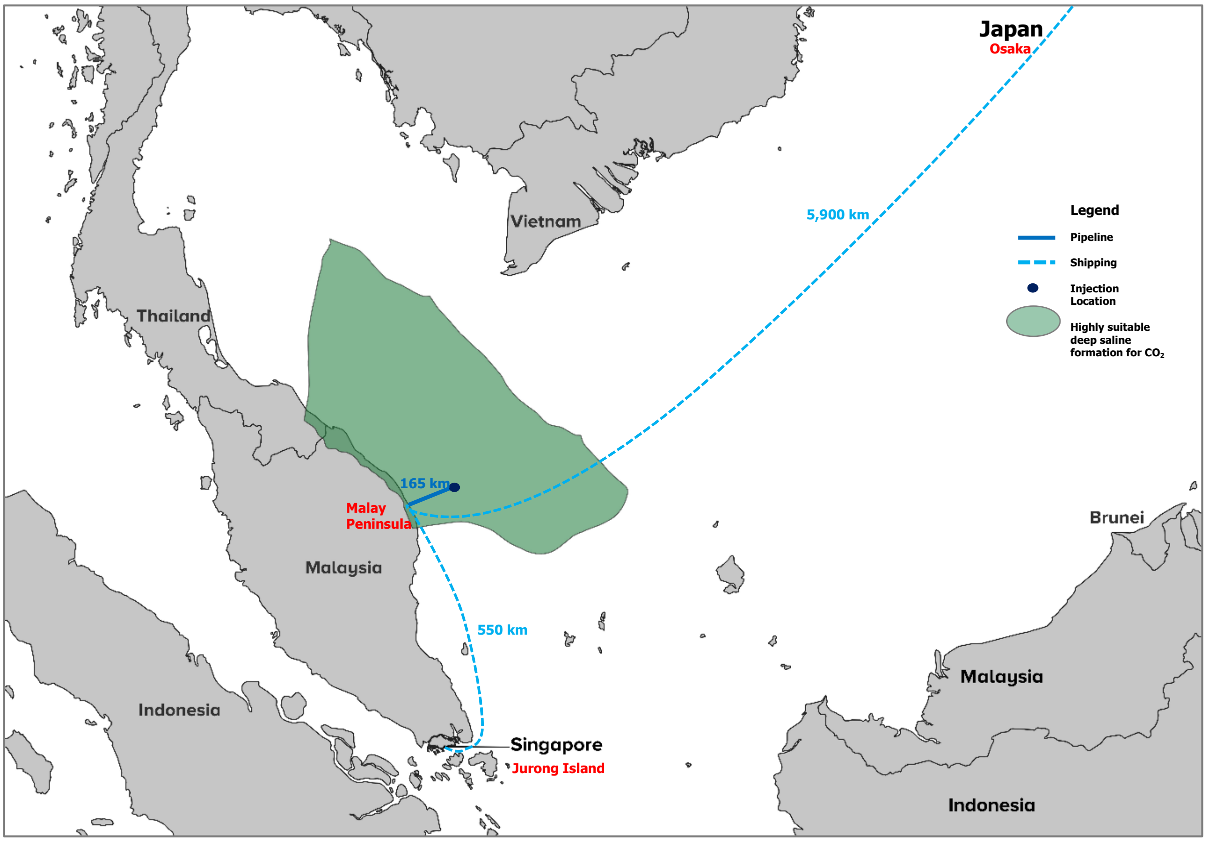
This section focuses on the design and cost of a hypothetical CCS network in the APAC region. This CCS network is then compared to the costs of individual vertically integrated CCS projects for all CO_2 sources considered in the study to demonstrate their cost benefits.

The CCS network covers various aspects of networks design, including multiple characteristics promoting the use of networks globally, including shared infrastructure for multiple CO_2 sources or emissions clusters and international transport of CO_2, supporting industries with limited or no locally available storage.

2.6.1. CCS Network Configuration

The map in Figure 2.8 shows the hypothetical CCS network that has been conceived for this study.

Figure 2.8. Proposed CCS Network on the Malay Peninsula



Source: GCCSI.

The hypothetical CCS network is centered around highly suitable storage in offshore waters off the Malay Peninsula on the east coast of Malaysia. Industrial clusters on the Malay Peninsula, Jurong Island Singapore and Osaka Japan supply the CO_2 that requires storage.

CO_2 from emissions sources in Jurong Island Singapore and Osaka Japan form CCS hubs where CO_2 is transported by ship to Malay Peninsula for further pipeline transport with local Malay Peninsula CO_2 sources to the offshore injection location.

2.6.2. Vertically Integrated CCS Project Configuration

The vertically integrated projects follow the same intended routes given in Figure 2.8. The key difference between the vertically integrated projects and the CCS network is the infrastructure design to transport the CO_2 from each source to the storage location in the Malay Peninsula, Malaysia.

2.6.3. CCS Network Emissions Sources

The emissions sources considered in this study were derived from estimates from operating data for industrial and power generation facilities located in each of Osaka, Japan, Jurong Island, Singapore, and the Malay Peninsula, Malaysia, using publicly available databases and GCCSI subscribed databases.

The following facilities and emissions were considered for transport of CO_2 for this CCS network. The names of each facility remain undisclosed, however the emissions generated will be representative of the expected emissions that could suit CCS in each location.

Table 2.2. Osaka, Japan, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 1	0.9
	Refinery 2	1.4
Chemical	Chemical Plant 1	0.5
	Chemical Plant 2	0.3
	Chemical Plant 3	1.0
	Chemical Plant 4	0.7
	Chemical Plant 5	0.3
	Chemical Plant 6	0.1
	Chemical Plant 7	0.1
Steel	Steel Plant 1	3.1
Power	Power Plant 1	3.2
Total		11.5

Source: GCCSI

Table 2.3. Jurong Island, Singapore, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 3	1.8
	Refinery 4	1.2
Chemical	Chemical Plant 8	0.4
	Chemical Plant 9	0.5
	Chemical Plant 10	0.1
	Chemical Plant 11	0.2
	Chemical Plant 12	0.9
	Chemical Plant 13	4.1
	Chemical Plant 14	0.5
	Chemical Plant 15	1.5
	Chemical Plant 16	1.0
	Chemical Plant 17	1.1
	Chemical Plant 18	0.4
	Chemical Plant 19	0.2
Power	Power Plant 4	1.6
	Power Plant 5	2.5
	Power Plant 6	0.4
	Power Plant 7	3.0
	Power Plant 8	0.1
	Power Plant 9	2.4
	Power Plant 10	2.9
Total		26.8

Source: GCCSI.

Table 2.4. Malay Peninsula, Malaysia, Industrial Emissions

Industry	Plant	CO_2 Emissions (Mtpa)
Refining	Refinery 5	0.5
Chemical	Chemical Plant 20	0.4
	Chemical Plant 21	1.9
	Chemical Plant 22	0.5
	Chemical Plant 23	0.3
	Chemical Plant 24	0.1
	Chemical Plant 25	0.2
	Chemical Plant 26	0.2
Power	Power Plant 2	2.0
	Power Plant 3	1.4
Total		7.5

Source: GCCSI.

2.6.4. Design Basis

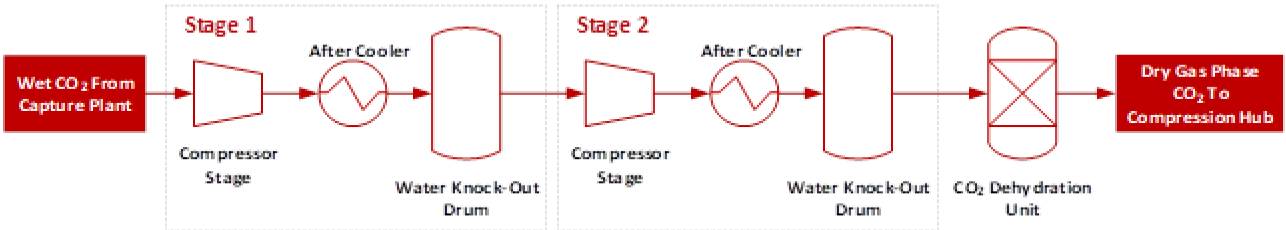
The following design assumptions were used in the design of the CCS network.

➢ **Transport from Osaka, Japan, and Jurong Island, Singapore, to the Malay Peninsula**

CCS Network Design

- CO_2 from each source plant (power generation or industrial plant) in Osaka, Japan, and Jurong Island, Singapore, is assumed to require 5km of piping to reach the CO_2 port for liquefaction for ship transport. For some CO_2 sources the distance may be less following more rigorous design, however for this level of design this is sufficient.
- Each CO_2 source in Osaka, Japan, and Jurong Island, Singapore, is compressed modestly on-site at each capture facility and remains in the gas phase followed by CO_2 dehydration. Two-stage compression is employed, sufficient to deliver CO_2 at 7 bar abs (6 bar gauge) for liquefaction at the port in preparation for shipping.

Figure 2.9. Gas-Phase Two-Stage Compression and Dehydration Located at Each Burrup Peninsula CO_2 Source Plant



Source: GCCSI.

- CO_2 transport from Osaka, Japan, to the Malay Peninsula, Malaysia, is a distance of 5400 km and from Jurong Island, Singapore, to the Malay Peninsula, Malaysia, is a distance of 500km.
- Ships are designed for low pressure CO_2 storage at 7 bar abs and for total volumes of 43,000 m^3 CO_2, or 50,000 tonne CO_2. Low pressure transport is considered for this study due to the large scale volumes and distances travelled by ship in this study, noting that is yet to be proven at a commercial scale.
- Onshore source liquefaction, storage and loading facilities in either Osaka, Japan, and Jurong Island, Singapore, are sized for the overall CO_2 volumes for each location.
- Onshore destination unloading, storage and conditioning facilities on the Malay Peninsula, Malaysia, are sized for the overall CO_2 volumes for each location.

- Storage at both the source and destination locations is sized at 120% of the overall ship capacity for a given shipping transport stage based on experience in LNG shipping and to balance the flexibility and cost efficiency (BEIS, 2018) .
- The duration of mooring, loading, and departure at the export hub is set to 12 hours (ZEP, 2011).
- The average shipping speed during transport is assumed to be 26 km/h (14 knots) (ZEP, 2011)
- The duration of mooring, unloading, and departure at the receiving facility is considered to be 12 hours (ZEP, 2011)
- A ship is considered to operate 8400 hours per year, leaving 360 hours for annual maintenance and repairs (ZEP, 2011).

Vertically Integrated CCS Projects

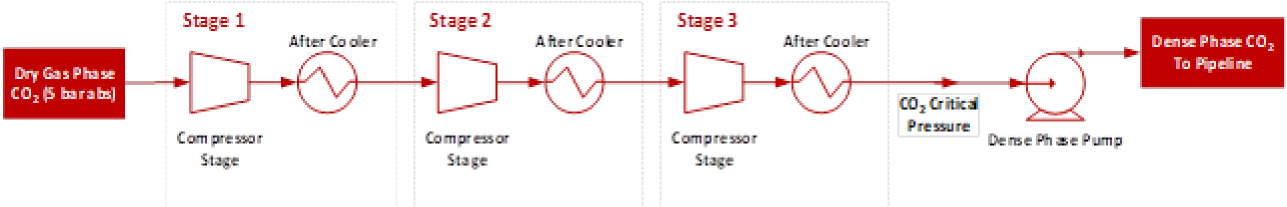
Key design assumptions from the CCS network design are applicable for each of the vertically integrated projects. Ship size remains unchanged, however in more detailed design would focus on optimisation of ship size to meet the scale of each CO_2 source.

➢ Transport from the Malay Peninsula to the Storage Location

CCS Network Design

- CO_2 from each source plant (power generation or industrial plant) on the Malay Peninsula, Malaysia, is assumed to require 5km of piping to reach a CO_2 compression hub for further transport. For some CO_2 sources the distance may be less following more rigorous design, however for this level of design this is sufficient.
- Each CO_2 source on the Malay Peninsula, Malaysia, is compressed modestly on-site at each capture facility and remains in the gas phase followed by CO_2 dehydration. Two-stage compression is employed, sufficient to deliver CO_2 to the CO_2 compression hub at 5 bar abs (6 bar gauge)
- The CCS compression hub has three-stage gas compression compressing the aggregated dry CO_2 from 5 bar abs up to the CO_2 critical pressure (approximately 73.8 bar abs). Above the critical pressure CO_2 is in the dense phase and behaves like a liquid and can be pumped. A dense phase pump provides the necessary compression above the critical pressure to ensure CO_2 can be transported to the storage location at the required injection pressure.

Figure 2.10. Three-Stage Compression and Umping Arrangement at Main Compression Hub



Source: GCCSI.

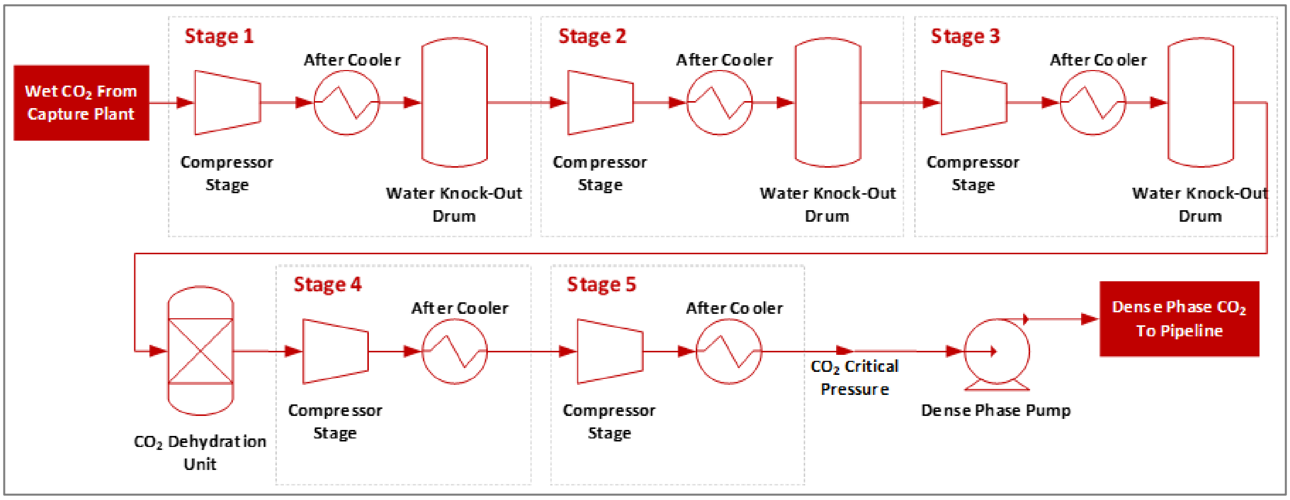
- Each CO_2 source from Osaka, Japan, and Jurong Island, Singapore, undergoes conditioning to bring the CO_2 up to be transported to the storage location at the required injection pressure. For this study heating of the CO_2 is incorporated in the conditioning costs with the unloading facilities for ship-based transport. Dense phase pumping has been assumed to bring the CO_2 up to the required transport pressure.
- CO_2 is transported from the Malay Peninsula 165km by offshore pipeline to the injection location.

Vertically Integrated CCS Projects

Key design assumptions from the CCS network design are applicable for each of the vertically integrated projects with the inclusion of the following assumptions.

- Each CO_2 source on the Malay Peninsula, Malaysia, is compressed by five-stage compression and dense phase pumping with dehydration providing the necessary compression to ensure CO_2 is at conditions for transport to the storage location.

Figure 2.11. Five-stage compression, Dehydration, and Dense Phase Pumping



Source: GCCSI.

➢ Other general assumptions and data

Pipeline and Compression

- All pipelines are sized for the overall CO_2 flow expected for that given pipeline up to the maximum standard nominal pipe size of 600mm for dense phase transport and 900mm for gas phase transport.
- Dense-phase CO_2 lines sized for 2 m/s CO_2 velocity (Peletiri et al., 2018)
- Gas-phase CO_2 lines sized for 20 m/s CO_2 velocity (Sinnot and Towler, 2009, p.259)
- Steel schedule 160 piping was selected for dense/supercritical phase CO_2. With a maximum allowable working pressure of 253 bar (Atlas Steels, 2010), this pipe has thicker walls than conventional schedule 40 piping and is suitable for the pressures seen in CO_2 transport.
- Steel schedule 40 piping was selected for gas phase CO_2.
- Dense/supercritical phase operations must stay between two limits:
  - Pressure must be well above the critical pressure to avoid two-phase behaviour which can introduce mechanical stress and risk to piping integrity. In this study, that minimum pressure has been selected as 100 bar abs.
  - Pressure must remain below the safe operating pressure for the pipeline. This has been taken as 10% below the 253 bar abs maximum allowable working pressure, or 227.7 bar abs.
- Compression station elevation is 10m above sea level.
- The endpoint of offshore pipeline at the Malay Peninsula is 100m below sea level (sea floor).
- Destination pressure target for injection is 100 bar abs (ENI S.p.A, 2018, p. 10).
- Discharge temperature of CO_2 at the compression hub is 50°C.
- Seawater temperature is 25°C (affects CO_2 cooling in offshore lines).
- Overall heat transfer coefficient for the pipeline in seawater is 44.7 $W/m^2/K$ (Drescher et al., 2013, p.3055). This is used to model cooling in offshore pipelines.
- Soil temperature is 25°C (for CO_2 cooling in buried onshore line).
- 20% was added to route length to account for fittings losses when calculating pressure drop.
- The pressure ratio of each stage of compression is assumed to be the same.

- CO_2 is cooled to 50°C after each stage of compression. The high humidity rules out conventional cooling towers for cooling. It is anticipated that either air-cooling or seawater cooling will be used.
- Maximum power consumption for a compression train (all stages/pumps) is 40 MW electric. For cases requiring more power than this, multiple trains were used to keep individual power consumption below 40 MW (Mccollum and Ogden, 2006).

Shipping

- 10% was added to route length to account for weather events and other factors that may impact the shipping route taken.
- Boil-off during ship transport is neglected (ZEP, 2011)
- It is assumed the jetty length, ship length, and draft at loading ports are all acceptable for this case study.

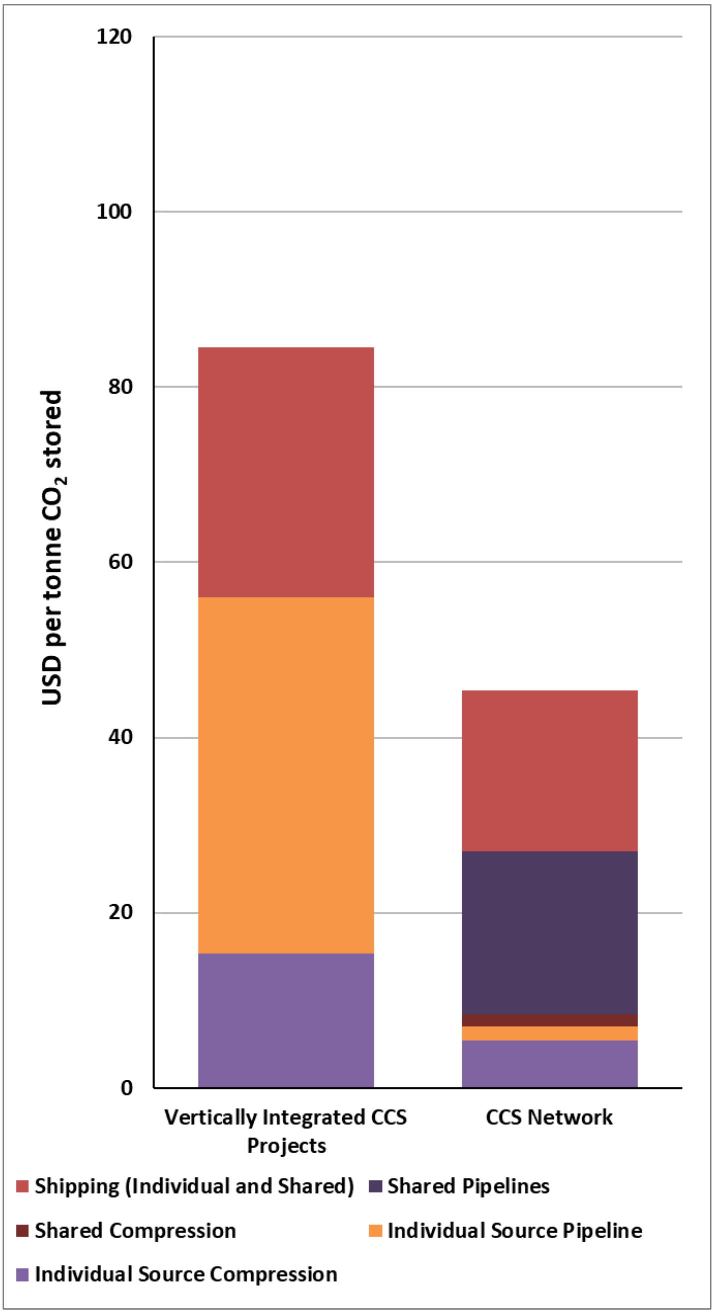
2.6.5. Cost Basis

The methods for estimating the capital and operating costs for the compression, pipelines and shipping infrastructure for the CCS network design are given in Appendix B. All costs shown are in United States dollars (USD) unless otherwise stated.

2.6.6. CCS Network Design Costs

A summary of the average cost components for the CCS network against the average costs for each of the individual vertically integrated CCS projects is given in Figure 2.12.

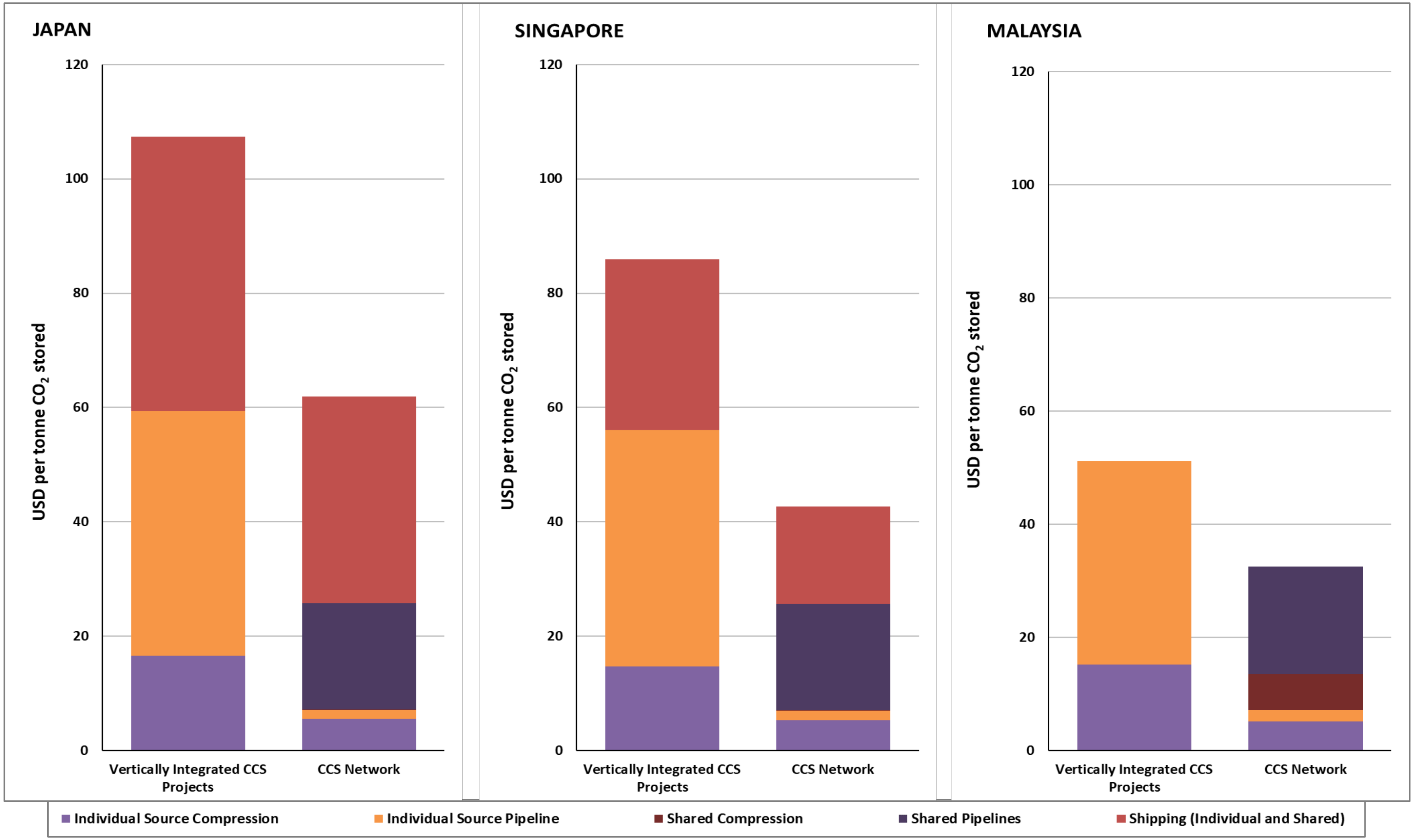
Figure 2.12. Overall Levelised Cost of Transport for the CCS Network Against the Vertically Integrated CCS Projects



Source: GCCSI

We can see clearly from an overall cost to store the CO_2 from the emitters supported by the CO_2 network is reduced by 45%. The cost benefits apply to all shared transport methods in this CCS network, including pipelines and shipping. While there is a substantial reduction in costs overall, the impact will vary for each of the emissions clusters and the individual emitters within each emissions cluster.

Figure 2.13. Levelised costs of transport for the CCS network against vertically integrated CCS projects for Japan, Singapore and Malaysia



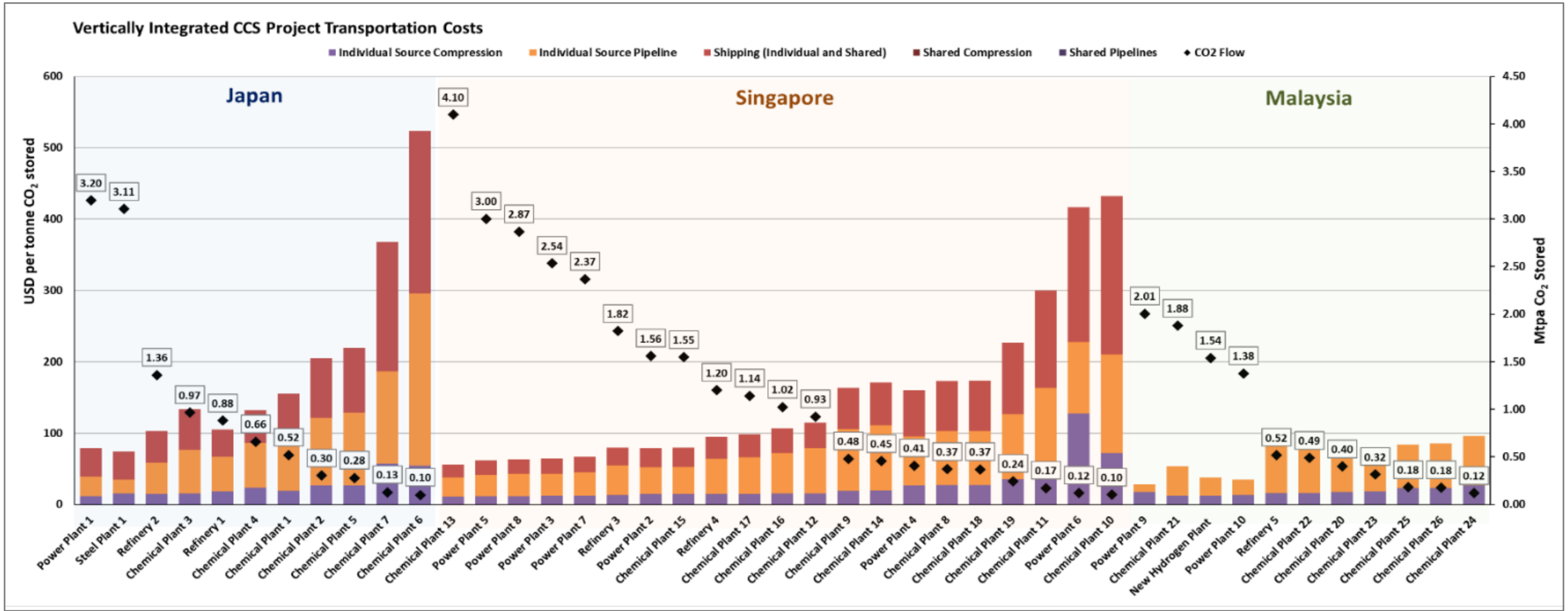
Source: GCCSI.

Figure 2.13 further details the cost benefits to each of the emissions clusters. We can see that the reduction in costs is generally similar for each of the emissions clusters, ranging from 37% to 50%. However, on a cost-per-tonne basis, this results in a considerably greater reduction the further the transport distance. This highlights how regional CCS networks could allow emissions clusters with limited or no locally available storage to gain access to regional storage opportunities cost-effectively if given support to develop.

Emission sources in each emissions cluster will see varying cost benefits depending on the scale of their emissions. CCS networks enable the shared transport and storage costs to be evenly distributed across all emissions sources on a cost-per-tonne basis. Therefore, the benefit for shared transport can be significantly greater for smaller emissions sources where CCS may otherwise be cost-prohibitive.

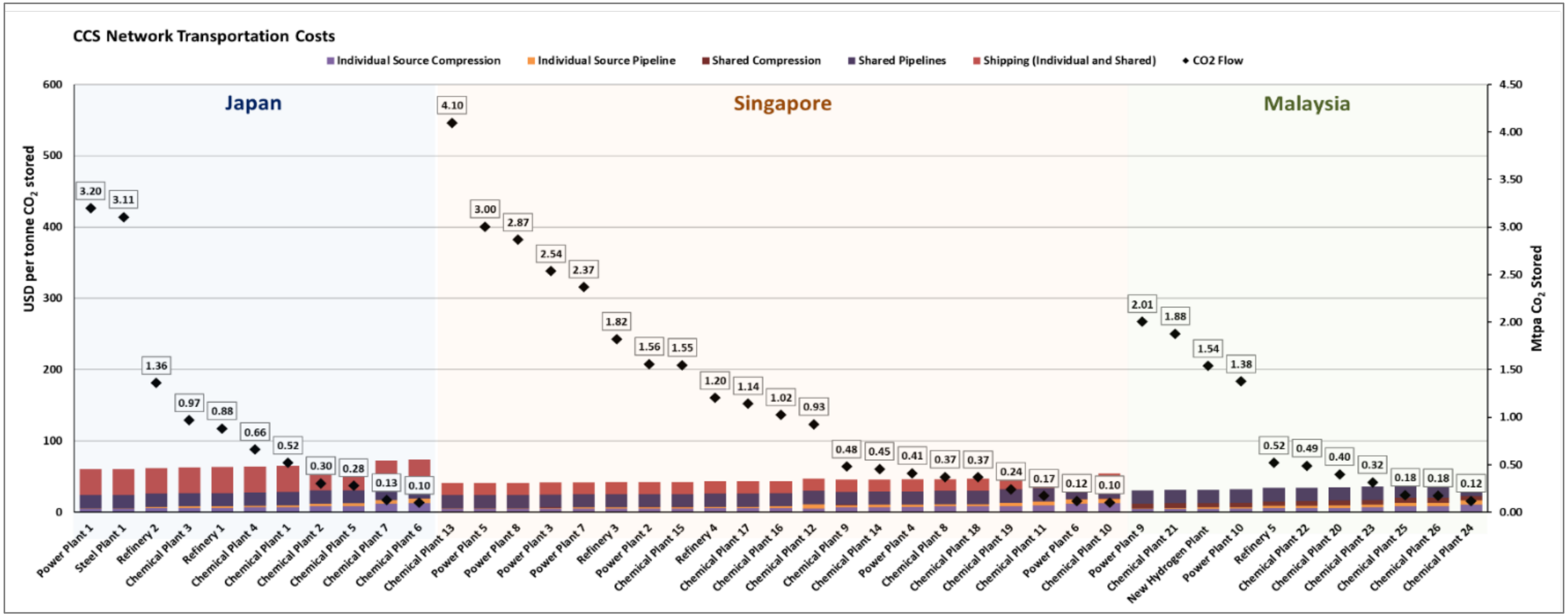
This is evident when comparing the costs of the individual source to storage CCS project versus the CCS network for each emissions source in Figure 2.14. For each emissions cluster the emissions sources are displayed from largest to smallest total CO_2 emissions to see the cost trends with scale of CO_2 flow.

Figure 2.14. Levelised Costs of Transport for the CCS Network Against Individual Source to Storage CCS Projects for Each Emissions Source



Source: GCCSI.

Figure 2.15. *Continued*



Source: GCCSI.

While all emissions sources see a reduction on a cost-per-tonne basis through shared infrastructure, the emissions sources with smaller total CO_2 emissions see the greatest benefit. For smaller emission sources in Japan and Singapore, the shared costs for CCS networks offer up to a 90% reduction.

2.6.7. Conclusions and Recommendations

The development of CCS hubs and clusters, bringing together a number of different CO_2 emissions sources and/or storage sites in a connected network, offers participants several advantages over vertically integrated CCS projects. Benefits include reduced costs and risk, enabling more cost-effective transport and storage from small volume sources, and maintaining investment and jobs in high-emitting industrial regions.

Actions that should be considered by project proponents and governments to facilitate the development of CCS hub and cluster networks include:

- Identification of emissions clusters and storage resources that could support the development of CCS networks in each country and regionally. This provides the initial starting point for strategically developing CCS networks.
- Support with resources and funding for the appraisal of CO_2 storage resources in a given country or region. Locally available storage resources will always be more cost-effective than leveraging regional storage resources. Identifying surplus storage resources for the needs of the current emission sources allows for opportunities for low-emissions industry growth and provides storage resources to neighbouring countries with limited or no locally available storage.
- Identify avenues for incorporating new industries (i.e. clean hydrogen or ammonia) with existing emissions clusters early in developing CCS networks.
- Early identification of regional CCS network opportunities. Regional CCS networks will in most cases be more complex with the transboundary movement of CO_2. Early identification of these CCS networks will enable project proponents and governments to work through the necessary steps to facilitate their development.
- Identify opportunities to fast-track the development of first-mover CCS networks to expedite knowledge growth and accelerate the development of further CCS networks.
- Well-planned, early engagement with stakeholders and the community in the vicinity of emissions clusters and potential CCS networks.

2.7. Regional Legal and Institutional Frameworks Necessary to Support CCS Hub and CO_2 Transport Networks

2.7.1. Introduction

Large-scale deployment of CCS in the region will require a coordinated effort between countries in Southeast Asia, to develop frameworks and platforms for successful and timely project delivery. Integrated upstream policy and robust institutional frameworks will be key to underpin regional project implementation. In addition, coordinated institutional frameworks, including coherent decarbonisation strategies, project approval and procurement strategies, and investment plans, will reduce project risk and enable capital investment.

In August 2023, the World Economic Forum (WEF) released a report, *'How (and why) to boost carbon capture, usage and storage to move towards net zero'*, in which they express support for boosting innovation in CCUS and call on further significant public and private investment in R&D. The report encourages governments to invest in CCUS infrastructure and to develop industrial clusters to generate economies of scale. The WEF argues that once CCS technologies become mainstream, governments need to consider making CCUS a legal requirement for most polluting industries. The WEF concludes that '*it is vital for governments to make CCUS policy a national priority, since UN IPCC assessments make it clear that the transition to net-zero cannot be delayed if the world is to avoid a humanitarian crisis on an unprecedented scale*'. (World Economic Forum, 2023)

In Southeast Asia, interest in CCUS is growing and as of July 2023, there are 13 commercial CCS facilities located in Indonesia (8), Malaysia (3), Thailand (1), and Timor-Leste (1). Only the Kasawari project in Malaysia is in construction, while the remaining eleven facilities are in development. The average capture capacity of these projects is 1.9 Mtpa. CCS development in ASEAN is considered at nascent stage.

In June 2021, a significant milestone was reached with the establishment of the Asia CCUS Network, which aims to facilitate collaboration on the deployment of CCUS in Asia. Regional approaches to CO_2 transport and storage infrastructure could enable faster and more widespread uptake of CCS in Southeast Asia. In particular, the development of large, shared CO_2 storage resources that can be accessed by multiple facilities and countries could support CCS investment in locations where storage capacity is either limited or where its development faces delays. In addition, as demonstrated in the previous section, economies of scale could be realised through establishment of industrial clusters that could access transport networks and shared storage facilities. (IEA, 2021a)

Project proponents in Southeast Asia continue to voice concern that existing frameworks will not support commercial scale deployment of CCS. There are many critical issues relating to CO_2 transport and storage that remain unaddressed by national legislation. Although there have been some noteworthy developments in the region over the past year, the absence of CCS-specific legislation remains a significant barrier and one which must be overcome for countries and industry to realise their commitments to emissions reduction. Timely action is essential in this regard, and the consequences of further delay are likely to prove significant.

Where countries are already involved in regional structures (such as the European Union or ASEAN), it makes sense for countries to employ collaborative efforts to achieve climate commitments as a collective. Regional cooperation will require robust legal and institutional frameworks to guide coordinated efforts towards the large-scale deployment of CCS.

The EU has succeeded in creating a regional directive for CCS, which covers related activities of all member states. In contrast to the EU, there is no overarching governing body for ASEAN with decision making powers equal to the EU Parliament, and there is a substantial disparity in income levels amongst the ASEAN member countries, both of which could pose a challenge for regional cooperation. Nevertheless, the cooperation between member states on CCS under the EU Directive could provide a good example to ASEAN nations, and the Directive could act as a guide in the development of a regional CCS framework for Southeast Asia. The EU Directive is discussed further in Section 2.7.2.

Legal and institutional frameworks necessary for the deployment of CCS cover a broad spectrum of activities across the lifecycle of a CCS project, and will necessarily include international, national and domestic aspects. The diagram below sets out key elements to be considered in CCS-related legal and institutional frameworks to be developed for the region.

Table 2.5. Components of CCS-Specific Legal and Institutional Frameworks

Legal Frameworks	Institutional Frameworks
• Transboundary regulation of CO_2 transport and storage • Interaction with wider international and national maritime laws • Alignment with wider health and safety legislation • Classification and ownership of CO_2 • Access/rights to potential storage sites • Authorisation of storage activities • Monitoring and verification obligations • Closure and post-closure aspects of operations	• Partnering on CCS R&D activities • Coordinated project planning and development • Coordinated government and company procurement frameworks • Coordinated project investment activities • Coordinated effort to access international funding, including development finance and export credit opportunities

Legal Frameworks	Institutional Frameworks
• Rights and responsibilities of operators and relevant authorities across the full project lifecycle • Treatment of long-term liability • Financial security • Carbon markets • Risk management across all stages of the CCS project lifecycle • GHG emissions accounting and reporting frameworks	

Source: GCCSI.

A comprehensive CCS legal and regulatory framework for the region must balance competing interests of international, national and local governments, and private sector stakeholders, including financiers, insurers and the public. Legal and institutional frameworks for the region as a whole, should therefore carefully consider existing CCS legislation (international and national) and address potential conflicts that could delay transboundary CCS operations.

2.7.2. Regional Legal and Regulatory Frameworks for Southeast Asia

The most critical issues to consider in the development of a regional legal framework for CCS in Southeast Asia are discussed below.

2.7.2.1. International Legal Frameworks - London Protocol Implications for Transboundary Transport and Storage of CO_2

The emergence of new markets and applications for CCS technologies, enhanced or revised national commitments to achieving net-zero and wider commercial opportunities afforded by the deployment of CCS networks, has led to greater interest in CCS project opportunities beyond national boundaries. In recent years, this focus has also been strengthened further by the development of several regional cooperation initiatives aimed at advancing deployment of the technology, most notably, the development of a transboundary transport and storage project off the coast of Norway in the North Sea.

2.7.2.2. Transboundary transport of CO_2

Project proponents, policymakers and regulators have to consider the legal implications of transporting captured CO_2 across territorial boundaries, and between nations. The most significant of these legal and regulatory considerations is found within Article 6 of the

London Protocol, which prohibits '*the export of wastes or other matter to other countries for dumping or incineration at sea*'. Prior to 2009, the transboundary transportation of CO_2 for geological storage was prohibited under this provision. However, in October 2009, an amendment to Article 6 of the Protocol was adopted by the Parties to enable transboundary movement of CO_2, for the purpose of subsequent offshore geological storage.

The 2009 amendment requires an agreement or arrangement be reached between countries who wish to export and receive the CO_2, whether the export is to a Contracting or non-Contracting Party (International Maritime Organisation, 2018). While an agreement refers to a legally binding agreement, which could be a Memorandum of Agreement or a treaty between the two countries, an arrangement is a non-binding agreement such as a Memorandum of Understanding (MoU). Any agreement or arrangement, must ensure that the standards of the Protocol are fully observed, including the confirmation and allocation of permitting responsibilities between the exporting and receiving country. The requirement applies to any arrangement or agreement between Contracting parties, as well as those between Contracting and non-contracting Parties.

Notwithstanding the adoption of the amendment in 2009, an insufficient number of parties have ratified for it to enter into force. Two thirds of the Protocol's Parties will be required to ratify, for the amendment to enter into force for all Parties. To date, only ten countries have ratified the amendment: Norway, Sweden, Finland, Netherlands, Estonia, United Kingdom, the Islamic Republic of Iran, Denmark, Belgium and the Republic of Korea.

At the 2019 meeting of the Contracting Parties to the Protocol, a joint proposal was submitted by the governments of Norway and Netherlands, in an attempt to address the impasse. The proposal, which was ultimately agreed to by the Parties, enables the provisional application of the 2009 amendment, giving 'consent to cross-border transport of carbon dioxide for the purpose of geological storage without entering into non-compliance with international commitments.'

The resulting agreement enables those countries, who wish to export their CO_2 for storage in another country's territorial waters, to avail themselves of the provisions of the 2009 amendment, in advance of its entry into force. Parties wishing to undertake activities of this nature will be required to provide a declaration of provisional application and notification of any arrangements or agreements to the International Maritime Organisation. Parties will however be required to meet the standards prescribed by the Protocol.

The removal of this legal barrier is considered a key driver for enabling several CCS projects to move forward. Project proponents developing a project that includes the transport of CO_2 from countries to a storage site in another country's territorial waters, would also be able to avail themselves of these provisions.

2.7.2.3. Storage of CO_2 - Allocation of Responsibilities

The transaction-based nature of CO_2 export agreements or arrangements brings to light several issues that exporting and receiving parties will need to consider. The Guidance on the implementation of the London Protocol, (the Guidance) published in the report of the 35th meeting of the Contracting Parties, provides specific information and recommendations that clarify Annex 2 obligations for export situations (International Maritime Organisation, 2013). The Guidance's allocation of responsibilities relating to Annex 2 within agreements is discussed below.

CO_2 Stream Properties

Regarding the properties of the CO_2 stream, it is considered most likely that the exporting country would characterise the composition, properties and quantity of the CO_2 stream. The exporting country would share this characterisation with the importing country, so that the agreement or arrangement reflects the expected quality of the CO_2 stream and any special precautions or mitigatory measures that may be needed to secure import and storage of the CO_2 stream. The country receiving the CO_2 stream would need to reassure itself of the quality of the characterisation and may undertake its own characterisation if necessary.

Disposal Site Selection and Characterisation

The country receiving the CO_2 is considered better suited to select and assess the storage site and should share the characterisation with the exporting country. In this regard, competent authorities in both countries are encouraged to apply the Specific Guidelines (NOAA, 2007) and share data. However, in the case of export between Contracting and non-Contracting Parties, the responsibility for ensuring that the site assessment is sufficiently rigorous, lies with the Contracting Party and to this end, the Party should be satisfied that the provisions of Section 6 of the Specific Guidelines on selection and assessment of a storage site are reflected in the agreement.

Assessment of Potential Effects

Similarly, the receiving country, in whose territory the storage site will be situated, should assess the potential effects of storage and share the information with the exporting country. A Contracting Party, in the case of CO_2 export transaction with a non-Contracting State, should ensure that the assessment of potential effects has been undertaken in accordance with Section 7 (Assessment of Potential Effects) of the Specific Guidelines. The country receiving the exported CO_2 for storage will undertake verification of compliance and field monitoring and risk management arrangements but would need to share this assessment with the exporting country. In the case of export to a Non-contracting Party, a Contracting Party should ensure that the provisions of Section 8 (Monitoring and Risk Management) of the Specific Guidelines have been considered in the

CO_2 export agreement.

Permit and Permit Conditions

Annex 2 of the Protocol requires that any permit issued must contain data and information relating to the types and sources of material to be dumped, the location of the dump sites, the method of dumping and monitoring and reporting requirements. These permits are also required to be regularly reviewed. A Contracting Party in the transaction must ensure that the agreement considers Section 9 of the Specific Guidelines in this regard and provides for the review of a non-Contracting Party's permits.

2.7.2.4. Acceptance and Application of the London Protocol and Its Amendments

One example of the practical application of the London Protocol as it relates to the transboundary transport of CO_2, is the collaboration between European countries to establish a cross-border, open-source CO_2 transport and storage network in the North Sea (Northern Lights Project). To enable this transboundary transport project within the confines of the London Protocol, Norway, the Netherlands, and Denmark have deposited declarations of provisional application of the 2009 amendment to Article 6 of the London Protocol, and Finland and Belgium are preparing such declarations. Further, on 26 September 2022, Denmark and Belgium availed themselves of the provisional application of the 2009 amendment and signed the first bilateral arrangement on cross-border transportation of CO_2 for the purpose of permanent geological storage. (European Commission, 2022a)

There remains uncertainty however, with a number of national governments who are Parties to the London Protocol still to commit to adoption of the Protocol's amendments or enter into formal agreements with other nations to enable transboundary movement of CO_2. While several European Parties have entered into these agreements to facilitate projects in the North Sea, formal adoption and agreement has been slower in other parts of the world where transboundary operations are proposed.

Amongst Southeast-Asian nations, the Philippines is the only nation that has ascended to the London Protocol but has not yet ratified the 2009 amendment to Article 6.

Australia is making progress towards regional cooperation on CCS. The recent recommendation by the Australian government's House Standing Committee on Climate Change, Energy, Environment and Water to ratify the 2009 amendment, is an important step in recognising both the significance of the Protocol and the role of CCS in the region. Further, the subsequent passing of legislation by the Australian parliament to enable a permit to be granted for the export of carbon dioxide streams from carbon dioxide capture processes for the purpose of sequestration into a sub-seabed geological formation, is another important step towards full ratification.

In addition to the London Protocol and other maritime agreements, attention must also be given to the wider body of domestic and international law that will apply to operations of this nature. Analysis suggests a variety of laws will apply to transboundary transport and storage operations, including environmental, health and safety laws. Policymakers and regulators must ensure that these too will not present further barriers to regional collaboration on CCS.

2.7.3. Regional Legal and Regulatory Frameworks for CCS

2.7.3.1. Cooperative Legal Framework – EU Directive Case Study

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide (the CCS Directive) provides a good example of an established legal framework between nations in a specific region, in this case the European Union (EU), for cooperation on the environmentally safe storage of CO_2. The implementation of the CCS Directive is underpinned by the Treaty on the Functioning of the European Union (TFEU), which established the European Community and governing structures (e.g. the Committee of the Regions) and includes the framework for economic, social and territorial cohesion of the European Community (European Commission, 2022b) The CCS Directive provides guidance across the entire life cycle of a CCS project, including CO_2 capture, transport and environmentally safe storage in geological formations in the EU. EU Member States were obliged to transpose the CCS Directive into national laws.

On 30 September 2022, the European Commission released a '*Commission services analysis paper for the Information Exchange Group (IEG) under Directive 2009/31/EC*' (the Paper) discussing the EU legal framework for cross-border CO_2 transport and storage in the context of the London Protocol. The purpose of the Paper was to assess the alignment of the CCS Directive with the London Protocol provisions, and to clarify what is required for countries in the European Economic Area (EEA) to comply with the provisions of Article 6 of the Protocol (European Commission, 2022b)

The Paper concludes as follows:

'There is a substantive alignment between the requirements of the London Protocol and the legal framework in place in the EEA for the capture, cross-border transport and safe geological storage of carbon dioxide between EU Member States and EEA countries.

Therefore, Directive 2009/31 and Directive 2003/87, which bind all the Member States, can act as a relevant 'arrangement' between the Parties in the meaning of Art. 6(2) of the London Protocol. Similarly, the EEA treaty and the incorporation of the two directives concerned in the EEA legal regime provides the necessary arrangement with EEA partners.

Member States that are party to the London protocol could conclude additional bilateral arrangements with other EU Member States and EEA partner countries only on issues that are not covered by the directives. These additional bilateral arrangements should be strictly *limited to the residual issues not covered by EU law and they should not refer to the subject matters covered by EU rules.'*

The key advantage of having the provisions of the London Protocol included in Directive 2009/31 (CCS Directive), is that the Directive becomes an acceptable 'arrangement' between CO_2 exporting and importing countries under Article 6 of the London Protocol. Both countries are therefore compliant with the requirements of Article 6, and a Contracting Party to the Protocol will not have to ratify the amended Article 6. A declaration of provisional application, and a notification of the arrangement created under the Paper must still be submitted to the IMO. The advantage of having Directive 2003/87 (Directive establishing the EU ETS) tied to the CCS Directive is that it creates a mechanism for emissions trading and surrendering of allowances in the case of CO_2 leakage during transport and storage between Member States and EEA countries.

The creation of an overarching arrangement that complies with the provisions of the London Protocol could substantially reduce the time to establish bilateral agreements between exporters and importers of CO_2 in the same region, and standardise issues governed under such an arrangement across participating countries. It would also lead to much less complicated bilateral agreements, which would only cover residual issues not embodied in the overarching arrangement.

Issues that must be covered by an overarching arrangement (to comply with Article 6 of the Protocol) include:

- *'confirmation and allocation of permitting responsibilities between the exporting and receiving countries, consistent with the provisions of this Protocol and other applicable international law; and*
- *in the case of export to non-Contracting Parties, provisions at a minimum equivalent to those contained in this Protocol, including those relating to the issuance of permits and permit conditions for complying with the provisions of annex 2, to ensure that the agreement or arrangement does not derogate from the obligations of Contracting Parties under this Protocol to protect and preserve the marine environment'*. (Government of the United Kingdom, 2009)

Any specific issues involving country boundaries, facilities, infrastructure, etc. would be covered in the bilateral agreement between the exporting and importing countries.

A cooperative regional framework for the deployment of CCS in Southeast Asia could follow the same model as the EU, in particular:

- Developing a regional legal framework with regulatory provisions for CCS (similar to the EU's CCS Directive), under ASEAN. Such a framework should consider creating a platform for trading of carbon credits between ASEAN countries and facilitation of physical movement and storage of CO_2 between ASEAN countries.
- Aligning the regional framework with the London Protocol provisions. Such a regional framework could act as a legitimate 'arrangement' between Southeast Asian nations

who wish to enter into transboundary CO_2 transport and storage transactions. Bilateral agreements/arrangements between Southeast Asian nations would then only need to cover any specific issues not covered by the regional framework.
- Adopting existing national legislation related to site selection, permitting procedures, health and safety requirements, and other provisions across the CCS value chain, into the regional framework.
- Recommending or encouraging the adoption of the regional framework into national legislation, recognising the impact on each country's respective NDC.

2.7.3.2. Cooperative Regulatory Framework

The development of CCS regulations to facilitate project development and operations in Southeast Asia is limited, although Indonesia and Malaysia have made progress in this regard. Legislation in many nations would see CCS operations regulated under existing regimes governing oil and gas or mining operations, however there is uncertainty as to their capacity to adequately regulate commercial-scale deployment of CCS.

Key issues to address in CCS-specific regulations (that may not be adequately covered in existing industry frameworks) include:

- Classification and ownership of CO_2
- Access or rights to potential storage sites
- Authorisation of storage activities
- Monitoring and verification obligations
- Closure and post-closure activities
- Treatment of liability (also beyond site closure)

The '*ASEAN Guidelines on Good Regulatory Practice*' establishes principles to the preparation and application of technical regulations. The aim of these guidelines is to assist ASEAN Member States in meeting their international obligations under the World Trade Organisation's Technical Barriers to Trade (TBT) Agreement. These guidelines could provide a starting point for the development of CCS-specific regulations, as they have already been accepted by ASEAN Member States and set out a clear path for development of technical regulations and regulatory cooperation in the region. (The ASEAN Secretariat, 2019)

Australia is far advanced in terms of CCS regulation, and its regulatory approach could provide good guidance for CCS regulations in ASEAN. In 2005, the Ministerial Council on Mineral and Petroleum Resources (MCMPR) published the Australian Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage, '*to facilitate the introduction of CCS activities in an efficient, effective and safe manner*'. (Ministerial Council on Mineral and Petroleum Resources (MCMPR), 2005) Subsequently, the Offshore Petroleum and Greenhouse Gas Storage Act 2006 was enacted, supported by five regulations, governing GHG injection and storage activities, resource management and administration, environment, safety and regulatory levies respectively.

The National Offshore Petroleum Titles Administrator (NOPTA) and the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) perform regulatory functions for offshore greenhouse gas storage activities:

- NOPTA administers offshore greenhouse gas storage titles in Australian Commonwealth waters.
- NOPTA publishes information about titles and applications on the National Electronic Approvals System (NEATS) website.
- NOPSEMA independently regulates offshore petroleum and greenhouse gas storage health and safety, well integrity, and environmental management.
- NOPSEMA also assesses and accepts environment plans. (Department of Industry, n.d.)

The Australian regulatory model may provide a reference point for regulators for the development of a Southeast Asian regional regulatory framework.

2.7.3.3. Enabling Policies

To successfully deliver cross-border CCS projects, reduce project risk and attract the necessary investment, enabling policies must be developed that:

- Support stable, long-term revenue streams by placing an appropriate value on captured CO_2 (carbon pricing).
- Overcome value chain risk by establishing CCS networks and hubs (moving away from a single-emitter-to-single-storage-facility model, where risk of unavailability of one component affects the whole value chain).
- Manage long-term storage liability during and beyond the CCS facility's operating period.
- De-risk projects through government funding support – this may be in the form of direct capital grants, operating subsidies, tax credits and exemptions, risk sharing models for transport infrastructure, regulated asset base, contracts for difference, regulated carbon markets, etc.
- Enable storage resource appraisal in the region, which will be key for cross-boundary operations.

2.7.4. Models for Regional CCS Cooperation

Article 6 of the Paris Agreement forms the basis for international cooperation to meet Nationally Determined Contributions (NDCs). In particular, Articles 6.1, 6.2 and 6.4 set out the broad guidelines under which countries could cooperate to achieve their respective goals.

'Article 6.1. Parties recognize that some Parties choose to pursue voluntary cooperation in the implementation of their NDCs to allow for higher ambition in their mitigation and adaptation actions and to promote sustainable development and environmental integrity.

Article 6.2. Parties shall, where engaging on a voluntary basis in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards NDCs, promote sustainable development and ensure environmental integrity and transparency, including in governance, and shall apply robust accounting to ensure, inter alia, the avoidance of double counting, consistent with guidance adopted by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement.

Article 6.4. A mechanism to contribute to the mitigation of GHG emissions and support sustainable development is hereby established under the authority and guidance of the [Conference of the Parties (COP)] for use by Parties on a voluntary basis. It shall be supervised by a body designated by the COP, and shall aim:

(a) To promote the mitigation of GHG emissions while fostering sustainable development;

(b) To incentivize and facilitate participation in the mitigation of GHG emissions by public and private entities authorized by a Party;

(c) To contribute to the reduction of emission levels in the host Party, which will benefit from mitigation activities resulting in emission reductions that can also be used by another Party to fulfil its NDC; and

(d) To deliver an overall mitigation in global emissions.'

Key to the successful implementation of a cooperation mechanism will be the establishment of an accounting framework that addresses diversity of target types, and individual actions and measurements proposed by participating countries. Such an accounting framework should avoid double counting and 'hot air' transfers (credits for activities that would have happened anyway under Business as Usual).

In a recent paper published by the IEAGHG (IEAGHG, 2023), various models for international cooperation on CCS are identified and the merits of each discussed. These models broadly consider the application of Article 6 to CCS through two potential approaches:

- Trading of emissions allowances and reduction/removal credits arising from linked carbon markets or emissions trading systems
- Targeted approaches that base cooperation on demand for and supply of carbon storage across country boundaries (and related creation of offsets)

These approaches are not mutually exclusive, but aim to create two tradeable units, namely a carbon reduction/removal unit (CRRU) and a carbon storage unit (CSU) that could be traded under three potential models, to meet the requirements of a successful accounting framework:

Model 1 – Linked carbon pricing policies between countries (trading of CRRUs)

Under this model, CRRUs are awarded to operators of CO_2 capture facilities or a CCS project with several entities cooperating. Trading of CRRUs could take place either directly between governments or involve companies for compliance or voluntary purposes.

Model 2 – Voluntary system of storage targets for fossil fuel producers (using CSUs to drive CCS deployment)

Under this model, fossil fuel companies with net zero targets voluntarily implement CSUs to track progress and demonstrate achievement of net zero emissions (bottom-up approach). Governments could support this by requiring national fossil fuel suppliers to demonstrate commitment to geological storage. This type of supply-side offsetting is currently being considered by both the UK and the Netherlands.

Model 3 – Multilateral 'CCS club' of Parties to the Paris Agreement (select group of countries with a common interest in fossil fuel production and CCS, adopting CSUs as a means to cooperate on a plurilateral basis)

This model follows the same principles as Model 2 but is based on country pledges to geological storage, as opposed to corporate targets (top-down approach). The aim would be to establish a system of CSU transfers between member countries, initially under bilaterally agreed quotas, and evolving to CSU transfers between member countries with storage targets in their respective NDCs. (IEAGHG, 2023)

Below, we discuss some issues around these models, and their potential to support cooperation on CCS in Southeast Asia.

2.7.5. Integrated Regional Emissions Trading System (ETS)

Carbon markets provide an additional and important lever to reach net zero by 2050, but it should not be seen as the silver bullet to fight climate change. Companies must reduce their carbon footprint as a first action, through avoidance and removal projects, including CCS (technology-based removal) before considering offsets.

Carbon markets operate on either a compliance or voluntary basis. Compliance markets are regulatory markets where carbon allowances/credits are traded to meet regulatory targets or obligations. Voluntary markets are unregulated, and credits are traded on a non-obligation basis. Voluntary markets are still in early stages of development, however in 2022, the World Bank reported that the total value of the global voluntary carbon markets exceeded US$1 billion and continues to grow (The World Bank Group, 2022) It is estimated that the economic opportunities that could be created through a Southeast Asian carbon market will be US$10 billion by 2030. (Bain & Company, 2021)

ASEAN nations are at various stages of development in terms of committed emissions reduction targets, and formulation of legal and regulatory frameworks for CCS. The establishment of an integrated carbon market for the region may therefore be challenging, or at least a long process.

In a number of ASEAN Member States, carbon pricing and carbon markets have been or are in the process of being developed for both the public and private sectors. On 2 August 2023, the Financial Services Authority of Indonesia (Otoritas Jasa Keuangan, or OJK) issued ‘Rule no. 14 of 2023 on Carbon Trading on Carbon Exchange’. This rule sets out the standard criteria for carbon units that will be traded on a carbon exchange, as well as the licensing requirements for any company that wants to apply to become a carbon exchange. (Baker McKenzie, 2023) Indonesia aims to launch onshore trading by the end of 2023. The Rule allows the facilitation by an exchange of cross-border trade, which opens up the possibility of a Southeast Asian carbon market.

Most offset transactions in Southeast Asia are however done through brokers or directly by developers, with a large variance in margins and low correlation with quality. Also, the carbon futures market is still immature. (Bain & Company, 2021) An integrated (regional) credible carbon trading exchange could address these issues, and provide transparency, quality and price certainty to traders.

It is important to explicitly show the role that CCS should play in carbon markets, e.g. circumstances under which CCS projects could generate carbon credits; and clarity on the facility that could claim credits (capture facility or storage facility) to avoid double counting.

In March 2023, JSA published a *‘Handbook for CCS Carbon Credits’*, reporting the outcomes of an international workshop held to discuss global carbon markets as a way towards ASEAN decarbonisation. (JOGMEC, 2023) The report advocates for the recognition of the value CCS projects add to reducing CO_2, and a conversion of that value to carbon credits that could improve economic efficiency of these projects. The report discusses a number of current carbon emission trading schemes around the world, and how leveraging existing methodologies could accelerate the implementation of a carbon market in Southeast Asia.

Currently only a few carbon trading schemes include CCS as an eligible method. Amongst these are the Australian ACCU Scheme, the (ACR), the Verified Carbon Standard (VCS), Puro.earth (CCS methodology does not cover CO_2 captured from fossil fuels) and Canada’s Alberta Emission Offset Scheme (AEOS). The table below gives a high-level overview of the key CCS provisions of each of these schemes.

Table 2.6. Overview of CCS in Key Carbon Trading Schemes

(as of January 2023)

	ACR (USA)	AEOS (Alberta, Canada)	ACCU (Australia)	Puro.earth (International)	VCS (International)
Purpose	Compliance (California compliance offset programme) and voluntary	Compliance offset for TIER	Compliance offset for safeguard mechanism, and voluntary	Voluntary	Voluntary (eligible for compliance offset in some areas)
Approved CCS method/ guideline	2015	2015	2021	2022	2023 (tentative)
Legal framework	US federal/state	Canada federal/province	Australia commonwealth/province	US EPA (Class I, II, IV) or EU CCS Directive Equivalent	-
Applicability	CCS and CO2- EOR	CCS and CO2- EOR	CCS	DACCS and BECCS with EOR+	CCS, DACCS, BECCS (tentative)
Projects	5 projects	1CCS (Quest) 1CO2- EOR (MEglobal)	Moomba	AspiraDAC project, BECCS Norway	n/a
Credit buffer	10% (optional)or private insurance	0%~50% depending on project type for EOR	3%	10% for all projects (not just CCS)	Determined per project based on risk assessment

	ACR (USA)	AEOS (Alberta, Canada)	ACCU (Australia)	Puro.earth (International)	VCS (International)
		None for CCS			
Long-term monitoring	Minimum of 5 years of monitorin g after end of project term.	Minimum of 10 years after end of crediting period	15 years of extended accounting period after end of crediting period	n/a	Minimum of 10 years required for combined duration of monitoring post- injection until storage site closure and post- closure.
Site closure	Only reference is made to 'transfer of responsibi lity'	Reference to post-closure monitoring in accordance with the appliable regulation	Reference to extended account period monitoring in 107ccorda nce with the appliable regulation	n/a	Storage site closure conditions need to be specified and closure plan needs to be documented.

Source: Mitsubishi Research Institute (JOGMEC Handbook for CCS Carbon Credits).

These schemes with CCS methodologies could act as a base for the design of a Southeast Asia CCS methodology to be incorporated into a regional emission trading system. Inputs from ASEAN Member States will be imperative, as the business and regulatory environments vary between countries.

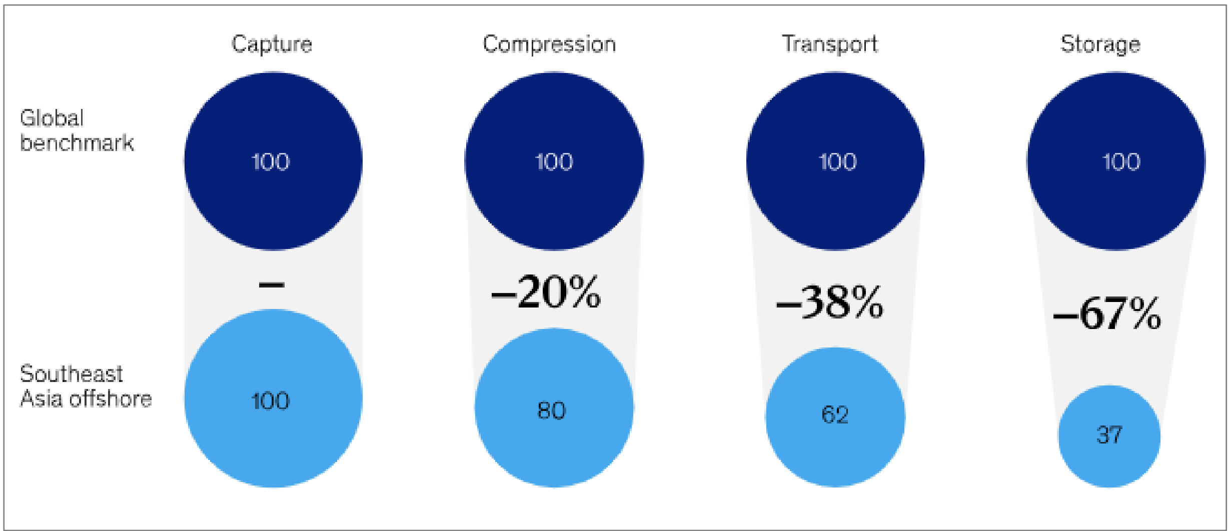
Linking ETSs is challenging on a technical, legal and political level, as it requires a high degree of harmonisation between the ETSs scope of coverage, emissions caps, legal nature of allowances, method of allowance allocation, MRV, methodological consistency, eligibility of offsets, etc. In addition, voluntary and compliance markets are becoming increasingly intertwined. Clear and consistent rules around CCS and carbon markets will be imperative for the success of a regional carbon credits trading system.

2.7.6. Project Considerations

2.7.6.1. Cost competitiveness of Southeast Asia

CCS projects in Southeast Asia have the potential to attract significant investment, since capture, utilisation and storage costs compare very well against global benchmarks – storage costs are estimated to be around 65% lower than the global average. (McKinsey & Company, 2023)This competitive advantage could contribute to better NPVs for CCS projects in the region than elsewhere in the world. However, this will only materialise in an environment of policy certainty and stable revenue streams based on an appropriate value placed on captured CO_2.

Figure 2.16. Carbon Capture, Utilisation, and Storage Costs in Southeast Asia, Compared to global Benchmarks



Source: McKinsey & Company.

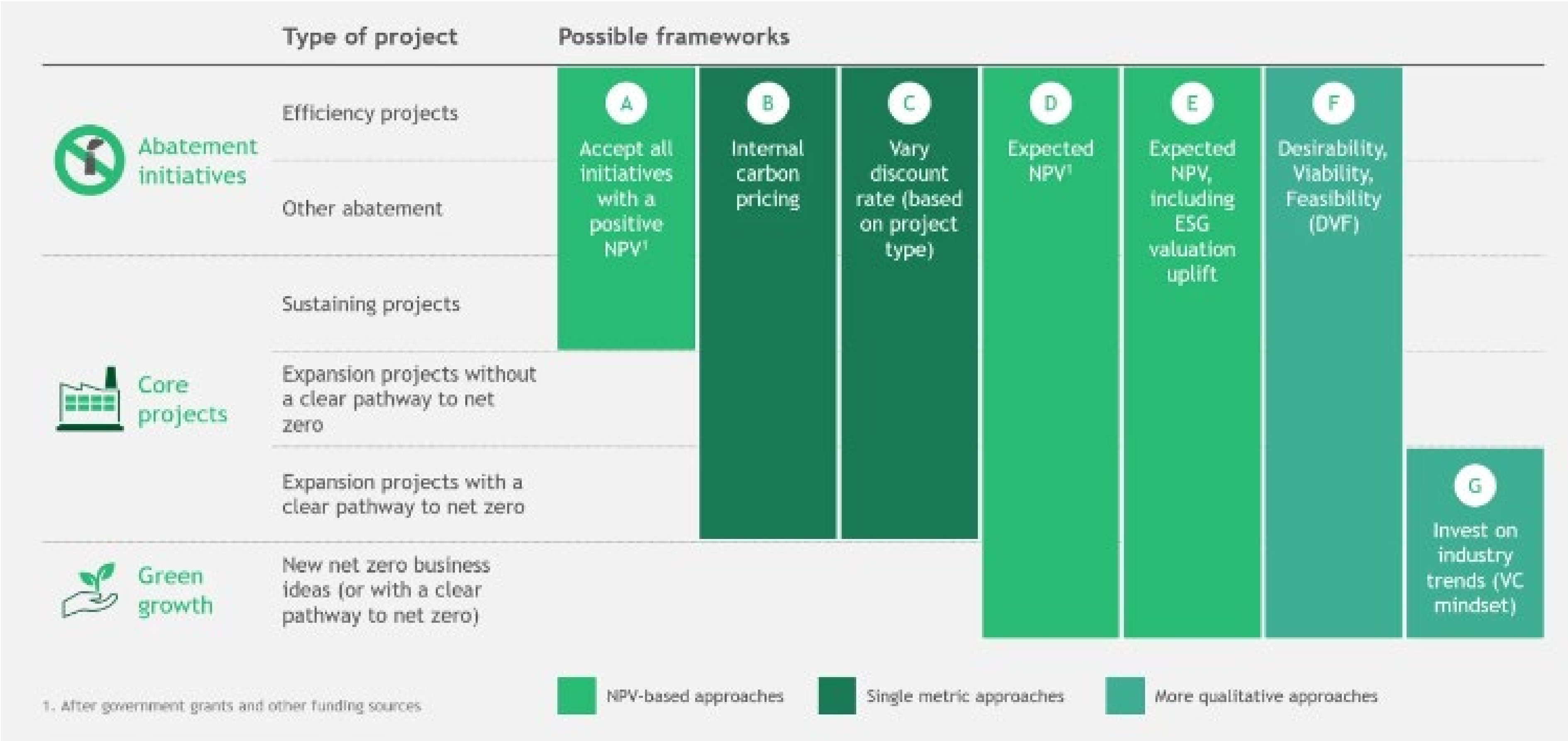
To capitalise on this advantage, development of enabling policies, and collaboration between the public and private sector to develop business models that will ensure commercial viability of CCS projects, will be key to attract the investment needed for large-scale deployment of CCS in the region.

2.7.7. Integrated Investment Frameworks

International financial support is essential for the deployment of CCS in Southeast Asia. This will include access to grants and loans from commercial banks and development finance institutions, as well as partnerships with industry players outside ASEAN. Government to government funding could also be an avenue for funds to flow from the greater APAC region to ASEAN, to achieve the climate goals as a collective in APAC.

Investors are increasingly looking to companies that have integrated sustainability built into their strategies and performance measures, and markets are actively pricing debt and equity based on climate performance. Boston Consulting Group (BCG) notes seven frameworks that are essential for investors to evaluate green and abatement projects: (Boston Consulting Group, 2022)

Figure 2.17. Frameworks for Evaluating Green Investments



Source: Boston Consulting Group

Note, abatement initiatives are included in the types of projects investors will be interested in as part of a sustainable investment portfolio; and NPV-based approaches feature strongly in these frameworks. Based on the cost competitiveness discussion above, this places CCS projects in Southeast Asia in a good position to attract international private funding.

BCG also comments that '*for core and abatement projects, perhaps the most obvious factor to incorporate is a carbon price*'. Carbon pricing can be established either through carbon taxes or emissions trading systems (ETS). One example of an ETS is a cap-and-trade system (such as the EU's ETS), where supply and demand will determine the carbon price (price of a carbon credit unit). Further examples include voluntary offsets and baseline compliance offsets.

Carbon markets are important in the fight against climate change and investors will be more likely to invest in countries or regions with active carbon markets. An active carbon market in Southeast Asia, placing a value on abated carbon emissions in the region, will underpin investment in abatement projects such as CCS.

2.7.8. Institutional Frameworks in Southeast Asia

For successful deployment of CCS in Southeast Asia, collaboration should extend beyond cooperation between national governments. Companies in the region could form partnerships and work together on cross-sector CCS value chains, creating materiality to increase government buy-in, accelerating technology development, bringing together capabilities across the value chain, and de-risking project execution. (McKinsey & Company, 2023)

Collaboration and/or partnerships between companies could be beneficial in the following areas:

- Partnering on CCS R&D activities, including co-funding and sharing of relevant technical information.
- Coordinated project planning and development, which may take the form of joint ventures to perform environmental studies, feasibility and FEED studies, and delivery of pilot projects.
- Coordinated government and company procurement frameworks.
- Coordinated project development activities, including co-development of project approval timelines and milestones, stakeholder and community engagement activities, collaboration with academic institutions, non-governmental organisations, the media, etc.
- Coordinated efforts to access international funding, including development finance and export credit opportunities.

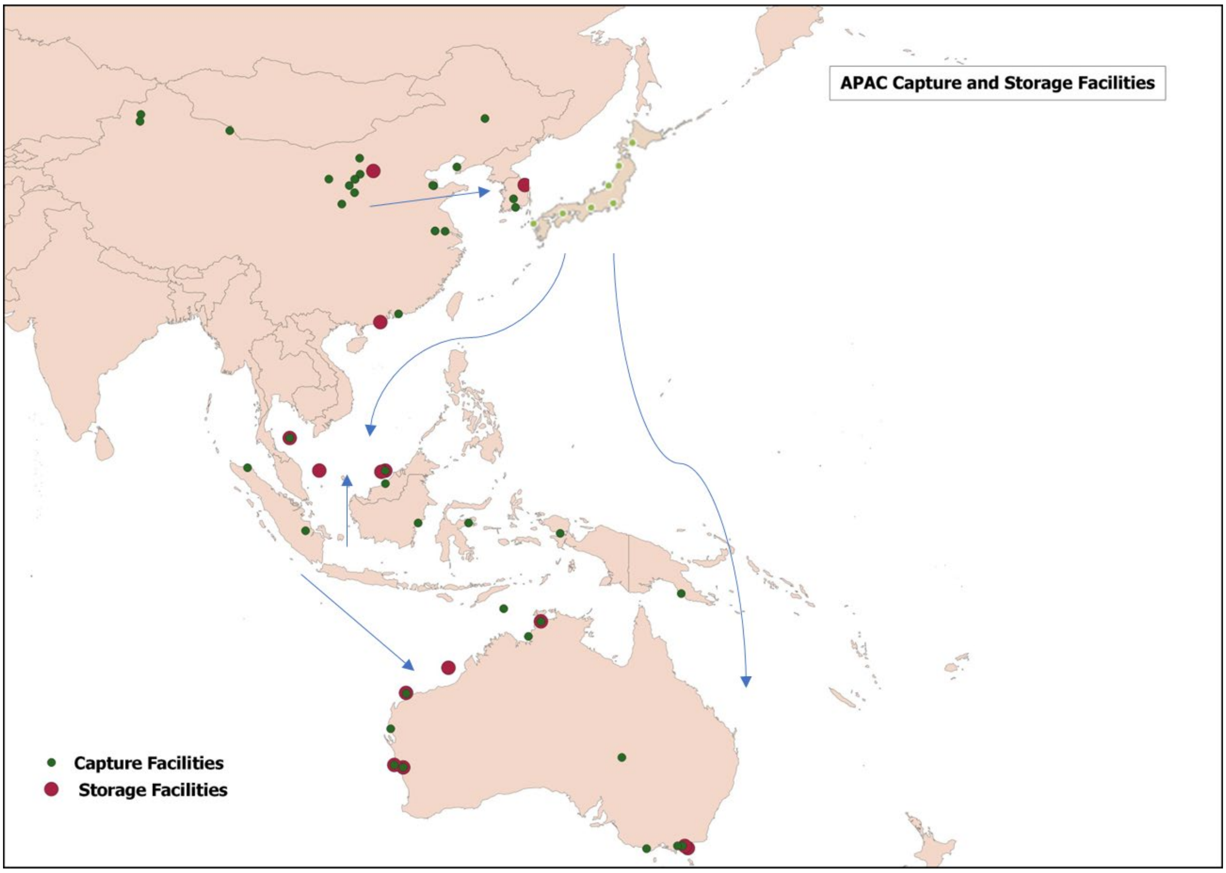
2.8. Asian CCS Value Chain Centre

The Global CCS Institute's CCS Readiness Index 2018 revealed Southeast Asian nations generally have low CCS readiness. Notably, Indonesia, Malaysia, Thailand, Viet Nam and the Philippines individually scored between 21-31 out of a possible 100. (Global CCS Institute, 2018)This is mainly due to policy uncertainty and lack of a clear enabling regulatory environment for CCS. There have been some policy developments in the region since 2018, however the conclusions of 2018 remain valid in 2023.

2.8.1. The Opportunity

Southeast Asia and the wider APAC region present a significant opportunity for CO_2 flows, as indicated in the map below (showing existing facilities in development or operation), and addressing the policy and regulations barrier, this region could see significant activity in CCS.

Figure 2.18. Potential pan-Asia CO_2 Capture and Underground Storage Network



Source: GCCSI.

Whilst there are clear challenges to the large-scale deployment of CCS in Southeast Asia, it is imperative for governments and companies in the region to take decisive action in terms of collaboration on policy and project development, to elevate the region as a significant contributor to global decarbonisation efforts.

CCS has many challenges, ranging from economic viability, regulatory gaps in some countries, the need for capacity building, cross-boundary cooperation, etc. For CCS to succeed, collaboration between government, industry, financial institutions, researchers, and international organisations will be imperative. To simplify collaboration efforts, one organisation acting on behalf of the region could lead to more efficient and expedient processes, and avoid duplication of work and multiple efforts towards the same goal.

The establishment of a centralised body, such as a CCS Value Chain Centre (VCC), to coordinate and administer regional efforts, could accelerate CCS deployment in the region. At the international workshop hosted by METI, JOGMEC and IETA – 'Global carbon markets and CCS: Towards ASEAN decarbonisation', it was recommended that collaboration around CCUS in Southeast Asia should also take maximum advantage of the frameworks developed by the Asia Zero Emissions Community (AZEC) – an initiative jointly initiated by Japan and Indonesia in 2022 (Asia Zero Emission Community, 2022), and the Asia Energy Transition Initiative (AETI) – an initiative of the Japanese government to support the energy transition through funding, development of technologies and capacity building on decarbonisation technologies in Asian countries. (Government of Japan (METI), 2022).

AZEC – a potential platform for the establishment of a VCC

On 4 March 2023, the Ministers of eleven APAC countries, including the majority of ASEAN nations, met to discuss collaboration on the energy transition and decarbonisation efforts. A joint statement was released, in which these countries agree to cooperate and act on initiatives, including CCUS. (Asia Zero Emission Community (AZEC), 2023a) It was stated that '*promotion of international cooperation for CCUS/Carbon recycling development in Asia is highly desirable*.' The joint statement further indicates that the participating countries commit to take collaborative actions through the AZEC platform aimed at:

- *'development, demonstration, and* ***deployment of decarbonization strategies, plans, businesses and technologies*** *such as energy efficiency, renewables, hydrogen, ammonia, energy storage, bioenergy, carbon capture, utilization and storage (CCUS);*
- ***financial support for investments in decarbonization infrastructure*** *including the power grid and the development of clean energy supply chains, including for critical minerals and materials;*
- ***development, harmonization, and securing interoperability of standards*** *of decarbonization technologies, and strengthening of human resource capacity in the area.* (Asia Zero Emission Community (AZEC), 2023b)

The first meeting of AZEC was held in June 2023, in which ERIA participated and highlighted several transition matters, including transition technology and finance challenges. Out of this meeting, three research projects were identified – developing a masterplan for hydrogen and ammonia, the introduction and utilisation of CCS, and acceleration of utilising the Bilateral Crediting Mechanism. (ERIA, 2023)

These public commitments enhance the potential for a regional body, coordinating decarbonisation efforts, to be supported by ASEAN nations. The AZEC collaboration could provide an ideal platform to establish a VCC, not only for ASEAN, but also including significant trading partners in the broader APAC region, who bring a wealth of expertise and experience in the development of standards, regulatory frameworks and cooperation agreements.

2.8.2. Focus Areas for a CCS VCC

The VCC should develop a programme of work to lay the foundation for regional cooperation on CCS. This may include the following:

2.8.2.1. Policy, Regulations, and Standards

The VCC, as a coordinating body, could review and make recommendations on how existing national policies, legislation and regulatory frameworks could be adapted to accommodate and enable regional CCS activities, including identification of near- and mid-term activities to support national regulators and policymakers to align national CCS policies to enable collaboration in the region. In collaboration with national policymakers and regulators, the VCC could implement the ASEAN CCS Roadmap currently under development by the ASEAN Center for Energy. As a regional body, the VCC could act as an advisory body, tasked with monitoring national CCS legislation and regulation development in the region, in line with the ASEAN CCS Roadmap and make recommendations to regulators as appropriate.

In addition, the VCC could coordinate the development of an ASEAN CCS Regulatory Principles guideline, based on the existing 'ASEAN Guidelines on Good Regulatory Practice' to provide guidance on the approach to developing CCS-specific regulation for the region.

The VCC could also play a role in the standardisation of CCS, based on international standards and global best practice and through collaboration with other associations in the climate change space.

One opportunity available to the VCC is to collaborate with the International Association of Oil and Gas Producers (IOGP), who launched a Carbon Capture, Transportation and Storage Committee in 2022, to share technical lessons learned from pilot projects, and to accelerate the standardisation of CCS technologies and processes, to improve cost, scheduling, risk and safety, which will underpin widespread deployment of CCS technologies. The IOGP Committee identified five deliverables for 2022-23, including:

- Review existing CCS standards and guides, and develop proposals for amendments or new standards based on operators' practical experience and best practice.

- Recommend practice(s) for measuring, monitoring and verification plans, including post-injection and closure, to mitigate long-term storage liabilities.
- Develop a common methodology to address evaluation of net CO_2 avoidance based on a lifecycle approach.
- Provide risk assessment tools and checklists for storage projects.
- Propose a standard economic methodology to compare different carbon capture technologies mainly in upstream facilities.

APAC members of the IOGP include Petronas, PTTEP, Pertamina, Brunei Shell Petroleum, CNOOC, INPEX, Kazmunai Gas, ONGC, Prime Energy, Woodside Energy, SOCAR, NCOC, Beach Energy, and Australian Energy Producers. (IOGP, 2022)

2.8.2.2. Network and Infrastructure Planning

Infrastructure planning and development across the region will have to be done as a collaborative effort between countries, to maximise potential for CCS deployment. Coordination of these activities could be undertaken by the VCC, including establishing and overseeing working groups between ASEAN nations, to accelerate the various aspects of CO_2 capture, transport, and storage. This may include planning and development of CCS networks, hubs and pipeline infrastructure, and appraisal and development of storage resources. These activities could be undertaken by multi-governmental working groups, as appropriate, connecting emitters, storage operators and network service providers in the region. Working groups could be reporting directly to the VCC.

In terms of transporting CO_2 cross-boundary, the VCC could also coordinate the development of cross-border and cross-sector CCS hubs, transport and storage networks, planning of transboundary transport routes, and the development of transboundary CO_2 transport agreements (bilateral agreements/arrangements required under the London Protocol). Similar to the EU, the VCC could develop an overarching regional arrangement under Article 6 of the London Protocol. This will reduce complexity of bilateral agreements, in that bilateral agreements will only deal with residual matters not provided for in the regional arrangement.

2.8.2.3. Funding for CCS Infrastructure/Projects

As with any large cross-border infrastructure project, including pipelines, there will be transboundary regulatory issues that must be resolved to reduce uncertainty for investors and lenders. In instances where CO_2 exporters and importers have completely separate planning and approval processes or potentially contradictory standards and permitting requirements, project sponsors will look for certainty embedded in bilateral agreements or treaties between nations for transboundary movement of CO_2.

To support investment in CCS projects in the region and to provide certainty to project sponsors and financiers, the VCC could act as a representative body for ASEAN countries, seeking foreign direct investment and other forms of climate finance. A coordinated multi-national approach will enhance negotiation power and reduce counterparty risk for investors.

The VCC could also coordinate broader climate commitments for ASEAN nations, including government funding support for cross-boundary projects and networks, international finance accessibility, the broader energy transition across the region, emissions reduction targets, and a potential integrated carbon market.

2.8.2.4. Storage Resource Appraisal and Development

For regional coordination of storage activities, it would be important to keep a database of storage resources in the region, with details of characterisation, stage of development, capacity, permitting status, etc. In support of the development of European storage resources, the EC funded the Storage Potential in Europe (CO2StoP) project, through which onshore and offshore storage capacity in EU member states was assessed. The project created a dataset of geological parameters, which could be consistently applied for all regional storage resource assessments. The database is publicly accessible and provide storage data per country. (SETIS, 2020)

The CO2StoP project methodology is said to have made significant progress towards calculating probabilistic estimates of the CO_2 storage resources in Europe, in a way that will allow comparisons with other regions, such as the U.S. The IEA has recommended that the first step in all CO_2 storage estimates should be to estimate the Technically Accessible CO_2 Storage Resource (TASR). CO2StoP's calculation engine is capable of producing a TASR that is very similar to that of the US Geological Survey. The CO2StoP methodology could therefore provide a basis from which an ASEAN calculation engine could be developed.

Similar to the EU, the VCC could become the official custodian of an ASEAN geological storage calculation engine and database, accessible to project proponents in the region. The VCC would be well placed to coordinate data gathering and inputs, and to centrally maintain the system in collaboration with national authorities. Streamlining CCS regulatory processes across the region will be important to ensure regulatory requirements do not delay deployment of CCS. The VCC could set up a task force or working group comprising of regulators from ASEAN member countries, to streamline national licencing and permitting processes across the lifecycle of a storage project, i.e. from exploration to post-closure monitoring.

The VCC could also coordinate the development of a regional framework for risk assessment and management of CO_2 storage in geological formations. Such a framework could also include monitoring plans for storage facilities, and the VCC may take on the role to perform third party verification for storage facilities in the region. This will ensure consistency and may reduce the time it takes to perform these activities.

Chapter 3

Legal and Policy Framework for Deployment of CCUS in Asia Region, focused on ASEAN

Ian Havercroft, Eric Williams, Nabeela Raji, Matthew Loughrey, Joey Minervini, Errol Pinto, and Alex Zapantis

3.1. Introduction

The ASEAN region presents a dynamic and challenging environment for the deployment of CCS. Countries within the region represent a significant proportion of the world's emissions-intense industry, with many still demonstrating a growing dependence on fossil energy. Set against this, however, are several nations' strengthened emissions reduction targets for 2030 and pledges to achieve net zero emissions in the period between 2050 and 2065. CCS technologies are expected to play a significant role in addressing these twin challenges.

New project-level developments across the region are demonstrative of the emphasis now being placed upon the technology. Recent project announcements, led by the oil and gas sectors, offer significant potential for decarbonising the region's natural gas operations, and are positioned as a key aspect of several countries' transition pathways towards clean energy. Regulators and policymakers across the ASEAN region are now considering how their domestic policy and regulatory settings may be strengthened and improved, to support these ambitions for the technology's deployment.

In many instances, the development of CCS-specific policies, laws and regulations are now a priority, with several early projects announced and in development. Some ASEAN nations are now well-advanced in their legal and regulatory preparedness, with the Indonesian government and the Malaysian state of Sarawak releasing CCS-specific legislation that will regulate CCS operations within their territories. Processes to develop and implement national regulatory frameworks are also underway in Thailand and Malaysia, with both countries currently undertaking preparatory work aimed at supporting the development of law and regulation.

While the pace at which individual jurisdictions are addressing these issues varies greatly, several shared ambitions may be identified amongst the ASEAN nations. Recent reports, workshops, and wider intergovernmental fora have consistently highlighted aspirations to develop and implement domestic CCS-specific legal regimes, as well as the need to collectively address wider intergovernmental issues that will impact transboundary CCS operations in the region. A wide range of practical and technical issues have also been identified as critical to the development of CCS-specific law and regulation, as part of these discussions.

One important element that has emerged in supporting ASEAN nations' ambitions, is the timely provision of guidance and support, from within the region and internationally. While work is already underway within several nations, regulators, and policymakers from across the ASEAN region have expressed a desire for further information and assistance to support these regulatory processes. The practical experience of other jurisdictions, gained from developing and implementing their own regulatory models, is an invaluable resource for ASEAN governments when designing their domestic CCS-specific regimes. To this end, direct engagement with policymakers and regulators from Australia, the United States, Canada, and Europe, has been sought by several governments in the region.

A further source of information for those seeking to develop their regulatory regimes, are the variety of assessment and guidance frameworks that have been developed over the past decade. Produced by several intergovernmental, research and academic institutions, including the Institute, these materials are aimed at supporting the promotion and development of CCS-specific legislation, or as a means of assessing national frameworks' ability to regulate the CCS process. For regulators and policymakers in the ASEAN region, these resources also offer insight into the key elements and principles that underlie several of the early CCS-specific legal and regulatory frameworks.

The aim of this report is to build upon the work and dialogue underway within the ASEAN region, and the existing array of analytical materials, to provide national regulators and policymakers with regionally focused guidance that may support their activities. As such, these materials offer a targeted, ASEAN-centric review, of the issues identified by stakeholders as critical to the deployment of policy, law and regulation in the region.

3.2. Overview and Methodology

The Institute's guidance builds upon a wider, extended programme of work that has been undertaken in the region over the past 12 months. These activities have included the formal review of national and regional approaches to the design and development of CCS-specific legal and regulatory frameworks, as well as extensive consultation with key stakeholders. An important aspect of this engagement has been the Institute's Southeast Asia CCS Accelerator (SEACA) initiative, which has seen the Institute collaborate with governments, multilateral organisations, and the private sector, to examine the critical issues for supporting CCS deployment in the region. The outputs of this initiative have also been shared with the Economic Research Institute for ASEAN and East Asia (ERIA), which is responsible for coordinating the Asia CCUS Network.

3.2.1. Stakeholder Engagement

In developing the guidance, the Institute has engaged extensively with policymakers and regulators from the ASEAN region and beyond, as well as with key stakeholders with expertise in the development of CCS-specific policy law and regulation. The feedback, and issues raised in these interviews, have been reflected in the materials addressed throughout the sections of the report.

In addition to the engagement undertaken within the auspices of the SEACA programme, the Institute has conducted multiple interviews with regulators and policymakers in the ASEAN region. These structured, formal interviews sought to gain a more detailed understanding of regional priorities and concerns, as well as the work already underway in several ASEAN nations. Interviews were also conducted with policymakers and regulators outside of the region. In these instances, the interviews afforded an opportunity to discuss the approach adopted to the development and operation of CCS-specific regimes, and to examine broader topics such as transboundary movement and carbon accounting.

Several further interviews were conducted with industry stakeholders, academics, and legal professionals, that have broad experience of the policy, legal and regulatory environment across the ASEAN region. Consultation with these parties offered important insight into the design and implementation of CCS-specific regimes, as well as the issues that will be critical for supporting commercial deployment of the technology. Once again, these stakeholders' views and feedback are reflected in the content of the final guidance.

3.2.2. Review and Analysis

In addition to stakeholder engagement, the Institute conducted a detailed assessment of national approaches to the design and implementation of legislation. The review examined the status of policy, law and regulation in ASEAN nations, the CCS-specific legal and regulatory regimes that have been developed in many jurisdictions around the world, and the examples of assessment and guidance frameworks that have been developed to assist policymakers and regulators.

Examination of current regulatory regimes in the ASEAN nations was undertaken, to determine the extent to which CCS activities may be regulated under existing law and regulation. In addition, the latest policy, legal and regulatory developments and initiatives in these jurisdictions were reviewed, to identify key issues, and wider gaps and barriers that will require legislative intervention.

Several CCS-specific legal and regulatory regimes, developed within the region and internationally, were also reviewed. A particular focus of this analysis were the critical elements of these regimes, and the approaches adopted by policymakers and regulators when designing and implementing the individual frameworks. In addition to the CCS-specific Regulation released by the Indonesian government in early 2023, the review has also drawn upon the legislation enacted in Australia, Europe, the United States and Canada.

A further input into the development of the guidance, was an examination of the core issues identified by various technical assessments and guidance models, that have been created by intergovernmental and academic institutions over the past decade. The result of detailed, jurisdiction-specific analyses, these materials provide a practical guide to the experiences of policymakers and regulators to-date.

3.2.3. Structure

The final guidance is set out in Parts 3.3-3.6 of this report, with each section focusing upon a discrete set of issues for policymakers and regulators in the ASEAN region. When reviewed as a whole, it is hoped that these sections will provide clearly defined and regionally focused information, to support ASEAN governments in their development and implementation of CCS-specific policy and legislation.

3.3. Policy Architecture for CCS – Overarching Considerations

A country's overarching policy architecture for CCS has proven an important precursor to the removal of barriers to investment in the technology, and often a necessary step for promoting the development of supportive legal and regulatory frameworks.

3.3.1. Integration of CCS within Wider Domestic/International Commitments

The most recent report from the UN Intergovernmental Panel on Climate Change (IPCC) has reaffirmed the vital role of CCS technologies in achieving global climate goals. The greatest need for CCS exists in hard to abate sectors, particularly those with process emissions and in economies that rely upon fossil fuels to support their economic growth. Consequently, it is imperative that CCS advances rapidly in Southeast Asia which hosts a significant proportion of the world's emissions-intense industries and has a growing dependence on fossil energy to meet domestic demand and support economic growth.

Net zero ambitions and potential commercial opportunities for significant emissions reductions through the deployment of CCS has led many governments across the Southeast Asian region to include formal support for the technology within their international and national climate commitments and domestic energy policies. Whilst CCS projects are being developed in this region, gaps in policy, regulation and storage resource development present significant headwinds to reaching FID.

In the corporate world, with ever increasing Environmental, Social and Governance (ESG) pressure on corporations, particularly in regard to climate change ambitions, more companies have established net-zero targets by 2050. Corporations operating in the Southeast Asian region are no exception, and many have taken actions to reduce their operational emissions. Corporate sustainability and climate change targets are a key driver for emissions reductions measures.

Policy incentives to facilitate investment in CCS, in particular CO_2 storage, are mostly lacking in the region, although Indonesia and Malaysia have made significant progress. Future investment in CCS in Southeast Asia will depend on the establishment of legal and regulatory frameworks and policy incentives, creating the right environment to attract international finance.

3.3.2. Energy Roadmaps/Climate Strategies

As the net zero emissions target by mid-century draws closer, the need for regional and international cooperation is increasing. Several countries in Southeast Asia have pledged or written into policy a net zero target by 2050, including Singapore, Thailand, Viet Nam and PNG. Indonesia is proposing to reach net zero by 2060. Achievement of these targets will rely on national strategies setting out achievable implementation measures, as well as regional cooperation to advance the achievement of global emissions reduction targets.

3.3.2.1. National CCS Roadmaps/strategies

On a national level, several countries in Southeast Asia have stated ambitions to reach net zero by or beyond mid-century and have established (or are in the process of establishing) strategies or roadmaps to guide their energy transition - some of them including CCS/CCUS.

- Singapore

Singapore will also aim to achieve net zero emissions by 2050. A key enabler for achieving net zero emissions by 2050 will be a carbon tax, which formed part of the climate commitments package announced in 2022. (National Climate Change Secretariat, 2022) The carbon tax will be set at \$25/tCO_2e in 2024 and 2025 (up from \$5/tCO_2e in 2023), and \$45/tCO_2e in 2026 and 2027, aiming to reach \$50-\$80/tCO_2e by 2030. Carbon pricing provides a clear price signal to heavy-emitting industries to decarbonise. The strengthened carbon price could pave the way for these industries to start investing in CCS as a tool to reduce emissions.

Under Singapore's Green Plan 2030, Singapore is developing its position as a centre for carbon exchanges to facilitate carbon trading, and as a centre of expertise and service delivery for initiatives associated with CCUS projects. These include the financing of low-carbon development, low emissions, and emissions reduction projects, consultancy, assessment, reporting, and verification within Southeast Asia and the broader international community. (The government of Singapore, 2023)

In the Addendum to Singapore's Long-Term Low-Emissions Development Strategy released in 2022, Singapore states it support for global carbon pricing, as a mechanism to enable countries to internalise negative externalities of carbon emissions, without compromising their international competitiveness. This clearly indicates Singapore's intentions to collaborate bilaterally, regionally and internationally to play its part in reducing global carbon emissions.

The government has also emphasised the role of low-carbon technologies in achieving its emission reduction and net zero targets. In its 2020 Long-Term Low-Emissions Development Strategy, for example, Singapore identifies investment in CCS as one of four key avenues for achieving national emissions reduction goals. Furthermore, the NCCS, together with the country's Economic Development Board, commissioned a study in 2021, to examine the role of CCUS in addressing the emissions of the energy and chemicals sectors in Singapore.

In November 2023, Singapore's Economic Development Board released a statement that Singapore aims to realise at least 2 million tonnes of CO_2 capture potential by 2030, as part of a strategy to make its Jurong Island oil refinery more sustainable. Storage options are being explored across Southeast Asia, and regional cooperation around cross-border transport and storage of CO_2 will be imperative to support plans for carbon capture in Singapore.

- Indonesia

The Ministry of Energy and Mineral Resources' (MEMR) Roadmap to Net Zero Emissions by 2060 in Energy Sector identifies CCUS as a key technology for managing emissions associated with industry, electricity generation and fuel consumption. The Roadmap aims for the capture of 6 metric tonnes of CO2 onwards from 2030, with the ultimate goal of 190 metric tonnes of CO2 annually in 2060. In addition, the Ministry of Energy and Mineral Resources is targeting the establishment of 16 CCS/CCUS projects to be operational by 2030. These developments should be considered within the wider context of the Indonesian government's commitment to phase-out of coal fired power generation, indicating the major role CCS technologies is expected to play in decarbonising the sector.

The National Medium Term Development Plan for 2020-2024 (PR No. 18 of 2020) is a national legal and policy document. It lays out Indonesia's policy direction and strategies and provides sectoral guidance on policy measures for energy, water security, maritime, and food security to name a few. While the document does not list CCS for GHG emissions reduction, it discusses carbon sequestration as a mitigative strategy for the forestry sector through afforestation and reforestation. There could be scope to include CCS under the policy measures for resilience and low-carbon development to support GHG emissions reductions.

In February 2023, an ETS for the power generation sector was launched, and is still under development. Indonesia has also proposed the implementation of a carbon tax – this has been postponed until 2025.

Indonesia is also a party to the Just Energy Transition Partnership (JETP) - a $20 billion fund earmarked for investment in clean energy and designed to funnel money from wealthy economies to some of the high-emitting developing economies of the world. One of the requirements of the JETP is for Indonesia to prepare a roadmap to accomplish its energy transition goals and milestones towards achieving net zero by 2050.

In November 2023, Indonesia released a Comprehensive Investment and Policy Plan (CIPP)(JETP Secretariat, 2023), under the JETP, following the signing of the energy transition funding agreement during the G20 Summit in the same month. CCS has not been included in any specified key areas for investment. Under '*Investment Focus Area 2: Early CFPP Retirement and Managed Phase-out*', Indonesia will retire only two coal-fired power plants totaling 1,700MW and that only in 2037. Further, much of the existing coal-fired power plants will continue to operate but efforts will be made to minimise their output.

According to the CIPP, much of the coal-fired power is used by smelting facilities - approximately 9GW out of the total 13-14GW. It is estimated that a further 20GW could be added by 2030, if all planned captive coal power plants in Indonesia are realised. The CIPP notes that a significant shift in business plans technology choices and regulation will be needed to mitigate the impact of this planned increase in coal-fired power.

The CIPP also rightfully notes that *'Further work is required at more granular levels to better assess coal transition strategies considering Indonesia's decarbonization objectives, system adequacy and flexibility needs, and financial and contractual issues. Coal transition pathways are likely to entail combinations of strategies…'*(*Comprehensive Investment and Policy Plan 2023*, 2023)

In an environment of increasing power needs, CCS could play an important role in balancing reliable energy supply to industry, growing the economy and achieving decarbonisation targets. Combining the large-scale deployment of CCS with the phasing-in of renewable energy will enhance reliability and availability of the power network, whilst reducing emissions from coal-fired power plants in the long term.

- Thailand

At the UN Climate Change Conference of the Parties (COP26) in 2021, Thailand committed to carbon neutrality by 2050. The country's Long-term Low Greenhouse Gas Emission Development strategy sets out several key actions to achieve a low-carbon energy transition, and under its National Energy Policy (NEP2022) CCS has been included as a critical tool to reduce GHG emissions in an environment of increased energy demand. (*Carbon Capture Utilization and Storage (CCUS): A Key Decarbonization Technology for Thailand and the Region*, 2023)

Climate and energy policies have, to some extent, recognised the potential role that CCS may play in achieving the country's mitigation objectives. CCS was originally highlighted in Thailand's Climate Change Master Plan, as part of its strategy focused upon mitigation and low carbon development. The plan proposed that feasibility studies on CCS in the power production sector be conducted, as part of efforts to address mitigation in the wider power generation and energy supply sectors.

Thailand is currently in the process of drafting a National Energy Plan (NEP), which would include principles for the country's Energy Policy, aiming to reach net zero emissions by

2065. The development of such a plan clearly shows commitment from the Thai government to climate mitigation action, as it covers a broad spectrum of areas where action could be taken towards decarbonisation. The NEP will set guidelines for five sub-plans, including:

- Thailand Power Development Plan
- Renewable and Alternative Energy Development Plan
- Energy Efficiency Plan
- Natural Gas Management Plan
- Fuel Management Plan

The Natural Gas Management Plan includes a focus on future procurement to strengthen the energy system and import of LNG to promote Thailand as a regional LNG hub. Going forward, CCS will be important to include in the Natural Gas Management the Fuel Management Plans, as a decarbonisation tool to balance increased fossil fuel imports against decarbonisation targets and the country's committed NDC.

Recent project announcements, and increased emission reduction efforts are likely to result in far-greater levels of activity in the coming years. In this regard, state owned PTT Exploration and Production Public Company Limited (PTTEP) has highlighted its ambitions to undertake transnational CCS activities in the Lang Lebah field in offshore Malaysia in late 2023. The state-owned company is also anticipating it will take a final investment decision for the Arthit CCS pilot project in 2023. (*CCS Development in Thailand*, 2022)

- Malaysia

Malaysia is anticipating economic and population growth of 2% per annum until 2050. This growth is expected to fuel a rise in energy demand over the same period.

Following the update of its NDC in 2021, the 12th Malaysia Plan and the National Energy Policy (NEP 2040) have been developed, setting out key priorities towards achieving the NDC. In addition, several strategic roadmaps are in the process of being developed, to support the implementation of the NEP 2040. Of key importance is the National Energy Transition Roadmap (NETR) which will outline the overarching strategy and key initiatives to expedite energy transition efforts. The NETR outlines six levers and ten catalyst projects, aiming to reduce GHG emissions by at least 10 million tons per annum. One of these levers is CCUS and includes two catalyst projects – the development of a regulatory framework by the Ministry of Economy; and the development of the Kasawari CCS project by Petronas.

In August 2023, the government announced Phase 2 of the NETR, which will focus, amongst others, on biomass, CCS, and hydrogen integration. Phase 2 is said to include 'more actionable items', including getting CCS and hydrogen infrastructure ready. (*Phase Two of NETR to Focus on Biomass, Waste-to-Energy, Carbon Capture*, 2023) The six energy transition levers now include 50 initiatives and five enablers - financing and investment; policy and regulation; human capital and just transition; technology and infrastructure;

and governance and implementation.

NETR also includes the Responsible Transition Pathway 2050, that outlines the energy sector's pathway to reduce GHG emissions from 259MtCO_2e in 2019 to 175 MtCO_2e by 2050. This pathway is based on modelling that suggests natural gas will still account for 56% of the total primary energy supply by 2050, while renewable energy will increase to 22% of the total by then. (Harinderan, 2023) It is clear that the focus on CCS in the second phase of the NETR will be important to achieve climate targets, as natural gas will continue to play a key role in meeting Malaysia's energy demands throughout the transition to a low-carbon economy.

In line with its policy commitments, the Malaysian Government, building upon its foundations and connections into the well-established oil and gas industry, is also positioning itself to be a CCUS leader in Southeast Asia. The state-owned company, Petronas plans to create clusters to share infrastructure and achieve economies of scale, with an eye to becoming a regional sequestration hub. The company's approach could generate new revenues for Malaysia and facilitate the capture of CO2 from smaller sources. It is suggested that 60% of storage capacity will be allocated to Malaysia – for Petronas and partners – while the remaining 40% will be made available to other users. In line with this ambition, the recently released National Energy Transition Roadmap outlines a plan to develop multiple CCUS hubs in Malaysia by 2030 and 2050 to be facilitated by addressing regulatory and policy barriers, including the development of a facilitative regulatory framework, incentive mechanisms, infrastructure, negotiating transboundary CO_2 export and import agreements and promoting local CO_2 utilisation in industry.

While Malaysia has begun developing a CCS-specific regulatory framework, it will likely be based upon the existing oil and gas regulatory regime. The country has been engaged in consultations that the Federal and State levels with input from the corporate sector to align the relevant policy and regulatory frameworks since 2021. Malaysia's net zero and NDC commitments have likely played a role in its intention to set up a domestic ETS. The Ministry of Environment and Water released a report titled 'National Guidance on Voluntary Carbon Market Mechanisms' in 2021. Participation guidance for entities interested in international carbon markets could be forthcoming. In December 2022 Malaysia launched of the Bursa Carbon Exchange, the world's first VCM platform that is also Shariah-compliant. (*Emissions Trading Worldwide: Status Report 2023*, 2023)

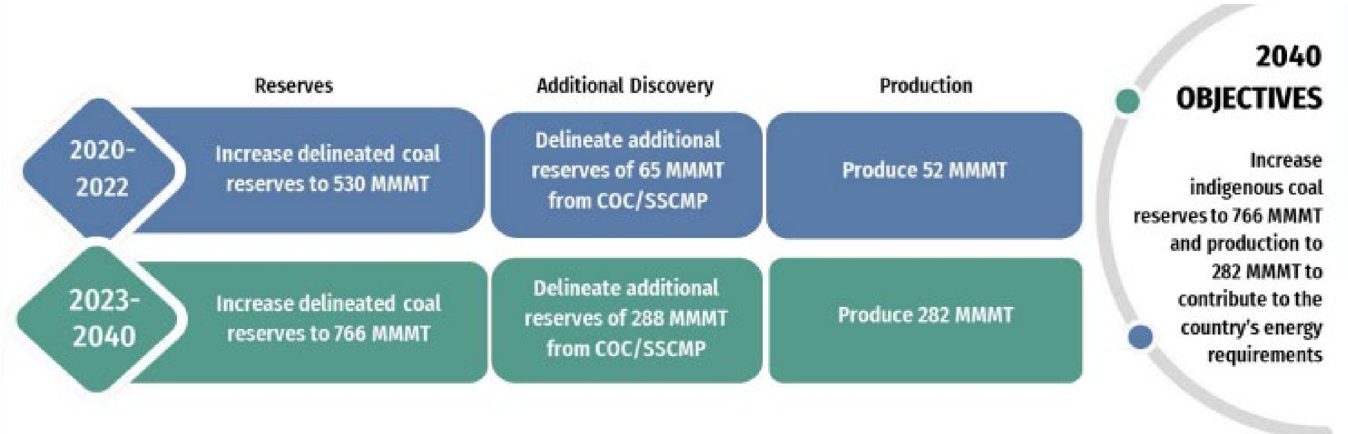
Petronas has announced two CCUS projects, including the Kasawari and Lang Lebah projects. The Kasawari CCS Project reached a positive final investment decision in October 2022 (announced in November 2022). Located offshore from Sarawak and linked to the Kasawari Gas Development, the operation is expected to begin in 2025 to reduce CO_2 emission from high CO_2 gas resources. The project is part of the organisation's broader objective of achieving net-zero by 2050.

- Philippines

In 2019, the government of the Philippines released the National Climate Change Action Plan 2011-2028 (NCCAP), which established seven areas of government focus for adaptation and climate mitigation action. Sustainable energy is one of these areas. Following the release of the NCCAP, the government also released the Philippine Energy Plan 2020 – 2040 (PEP) – a second comprehensive energy blueprint to support the energy transition towards 2050. The PEP is a living document and the latest update was made in 2023. (*Philippine Energy Plan 2020 – 2040, 2023 Update*, 2023)

The PEP contains several plans/roadmaps for various components of the energy mix. Under the Clean Energy Scenario, the PEP provides ambitious plans, policies and targets on renewable energy, natural gas, alternative fuels, and energy efficient technologies. Included in the Plans and Programs for energy, is the Upstream Coal Roadmap, depicted below.

Figure 3.1. Upstream Coal Roadmap – PEP 2023 Update



Source: Philippine Energy Plan 2020 – 2040, 2023 Update.

The plan estimates an increase in industry demand for coal until 2040, with a predicted annual growth rate of 10.1% from 2023 to 2040.

To comply with the Philippine Clean Air Act, the government committed to continue to assist the coal industry mitigate the environmental impact of this growth in coal production, through amongst others, the promotion of clean coal technologies and social acceptability of coal, as well as determining the applicability of technologies such as CCUS.

The predicted growth in demand for fossil fuel in the Philippines until 2040, and the government's stated intention to explore the use of CCUS create a massive opportunity for large-scale deployment of CCS technology.

- Viet Nam

International studies have highlighted the considerable potential for deploying CCS in Viet Nam, in the context of the nation's rapid growth and anticipated increase in energy use and emissions, which will see continued reliance on fossil fuels. Viet Nam also possesses significant storage potential and completed assessments suggest there are considerable storage resources, when compared to their national emissions. In the context of Viet Nam's emissions reduction targets.

Notwithstanding the nation's potential, Viet Nam has yet to develop a formal policy commitment towards deploying the technology. In 2005, in partnership with two Japanese companies, the Viet Namese/Russian joint venture Vietsovpetro, proposed the first CCS/EOR project under the Kyoto Protocol's Clean Development Mechanism (CDM). Although ultimately the project was not approved, the country proved an early mover in the discussion surrounding the inclusion of the technology within the CDM.

More recently, there has been some indication of the nation's desire to deploy the technology. At COP 26, Viet Nam communicated its aim to conduct research on technologies and implement solutions for carbon capture and storage in certain fields.

In August 2023, the Viet Namese government released its National Energy Master Plan (NEMP), laying out foundations for national energy security, reduce carbon emissions to meet the country's commitment to net zero by 2050, and to ensure the energy industry is independent and self-sufficient.

The NEMP estimates an economic growth of 7% per annum until 2030, and between 6.5% and 7.5% per annum from 2031 to 2050. It further estimates the demand for oil in the energy mix will grow by 16-22 million tonnes per year until 2030, and 16-17 million tonnes per year thereafter until 2050. Crude oil production is also predicted to grow steadily until 2050. Natural gas and coal will both continue to play an important role in Viet Nam's energy mix until 2040, with natural gas production set to grow over this period whilst coal mining is predicted to slow down from 2030 onwards.

To reach its climate commitments amid the predicted growth in fossil fuel production and demand, the NEMP states that CCUS will be expanded at industrial production facilities and power plants to achieve a capture capacity of around 1 Mtpa of CO_2 by 2040 with the aim of reaching 3 to 6 Mtpa by 2050. (*Viet Nam Briefing – Viet Nam's National Energy Master Plan: Key Takeaways*, 2023)

- Brunei Darussalam

Oil and gas forms the backbone of Brunei's economy with gas powering 98,95% of its domestic electricity demand. In recent Brunei has repeatedly called for natural gas to play a larger role in the energy transition in Southeast Asia, recognising that Brunei has limited potential for renewable energy due to its size and other geographical constraints.

Although Brunei has made some commitment to transition to cleaner energy, fossil fuels are predicted to continue to form a large part of the energy mix until 2050. Brunei aims to raise its renewable energy contribution to overall power generation to 30% and to achieve a 45% reduction in emissions intensity by 2035.

Flaring of gas, especially at its offshore gas reserves, is currently used to reduce GHG emissions. It will be vital for Brunei to introduce low carbon technologies and decarbonisation measures to achieve its climate targets, however there is currently no legislative or regulatory frameworks in place to support the deployment of CCS. ('Brunei Banks on Technology to Preserve Its Economic Lifeline: ,' 2021)

An MoU was signed between Shell Eastern Petroleum and Brunei Shell Petroleum to explore CO_2 transport and storage options in Brunei and Singapore, however, the government has not announced any further policy commitments or mechanisms to support projects. ('Shell to Explore Carbon Transport and Storage in Brunei and Singapore,' 2022)

3.3.2.2. ASEAN Strategy for Carbon Neutrality

In August 2023, at the 55th ASEAN Economic Ministers' Meeting in Semarang, Central Java, Ministers from member countries endorsed the ASEAN Strategy for Carbon Neutrality (the Strategy), setting an ambitious course for a regional carbon-neutral future. Economic benefits from this strategy are estimated to range between 9%-12% increase in GDP for Cambodia, Lao PDR, Myanmar and Viet Nam; an increase of between 4%-7% for Indonesia, Malaysia, Thailand and the Philippines; and an uplift of 1%-2% for the high-income countries of Singapore and Brunei. (ASEAN, 2023)

The Strategy aims to accelerate an inclusive transition towards a green economy, fostering sustainable growth and complementing national efforts as part of a regional collective effort. The Strategy promotes four key outcomes for the region: (ASEAN, n.d.)

- Developed green industries: To unlock ASEAN manufacturing and export potential and capture the full value of regional green value chains.
- Interoperability within ASEAN: To accelerate the rollout of green technologies at scale, enabling exchange of green electricity, products and feedstocks.
- Globally credible standards: To ensure ASEAN remains a top destination for international capital to increase liquidity in regional markets.
- Green capabilities: To develop green talent and expertise within ASEAN to drive the energy transition.

The Strategy includes eight targeted sub-strategies with sixteen underlying priority initiatives that will give impetus to implementation of the strategy. Following, is a high-level overview of the first of these sub-strategies, '*Accelerate green value chain integration'* with comments on key considerations for CCS-specific policies under the identified activities.

Table 3.1. High-Level Overview of the ASEAN Strategy for Carbon Neutrality on CCS-Specific Policies

	Strategy	Priority Initiatives	Considerations for CCS Policy Architecture
1	Accelerate green value chain integration	- Identify and boost opportunities for greenification of the manufacturing value chains regionally - Enable ASEAN feedstocks pathways for biofuels to capture global markets - **Coordinate development of regional policies and regulations to support CCS/CCUS infrastructure**	Industrial manufacturers (typically high emitters) are increasingly under pressure to decarbonise their operations and reduce GHG emissions. A coordinated regional effort to develop policies and regulations to support the large-scale deployment of CCS/CCUS in the region, could lead to greener manufacturing value chains, especially for hard to abate industries (cement, steel, etc.). Key considerations for regional CCS policies include: Transboundary transport of CO_2 between member countries: - Adoption of the provisions of the London Protocol into national legislation, to allow for export of CO_2 between ASEAN nations and the wider APAC region. - Coordination of bilateral agreements / arrangements required under the London Protocol, which may vary in form and content, depending on whether CO_2 exporting and importing countries are Parties to the Protocol or not.

	Strategy	Priority Initiatives	Considerations for CCS Policy Architecture
			- Coordination of the ratification of the 2009 and 2013 amendments to Article 6 of the London Protocol, following bilateral agreements / arrangements. Development of storage resources in the region: - A collaborative approach to storage resource identification, site characterisation, storage assessment, site planning, and project development. - Coordination of government and private funding for CO_2 storage resource development. - Development of a coordinated set of CCS regulations for the region, covering storage permitting processes, facility operations, and closure and post-closure obligations in terms of monitoring, reporting and verification; and financial liability. Coordination of regulations: - Establishment of a regionally relevant regulatory framework for CCS, consolidating emission reduction efforts

	Strategy	Priority Initiatives	Considerations for CCS Policy Architecture
			in Southeast Asia (see example below) - Development of regionally applicable standards for CCS projects and operations. - Adoption of the regional CCS framework and standards into national legislation. - Coordination of regulatory obligations to avoid conflicts in transboundary CCS operations.
2	Promote regional circular economy supply chains	- Upgrade ATIGA to comprehensively include circular products	N/A
3	Connect green infrastructure and markets	- Enable regional power trading, physical interconnection, and policy cooperation - **Enable interoperability of regional transport and logistics infrastructure**	Key considerations for regional CCS policies include: Development of regional CCS transport networks: - Establish a regional body to coordinate national efforts to provide financial support and other policy incentives for the development of CO_2 transport infrastructure in the region. - Development of a regional plan for establishment of CO_2 capture hubs/clusters and transport networks, which will leverage economies of scale to

	Strategy	Priority Initiatives	Considerations for CCS Policy Architecture
			reduce risks and costs of regional projects.
4	Enhance interoperable carbon markets	- **Harmonise measurement, reporting and verification (MRV) standards and policies to access global liquidity and regional carbon sink potential**	Key considerations for regional CCS policies include: Regional MRV policies applicable to CCS: - Development of regional regulations for MRV, including MRV obligations as they relate to transport and storage operations in the region. - to oversee alignment of national MRV regulations with a regional set of regulations. - Establishment of a regional representative body to act on behalf of ASEAN member countries as a whole, to negotiate private finance for regional or cross-boundary projects, and access development funding on behalf of the region for deployment of CCS.
5	Foster credible and common standards	- Promote regional energy efficiency and conservation - **Establish globally credible regional GHG inventory to flow from national reports** - **Standardise globally credible frameworks for corporate climate reporting**	Key considerations for regional CCS policies include: Coordination of regional GHG inventory, national targets and regional reporting: - Creation of a regional database, tracking national GHG emissions against targets and NDCs.

	Strategy	Priority Initiatives	Considerations for CCS Policy Architecture
			- Establishment of a regional framework for climate reporting, based on best practice and similar reporting frameworks.
6	Attract and deploy green capital	- Encourage adherence to ASEAN Taxonomy on Sustainable Finance - Promote de-risking through adoption of innovative sustainable finance instruments - Incentivise green fund managers to locate in ASEAN, and local funds to develop	See 4 above
7	Promote green talent development and mobility	- Establish green skills taxonomy and facilitate movement of natural persons	N/A
8	Offer green best practice sharing	- Facilitate best practice sharing to support effective just transition at national level - Conduct capability building for sustainable infrastructure and smart cities	N/A

Source: ASEAN Strategy for Carbon Neutrality.

This Strategy reflects ASEAN's bold ambition for economic integration and positioning the region for a carbon-neutral future. It promotes a coordinated effort between ASEAN nations on several fronts to combat climate change and meet set targets over the next three decades.

This same ambition has been evident in Europe, where a host of regional regulations have been implemented to govern CCS activities and GHG emission reduction strategies in a harmonised manner across the European Union. ASEAN could draw on the experience of the EU and look to frameworks and regulations established to harmonise efforts between

EU Member countries covered under the EU ETS, to give effect to the ASEAN Strategy for Cabron Neutrality. A few pertinent examples of EU Regulations that could provide a good basis for consolidation of climate efforts are provided below.

- Overview of the EU's regulatory framework aiming to **consolidate emission reduction efforts** across the EU.

Effort Sharing Regulation – European Union
An example of a collaborative, regional policy framework which governs cooperation between countries in the same region, and which forms part of the region's climate and energy policies, is the EU's Effort Sharing Regulation. This Regulation establishes binding national GHG emissions targets for 2030, and emission limits for each of the EU Member Staes, and covers several sectors – transport, buildings, agriculture, small industry and waste. The Regulation covers approximately 60% of the EU's total domestic emissions. Targets set through this Regulation recognise the capacity of each Member State to take action, and therefore more ambitious targets are set for higher income States than for lower income States to allow for a fair and cost-effective effort required from each Member State. The Regulation allows certain Member States to use a limited amount of ETS allowances to offset emissions in the effort-sharing sectors. In addition, all Member States may use up to 131 million credits from the Land Use sector to offset emissions. Member States may bank surpluses (up to a limit) in years when emissions are lower than allocations, for use in future years; and may borrow (up to a limit) against the following year's allocation where targets are not achieved. These flexibilities are taken into account when targets for subsequent years are set, and where Member States do not achieve their targets (reported annually to the European Commission), they are required to submit an appropriate plan of action. Source: European Commission, 2021a.

- Overview of the EU's **monitoring, verification and reporting framework** aiming to consolidate data and review compliance of EU Member States at a central point.

Monitoring, Reporting and Verification of EU ETS emissions – European Union
For the EU ETS to operate effectively, the EU adopted a monitoring, reporting and verification system for Member States to report GHG emissions on an annual basis. This annual procedure together with all the associated processes is known as the ETS Compliance Cycle. All industrial facilities and aircraft operators covered by the EU ETS are required to have an approved MRV plan for monitoring and reporting annual emissions. This plan

also forms part of the permit to operate that is required for industrial facilities. An emissions report is required to be submitted every year, and data in the report must be verified by an accredited verifier by 31 March of the following year. Once verified, operators must surrender the equivalent number of allowances by 30 April of that year.

The MRV system is coordinated by the European Commission, who provides guidance and publish tools to support Member States in understanding requirements and complying with the relevant regulations. The Commission also promotes a harmonised and cost-effective application of the MRV regulations throughout the EU ETS countries.

The rules related to the Compliance Cycle are contained in two regulations – the Monitoring and Reporting Regulation, and the Accreditation and Verification Regulation.

Source: European Commission, 2021b.

3.3.3. Paris Commitments/NDCs and CCS Specific Commitments

The past two years have seen increased focus amongst Southeast Asian nations to set national climate targets, and to contribute to global emission reduction targets. This is evident in the updates to NDCs by countries in the region since 2021 and national strategies and targets released in this period.

This section discusses current global climate contributions from Southeast Asian nations, and specific CCS/CCUS commitments included as part of NDC implementation measures.

3.3.3.1. Singapore

Singapore submitted an updated version of its original NDC, in November 2022, which highlights the nation's intention to reduce emissions to around 60 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 2030, after peaking its emissions earlier.

The country has focused its mitigation efforts across several key sectors, in particular the reduction of fossil fuel use as part of power generation. In this sector, the government has supported the shift towards the greater use of gas and highlights the percentage of natural gas used in electricity generation has increased from 19% to more than 95%, between the years 2000 and 2022. An increased focus upon reducing the use of fuel oil and the more widespread deployment of solar PV, are also important initiatives. (*Singapore's Update of Its First Nationally Determined Contribution (NDC) and Accompanying Information*, 2022)

3.3.3.2. Indonesia

In September 2022, Indonesia announced a net zero target for 2060. Indonesia also submitted an updated NDC at the same time, with an increased emission reduction target from 29% to 31.89% unconditionally and from 41% to 43.20% conditionally by 2030. (*Enhanced Nationally Determined Contribution*, 2022)This enhanced NDC is a step towards Indonesia's second NDC, which will be aligned with the Long-Term Strategy on Low Carbon and Climate Resilience 2050, and the trajectory to reach net zero by 2060 or sooner (after emissions peaking in 2030).

It is anticipated that CCS and CCUS will play an important role in the achievement of this target, with storage capacity currently under assessment in the Arun Field, East Kalimantan and Sunda Asri Basin. These storage resources place Indonesia in a firm position to store its own CO_2 emissions, and also provide a storage service to neighbouring countries.

Several of the government's more recent climate change and energy-related policies and announcements have explicitly acknowledged the critical role of the technology in facilitating Indonesia's energy transition. In May 2023, the government of Indonesia reiterated the importance of cross-border CO_2 transportation and storage and is currently drafting a regulation to allow for transboundary transport of CO_2 and storage in Indonesia.

3.3.3.3. Thailand

Under the Paris Agreement, Thailand has made a commitment to reach carbon neutrality by 2050 and net zero emissions by 2065. In November 2022, Thailand submitted a second update to its original NDC, committing to reduce its GHG emissions by 30% from the business-as-usual level, by 2030. The update also includes a conditional increase of up to 40%, subject to adequate and enhanced access to technology development and transfer, financial resources and capacity building support. (*Thailand's 2nd Updated Nationally Determined Contribution*, 2022)

3.3.3.4. Malaysia

Malaysia submitted a revised NDC in 2021, unconditionally committing to cut carbon intensity against GDP by 45% compared to 2005 levels, by 2030. The revision represents a 10% increase from the previously submitted NDC, which clearly indicates Malaysia's commitment to decarbonise its economy and collaborate globally to achieve this target.

Malaysia has been recognised as the best country in Southeast Asia on the Energy Transition Index, by the World Economic Forum, mainly based on its diverse, reliable and accessible energy supply, and the low cost of electricity. This has been achieved largely through production from own oil and gas reserves, which reduced Malaysia's dependence on imports. However, GHG emissions from the energy sector account for 78.5% of Malaysia's total emissions. This poses a challenge, not only in terms of achieving the NDC, but also in terms of competitiveness in global markets. It is estimated that the EU's Carbon Border Adjustment Mechanism (CBAM) will impact 57% of Malaysia's total exports, which will have a knock-on effect on the economy. (Harinderan, 2023)

The NDC does not explicitly refer to CCS, however it will be imperative for Malaysia to implement a comprehensive strategy that balances decarbonisation with the predicted growth in energy demand. As natural gas will remain an important component of the energy mix until 2050, CCS may be the most compelling solution to reduce emissions from the energy sector in particular (but also in other sectors such as cement and steel) and achieve the committed NDC.

3.3.3.5. The Philippines

In April 2021, the Philippines submitted an updated NDC, committing to GHG emissions reduction and avoidance of 75% by 2030, of which 2.71% is unconditional and the remaining 72.29% is conditional. The NDC covers the sectors of agriculture, wastes, industry, transport, and energy. Although CCS is not mentioned in the NDC, the document states implementation and mitigation commitments will be undertaken through bilateral, regional and multilateral cooperation, showing clear intention from the Philippines to collaborate with other Southeast Asian nations to combat climate change. (*Nationally Determined Contribution*, 2021)

3.3.3.6. Viet Nam

Viet Nam submitted an update to its NDC in 2022, increasing its unconditional GHG emissions reduction target to 15.8% against its 2010 business-as-usual scenario, and its conditional contribution to 43.5%, by 2030. (*Nationally Determined Contribution*, 2022) Viet Nam has also committed to achieving net zero emissions by 2050, a target that has been enshrined in legislation since July 2022.

The NDC sets out measures to promote the implementation of the NDC, two of which include specific references to CCS, i.e. '*Science and Technology Development*' and '*Promoting international cooperation in climate change response*'.

Under the '*Science and Technology Development' measure,* CCS is included as an innovation to be promoted domestically; and under the '*Promoting international cooperation in climate change response'* measure, CCS is included in the list of measures having cross-border impact on climate change response activities, and for which international cooperation on research and development will be promoted.

3.3.3.7. Brunei Darussalam

Brunei submitted its first NDC under the Paris Agreement in 2022, committing to achieve a 20% reduction in greenhouse gas emissions by 2030 in comparison to the business-as-usual scenario. Brunei outlines in its NDC that the country aims to adopt a multi-sectoral climate change mitigation strategy to deliver its climate related ambitions. The document refers to the Brunei Darussalam National Climate Change Policy (BNCCP) launched earlier in 2020, which outlines the principles, values and strategies that will underpin the achievement of the updated NDC. (*Brunei Darussalam Nationally Determined Contribution (NDC)* , 2020)

Although CCS is not specifically mentioned in the NDC submission, there is reference to the introduction of a carbon price by 2025, which would be applicable to all industrial facilities emitting above a specified threshold. This could stimulate interest in CCS as a tool to avoid excess GHG emissions.

3.3.4. Consideration and Position of CCS in Existing or Proposed Incentives and Support Mechanisms

3.3.4.1. Carbon Credits/Tax Credits/Funding/Finance

Below is a summary of fiscal incentives, public finance and market mechanisms in key Southeast Asian countries.

Table 3.2. Fiscal Incentives, Public Finance, and Market Mechanisms

Country	Rating	Gaps	Recommendations
Fiscal incentives			
Indonesia	✗	• Indonesia's carbon tax is under consideration.	• Implement strong fiscal incentive policies. • Supplement carbon taxes with strong fiscal incentive policies such as tax credits. • Current best practice includes tax relief similar to the 45Q programme under the inflation Reduction Act (IRA) in the United States.
Singapore	✓	• Singapore's carbon tax was implemented in 2019.	
Malaysia	✗	• Malaysia has discussed implementing a CCS tax credit. • The other countries do not have a formal fiscal incentive policy in place that supports CCS or action on climate change that could be broadened to support CCS.	
Thailand	✗		
Brunei	✗		
Singapore	✗		
Viet Nam	✗		
Public finance			
Indonesia	✗	• Singapore committed public finance for research and development and demonstration projects on low-carbon energy technology solutions. See section below this table.	• Make available public funding for CCUS Research and Development, Pilot projects and support to commercial CCS facilities. • International cooperation to secure development
Malaysia	✗		
Thailand	✗		
Brunei	✗		
Singapore	✓		

Country	Rating	Gaps	Recommendations
Viet Nam	✗		funding from international development banks and finance institutions.
Market mechanisms			
Indonesia	✓	• Indonesia launched an ETS in 2023. See section below this table.	• Ensure CCS is included in the ETS that Indonesia established in 2023.
Malaysia	✗	• Malaysia announced the implementation of a voluntary carbon market (VCM) in 2022 and is exploring the implementation of a domestic ETS and carbon tax.	• Ensure CCS is included in Malaysia's national ETS that is under consideration.
Thailand	✗	• Thailand launched a voluntary carbon credit exchange (FTIX) in 2022.	• Ensure CCS is included in Thailand's national ETS that is under consideration.
Viet Nam	✗	• Viet Nam plans to establish and operate a national carbon trade exchange as a pilot from 2025, aiming for full operations by 2028.	• Ensure CCS is included in Viet Nam's ETS. Policies were announced in 2022 with other technical considerations to be developed by 2025.
Singapore	✗	• Singapore's Climate Impact X (CIX) launched in 2021 as a global marketplace and exchange for carbon credits.	• Ensure CCS is included in Singapore's global ETS.
Brunei	✗	• Formal market mechanisms do not exist in these countries.	• Formal market mechanisms need to be established in these countries that include CCS.
Institutional strength and Government Support			
Indonesia	✓	• Indonesia has an opportunity to coordinate national CCS policy around the 2023 CCS regulations.	• Continue support for Indonesia's Ministry of Energy and Mineral Resources 2023 CCS

Country	Rating	Gaps	Recommendations
			regulations - MEMR 2/2023 that has synergies with CCS. • Ensure CCS is included in Indonesia's Net Zero by 2060 commitment – in discussion. • The Indonesian Government should continue support for the National Action Plan Addressing Climate Change mentions CCS (2007).
Malaysia	✗	• While institutional support for actions to reduce emissions exists in these countries (Brunei needs to establish support), it is essential that CCS is not excluded.	• Ensure CCS is included in Malaysia's Plan for emissions reduction; however, the commitments are not clear.
Thailand	✓		• Continue support for Thailand's updated NDC that mentions CCS. • Expand support for CCS formally through policy, law, and regulation.
Brunei	✗		• Establish support for CCS through formal institutional support.
Singapore	✗		• Ensure CCS is included in Singapore's Net Zero by 2050 Strategy/Policy.
Viet Nam	✗		• Ensure CCS is included in Viet Nams NDC commitment.
Information sharing and International Collaboration			
Indonesia	✓	• These countries have an opportunity to update their information sharing capabilities and guidance	• Continue support for the following: o Member of the Clean Energy Ministerial's CCUS Initiative.

Country	Rating	Gaps	Recommendations
		through regional collaborations.	○ Indonesia is a contributor to the Green Climate Fund. ○ Indonesia has a current state of affairs document with some recommendations for the future. ○ CCS is mentioned only in the abbreviations list in Indonesia's 2012 Technology Needs Assessment.
Malaysia	✓		• Continue support as a participating country on ISO/TC 265 Carbon dioxide capture, transportation, and geological storage.
Thailand		• Thailand has a dated roadmap (2016) that mention CCS.	• Update dated references to CCS with the latest in the industry's learnings.
Brunei	✘	• The country does not currently share information on CCS.	• Brunei has opportunities to collaborate in the Southeast Asian region and to exchange information.
Singapore	✓	• Singapore has an opportunity to update their guidance and collaborative efforts through by extending regional partnerships.	• Continue support for the following: ○ Australia and Singapore signed an MOU in 2020. ○ Collaboration through the Global Clean Energy Action Forum funding for Clean Energy Technology Demonstrations.
Viet Nam	✘	• The country does not currently share information on CCS.	• Viet Nam has opportunities to collaborate in the Southeast Asian region and to exchange information.

Source: GCCSI.

Singapore – Public Finance

The low-carbon transition for industry, the economy and society as whole - promoted through Singapore's Long-Term Low-Emissions Development Strategy (2022) - is proposed to be achieved through four key initiatives, including *'Investing in low-carbon technologies, e.g. carbon capture, utilisation and storage (CCUS), and use of low-carbon fuels'*.

Under the Low-Carbon Energy Research (LCER) Funding Initiative, S$55 million was awarded to support 12 research projects on low-carbon hydrogen and CCUS and S$129 has been reserved for a second phase of the funding programme. In addition, Singapore is exploring potential CCUS deployment pathways, where carbon captured from industrial facilities could be utilised as feedstock for synthetic fuels or building materials (through mineralisation) or stored in sub-surface geological formations. (*12 Projects Awarded $55 Million to Accelerate Decarbonisation in Singapore*, 2021)

Singapore is highly dependent on international cooperation on decarbonisation efforts, and advocates for close bilateral, regional and plurilateral cooperation on decarbonisation. This includes collaboration on carbon markets, green finance, and low-carbon technologies. Singapore has already signed MoUs on carbon credits collaboration with countries including Indonesia, Colombia Viet Nam, Brunei and Marocco – in line with Article 6 of the Paris Agreement.

Indonesia – ETS (*Indonesia Launches Emissions Trading System for Power Generation Sector*, 2023)

In February 2023, Indonesia launched a mandatory, intensity-based emissions trading system (ETS) for the power generation sector. The ETS will cover facilities with a production capacity of more than 100MW, with the aim to also include smaller facilities in the future. 99 coal-fired facilities will be included from the start, covering 81.4% of Indonesia's national power generation capacity. Intensity targets will be set, and it is expected that allowances worth 20 million tCO_2e will be allocated.

The ETS will be implemented in three phases, covering coal-fired plants connected to the grid in the first phase (2023-2024), and including oil and gas-fired plants, and coal-fired plants not connected to the grid in phases two (2025 – 2027) and three (2028 – 2030).

The ETS launch followed a series of government-issued regulations, including 'Regulation No. 46 on Environmental Economic Instruments' in 2017, 'Presidential Regulation No. 98 on the Instrument for the Economic Value of Carbon' in 2021, Regulation 21/2022 'Guidelines for Carbon Economic Value Implementation' in 2021/22, and The MEMR's Regulation 16/2022 'Guidelines for Carbon Economic Value Implementation for the Power Generation Sub-sector' in 2022.

The ETS will operate as a hybrid cap-and-trade system, alongside a carbon tax announced in 2021, as part of 'Law No. 7 on the harmonisation of Tax Regulations'. This carbon tax has however been delayed and is expected to only come into effect in 2025.

Pertamina - JBIC

In November 2022, JOGME (JBIC) signed an MoU with Pertamina to strengthen cooperation between the two organisations, in support of Indonesia's commitment to achieve net zero emissions by 2060 or earlier. The MOU promotes collaboration between Pertamina and Japanese companies in renewable energy, hydrogen, ammonia, and CCS. JBIC will provide financial support to further Indonesia's decarbonisation goals. (*JBIC Signs MOU with National Oil Company of Indonesia, Pertamina*, 2022)

3.3.4.2. Transboundary Bilateral Agreements

- Singapore-Australia

Singapore is progressing options to provide services around CCUS projects, both to address national emissions liability and emissions reduction commitments, and to enhance the nation's role as a hub/cluster for CCUS projects within the Southeast Asian region.

In October 2022 Singapore and Australia signed the Singapore – Australia – Green Economy Agreement. The agreement builds upon earlier commitments, including the recent Low Emissions Solutions MOU, and will target a cooperative approach between the two nations towards supporting the transition to net zero emissions. The arrangement and the text of the agreement contain positive signals for collaboration around CCUS activities. The Agreement references the technology specifically under the '*Principles of Green Economy Cooperation*'.

- Brunei-Singapore

In October 2022, Shell Eastern Petroleum, a unit of Shell Plc, and Brunei Shell Petroleum (BSP) signed a MoU to explore carbon transport and storage options in Brunei and Singapore. The government of Brunei Darussalam and Shell group own 50% in BSP. This initiative has the potential to form part of a CCS hub in Southeast Asia. (*Shell Signs MoU to Explore Carbon Transport, Storage Options in Brunei and Singapore*, 2022)

Under the MoU, the parties will evaluate the technical and commercial feasibility of CO_2 storage in Brunei Darussalam and CO_2 transport solutions from Singapore. The two countries will also cooperate on policy development to support the implementation of the MoU.

Shell has set a corporate target of net zero emissions by 2050 and has expressed ambition to have access to at least 25 Mtpa of storage capacity by 2035. (*Shell to Explore Carbon Transport and Storage in Brunei and Singapore*, 2022)

- Pertamina – ExxonMobil

In May 2022, Pertamina and ExxonMobil signed a Joint Study Agreement (JSA) to assess the potential for large-scale deployment of low-carbon technologies, including CCS. The agreement builds on the MoU signed between the two companies in 2021, to advance CCS efforts in Indonesia. This collaboration will support Indonesia's ambition to reach net zero emissions by 2060.

This JSA will set the precedent for developed countries cooperating with developing countries to implement global climate solutions. (*Pertamina Cooperates with ExxonMobil to Study CCUS Technology Application in Three Oil and Gas Field Areas*, 2022)

- Petronas – South Korean Companies

In August 2022, Petronas signed MoUs with six South Korean companies to undertake conceptual and feasibility studies, aiming to establish a full CCS value chain. The MoU will include the evaluation of potential CO_2 storage sites in Malaysia, and exploration of other areas across the value chain, including cross-border CO_2 transportation and suitable capture technologies. The MoUs bring Malaysia closer to the establishment of a regional CCS hub in the country. (Petronas, 2022)

3.4. Designing CCS-Specific Law and Regulation

The development of CCS-specific legal and regulatory frameworks has been a key policy response of governments in various jurisdictions worldwide. Several jurisdictions across North America, Europe and in Australia have now successfully developed and implemented regulatory frameworks for the technology. The experience and processes adopted by these jurisdictions in developing and implementing their regulatory models, offer important insights for other governments seeking to design their own domestic CCS-specific regimes.

In the ASEAN region, where legal and regulatory frameworks to facilitate CCS activities are largely absent, regulators and policymakers will inevitably be required to consider several preliminary factors in the design and architecture of their legal and regulatory frameworks. The following sections examine these issues in greater detail.

3.4.1. Approach to Developing CCS-Specific Legislation

Regulators and policymakers, when designing CCS-specific legal and regulatory frameworks to-date, have adopted one of three approaches to regulating the technology. One option has been to enhance existing regulatory frameworks, usually permitting models regulating resources operations, to include CCS-specific provisions, while a further has been to enact stand-alone CCS-specific legal frameworks. The latter has largely resulted in singularly focused framework legislation, while the former has seen CCS activities included within broader, well-established regimes. A further option is the development of project specific legislation to regulate the operation of a sole CCS project; an example of which may be found in the legislation regulating the Gorgon CO_2 injection project.

For regulators and policymakers in the early stages of the legislative process, the decision whether to develop a full, stand-alone CCS regulatory framework, or to amend an existing regulatory pathway, may be influenced by several critical factors. While national specificities will ultimately guide the approach taken, several issues have been highlighted by early regulators in their adoption of a particular model.

3.4.1.1. Supporting Domestic Policy Priorities

A nation's domestic policy regarding the technology's deployment, will play a critical role in determining the regulatory pathway to be adopted by national policymakers and regulators. In some instances, this will require the reconciliation of a variety of critical, and at times potentially competing, factors when finalising the regulatory approach.

While several countries in the ASEAN region have outlined their ambitions for the technology as part of their future climate change mitigation and net zero strategies, many have similarly expressed their vision for CCS as a part of ensuring national energy security and sustaining domestic industry. To this end, policymakers and regulators may consider their domestic policy approach when determining the appropriate legal basis for a future regulatory framework, and, whether this issue is better addressed by a stand-alone or modified existing legal regime.

One example where this may prove significant, is where a nation's policy approach is to recognise other forms of CO_2 injection activities, beyond purely geological storage. In many jurisdictions across the ASEAN region, CO_2 injection is already regulated under existing and well-defined regulatory frameworks governing the resource sector, and consequently, there may be merit in utilising these regimes as the basis for regulating CCS activities. This topic is addressed further, in Section 3.4.2.

The immediacy of domestic policy commitments to emissions reduction, or the deployment of demonstration projects, may similarly impact the weight afforded to selecting a particular legal and regulatory approach. The time taken to incorporate CCS activities within existing regulatory regimes, for example, may ultimately prove more efficient in the near term, than the development of a dedicated CCS-specific framework ab initio. Regulators may choose therefore to use existing regulatory regimes to undertake demonstration projects, and use the regulatory lessons learned from these early activities to inform the later development of a more comprehensive stand-alone regulatory framework.

3.4.2. Role of Existing Regulatory Pathways

The Institute's review of ASEAN nations' legal and regulatory regimes reveals that only two countries have taken steps to introduce CCS-specific legislation. At the time of writing, only Indonesia and the Malaysian state of Sarawak have introduced detailed legal and regulatory frameworks that will regulate future storage operations. The regimes offer the first examples of CCS-specific legislation in the region.

For the wider ASEAN nations, which have yet to develop CCS-specific legal and regulatory frameworks, national policymakers and regulators may be required to rely upon existing regulatory regimes to facilitate early projects. A review of national law and regulations across the ASEAN region, suggests that in many instances these nations already have a body of legislation that would be applicable to CCS operations. Legislation governing the regulation of existing mining, oil, and gas activities, together with broader provisions found in national environmental, property and planning laws, will likely be relevant to aspects of the CCS project lifecycle.

In the context of determining a formal, long-term pathway for regulating commercial-scale deployment of the technology, these existing legal and regulatory regimes must be formally assessed. Several factors will likely prove key to a final decision regarding their utility, however, determining the readiness and adequacy of national legal and regulatory regimes will be central to this assessment.

When undertaking a review of this nature, policymakers and regulators will need to consider the ability of existing legislation to effectively regulate all aspects of the CCS project lifecycle. While existing permitting and licensing regimes, for example, may adequately manage the more familiar elements of the CCS process, it is unlikely that they will address the novel elements required of a CCS-specific regulatory framework.

A further, important consideration will be how, and indeed whether, existing legal and regulatory regimes may be amended or adapted to incorporate CCS activities. In some instances, as has been seen in several jurisdictions around the world, CCS-specific provisions may be readily incorporated within existing regulatory frameworks. Similarly, minor amendments to include or exclude CCS operations from the scope of current legislation, may also afford an efficient means of regulating the technology. The efficacy of this process, when compared with other means of regulating the technology, will be a significant factor in determining a future pathway.

3.4.3. Social License Considerations

The Institute's interviews with regulators, policymakers and industry have revealed that a nation's decision to establish a stand-alone framework or enhance existing legislation, may also be influenced by social license considerations.

The perceived risks of CO_2 storage activities, in comparison to other industries or other emissions reduction technologies, have been highlighted as a key factor shaping public opinion for the technology in several jurisdictions. The public's view of CCS activities will, therefore, hold implications for the approach to be adopted to regulate the technology. Policymakers and regulators interviewed in the ASEAN region, suggested that a lack of knowledge, or indeed a negative perception, as to the role of the technology and its decarbonisation potential are important considerations in their jurisdiction. The issue of stakeholder engagement is considered in greater detail in Section 3.4.5 below.

The establishment of a stand-alone regulatory framework may assist in differentiating CCS activities from other industry sectors and strengthen public perception regarding the climate change mitigation objectives that underpin the technology. An example of this approach can be seen in the case of the newly established regulatory framework to facilitate the offshore wind industry in Australia. In this instance, the approach has brought clarity and highlights the clean energy and emissions reduction objectives that underpin the regulatory framework.

The formal association of CCS activities with emissions intensive industries, through CCS-specific amendments to existing petroleum recovery or mining legislation, may serve to undermine the acceptance or support for the regulatory framework in some jurisdictions. For regulators seeking to develop a CCS-specific regime, in jurisdictions where social licence issues are likely to prove a significant factor, a stand-alone framework may be preferable. Ultimately, however, regulators will need to balance these considerations with the need to expedite the development of a regulatory framework to accelerate deployment in their jurisdictions. The urgency of the challenge may lead to regulators choosing to enhance existing legislation to accommodate CCS.

KEY MESSAGES

- The approach to regulating CCS activities is an important preliminary consideration for governments seeking to develop a CCS-specific legal framework. Regulators and policymakers have historically demonstrated a preference for one of two pathways; a stand-alone regulatory framework or enhancing existing oil and gas legislation to regulate CCS activities.
- While various factors will ultimately shape the approach adopted, in the context of the ASEAN region, domestic policy priorities and social license considerations are two critical factors that may guide policymakers.
- For nations which have established regulatory frameworks governing the resources sector and face the challenge of balancing economic growth with emissions reduction commitments, efficiency and urgency considerations may determine the pathway chosen.

PRIORITY ACTIONS FOR REGULATORS AND POLICYMAKERS

- Evaluate national policy priorities relating to climate change mitigation, energy security and economic development to evaluate the objectives that will underpin CCS-specific legislation and the preferred pathway for regulating the technology.
- Engage the wider public to better understand public sentiment towards CCS, and to gauge the public's level of knowledge and awareness of the technology's role in reducing greenhouse gas emissions.
- Review existing legal and regulatory frameworks relating to resources, energy, environment, property and planning, the adequacy of these regimes in regulating the novel aspects of CCS and the possibility of amending or adapting these frameworks to regulate CCS activities throughout the project lifecycle.

3.4.4. Scope of Frameworks

CCS projects that feature the dedicated geological storage of CO_2 have been the focus of regulators when establishing regulatory frameworks for the technology to-date. CCS technologies, however, constitute a far broader suite of applications and support decarbonisation across a range of sectors, from power generation to industrial activities.

In developing a legislative framework to regulate the CCS process, policymakers and regulators will be also required to consider the inclusion of these applications within the scope of their proposed regulatory models. The approach that will ultimately be adopted, must depend on the objectives underpinning the legislative framework for the technology, in light of the climate change mitigation, energy transition and economic development strategies of each country.

3.4.4.1. Permitting Various Applications

One application of CCS, that has been historically practiced in countries with well-established oil and gas sectors, is CO_2-Enhanced Oil Recovery (CO_2-EOR). The regulation of CO_2-EOR operations has typically been addressed under existing oil and gas legislation, with the activity proving an important feature of oil and gas extraction operations in many jurisdictions around the world.

In the United States the underground injection of fluids, including CO_2 for the purposes of EOR, has been a long-standing practice. Federal regulations for such activities have been in force since the 1980s, under the Class II well category of the US Environmental Protection Agency's Underground Injection Control (UIC) Program (US Environmental Protection Agency, 2023). The Class II categorisation constitutes a separate permitting pathway to those projects involving the dedicated geological storage of CO_2, which are regulated under the UIC Program's Class VI well category.

In Australia a similar approach has been adopted, and CO_2-EOR projects may proceed under existing Commonwealth and state-level provisions relating to petroleum recovery activities. A further permitting pathway has been established for projects involving the dedicated geological storage of CO_2. In other jurisdictions, CO_2-EOR projects have been excluded from the scope of regulatory frameworks entirely. The EU CCS Directive, for example, does not regulate Enhanced Hydrocarbon Recovery activities, save for instances where operators combine these recovery operations with permanent geological storage(Directive 2009/31/EC Of The European Parliament and of the Council, 2009).

In the ASEAN region, Indonesia's MEMR 2/2023 legislation includes both CCS and CCUS activities within its scope, however, these applications have been limited to the upstream oil and gas sector. In this regard, MEMR 2/2023 defines carbon capture utilisation and storage (CCUS) as an effort to reduce emissions and increase oil and gas production through the injection, utilisation and storage of CO_2 emissions (Minister of Energy and Mineral Resources Regulation Number 2 of 2023 Concerning Implementation of Carbon

Capture and Storage, as Well as Carbon Capture, Utilization and Storage in Upstream Oil and Gas Business Activities, 2023).

3.4.4.2. The Inclusion of Carbon Dioxide Removal (CDR) within CCS-Specific Legislative Frameworks

A widespread and growing consensus as to the critical role of carbon dioxide removal (CDR) in achieving net zero emissions by 2050, has brought technologies such as direct air capture and storage (DACCS) and bioenergy with CCS (BECCS) to the forefront of national policy discussions (Smith et al., 2023).

In countries where these technologies are anticipated to play a role in meeting emissions reduction targets, policymakers and regulators will be presented with novel and unique regulatory challenges. Issues relating to, amongst others, construction and infrastructure, land access, property rights and ownership of CO_2 and accounting and reporting have all been highlighted (Hester, 2018). As such, regulators may be required to consider the inclusion of these technologies within the scope of their frameworks and ensure the adaptability of existing frameworks to accommodate technical advancements in CDR technologies.

KEY MESSAGES

- Regulators and policymakers may decide to expand the focus of regulatory frameworks to include the broad suite of applications that constitute CCS technologies across the industrial and power sectors. The inclusion of various applications will depend on the objectives underpinning the legislative framework for the technology, which may relate to the nation's climate change mitigation, energy transition and economic development priorities.
- Permitting approaches may differ for various applications and separate permitting pathways may be established for specific applications. In some countries, certain enhanced hydrocarbon recovery applications, such as Enhanced Oil Recovery (CO_2-EOR), have been excluded entirely from the scope of CCS-specific frameworks.
- The significant role that emerging technologies such as carbon dioxide removal are expected to play in facilitating the net zero transition, will require regulatory frameworks to be adaptable and flexible to accommodate the novel and unique regulatory issues associated with these technologies.

PRIORITY ACTIONS FOR REGULATORS AND POLICYMAKERS

- Identify the specific applications to be covered by the scope of domestic regulatory frameworks.
- Review the extent to which existing regulatory frameworks, relating to resources, environment, property, and planning, may support dedicated geological storage and enhanced hydrocarbon recovery projects.
- Ensure CCS-specific regulatory frameworks remain future focused and are adaptable to reflect the technological advances associated with various applications and emerging technologies.

3.4.5. Detailed Review and Assessment of Domestic Regimes

The processes undertaken by regulators and policymakers, when considering their response to CCS activities, have also proven important factors in determining their ultimate approach to the nature and design of regulatory frameworks. In some of the early-mover nations, policymakers and regulators have completed targeted policy, legal and regulatory studies aimed at examining this very issue. While broader reviews of this nature are not uncommon during the development of legislation, these more targeted, assessment exercises have proven the basis of several of the more comprehensive CCS-specific frameworks enacted to-date.

CCS specific review processes of this nature may also be accompanied by periods of formal and informal consultation. The engagement of a wide variety of critical stakeholders, in addition to those engaged through pre-existing consultation processes, will likely result in the exposure and consideration of far broader range of issues and potential solutions. Previous examples of these processes have seen the formation of working groups that include industry, academia, and research institutions.

Wider international experience may also prove informative for those developing CCS specific legislation, and policymakers and regulators around the world have at times benefitted from engagement with stakeholders that have experience of addressing these particular issues. While several established fora may offer a platform for dialogue of this nature, national regulators and policymakers may seek to establish wider formal and informal dialogue with a variety of international stakeholders to assist in their assessment and decision-making processes.

KEY MESSAGES

- Regulators and policymakers in several jurisdictions have benefited from targeted studies and assessment exercises. In many instances these activities have afforded important inputs into well-structured and comprehensive regulatory frameworks.
- Inclusive consultation processes involving a diverse group of stakeholders from industry, academia, and research institutions, may contribute to a more comprehensive and holistic understanding of regulatory issues relating to CCS.
- Learning from the experiences of early-mover nations and engaging with international stakeholders provides valuable insights and expertise in the development of regulatory frameworks for CCS. Policymakers and regulators can benefit from established international forums and engagement in formal and informal dialogues to inform their decision-making processes regarding CCS-specific legislation.
- Within the region, the experiences of the governments of Indonesia and Thailand offer tangible examples of the processes involved in developing regulatory frameworks for CCS. Both countries have undertaken collaborative, iterative processes, that have engaged a diverse group of stakeholders across various levels of government.

PRIORITY ACTIONS FOR REGULATORS AND POLICYMAKERS

- Establish dedicated processes, that engage all relevant stakeholders within government, to examine and consider the relevant policy, legal and regulatory issues. Activities may include the conducting studies to obtain an understanding of the nuances required in regulating CCS technologies.
- Engage a diverse range of expert stakeholders from across industry, academia, research institutions and civil society, to gather expert perspectives on the regulation of the technology.
- Leverage international expertise through dialogue with international stakeholders experienced in addressing CCS regulatory challenges. Engage in formal discussions or collaborations through established platforms to benefit from international insights and experiences.

3.4.6. Identifying and Designating a Regulatory Authority

The development, implementation and administration of CCS-specific legal and regulatory frameworks will ultimately involve a range of government stakeholders. The experiences of jurisdictions that have already implemented their CCS-specific regimes and have regulated early CCS projects, suggests that a wide-variety of government departments and regulators will play a role in regulating CCS operations, throughout the project lifecycle. A failure to designate a lead agency, or to provide clarity as to specific regulatory responsibilities, has the potential to cause significant delays to decision-making and ultimately, the deployment of projects.

In addition to clearly designating a lead authority and identifying wider regulatory authorities, the coordination of the various regulatory functions will also be of critical importance, if projects are to progress efficiently through each stage of the project lifecycle. Early-mover nations, which have already developed their legal and regulatory frameworks, clearly identify the lead authority, agencies, and ministers responsible for awarding and administering CCS authorities within the relevant legislation.

Regulatory regimes will also require ongoing interaction between the relevant regulators and agencies, particularly where each may bear very distinct responsibilities under the regulatory framework. To address these potential conflicts, policymakers and regulators may wish to consider how regulatory regimes may be better streamlined or coordinated, to remove any potential obstacles that may cause unnecessary delay within the regulatory process.

Notwithstanding the efforts undertaken to-date, many of the government departments and agencies responsible for administering these regimes have limited CCS-specific experience. This issue is exacerbated further, when responsibility for permitting and administration of a regime extends beyond the lead agency, to include wider government departments and regulatory authorities. A lack of familiarity with CCS and the challenges associated with regulating activities throughout the project lifecycle, may ultimately lead to delay as a regulatory body acquaints itself with both the technology and the authority's consequential roles and responsibilities.

KEY MESSAGES

- CCS-specific frameworks may build upon existing licensing regimes and in some instances rely upon established pathways to regulate discrete aspects of the CCS process. The resulting regulatory frameworks will therefore require the involvement of numerous regulatory authorities and/or agencies, as permits and licenses are sought for capture, transport, and storage activities.
- Many of the government departments and authorities likely to assume roles and responsibilities in the regulation of the technology, throughout the project lifecycle, will be unfamiliar with the technology. There is a risk of delay or a disconnect within the regulatory process, where these stakeholders take time to familiarise themselves with the technology and new regimes.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Government should identify and formally designate a lead government department or regulatory authority, to promote the development and implementation of a CCS-specific regulatory regime.
- The lead authority or department may then act as a coordinator to ensure that all relevant policy and regulatory entities are engaged and familiar with their roles and responsibilities, as part of the regulatory process.
- Governments may wish to consider developing an education and capacity development programme, aimed at familiarizing the relevant policy and regulatory stakeholders with the technology and their roles and responsibilities within the regulatory process.

3.4.7. Stakeholder Engagement in the Development of Legislation

CCS projects are large infrastructure projects that will engage a diverse range of stakeholders, including the government, industry and the wider public. The nature of CCS operations, for example the scale and longevity of the impact of CCS activities upon the physical environment and the climate change mitigation objective that underpins the technology's deployment, have implications for each of these stakeholders. It is critical therefore, that a national legal and regulatory framework for CCS projects is developed with input from all relevant stakeholders. A regime that reflects the interests and distinct impacts of CCS activities, may help provide certainty for investors and operators of projects, assist in reducing administrative inefficiencies leading to permitting delays, and increase public confidence in the regulatory framework governing the technology.

Project operators have frequently cited regulatory uncertainty and lack of clarity in relation to issues such as pore space ownership, liability, and risk management, as significant barriers to developing projects. Plans for regional hubs, shared transport and infrastructure, and transboundary project models, are also increasingly dependent upon regulatory certainty. Proponents of these type of projects have also highlighted a variety of wider regulatory issues that may arise under these particular project models, including offtake agreements, public-private partnerships, production sharing contracts. These considerations involve coordination and the clarification of regulatory obligations between them (International Energy Agency, 2022).

The regulatory agencies and departments within government, that will be charged with overseeing and regulating projects, will also need to be equipped with the technical and regulatory capacity to ensure the efficient and smooth administration of a CCS-specific regulatory framework. Regulatory frameworks may also be developed at both national and sub-national levels and regulatory functions may be allocated to government agencies across local, state and national levels (Asian Development Bank, 2013). Consultation with the relevant government stakeholders to ensure the closer alignment of regulatory frameworks across various levels of government will be necessary to reduce potential conflict.

Widespread commercial deployment will also be dependent upon the public's perception of the technology. The impact of projects upon the environment, climate change goals, land-use, property rights, and human health and safety have all been highlighted previously as critical concerns. For CCS projects in particular, a lack of understanding of the CCS process, as well as its role in mitigating the impacts of climate change, have been found to be persistent issues and led to misinformation and skepticism(Asian Development Bank, 2013).

An example of a more specific community concern, recognised across various regions, has been the reluctance of private landowners to allow the development of transport pipelines and storage facilities on their land due to 'not-in-my-backyard' sentiments and concerns as to the technology's safety (Braun, 2017; Krause et al., 2014). In the ASEAN context, developing a regulatory framework that addresses these concerns will require consultation and input from the public. While stakeholder engagement may be required as part of a government's strategy to accelerate its deployment within a country, the development of legislation to facilitate CCS will likely require a separate engagement process, as highlighted by several of the regulators and policymakers interviewed by the Institute.

The Institute's interviews revealed that several ASEAN policymakers and regulators have already identified the lack of public awareness of the technology, as a concern in their individual jurisdictions. In these instances, interviewees thought it was critical that misconceptions regarding the environmental and safety implications of the technology were addressed and emphasised the role of private companies in awareness campaigns and educational initiatives.

For many ASEAN nations, a challenge lies in balancing the need to address these stakeholder interests, with the urgency required to develop and implement CCS-specific legislation. A lengthy consultation process that delays the regulatory process, may in turn postpone necessary project investment. Ultimately, national policymakers and regulators must adopt an approach that considers the need to ensure a fair, participative role for relevant stakeholders and caters to the urgency of the task of developing domestic legislation to support the technology's deployment.

KEY MESSAGES

- CCS projects are large, multi-faceted infrastructure projects that will invariably engage a variety of stakeholders from government, industry and the wider public. The development of legislation to regulate these activities will require policymakers and regulators to consider these stakeholders' interests and concerns as part of the process.
- Failure to adequately address the views of these stakeholders when designing and implementing legislation, may ultimately lead to dissatisfaction with the final regulatory framework. This in turn may lead to further inefficiencies or challenges to the deployment of CCS projects.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Government, through the lead regulatory authority, may undertake a formal process of public consultation to ensure interested parties are afforded the opportunity to provide their feedback and that this information is formally captured.
- A formal information programme, delivered by government and/or third-party expert organisations, may be delivered in-tandem with the public consultation effort. A programme of this nature could seek to clarify the role of CCS in addressing domestic climate change commitments or address any misconceptions surrounding the technology.

3.5. Overarching Legal and Regulatory Considerations

The development of CCS-specific legislation will require regulators to consider several wider or overarching legal and regulatory issues that may also impact the regulation of the technology. These issues, which are not confined to the technicalities and phases of a CCS project lifecycle model, are discussed in detail in the following sections.

3.5.1. International Obligations and Considerations

The nature of many contemporary CCS operations requires consideration of their legal position under broader international and regional legal and regulatory frameworks. While early CCS projects involved sub-surface geological CO_2 storage, within the onshore territory or offshore marine environment of a single jurisdiction, recent years have seen a stronger focus upon the development of projects with a transnational dimension to their operation. In the ASEAN region, several governments and proponents have signalled a greater focus upon storage projects of this nature.

CCS projects under consideration in the region, include a maritime aspect with CO_2 transported across international borders for storage in other jurisdictions. Projects of this nature will require close coordination between governments and companies from different countries, in the implementation of cross-boundary CCS value chains. Early assessments have identified that both conventional and transboundary project models hold implications under various international and regional legal frameworks relating to climate change, the law of the sea, and the prevention of pollution in the marine environment (UNFCCC Subsidiary Body for Scientific and Technological Advice, 2012).

Table 3.3 sets out the international legal frameworks that are potentially applicable to CCS projects. The table identifies the ASEAN nations that are parties to these agreements.

Table 3.3. International Law Frameworks Applicable to CCS Activities

Agreement	Southeast Asian Parties	Description	Application to CCS
The United Nations Convention on the Law of the Sea (UNCLOS) of 1982	Brunei, Indonesia, Malaysia, Philippines, Singapore, Viet Nam, Thailand	The United Nations Convention on the Law of the Sea (UNCLOS) of 1982 establishes an overarching framework agreement which regulates the various uses of the world's oceans and seas and creates specific obligations on states to protect the marine environment.	CCS is not specifically mentioned within the text of UNCLOS, so it may not be said to expressly regulate CCS activities. However, Article 192 of UNCLOS creates an obligation for States to protect and preserve the marine environment in each of their territorial zones of the sea. Similarly, Article 194 obliges States to use necessary measures to 'prevent, reduce and control pollution of the marine environment from any source'. States are further obliged to ensure their activities do not negatively impact the environment of other States and adopt domestic laws and regulations which prevent marine pollution stemming from land-based activities, seabed activities subject to national jurisdiction, dumping, vessels and through the atmosphere. These provisions may have implications for several CCS project activities, from transport of CO_2 via ships or pipelines, and monitoring of CO_2 stored to prevent CO_2 leakage. However, it is unlikely that the position of CCS would be clarified through UNCLOS as it is a framework law which sets the scene for the elaboration of precise obligations in other specific laws such as the London Convention and Protocol

Agreement	Southeast Asian Parties	Description	Application to CCS
			(Havercroft and Purdy, 2007).
The London Protocol of 1996 under the London Convention of 1972	Philippines	The London Convention of 1972 was the first international agreement to provide protection to the marine environment from the deliberate disposal at sea of wastes, however, it was decided in the 1990s that it required modernisation in the form of the 1996 Protocol. The London Protocol of 1996, which entered into force in 2006, supersedes the Convention for those parties to the Convention which have subsequently become parties to the Protocol. The Protocol adopts a stringent, precautionary approach to the disposal of wastes, with Parties required to prohibit the dumping of all wastes at sea, save for those listed in the Protocol's Annex.	The London Protocol's Annex currently includes the category consisting of '*Carbon dioxide streams from carbon dioxide capture processes for sequestration*' which provides a formal basis for the regulation of CO_2 sequestration in sub-seabed geological formations under the Protocol's mechanisms. The Protocol, and in particular its implications for the transboundary movement of CO_2, is considered in greater detail in Section 3.5.2.
International Convention for the Prevention of Pollution from Ships 1973 (MARPOL)	Indonesia, Malaysia, Philippines, Singapore, Thailand, Viet Nam	MARPOL is the primary international agreement for regulating the prevention of pollution by ships. MARPOL seeks to prevent and regulate both pollution and accidental pollution caused by routine shipping operations.	While there is currently no reference to CCS operations within the text of the convention, several amendments have been made to the Annexes to MARPOL, to address the prevention of pollution from shipping. Annex III to MARPOL sets out regulations for the prevention of pollution by harmful substances carried by sea in packaged form. In the context of CCS, the transboundary shipment of CO_2 in gas cylinders or in liquefied form may need to comply with the

Agreement	Southeast Asian Parties	Description	Application to CCS
			requirements set out in Annex III to MARPOL (UNFCCC Subsidiary Body for Scientific and Technological Advice, 2012). Annex VI to MARPOL regulates the prevention of air pollution from ships. A 2018 amendment to Annex VI to MARPOL obliged ships of 5,000 gross tonnage and above to collect consumption data for each type of fuel oil used by the ship, which is to be reported to the flag State after the end of each year.
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal 1989	Brunei, Indonesia, Philippines, Malaysia, Thailand, Singapore	The Basel Convention governs the international trade of hazardous waste with the underlying aim of protecting human health and mitigating risks to the environment. The Convention calls for the reduction of waste production and establishes an international regime for controlling the transboundary movement of waste. A key principle established by the convention is that waste generated by one country should be disposed of within that country. The Convention provides that international trade in hazardous waste is subject to obtaining the prior consent of the receiving country, which is entitled to prohibit this transport. The Basel Convention defines waste as	The provisions of the Basel Convention raise questions as to whether CO_2 is to be treated as a hazardous waste under the Convention. Thus far, CO_2 has not been mentioned in the Convention or included in the Annexes of the convention as a hazardous substance. However, several provisions of the Convention may be extended to CO_2, bringing it under the scope of the Convention. For example, the characteristics of substances listed within Annex III of the Convention, such as corrosiveness and toxicity may be extended to CO_2, particularly where CO_2 from CCS operations is mixed with other substances. Furthermore, Annex IV of the Convention relates to various types of waste disposal operations, including deep injection and release via

Agreement	Southeast Asian Parties	Description	Application to CCS
		'substances or objects which are disposed of … by the provisions of national law'' and the characteristics of hazardous wastes are listed in the Convention's annexes. Contracting Parties are also able to add other categories of waste that are considered hazardous within their national laws and are required to notify the Secretariat of the Convention in such event. International cooperation underpins the Basel Convention, as Parties are required to cooperate by sharing information, monitoring the impact of trading hazardous waste on human health and the environment and developing technical guidelines and codes of practice relating to such disposal. An amendment to the Basel Convention was introduced in 1995 prohibiting the shipment of waste from developed (namely the EU and OECD nations) to developing countries, lacking the legal, technical, and administrative capacity to ensure environmentally safe disposal. Furthermore, the Protocol to the Basel Convention establishes a regime for the allocation of liability for accidents while transporting hazardous waste. However, both	sub-seabed injection into the seas/oceans. If CO_2 is covered by the scope of the Convention, this will hold implications for implementing transboundary CCS projects. Firstly, if CO_2 is treated as a hazardous substance, potential conflicts may arise between states that have chosen to prohibit transport or transit of CO_2 into or over its territory and those states that have allowed these activities. The Convention also only allows hazardous waste to be transported from states that lack the adequate storage and technical capacity to dispose of waste within their own territories. If CO_2 is covered by the Convention, this provision may restrict the export of CO_2 for disposal overseas. To overcome the ambiguities under the Basel Convention relating to CO_2 further clarification is required either in the form of an amendment to the Convention or a determination from the Secretariat to the Basel Convention regarding the treatment of CO_2 under the Convention(UNFCCC Subsidiary Body for Scientific and Technological Advice, 2012).

Agreement	Southeast Asian Parties	Description	Application to CCS
		the 1995 amendment and Basel Protocol are yet to enter into force. A list of substances that constitute waste is defined within the Convention's Annexes.	

Source: GCCSI.

Several of the international agreements highlighted are primarily environmental treaties and as such, were not designed to facilitate large-scale CCS deployment. States will need to consider international environmental law principles such as sustainable development and the precautionary principle in the implementation of their international obligations under these frameworks. The application of these principles may pose a challenge to CCS projects, potentially leading to project permit delays or necessitating the fulfillment of additional environmental impact requirements when conducting injection operations (UNFCCC Subsidiary Body for Scientific and Technological Advice, 2012).

For regulators and policymakers in the ASEAN region, consistency and compliance with international law will be a key consideration when developing legal and regulatory regimes to facilitate CCS project activities. Of particular significance, will be whether a country is a party to an agreement and if they have implemented their obligations under the relevant frameworks within existing national and sub-national legal and regulatory regimes. Clarification of the position of CCS activities under relevant international law frameworks will be imperative for individual states in the region, to ensure there is consistency with national legislation and to maintain commitments under regional institutional frameworks[2].

3.5.2. The Legality of Transboundary Offshore CO_2 Storage Value Chains under the London Protocol

The focus in the ASEAN region upon advancing collaborative project models that involve offshore transboundary CCS activities, will require close consideration of international marine agreements. The 1972 London Convention and its 1996 Protocol, which are aimed at protecting the world's oceans from pollution, have been central to determining the legality of offshore CCS operations.

The 2006 amendment to the London Protocol has proven particularly significant for CCS activities and constituted formal recognition of the storage of CO_2 in sub-seabed geological formations within international law. The amendment inserts the category of '*Carbon dioxide streams from carbon dioxide capture processes for sequestration*' into the Annex of wastes that may be considered for dumping in the marine environment and provides a basis for the regulation of CO_2 sequestration in sub-seabed geological formations under the Protocol's mechanisms.

[2] For example, the ASEAN Joint Declaration on Hazardous Chemicals and Wastes Management, recognises the significance of the Basel Convention in ensuring the management of hazardous wastes and calls for consistency and effectiveness in the implementation of the Convention's provisions across the region.

Transboundary Considerations

Although the 2006 amendment allows the storage of CO_2 in sub-seabed geological formations, Article 6 of the Protocol, which is principally aimed at preventing the export of wastes to non-Parties, has the effect of similarly prohibiting the transboundary transportation of CO_2 for the purposes of geological storage. In October 2009, a formal amendment to Article 6 of the Protocol was adopted by the signatories to the London Protocol to allow for cross-border transport and export of CO_2 for geological storage (Resolution LP-3(4), 2009). However, the amendment required ratification by two thirds of the Protocol's contracting parties to enter into force and thus far, only the governments of Belgium, Denmark, South Korea, Sweden, Norway, United Kingdom, Netherlands, Finland, Estonia, and Iran have ratified this amendment. More recently, the government of Switzerland has also communicated its intention to ratify the amendment. To date, however, the amendment has not entered into force.

At the 2019 meeting of the Contracting Parties to the Protocol, agreement was finally reached to allow the provisional application of the 2009 amendment as an interim solution (IMO Document LC 41/17/Add.1, 2019). The agreement will now allow those countries, who wish to export their CO_2 for storage in another country's territorial waters, to implement the provisions of the 2009 amendment in advance of it entering into force. Adopting the resolution will not set a precedent and will only be binding upon those Parties that choose to be provisionally bound by the amendment. Parties still, however, will be required to meet the standards prescribed by the Protocol.

Figure 3.2 provides an overview of the respective obligations of Contracting Parties and Non-Contracting Parties when undertaking the transboundary export of CO_2 in the context of the 2009 amendment to the London Protocol and the 2019 Resolution accepting the provisional application of the 2009 amendment to the London Protocol (IEA, 2021b).

Figure 3.2. Cross-border maritime CO_2 transport under the 2009 Amendment and 2019 Resolution for Provisional Application of the London Protocol (IEA, 2021)

		LP status of country receiving CO_2 for storage:	
		Contracting party	**Non-contracting party**
LP status of country capturing CO_2 for export:	**Contracting party**	CPs must establish agreements or arrangements, depositing formal declarations to the IMO detailing compliance with environmental conditions related to the composition of CO_2 streams, and CO_2 storage	Exporting CP must ensure that control conditions and permits as applicable to CPs. CP must ensure agreements or arrangements are maintained by the receiving country
	Non-contracting party	Receiving CP must ensure that exporting country demonstrates appropriate consideration of incidental associated substances in CO_2 stream, and treatment if needed. CP must ensure agreements or arrangements are maintained by the exporting country.	Not governed by the LP; may be subject to UNCLOS

Note: LP = London Protocol; CP = Contracting Party.
Sources: IEAGHG (2021); IMO (2013).

Compliance with the London Protocol: Considerations for ASEAN Nations

In Southeast Asia, only the Philippines is a Contracting Party to the London Protocol and no country has ratified the 2009 amendment to Article 6 of the London Protocol, or deposited declarations to allow the provisional application of this amendment. To date, only the governments of Norway, the Netherlands, Denmark, Korea, the United Kingdom, Sweden and Belgium have deposited declarations announcing the provisional application of the 2009 amendment to the London Protocol within their jurisdictions.

To undertake projects that feature a transboundary component hosted by a Contracting Party to the Protocol, it will be essential for national governments in the region to ensure they comply with the provisional application requirements agreed by the Parties in 2019. National regulators and policymakers who are Contracting Parties to the Protocol will be required to support these projects, put into place the necessary agreements, and subsequently notify the IMO of their arrangements.

In the context of plans to initiate transboundary CCS projects, it is a key near-term priority for Southeast Asian nations to take steps to ratify the London Protocol and adopt the 2009 amendment to Article 6 of the Protocol to avail themselves of the provisional application requirements of this amendment.

KEY MESSAGES

- A wide variety of international agreements are to be considered when determining the legality of domestic or regional CCS operations.
- Activities involving the transport of CO_2 across international maritime zones and marine areas have implications under a broad range of international agreements, including those relating to the pollution of the marine environment, the safety of maritime transport, the transport of dangerous goods and the carriage of compressed gases.
- The London Protocol removed barriers to the technology's deployment and provided a basis under the Protocol's mechanisms for the regulation of CO_2 sequestration in sub-seabed geological formations. Recent amendments to this agreement offer an important pathway for facilitating the transboundary transportation of CO_2 for geological storage.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Undertake a detailed review of national commitments under wider international law, to determine their impact upon CCS operations.
- Investigate the implications of exporting/importing CO_2 from those countries which are Parties or non-Parties to the London Protocol.
- Develop secondary guidance to support project developers when advancing projects that feature the transboundary movement of CO_2.

3.5.3. Interactions with Wider Domestic Legal Frameworks

Irrespective of the pathway chosen to regulate CCS activities, a more extensive body of national laws and regulations will also be applicable to the capture, transport and storage operations of a CCS project. CCS projects have similar features to major oil and gas operations and industrial activities and as such, it is likely that legislation governing operational liabilities, pollution prevention and control, health and safety, planning and environmental impact assessment, will apply to the various aspects of the CCS process.

The scale and nature of CCS operations will require regulators and policymakers in the ASEAN region to consider the potential interactions and obligations triggered under wider domestic legislation, when developing their CCS-specific legal and regulatory frameworks. CCS-specific regimes may directly outline compliance requirements within broader legislation or include a general overarching provision requiring project operators to ensure compliance with existing laws and regulations relevant to activities within the CCS project lifecycle.

An example of this approach may be found in Indonesia's new legal regime for CCS and CCUS projects, established by MEMR 2/2023. In this instance, the legislation requires projects to draft plans on the mitigation and management of environmental, social and public impacts, in accordance with existing laws and regulations. The requirement will likely bring CCS and CCUS projects under the scope of Indonesia's existing AMDAL process. The process is Indonesia's system for conducting environmental impact assessments, and involves several elements, consisting of a Terms of Reference, an Environmental Impact Analysis Report, an Environmental Management Plan and an Environmental Monitoring Plan. At present, Indonesia's CCS regime does not clarify the exact obligations of project operators in relation to the AMDAL process. [3]

Many countries within the ASEAN region are seeking to conduct offshore CO_2 storage activities, develop storage sites in specific geographical regions of their territories, and undertake CO_2 export and import activities via ship. In these circumstances, it is likely that CCS activities will trigger domestic legislation relating to the environment, maritime shipping, natural resources, construction, planning health and safety.

In Malaysia, for example, it is likely that CCS project construction and development will be required to comply with additional obligations under the country's federal and state planning and construction laws. The Department of Environment, at the federal level will determine as part of its Environmental Impact Assessment review whether the project is consistent with local zoning requirements. However, the ultimate decision will be made by state and local authorities. There is currently no clarity as to how these various federal and state legal frameworks interact and apply in the context of CCS projects.

Clearly defining the obligations of project operators within wider national laws and regulatory regimes, through consequential amendments for example, will provide certainty and afford greater depth to national CCS-specific regulatory frameworks.

[3] Indonesia's Gundih CCS project, a small-scale CCUS pilot project at the onshore Gundih gas field, was the subject of an AMDAL during the early stages of the project (Asian Development Bank, 2019b).

KEY MESSAGES

- A substantial body of domestic legislation will ultimately apply to the entirety of a CCS project. For many nations within the ASEAN region, existing oil and gas operations will provide a good analogue for the various regimes that may also apply to CCS activities.
- Legislation relating to planning, land use, energy, health and safety, and environment protection matters will likely be applicable to CCS operations.
- In some jurisdictions, sub-national legislation (e.g. state level legislation) may also be applicable to CCS operations.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Undertake a detailed review of national legislation to determine key legal instruments applicable to CCS operations.
- As part of this review, policymakers and regulators should identify the wider approvals pathways for CCS projects, to reflect all necessary national and sub-national legislation. The review should also seek to clarify obligations for project proponents and determine responsibilities between various national and sub-national regulatory authorities.
- Identify overlapping permitting responsibilities between national and sub-national regulatory authorities and identify any potential challenges.
- The development of secondary guidance may assist project proponents in navigating the requirements of wider legal and regulatory regimes.

3.5.4. Enabling Emerging Project Models

Historically, many CCS projects were proposed as a single integrated system, incorporating a sole CO_2 capture plant with its own CO_2 transport and storage facilities. The CCS process associated with this project model, particularly the transport and storage elements of the project lifecycle, also share similar characteristics to traditional oil and gas activities. These characteristics have enabled existing oil and gas legislation to provide a useful starting point for the regulation of activities across the CCS value chain.

More recently, however, there has been a strong focus upon the development of networked projects, using shared transport and storage infrastructure to which multiple industrial point sources of CO_2 are connected. Some CCS developments, such as shipping projects, pipelines, or new storage facilities, do not involve CO_2 capture at all and handle CO_2 captured by third parties. An example of this type of project can be seen in the province of Alberta, Canada, where a growing number of multi-user storage-only facilities are being deployed to facilitate industrial decarbonisation (Government of Alberta, 2023).

In the ASEAN region, high domestic emissions, limited domestic storage potential and close geographic proximity to suitable storage sites in the territorial waters of neighboring countries, have also strengthened the case for the export and import of CO_2. Several countries and operators in the region are seeking to adopt a more collaborative approach towards exploring project models that involve the transboundary export and import of CO_2 for storage.

The need for a legal and regulatory framework that encompasses the new issues and risks that these project models entail, is a further consideration for regulators and policymakers seeking to regulate CCS. Shared transport and storage infrastructure linked to industrial clusters, for example, will involve multiple stakeholders and raise a variety of potential issues. In this instance, legislation will be required to consider the coordination of CO_2 storage licenses, the allocation of liabilities for leakage, clarity as to pore space ownership, technical requirements for receiving and storing CO_2, fair and equitable access to shared infrastructure and adequate dispute resolution mechanisms in the event of any conflict (International Energy Agency, 2022).

With proponents in several ASEAN nations considering transboundary CCS projects that involve storage hubs and shared transport elements, the development of legislation that addresses novel issues and ensures cooperation and clarity for the various stakeholders involved, will be essential for ensuring their deployment.

KEY MESSAGES

- Modern CCS projects, including those proposed and in-development in some ASEAN nations, increasingly feature networked elements, utilising shared transport and storage infrastructure.
- Projects of this nature will likely require policymakers and regulators to adopt new regulatory approaches for their management.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Timely engagement with project proponents to understand project proposals in development.
- Ensure that the development of any subsequent CCS-specific legislation adequately manages these new and emerging project models.

3.5.5. Eligibility under Carbon Crediting Mechanisms

In many jurisdictions, legislation plays an important role in supporting wider policy mechanisms employed by governments to incentivise CCS deployment. Governments frequently require compliance with CCS-specific legal and regulatory frameworks to qualify for incentive schemes that may promote or support the deployment of CCS, such as emissions trading or carbon crediting schemes.

There are several emissions trading mechanisms in operation worldwide, which provide operators or owners of CCUS projects the ability to acquire emissions credits and allowances for conducting emissions reduction activities. Examples include the EU Emissions Trading System (EU ETS), California's cap and trade programme and Alberta's Technology Innovation and Emissions Reduction (TIER) Regulation. The regulatory frameworks governing the operation of CCS projects are central to the generation of credits under these schemes. In the EU, for example, operators that successfully capture, transport and store CO_2 emissions in accordance with the provisions of the EU CCS Directive, are not required to surrender allowances for these emissions under the EU ETS.

Indonesia's new regime enables contractors to benefit from the carbon economic value created by CCS activities. The carbon economic value relates to the carbon credits generated from the emissions reductions achieved by CCS activities. Carbon credits may be delivered under the carbon trading scheme established in Indonesia under Presidential Regulation No. 98/2021 on Economic Value on Carbon, which currently recognises CCS and CCUS as an emissions reduction activity.

The interaction between the regulatory framework and any incentive schemes is critical to the commercial considerations that underpin many CCS projects. Clarifying the nature of this interaction, within the design and development of a CCS-specific regulatory framework, will be critical for eliminating inadvertent barriers to investment.

KEY MESSAGES

- Compliance with CCS-specific legal and regulatory regimes is an important feature of many carbon crediting schemes that offer support for CCS activities.
- Several examples of this interaction exist in jurisdictions around the world and enable project proponents to gain formal recognition of their geological storage operations, including the generation carbon credits.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Undertake a formal review of the inclusion of CCS activities within any existing or proposed domestic carbon crediting scheme or mechanism.
- Examine the legal and regulatory implications of formally recognising the geological storage of CO_2 within any existing or proposed scheme or mechanism.

3.5.6. Interaction with Reporting and Accounting Mechanisms

Regulatory frameworks play an important role in defining robust reporting and verification requirements and ensuring that emissions reductions associated with CCS activities can be accurately verified. As discussed in the preceding section, compliance with these regulatory requirements also enables project operators to realise their verified emissions reductions under established carbon crediting mechanisms or schemes.

National accounting schemes and regulatory programmes play a key role in this regard. For example, in Australia, the National Greenhouse and Energy Reporting (NGER) scheme is central to Australia's national greenhouse gas (GHG) accounting model and is the principal data source for preparing the national GHG inventory (Clean Energy Regulator, 2022). Under the NGER scheme, registered corporations that meet the prescribed thresholds under the scheme, are required to report annually on all greenhouse gas emissions, energy production and energy consumption from facilities under the operational control of the registered corporation or members of its group.

The NGER scheme has now been amended to explicitly recognise the role of CCS. The 2008 Regulations, that underpin the scheme, now include specific provisions regarding the treatment of emissions and CCS operations. Further guidance is also set out in the 2008 Measurement Determination and the accompanying Clean Energy Regulator (CER) guideline, which offer more detailed methodological and measurement provisions to enable reporters to appropriately report emissions from those facilities employing CCS during a reporting year. Emissions reductions reported and accounted for, pursuant to the NGER scheme, enable projects to qualify for carbon credits under mechanisms such as the Emissions Reduction Fund (ERF) in Australia.

Other notable examples of schemes which explicitly address CCS projects, include the EU Emissions Trading Scheme (EU ETS), the California LP(LCFS) and the US federal Greenhouse Gas Reporting Program.

3.5.6.1. Accounting and Reporting Obligations in the Context of Transboundary CCS Value Chains

In the context of transboundary CCS operations, national accounting schemes and regulatory programmes will need to consider a variety of factors. The involvement of multiple stakeholders from the countries involved in a transboundary CCS project, the allocation of responsibilities for the reporting of CO_2 captured at source and stored in the reservoir, as well as any necessary accounting of CO_2 leakage in the transport chain and storage reservoir, must all be addressed. An example of how reporting responsibilities can be allocated is to be found in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, which includes guidance on accounting for greenhouse gas emissions and removals that result from the CCS value chain(Intergovernmental Panel on Climate Change, 2006a).

The guidelines provide that where CO_2 captured in one country (Country A) is to be transported for storage in another country (Country B), Country A is required to report the amount of CO_2 captured, any emissions from transport or temporary storage that takes place within the territory of Country A, and the amount of CO_2 exported to Country B. Country B in turn is required to report the volume of CO_2 imported, any emissions from transport and temporary storage (within the territory of Country B) and any emissions from injection and geological storage sites (Intergovernmental Panel on Climate Change, 2006b).

Under this allocation of responsibilities, where CO_2 is received for storage from another country, a country will be required to report the volume of CO_2 received (imported) and any emissions associated arising from the transport, temporary storage, injection and storage of the imported CO_2.

For regulators and policymakers in the ASEAN region seeking to establish CCS-specific legal and regulatory frameworks, the clarification of reporting obligations of projects will be a key consideration. Regulatory frameworks relevant to CCS operations must also require adequate safeguards are in place to ensure that any injected CO_2 remains permanently stored. Such safeguards will be essential for demonstrating the integrity of emissions reductions associated with CCS projects.

KEY MESSAGES

- The detailed reporting and accounting of stored CO_2, as part of geological storage operations, is an important aspect of ensuring compliance with CCS-specific legislation and for ensuring the wider integrity of CCS operations.
- Several national greenhouse gas reporting frameworks have been amended to formally recognise the geological storage of CO_2 and provide formal methodologies for operators when reporting their storage operations.
- The 2006 IPCC Guidelines offer an important indication as to how national accounting schemes may manage the reporting of transboundary CCS operations.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Review current emissions reporting and accounting frameworks to determine the extent to which CCS operations may be addressed.
- Ensure clarity within domestic emissions accounting frameworks of the treatment of CO_2 subject to transboundary movement.

3.5.7. Developing National Protocols and Regulatory Guidelines

A further consideration for regulators and policymakers is the development of national protocols and regulatory guidelines to accompany CCS-specific legal and regulatory frameworks. National protocols that establish standardised requirements for various aspects of the CCS project lifecycle, such as site selection, assessment and approvals, and CO_2 transport, ensure uniformity in administering compliance procedures to regulators. Guidelines issued by regulators often provide the necessary context and specificity to project operators when navigating the complexity of CCS-specific legal and regulatory frameworks.

In 2010 the European Commission released four Guidance Documents to aid the European Member States in their implementation of the Directive on the geological storage of CO_2 (CCS Directive)(European Commission, 2023). The four documents, which were aimed at promoting consistency in application of the Directive's provisions, covered the following topics:

1. CO_2 Storage Life Cycle Risk Management Framework
2. Characterisation of the Storage Complex, CO_2 Stream Composition, Monitoring and Corrective Measures
3. Criteria for Transfer of Responsibility to the Competent Authority
4. Financial Security and Financial Mechanism.

Following an extensive period of consultation with experts from the Member States and other key stakeholders (including industry, academic and research communities and NGOs), final versions of the guidance documents were published by the Commission in late March 2011. Although these guidance documents are not legally binding, they have proven an important source of information for many parties in interpreting the key principles of the original Directive. These documents are currently under review and will be updated by the Commission to reflect experience to-date.

Guidance Documents for CO_2 Storage Activities: Examples from Australia

In Australia, two key regulatory authorities are responsible for administering the approvals process for CCS projects under Australia's Commonwealth Offshore Petroleum and Greenhouse Gas Storage Act of 2006, the National Offshore Petroleum Titles Administrator (NOPTA) and the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA). Both NOPTA and NOPSEMA issue guidance to industry on applying for various greenhouse gas storage authorities and complying with obligations relating to such authorities.

For example, to be granted an injection license to commence injection operations, the Offshore Petroleum and Greenhouse Gas Storage Act 2006 mandates that a project operator is required to obtain a declaration of the suitability of an identified GHG storage formation. NOPTA has issued guidance that notes that applicants will be required to define the 'fundamental suitability determinants' for the eligible storage formation, which will include the following:

- the amount of GHG substance that may be stored, noting that it must be at least 100,000 tonnes
- the particular GHG substance for which the storage formation is suitable to store
- the proposed injection point or points
- the proposed injection period
- any proposed engineering enhancements (if any) required
- the effective sealing feature, attribute or mechanism of the storage formation that enables permanent storage.

Project operators are also required to submit an environment plan prior to undertaking a GHG activity. The content of the Environment Plan is described in detail by NOPSEMA in the 'Environment plan content requirement' guidance note. For example, the Guidance note requires that project operators provide information on aspects such as:

- The activity and the environment
- Regulatory and other requirements and acceptable levels for impacts and risks
- Detailed analysis of impacts and risks
- Evaluation of impacts and control measures
- Environmental performance outcomes, standards and measurement criteria
- Public comments and adjustments
- Consultation process and ongoing consultation measures
- Implementation strategy and environmental management system

Source: Offshore Petroleum and Greenhouse Gas Storage Act 2006, Australia.

In the ASEAN region, Indonesia remains the only country that has established comprehensive CCS-specific legislation. Articles 53-55 of the MEMR 2 of 2023, however, mandates the authority administering the framework to provide guidance and supervision regarding the implementation of CCS and/or CCUS activities (Minister of Energy and Mineral Resources Regulation Number 2 of

2023 Concerning Implementation of Carbon Capture and Storage, as Well as Carbon Capture, Utilization and Storage in Upstream Oil and Gas Business Activities, 2023).

These examples demonstrate how national protocols and guidance may provide further detail to a CCS-specific legal and regulatory framework, and consequently afford greater certainty to project operators. Developing guidelines and protocols, which incorporate best practice and remain adaptive to project realities, also ensures the smooth and efficient implementation of regulatory frameworks.

KEY MESSAGES

- Supplementary guidance, in the form of national protocols or regulatory guidelines, offers important assistance to all project proponents when interpreting and utlising legal and regulatory frameworks.
- While the development of this type of guidance is not uncommon, policymakers and regulators in several jurisdictions have developed materials that will assist parties in their interpretation of the requirements of early CCS-specific frameworks.
- Policymakers and regulators may adopt an iterative approach to the development of these guidance materials, enabling them to be updated to reflect recent developments and best practice models.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Review existing national protocols and guidance that may support the development and interpretation of future CCS-specific legislation.
- Where legislation is being proposed or implemented, policymakers and regulators may consider the development secondary guidance to support project developers in complying with the new legislative requirements.

3.6. A CCS-Specific Legal and Regulatory Framework

The Institute's analysis, together with the outcomes of the accompanying interviews and workshops, reveals the principal concern of governments throughout the ASEAN region, remains the formal design of CCS-specific regimes. Notwithstanding the critical policy, legal and regulatory choices that will determine and underpin the architecture of future regimes - examined in the preceding sections of this report - policymakers and regulators in the region are also keen to identify and understand the issues and elements that comprise a CCS-specific regulatory framework.

The Institute's review similarly confirms that ASEAN governments and industry stakeholders throughout the region, recognise the need for national frameworks to be comprehensive and facilitative of the technology's deployment. While many regional governments remain in the early stages of designing their regimes, and yet to fully determine how they will regulate the technology, several have consistently noted the need to develop legislation which reflects the lifecycle of a CCS project. As such, these key stakeholders are seeking guidance as to how existing international best-practice may support these ambitions when developing regional approaches and national legislation.

The following section sets out the key issues and considerations to be addressed by ASEAN governments, as they navigate the design and implementation of domestic CCS-specific legislation. The content builds upon the earlier sections, which focused upon conceptual and related legal issues, to provide a regionally focused overview of a CCS-specific legal and regulatory framework.

3.6.1. Identifying the Key Elements of a Legal and Regulatory Framework

During a period of concerted action by some policymakers and regulators in the two decades since 2003, proponents of the technology have seen the removal of both national and international legal barriers to the technology, as well as the emergence of several comprehensive, jurisdiction-specific regimes. These legal and regulatory regimes have made significant contributions towards addressing the issues identified as obstacles or barriers to deployment. In many instances, the development of this legislation has led to the promotion of novel approaches to regulating the technology, within the bounds of domestic regulatory regimes.

The CCS-specific models, adopted across several jurisdictions in Europe, North America, Asia and Australia, have largely followed a similar approach and regulate the entirety or aspects of the CCS process. As highlighted in the preceding section of this report, in all but one instance, policymakers and regulators have also adopted one of two pathways to regulating the technology, deciding to either enhance existing regulatory frameworks with CCS-specific provisions or to enact stand-alone CCS-specific legal frameworks. While these regimes vary in their complexity, and contain nuances that reflect national requirements, they also share many commonalities in the way they address the novel challenges of the CCS process.

3.6.1.1. Assessment and Guidance Frameworks

A further, important tool for nations' seeking to develop their legal and regulatory regime for the technology, are the variety of assessment and guidance frameworks that are now available to regulators and policymakers. The past decade has seen the development of several of these frameworks, which have been developed with the aim of supporting the promotion and development of CCS-specific legislation, or as a means of assessing national frameworks' ability to regulate the CCS process. Developed by leading intergovernmental, research and academic institutions, these frameworks provide a useful insight into the key elements and principles that underlie may of the current CCS-specific legal and regulatory frameworks.

Several of these assessment and guidance frameworks were considered in the completion of this document:

- *CCS Legal and Regulatory Indicator (CCS-LRI),* Global CCS Institute, Melbourne, 2023.

The Institute's Legal and Regulatory Indicator provides a detailed examination and assessment of national legal and regulatory frameworks in 55 countries. Now in its fourth edition, the Indicator employs a legal and regulatory assessment model that considers a range of issues that have been determined to be essential for regulating a CCS project throughout its lifecycle. The resulting assessment provides an indicative guide as to the complexity of a nation's current regulatory model.

- *Legal and Regulatory Frameworks for CCUS: An IEA CCUS Handbook*, International Energy Agency, Paris, OECD/IEA 2022.

Developed by the International Energy Agency (IEA) in 2022, the handbook builds upon and updates the earlier *Carbon Capture and Storage: Model Regulatory Framework* that was developed in 2010. The handbook is a non-prescriptive resource and is intended as a guide for those seeking to develop legislation. The model highlights 25 essential issues that policymakers and regulators may consider when designing and implementing a CCS-specific regulatory regime. While ultimately high-level, the model draws upon existing frameworks and the experiences of several jurisdictions around the world.

- *Prospects for carbon capture and storage in Southeast Asia,* Asian Development Bank, Mandaluyong City, Philippines: Asian Development Bank, 2013.

The 2013 study, completed by the Asian Development Bank, included a detailed assessment of the legal and regulatory regimes of Indonesia, the Philippines, Thailand, and Viet Nam. Although the four nations do not currently have dedicated CCS-specific legislation, the report recognised that national regulators need not start from scratch and may develop their regimes based upon existing legal and regulatory pathways. To this end, the report proposed several issues that would need to be addressed to support the commercial development of CCS in these nations.

- *CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage,* World Resources Institute (WRI). Washington, DC: WRI, 2008.

The WRI Guidelines were developed to support project proponents, financiers, policymakers and regulators, in the design and operation of CCS projects. Although intended for a wide audience, the Guidelines highlight key considerations across the capture, transport and storage aspects of the CCS project lifecycle.

- *Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies,* APEC Energy Working Group, APEC Secretariat, September 2012.

The APEC study examined the CCS legal and regulatory regimes for nine developing economies, including: People's Republic of China, Indonesia, Republic of Korea, Malaysia, Mexico, the Philippines, Chinese Taipei, Thailand and Viet Nam. Noting the absence of CCS-specific legislation in these nations, the study reviewed existing laws and regulations that may be amended to address various aspects of the CCS project lifecycle. Included within the study is an assessment of each nation, by reference to nine key CCS-specific issues.

A review of these materials highlights a potentially wide number of issues that may be critical to the development of CCS-specific legal and regulatory frameworks. There are, however, several issues that have been consistently emphasised across the various frameworks, as significant when designing and implementing a CCS-specific regime. The following inexhaustive list, is indicative of some of the issues that were frequently identified in these resources:

- Rights associated with accessing the pore space.
- Authorisation/permitting of storage activities.
- Protection of the environment and human health
- Environmental impact assessment
- Transportation of CO_2
- Classification of CO_2
- Site selection and characterisation
- Monitoring, reporting and verification
- Liability throughout the project lifecycle
- Closure of a storage site
- Competition with other users and preferential rights issues.

For policymakers and regulators in the preliminary stages of considering or developing national legislation, these assessments offer an important insight as to the potential scope and level of detail that may be incorporated within a CCS-specific regime.

3.6.2. ASEAN Nations' Perspectives

As noted in earlier sections of this report, the Institute's research and interviews have revealed that in many ASEAN nations, policymakers and regulators will currently be required to rely upon a myriad of existing regulatory regimes to regulate a pilot or demonstration project. In many instances, the permitting or licensing frameworks governing existing mining, oil and gas activities would likely provide a starting point for regulation of CCS operations. It is highly unlikely, however, that these regimes in their present form would be able to support the commercial-scale deployment of the technology.

In addition to these resource or petroleum licensing models, a broad array of existing domestic environmental, planning and health and safety laws and regulations will also potentially apply to both pilot and early commercial operations in these nations. In many instances, these regimes would require further amendment or review, to readily accommodate CCS operations at a commercial scale project. In some instances, it was suggested that specific amendments may be required to either include or exclude CCS operations from the scope of these preexisting models.

Notwithstanding the incomplete nature of the current legal regimes and the absence of stand-alone, dedicated regulatory frameworks for the technology, the Institute's analysis and interviews revealed a range of issues identified as critical for ASEAN policymakers and regulators, including:

- Design and structure of a dedicated CCS regulatory framework
- Types of permits required to regulate CCS operations
- Pore space ownership
- Classification of CO_2 – a waste or pollutant
- Health and safety considerations for CO_2 transport and storage
- Assessment of environmental impacts and public consultation
- Monitoring and verification requirements
- Treatment of stored CO_2 and associated liabilities upon closure of a storage site.

The reconciliation of these issues and topics within domestic frameworks will be critical, as policymakers and regulators navigate the design of their CCS-specific regimes.

Indonesia's recently released legal and regulatory framework to facilitate CCS activities, provides an important and timely example of how a regional government has addressed many of these key issues within a domestic regime.

Design and Structure of Indonesia's New CCS-Specific Regime

Regulation No. 2 of 2023 on the Organization of Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS) for Upstream Oil-and-Gas Business Activities (MEMR 2/2023) is part of a suite of regulations introduced by the government to facilitate the country's energy transition and fulfill its climate change mitigation targets.

The new regulatory framework under MEMR 2/2023 builds on the existing legislative regime applicable to oil and gas exploration and production operations and provides a comprehensive framework for CCS and CCUS projects, including project operator and regulator roles and responsibilities, approval requirements, and monitoring and reporting obligations. In its current format, the Regulation addresses various aspects that relate to the implementation of CCS and CCUS in relation to oil-and-gas business activities.

The scope of MEMR Reg No. 2 of 2023 comprises the following matters:

- Organisation of CCS and CCUS
- Monitoring and Measurement, Reporting and Verification (Monitoring and MRV)
- Economic aspects and assets
- Emergency response systems
- Guidance and supervision
- Administrative sanctions.
- Post-closure transfer of liability

Source: Regulation No. 2 of 2023 on the Organization of Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS) for Upstream Oil-and-Gas Business Activities (MEMR 2/2023)

Source: GCCSI.

3.6.3. Developing a Permitting Model for CCS Activities

A permitting approach which reflects the CCS project lifecycle, and that allocates responsibilities across the entire duration of a CCS operation, is an important feature of the CCS-specific regimes that have been enacted to-date. While this type of permitting model may form the basis of a stand-alone regulatory framework, it may equally be included within an existing domestic licensing regime, of the nature of those regulating oil and gas activities.

A permitting model of this nature includes clearly defined processes and obligations, for both an operator and regulator, from an initial planning and exploration or pre-injection phase, throughout the operational lifetime of a project and beyond into a closure and post-closure period. Under this phased approach, an operator seeking to undertake CCS-specific activities will be required to obtain a series of authorisations, at key points in the project lifecycle, which enable the project to transition from the pre-injection phase, through the operational stage of a project and ultimately into the eventual closure and post-closure phase.

The various licences, permits and leases that may be awarded under a lifecycle permitting model of this nature, authorise and require operators to undertake specified activities, as determined by the relevant regulator. As illustrated in Figure 3.3, separate permits or licenses may be required for activities such as assessment or exploration activities to identify potential CO_2 storage sites and for the subsequent injection and storage activities within suitable CO_2 storage sites. In more comprehensive regimes, licenses may also be required for the construction and operation of CCS-related infrastructure and to operate CO_2 pipelines. Often however, these permits may already pre-exist in relation to oil and gas recovery projects and regulators may adapt these permits to enable CCS projects.

In some examples, such as the regime established under the Australian Commonwealth government's offshore Act or the model established under the EU CCS Directive, failure to obtain the required authorisation will be an offence under the statute. The rights conferred by each permit varies. The applications for these authorisations also include a variety of information requirements, and in many instances require the submission of detailed plans aimed at addressing an operator's approach to the management of the storage site. The relevant permits are typically revocable by the granting authority if the terms and conditions attached have not been complied with.

The CCS Permitting Model in Australia

Under the Australian Offshore Petroleum and Greenhouse Gas Storage Act of 2006 (OPPGSA), an operator seeking to undertake exploration for a potential storage site in Commonwealth waters, will be required to obtain a 'GHG assessment permit'. The permit enables the holder to conduct exploration activities for potential GHG storage formations and potential GHG injection sites, within the designated permit area.

An assessment permit may be transitioned to a 'GHG holding lease', where a declaration of an identified GHG storage formation is made and an operator wishes to delay injection and storage activities. In other instances, following the declaration of an identified GHG storage formation, injection and permanent storage activities are subsequently authorised under a 'GHG injection lease'.

The award of an injection licence entitles the holder to inject a GHG substance into an identified GHG storage formation within the licence area, provided that the injection well is situated within the licence area. The licence authorises the permanent storage of the injected GHG, as well as the equivalent rights to exploration and appraisal activities, which are afforded under either an assessment permit or a holding lease. Similar to all other forms of title under the Act, it is an offence to undertake these activities without authorisation.

Source: GCCSI.

It should be noted that as transboundary CCS project models are increasingly pursued, permitting models will span multiple jurisdictions and operators may need to consider compliance with more than one national regimes. Permitting issues for this type of projects may need to be clarified within domestic regulatory frameworks.

In the ASEAN region, where several state-owned enterprises are proposing to host CCS projects in partnership with private companies, permitting arrangements may again differ. The current situation in Indonesia offers a tangible example of how this may operate.

The Indonesian regime is distinct from other permitting regimes around the world, as CCS activities can only be conducted by a Contractor, appointed by the Ministry of Energy and Mineral Resources to carry out exploration and exploitation in a designated working area. This arrangement stems from the current model governing oil and gas resource exploration and production activities. Indonesia's oil and gas legislation, mandates that the state is responsible for these activities, and the country has established a system where private domestic oil companies earn the right to explore and produce oil and gas resources from the government by entering into cooperation contracts. The contracts represent a form of production-sharing agreement involving both state and private parties and that is beneficial to the Indonesian government.

Similarly, in the context of CCS projects, a Contractor, who is defined as a business entity, or permanent establishment, is authorised to conduct exploration and exploitation activities pursuant to a Cooperation Contract, which must be obtained from the Ministry of Energy and Mineral Resources. The state parties that are involved in a Cooperation Contract are SKK Migas and BPMA. A Contractor is also able to enter into a cooperation agreement with a third party to carry out CCS activities within a designated Working Area, subject to approval from SKK Migas and BPMA (Ashurst, 2023).

Under a Cooperation Contract, Contractors must propose a plan detailing how CCS and CCUS activities will be carried out within the designated working area (covered by a field development plan). The plan should include an assessment of the technical, economic, operational, safety and environmental and closure aspects of the proposed CCS or CCUS project.

As an approved proposal will lead to an amendment to the Cooperation Contract, Contractors through SKK Migas and BPMA may submit a proposal on the amendment to the Cooperation Contract for approval to the Ministry of Energy and Mineral Resources. If approved, the Cooperation Contract or field development plan covering the designated working area for the CCS or CCUS project will be amended.

Indonesia's permitting framework applicable to CCS projects is an example of a further layer within the permitting process and coordination with a variety of stakeholders, both public and private. This model, established in accordance with Indonesia's domestic oil and gas regime, centres around state ownership of oil and gas resources and the involvement of state-owned enterprises in CCS projects.

In other countries in the region where state-owned enterprises will be involved in advancing the technology, such as Malaysia and Thailand, permitting models may also need to be adapted to reflect the government's involvement.

3.6.4. Core Legal and Regulatory Issues Across the CCS Project Lifecycle – the Institute's Model

The Institute's interviews and research have been used in the development of the regulatory model, which is set out in Figure 3.3. The structure of the model and the issues that it addresses, reflect the feedback and experiences of multiple stakeholders from across the ASEAN region. It should be noted, however, that the requirements of national regulators and wider policy objectives may ultimately see this model modified to reflect individual jurisdiction's circumstances and preferences.

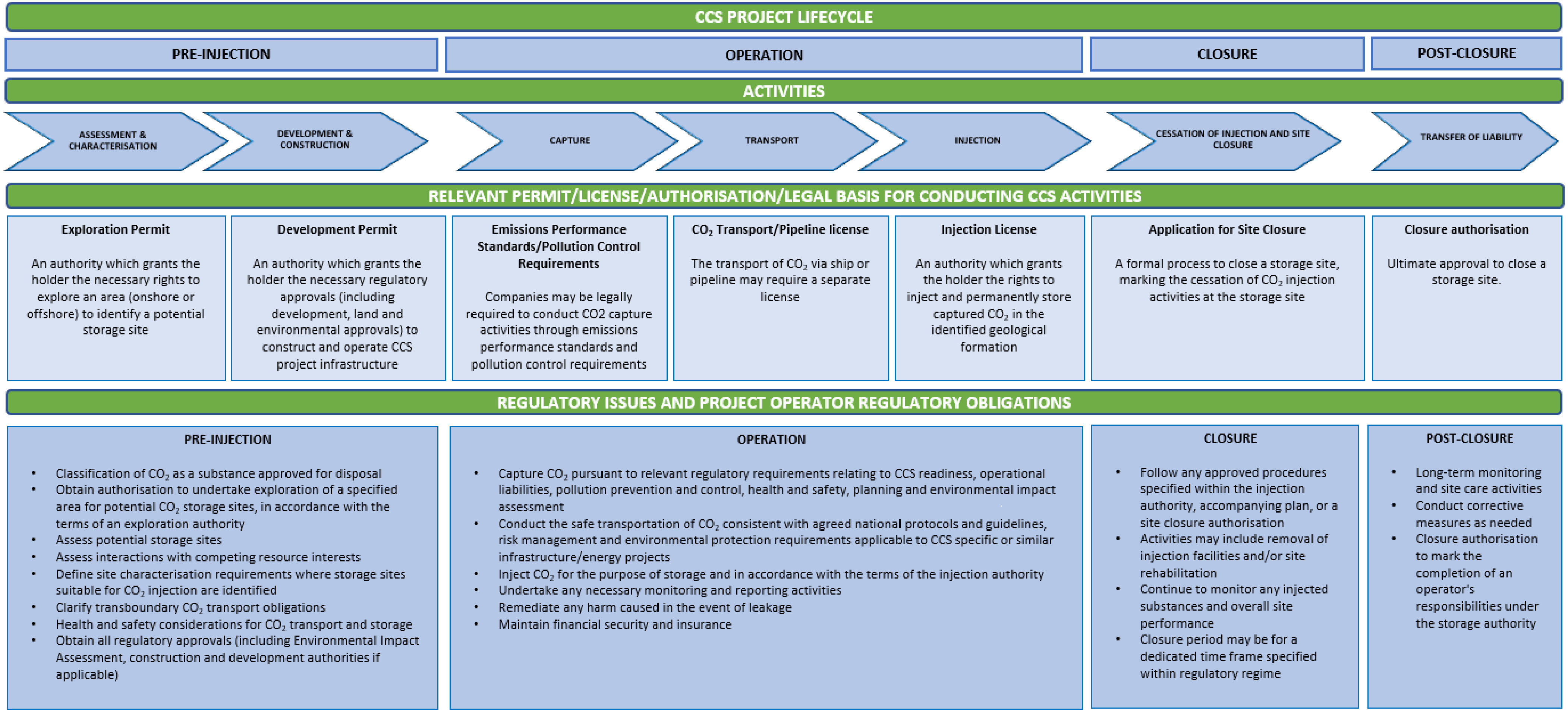
The subsequent sections of this report will examine at a high-level, the core legal and regulatory issues to be addressed in a CCS-specific legal and regulatory framework under the following four phases of a CCS project lifecycle, as depicted in Figure 3.3:

1. Pre-injection (assessment and development)
2. Operation
3. Closure
4. Post Closure

The discussion of regulatory issues under each phase provides an overview of the issue under consideration, together with examples of how it has been addressed within legal and regulatory regimes developed to date.

Where relevant, and for the purpose of illustration, approaches to the regulation of the issue in the ASEAN region are also provided. Significant gaps in national or regional legislation are also highlighted for the purpose of examination and review by national authorities. Key messages and priority actions for regulators in the region for the development of national regulatory frameworks addressing the aspects discussed under each phase.

Figure 3.3. The Regulation of the CCS Project Lifecycle



Source: GCCSI.

3.6.5. Pre-Injection

The pre-injection phase of a CCS project comprises the stage prior to the commencement of CCS operations. During this phase, proponents will likely undertake assessment activities aimed at determining the capacity and suitability of potential storage sites, as well as the planning and construction of necessary project infrastructure.

The following sections will explore these individual issues in greater detail.

3.6.5.1. Classification and Purity of CO_2 Streams

The classification of CO_2 within existing legislation is an important initial consideration for determining whether there are any specific legal obligations applicable to CCS projects. In instances where captured CO_2 is to be treated as a waste or a hazardous material, obligations applicable to waste management projects and environmental protection are likely to be triggered. A failure to adequately address this issue may subsequently obstruct or delay the authorisation and operation of CO_2 storage activities. To provide clarity, several jurisdictions, including the United Kingdom and United States, have formally excluded CO_2, captured for the purpose of geological storage, from their wider definitions of wastes or pollutants.

The composition of CO_2 streams for storage, is a further important consideration, particularly where these streams may contain or collect impurities during the capture, transport or injection phase of a CCS project. Several CCS-specific legal and regulatory frameworks address this issue by providing a qualitative definition for the CO_2 that will subsequently be injected into a CO_2 storage site.

In Australia, the Commonwealth's offshore Act defines the composition of greenhouse gas substances as '*carbon dioxide or a prescribed greenhouse gas in a gaseous or liquid state, or a mixture of carbon dioxide, any prescribed greenhouse gas substances and incidental greenhouse gas related substances*', so long as the mixture consists '*overwhelmingly*' of either or both carbon dioxide and the greenhouse gas substance prescribed in the legislation. A further definition of the term overwhelmingly has not been provided.

Under the EU CCS Directive, there are no technical specifications for the purity of the CO_2 stream. The legislation provides that '*a CO_2 stream shall consist overwhelmingly of carbon dioxide*'. A CO_2 stream may, however, contain incidental associated substances from the source, capture or injection process, or that have been added to assist in monitoring and verifying CO_2 migration. The concentrations of these incidental or added substances must remain at levels that ensure the integrity of storage operations and prevent risks to the environment and human health.

In the US, there is no uniform definition of CO_2 at either the federal or State levels, however there is generally some attempt to define the term. The Final Rules for Class VI

Wells promulgated under the federal Underground Injection Control (UIC) Program[4] define 'carbon dioxide stream' as '*carbon dioxide that has been captured from an emission source, plus incidental associated substances derived from the source materials and the capture process, and any substances added to the stream to enable or improve the injection process*'. The stream may also contain trace substances that have been added to assist in monitoring and verifying the CO_2 migration post-injection.

Amongst the ASEAN nations, Indonesia is currently the only nation that has developed a definition for CO_2 in the context of CCS operations. Within the new regulatory framework, CO_2 is covered under the definition of a greenhouse gas and is referred to as CO_2 captured from upstream oil and gas business activities and other industries. In contrast, in Viet Nam, CO_2 is regarded as a dangerous substance and there are currently strict requirements regarding its transportation via inland waterways and roads.

3.6.5.2. Ownership of the Pore Space within CO_2 Storage Sites

In many jurisdictions interests in the subsurface (including the pore space) are formally owned by the State, however, in several others the ownership and access rights are far more complex. As a result, it has proven critical for operators to determine property interests at a storage site, to acquire the necessary surface and subsurface rights for injecting and storing CO_2 in a particular geological formation. Regulators and policymakers in several jurisdictions have now introduced provisions within their CCS-specific frameworks, aimed at addressing this issue.

At the federal level in the United States, the Underground Injection Control programme does not cover pore space ownership. The federal Environmental Protection Authority (EPA) has clarified that property and land ownership rights are beyond the scope of its jurisdiction, and the Class VI UIC Program Regulations clearly state that a permit issued under the regulations do not operate to convey property rights. Consequently, property rights relating to CCS operations have typically been a matter addressed by the individual US states. Subsurface ownership of property rights varies from state to state, with different parties owning the pore space and mineral estates. In Montana, Wyoming and North Dakota, for example, legislation provides that ownership of the pore space is vested in the owner of the surface estate. As a result, provision is made for the leasing or transfer of pore space as a separate property interest from the surface(Jacobs & Craig, 2017).

In contrast to the complex system of ownership in the United States, policymakers and regulators in some jurisdictions have resolved the issue by declaring that ownership of

[4] The UIC Program regulates 6 types of underground injection wells, with Class II and Class VI wells being the most relevant in the context of CO_2 injection. Class II wells are used to inject fluids associated with oil and natural gas production and include wells used for enhanced recovery of oil and natural gas. Class VI wells are those used to inject CO_2 into underground geological formations for the purpose of long-term storage.

the pore space is formally vested in the state. This approach had been adopted in the Canadian Province of Alberta and the Australian state of Victoria.

In the ASEAN region, countries have yet to formulate a clear legal and regulatory position regarding pore space ownership in the context of CCS projects. Several nations, however, implicitly grant ownership of the geology of the subsurface to the State. In Indonesia, for example, there is no uniform provision clarifying ownership status, however, the constitution vests ownership of the land, water, and natural resources of Indonesia with the state. The use of subsurface areas also requires authorisation from the relevant statutory authority. Furthermore, the State is the ultimate owner of minerals and coal, and land titles do not give holders of the land any rights to minerals or coal located on or under the land.

A similar position may be found in Malaysia, where ownership of resources or land is allocated to the state or state entities under various legislative provisions. For example, Malaysia's Petroleum Development Act 1974 grants Petronas the exclusive rights to explore, exploit and obtain petroleum, whether onshore or offshore in Malaysia. Under this broad grant, Petronas' Production Management Unit exercises ownership of property rights associated with oil and gas exploration and production fields, by granting exploration and production rights through production sharing contracts. Similarly, under the Continental Shelf Act 1966, all rights to the exploration of the continental shelf and the exploitation of its natural resources are vested in Malaysia and exercised by the federal government.

Formally addressing these issues will be critical for the regulation of CCS activities, and in particular storage resource assessment, site development and CO_2 injection operations. In some instances, it is necessary for operators to formally acquire the surface and subsurface rights to undertake their proposed activities. In Australia, for example, where there is state ownership of the pore space, the Commonwealth's offshore legislation includes a formal application process to release offshore areas to potential operators. Under this 'acreage release' model, proponents are granted an opportunity to apply for a permit that will enable them to explore an area for permanent offshore storage locations.

Clarifying these rights also enables operators to evaluate impacts on other resource interests and take appropriate risk mitigation steps, in the event that injected CO_2 migrates within the subsurface. Liability for CO_2 during the operational phase of a project will normally remain with the operator of a site, who must have a right to store in the subsurface formation into which the CO_2 is being injected.

3.6.5.3. Ownership or Title to Stored CO_2

The movement of CO_2 across the CCS value chain also raises the issue of ownership or title to the CO_2, particularly where there are distinct entities involved in the capture, transport, and storage aspects of a project. Determining the nature of this ownership will be significant, for it will impact wider issues such as monitoring, reporting and verification obligations, and long-term liability (International Energy Agency, 2022).

In many instances, it is likely that ownership of CO_2 will be determined through commercial contracts between the operator of a storage or transport facility and the capture facility; however, regulatory frameworks may also play a role in determining this ownership. Where CO_2 injection activities are authorised under a CCS-specific permitting model, the permit conditions may clarify ownership obligations for the stored CO_2 during the operational phase of a project. In many instances, it is the operator of a storage facility, or the holder of an injection permit that is responsible for any CO_2 that has been injected and subsequently stored. Some jurisdictions also allow for the transfer of ownership of the CO_2 to the state, upon the closure of a project.

The issue of ownership or title to the CO_2 remains unaddressed in the ASEAN region, including in Indonesia which has established a CCS-specific regulatory framework.

3.6.5.4. Authorisation to Conduct Assessment for Potential CO_2 Storage Sites

Under a CCS-specific regulatory permitting model, an operator seeking to undertake exploration activities to identify a potential CO_2 storage site, will typically be required to obtain an exploration authorisation. In many instances, this step will be similar to the processes used for the permitting of oil and gas exploration activities and which may be found in many petroleum licensing regimes. Like these regimes, the application process for obtaining a CCS-specific authorisation may require operators to demonstrate their technical and financial capabilities, as well as provide detailed plans regarding their proposed activities.

The grant of an exploration authorisation may be made subject to particular conditions or a specified timeframe. It is likely that the authorisation will specify a designated area for operations. In some instances, parties seeking to undertake storage operations may be required to possess an exploration permit, prior to applying for an injection or storage authorisation.

The Australian federal government's offshore regime requires an operator, seeking to undertake exploration for a potential storage site in Commonwealth waters, to obtain a 'GHG assessment permit'. The permit enables the holder to conduct exploration activities for potential GHG storage formations and potential GHG injection sites, within the designated permit area. Similar provisions are to be found in the European Commission's CCS Directive, which has created an exploration permit to regulate the investigative activities necessary for selecting a potential storage site.

ASEAN nations may follow the same model in terms of establishing separate permits for the exploration phase of a CCS project. However, in the absence of CCS-specific legal and regulatory frameworks in many nations, it is likely that approvals for the exploration phase would be similar to the oil and gas sector. For example, in Malaysia, the Petroleum Development Act requires operators to obtain a license from Petronas for any oil and gas exploration and production activities.

In Indonesia, a Cooperation Contract, a form of production-sharing agreement involving both state and private parties, must be obtained from the Ministry of Energy and Mineral Resources to conduct exploration and exploitation activities for CCS and CCUS projects.

3.6.5.5. Site Characterisation Requirements

Site characterisation has been identified as a critical aspect of the CCS process and early legal and regulatory frameworks afford considerable weight to this activity. Where a potential CO_2 storage site has been identified pursuant to an exploration authority, project operators are typically required to undertake detailed technical assessments of the site to determine its suitability for injection and the permanent storage of CO_2. The completion of a detailed site characterisation process is a pre-requisite in an application for a subsequent storage authority under many permitting or licensing regimes.

Several examples of these processes have been developed and the assessment of CO_2 storage resources will ultimately involve a variety of discrete technical activities[5] including but not limited to:

- Geophysical data acquisition, encompassing 2D and 3D seismic surveys, gravimetric surveys, and Controlled Source Electro-Magnetic (CSEM) Surveys
- Drilling appraisal wells and injectivity tests
- Comprehensive core analysis programme, including porosity and permeability measurements, MICP, XRD, rock mechanics, SCAL, and RCAL analysis
- Well log analysis
- Fluid data analysis
- Subsurface modeling

Where a suitable storage site has been identified pursuant to a GHG Assessment Permit, awarded under the Australian government's offshore regime, a project operator may apply to the Minister for a declaration of an identified GHG storage formation. For this declaration to be granted, applicants will be required to demonstrate that the formation meets the requirements of an 'eligible storage formation'. The criteria for determining whether a storage site is an eligible storage formation are set out in the Act as 'Fundamental suitability determinants', and they cover a range of data points relating to the geological characteristics of the storage formation.

The EU CCS Directive also specifies criteria that are to be used for selecting suitable storage sites, and for ensuring that the sites selected for CCS activities do not pose any

[5] The site characterisation workflow is defined based on project technical and regulatory needs. In Australia, the high-level site characterisation workflows for existing CCS projects, such as Bayu Undan and Petrel CCS projects (Titles G-11-AP and G-7-AP), can be found on the National Offshore Petroleum Titles Administrator website.

risk of leakage or damage to the environment and human health. Annex I to the Directive sets out the criteria to be used for the characterisation and assessment of the potential storage complex and surrounding area. The Commission Guidance Document (GD2), released by the Commission in 2010 to aid Member States in their implementation of the Directive, offers a more detailed perspective of the proposed approach to characterising the storage complex and the requirements and criteria set out in Annex I of the Directive (Publications Office of the European Union, 2012) .

In the ASEAN region, Indonesia's MEMR 2/2023 establishes a host of geological and technical requirements relating to the locating of CO_2 storage sites, within the areas designated as 'Injection Target Zones'[6]. In addition, when applying for a Cooperation Contract to conduct CCS activities, contractors are required to submit an assessment of the geology, geophysics, and reservoirs, in addition to the engineering, safety, environment, evaluation and risk mitigation aspects of transport, storage and injection operations.

In other parts of the region, the absence of CCS-specific frameworks means that there are no CO_2 storage specific site characterisation requirements. However, it should be noted that as many of these countries have established oil and gas industries, subsurface information is already required under permitting regimes applicable to oil and gas exploration and exploitation activities. Assessments of CO_2 storage sites are largely similar to oil and gas resource assessments, and subject to amendment, the requirements within existing oil and gas legislation may be adapted to permit CO_2 storage site exploration activities.

Imposing detailed site characterisation and selection requirements is a key risk management strategy employed by regulators to minimise risks associated with the technology. A comprehensive regulatory framework will require the collection of key details relating to the geological characteristics of the storage site to inform not only storage site selection, but also the construction and operation of infrastructure and facilities associated with the project. International guidance and best practice relating to CO_2 storage, such as relevant ISO standards may provide a reference point for establishing detailed site characterisation requirements.

3.6.5.6. Construction and Development Requirements

The construction and development phase of CCS projects may require separate permits and approvals, depending upon the nature and location of the proposed facility. These approvals may be in addition, or complementary, to the existing environmental, planning, construction, and zoning requirements found in federal, state and local government regulations.

[6] Injection Target Zones include both hydrocarbon reservoirs and saline aquifers.

In Australia, the Commonwealth's offshore Act includes detailed provisions governing the construction and operation of pipelines and infrastructure in Commonwealth waters. A pipeline license will specify the design, construction, size and capacity of the pipeline, its route, and position in relation to the seabed. A further license issued under the Act, authorises the construction and operation of infrastructure facilities associated with greenhouse gas storage activities. The Act and secondary legislation, set out detailed application procedures for both licenses.

Examples of well construction requirements may also be found in the United States. The EPA's Underground Injection Control (UIC) Program's requirements for Class VI wells include requirements for injection wells to be cased and cemented, to prevent the movement of fluids into or between underground sources of drinking water. The casing and cement, used in the construction of each newly drilled well, is required to be designed for the life expectancy of the well. Wells must meet specific tolerance standards and use materials that will be compatible with fluids (in this case, the CO_2 stream) with which the materials may be expected to come into contact.

Current legal and regulatory frameworks in ASEAN nations do not address the design and construction phases of a CCS project. In the absence of specific provisions, wider national legislation relating to the environment, health and safety may be deemed applicable, which in turn may require projects to be designed and constructed in a specific manner. In Indonesia, for example, there are currently no specific requirements relating to design and construction of CCS projects. Regulation MEMR 2/2023, however, imposes various health and safety obligations on project operators, such as safety checks and monitoring requirements with the aim of preventing harm to the environment and human health. By implication, this requires the construction of projects in a manner that assures these objectives.

3.6.5.7. Environmental Impact Assessments

A regulatory framework governing CCS projects may require project operators to conduct dedicated environmental impact assessments (EIA), as a means of systematically evaluating and mitigating risks stemming from the potential effects of proposed CCS activities. These may reflect or be in addition to environmental impact assessment requirements under wider national environmental legislative and regulatory frameworks imposed on similar large infrastructure projects. Typically, EIA requirements mandate the identification of local and regional environmental impacts, as well as the approaches or measures necessary to minimise these impacts.

Examples of how EIA requirements may be applied to CCS operations, can be found in Europe and in the United States. In Europe, the CCS Directive amended the existing legal regime governing EIA, to integrate CCS activities within its scope. As a result, formal EIA assessments will be required as part of the planning process for CCS operations. In line with the provisions of EU law, this obligation has been transposed into the domestic laws of the EU Member States.

In the US, where there is no federal framework for environmental impact assessments for CCS projects, the White House Council on Environmental Quality released new guidance to promote the responsible development and permitting of CCUS projects. Elements included within this guidance include a focus upon facilitating federal decision making on CCUS projects and CO_2 pipelines, public engagement, understanding of environmental impacts, and carbon dioxide removal (The White House, 2022; US Federal Register, 2022).

In the ASEAN region, Indonesia's MEMR 2/2023 provides the only example of environmental impact assessment requirements applicable to CCS projects. The new regulatory regime for CCS and CCUS projects, requires projects '*to draft mitigation and management of environmental, social and public involvement impacts in accordance with the existing laws and regulations*', which will likely bring CCS and CCUS projects under the scope of Indonesia's AMDAL process. The AMDAL process is Indonesia's own system for conducting environmental impact assessments, and involves several elements, consisting of a Terms of Reference, an Environmental Impact Analysis Report, an Environmental Management Plan and an Environmental Monitoring Plan.

The Minister of Environment decides which business or activity requires an AMDAL, based on the scope of work involved, the proximity of the development to protected zones and their potential impact on the environment. The types of businesses and activities that are required to obtain an AMDAL are set out under regulations established by the Ministry for Environment. While not explicitly mentioned within these regulations, the scope of these regulations may be extended to cover CCS and CCUs projects.

In Malaysia, the Environment Quality Act 1974 requires an EIA to be prepared in consultation with the Department of Environment, for major projects with the potential to significantly impact the environment. The DOE's guidance on EIAs emphasises the need for EIAs to prioritise the issue of site suitability and ensure that sites are developed and managed in an environmentally safe manner. Although not explicitly applicable to CCS projects, these existing environmental requirements may still apply by extension, noting the likely scale of proposed CCS operations.

The examples highlighted demonstrate that several jurisdictions already have comprehensive environmental impact assessment frameworks that may be triggered where a CCS project is to be deployed. However, the application of these requirements is not immediately clear. Clarification as to the application of these requirements to CCS projects signals a commitment to risk mitigation, supports the streamlining of CCS-specific approval processes, and provides greater certainty for project operators with regard to their compliance obligations. The inclusion of the EIA process within the broader CCS-specific regulatory framework, also demonstrates a formal policy commitment to considering the environmental, social and economic impacts of a proposed project or development.

3.6.5.8. Public Engagement Requirements

Formal pathways for engaging and consulting the public, as part of the decision-making processes associated with major infrastructure projects, are an established aspect of many jurisdictions' planning and environmental legislation. Under these regimes, operators will likely be obliged to consult the wider public on their proposed operations, in a manner and format specified by the legislation. In some instances, national or supra-national legislation governing access to environmental information, may also afford the public rights to formal engagement and consultation procedures (APEC Energy Working Group, 2012; International Energy Agency, 2022; World Resources Institute, 2008).

CCS projects, by virtue of their size and nature, are likely to meet the thresholds set out in these existing regimes and will likely be subject to the regulatory requirements governing public engagement and consultation. Several of the early CCS-specific regimes have formally recognised this approach through consequential amendments to existing legislation, and by including formal engagement and consultation requirements in their permitting pathways.

Australia, the United Kingdom, and the USA already have established public consultation and notice requirements for CCS projects. In Australia, for example, the commonwealth's Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009 require greenhouse gas titleholders (CCS-specific permits or licenses) to undertake consultation with relevant stakeholders whose interests may be impacted by their activities. A report that includes a summary of all the consultations undertaken, including the merits of any objection or claim, must be submitted along with the Environmental Plan to the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) during the application process for a CCS-specific permit or license.

The United States has also recently released guidance by the White House Council on Environmental Quality outlining public notice requirements for CCS projects. This guidance seeks to promote responsible development and permitting of CCS projects. The guidance from the Council on Environmental Quality (CEQ) builds upon their 2021 report on Carbon Capture, Utilization, and Storage (CCUS) and aims to streamline environmental reviews for CCUS projects. It emphasises the importance of transparent evaluations and encourages agencies to conduct life cycle analyses for these projects, making the findings publicly available. Additionally, the guidance stresses the early integration of environmental justice and equity considerations into CCUS project planning to safeguard communities from potential adverse effects. Tribal consultation and stakeholder engagement plans are highlighted as crucial components, with a call for continuous and meaningful engagement throughout project development. Specific actions recommended include evaluating impacts on host communities, providing comprehensive information before consultations, and avoiding additional burdens on vulnerable communities. Ultimately, the guidance aims to foster the development of CCS projects in alignment with community perspectives and that ensures climate, public health, and economic objectives (The White House, 2022; US Federal Register, 2022).

Formal public consultation and engagement requirements for CCS operations are currently absent in the ASEAN region. Like other jurisdictions, however, these requirements may be extended to CCS activities under countries' wider legislative frameworks. In Malaysia, for example, formal participatory pathways are built into existing environmental and planning legislation. While there are currently no CCS-project-specific requirements, planning legislation requires state authorities to ensure that adequate opportunities are provided to the public to make representations regarding the structural plans of projects. The country's environmental legislation also requires public participation during environmental impact assessment of projects, with requirements to hold local hearings with the public when preparing detailed EIAs.

In Indonesia, as highlighted previously, there are currently no public consultation requirements for CCS and CCUS projects. However, activities and businesses that undertake the AMDAL process are required to engage the public, which is defined to include a broad range of stakeholders that may be impacted by the proposed activities.

3.6.5.9. Clarification of Obligations where There are Interactions with Existing Resource Interests

The CCS value chain involves infrastructure facilities and operations that span large geographical areas, both onshore and offshore. Inevitably, these operations will interact with a variety of pre-existing interests on the surface and subsurface, including other resource and industry interests. CCS-specific legal regimes may be required to resolve potential conflicts of interest and provide for the co-existence of CO_2 storage activities with these pre-existing interests. In the ASEAN region, CCS activities are anticipated to take place in areas currently utilised by the oil and gas industry and will likely involve the re-use of infrastructure and facilities for CCS operations. CCS operations will likely give rise to a plethora of interests that will require regulatory frameworks to provide coordination and conflict resolution (Global CCS Institute, 2019; International Energy Agency, 2022).

The Australian Commonwealth's offshore regime is illustrative of how these potential conflicts can be managed. Statutory titles to conduct CO_2 storage and petroleum activities, may be granted over areas where there are CO_2 titles or petroleum titles already in force. The management of these interests is carefully managed within the regime, and the impact on petroleum exploration and production activities is considered. The legislation distinguishes between two types of petroleum titles: pre-commencement petroleum titles and post-commencement petroleum titles. Pre-commencement titles are titles that were in existence before the CCS-specific amendments to the commonwealth Act came into effect in November 2008, while all other subsequent titles are post-commencement titles.

Where a potential conflict arises between a proposed CO_2 title and a pre-commencement petroleum exploration title, the Minister assesses whether the grant of the CO_2 title will have a 'significant risk of a significant adverse impact (SRSAI)' on the pre-commencement title. Where a risk is likely, the CO_2 title will not be approved. Alternatively, the Minister will also consider if there is a commercial agreement between the two titleholders before granting approval.

In the case of a later conflict, at the stage of granting a CO_2 injection license or a post-commencement title, the Minister will decide which activity should proceed based upon the public interest. However, once post-commencement titles have been granted, the Minister will apply the SRSAI test to determine whether a CO_2 title should be granted in respect of the conflicting area.

3.6.5.10. Transboundary CO_2 Storage Considerations

With government and industry across the ASEAN region increasingly pursuing opportunities to collaborate on regional CO_2 transport and storage projects, the resolution of legal and regulatory issues governing the operation of these activities will be critical. It will be important to ensure that issues of international and national law are addressed in a timely manner and that project proponents, policymakers and regulators have confidence in the regimes developed. Section 5 of this report provides a detailed examination of issues associated with transboundary operations.

With the conclusion of formal agreements between nations, and the development of national regimes to regulate storage activities, many issues will eventually be managed as part of the CCS permitting regime. At present, however, and in the absence of clear legal and regulatory frameworks for these operations, there are several elements and preliminary issues that are currently to be considered in the pre-injection phase. Examples of these issues include but are not limited to, bilateral agreements between nations, the allocation of liabilities for accidents and leakages, the reporting and accounting of transferred CO_2, transboundary environmental impacts and dispute resolution mechanisms.

KEY MESSAGES

- The pre-injection phase of a CCS project refers to the period prior to the commencement of CCS operations and will require regulatory approvals for conducting a variety of preparatory activities.
- Project proponents will typically be required to secure the relevant authorisations for exploration, construction, and development activities.
- Operators and regulators will be required to consider property issues relating to ownership of/access to pore space in the subsurface, as well as the classification of CO_2 and title to the CO_2 stored.
- CCS-specific regimes also include provisions governing site selection and characterization, and environmental impact assessments, with the aim of assuring the safety and permanence of CO_2 storage operations.
- The interaction between CO_2 storage operations and current or future petroleum activities, must be carefully considered.
- Legal and regulatory issues will arise in the context of transboundary project models, which will trigger obligations under international, regional, and national regimes. The absence of clear legal and regulatory frameworks for these operations, within international and national law, suggests this issue is addressed in the pre-injection phase and prior to operation.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Determine how captured CO_2 is to be treated within domestic legal frameworks. Consider the necessity of excluding it from the scope of current waste management legislation.
- Establish guidelines or standards regarding the purity and composition of CO_2 streams.
- Clarify and define ownership rights over subsurface geological formations and the pore space, potentially through legislation or regulatory amendments.
- Develop site selection and characterisation requirements to ensure that CO_2 storage sites are suitable for the safe and permanent containment of CO_2. Consider the need for secondary guidance to assist project developers in their interpretation of these requirements.
- Engage with regulators and policymakers in the region to support the development of a consistent approach to the transboundary movement of CO_2.
- Ensure that these activities and requirements are adequately captured within a domestic permitting framework.

3.6.6. Operation

The operation phase of a project refers to the period during which a CCS project is fully operational, and capture, transport and injection activities are being undertaken. Under a phased approach to permitting, similar to the one proposed in this report, an operator seeking to undertake storage activities will be required to obtain a specific storage authorisation when they transition from the pre-injection phase, through to this operational stage.

During this phase, CCS-specific regulatory frameworks, as well as broader legislation, will impose a wide variety of obligations upon an operator, relating to the capture, transport, and storage elements of the CCS value chain. Operators will be required to undertake specific tasks including, for example, monitoring, reporting and verification activities and the remediation of any damage caused by their operations.

3.6.6.1. CO_2 Capture

When developing early CCS-specific legal and regulatory regimes, regulators and policymakers have in many instances chosen to focus exclusively upon regulating the storage aspect of the CCS process. The decision to focus upon this element has been a deliberate policy choice, and indicative of the view that existing legislative instruments will adequately manage the capture element of the process. To this end, operators will need to comply with a range of regulatory obligations found within existing domestic laws and regulations governing industrial activities.

An example of this approach may be found within the European Union, where the CCS Directive made consequential amendments to existing EU environmental legislation, to address the risks associated with the capture process. A consequential amendment to the EU's Industrial Emissions Directive (IED) now enables national authorities to regulate CO_2 capture activities, in accordance with this Directive. Capture plant operators will be required to obtain and operate in accordance with a permit, to achieve the aims of the Directive. Public consultation requirements are also included within the Directive, and operators are required to use best available technology for capture activities (Odeh & Haydock, 2009).

The CCS Directive also made amendments to the Environmental Impact Assessment (EIA) Directive, to require that an EIA be undertaken for the capture aspect of the CCS process. Operators are obliged to undertake environmental impact assessments, as a part of the capture permitting process.

Within the ASEAN region, policymakers, regulators, and project proponents will likely be familiar with the application and operation of similar regimes, which are well-established in the context of other major industrial and infrastructure activities. Regulators may consider issuing guidance on the application of these frameworks to the capture phase of projects.

3.6.6.2. CO_2 Transport

Similar to the approach adopted to the capture aspect of the CCS process, many policymakers and regulators have chosen to regulate the transportation element under existing domestic regulatory frameworks. To this end, few of the CCS-specific regulatory models developed to-date, include detailed provisions governing the transport aspect of the CCS process.

The compression and transport of CO_2, as part of a CCS project, are likely to be governed by a variety of wider pipeline, health and safety, planning and environmental legislation. This legislation will aim to ensure the safe transportation of CO_2, in a manner consistent with both national protocols and guidelines for CCS-specific operations, and for similar infrastructure and energy projects. Regulatory frameworks also establish risk management systems for CO_2 transport activities.

For CO_2 transportation by pipeline, broader domestic legislation typically specifies requirements for the permitting, design, construction, testing, operation, maintenance and repair of pipelines. The Australian commonwealth's offshore regime, for example, includes detailed provisions applicable to infrastructure development and pipeline construction and operation in Commonwealth waters. The Act establishes an offence for conducting activities without the correct authorisation(s) and sets out procedures for obtaining infrastructure and pipeline licences. Operators of CO_2 pipeline operations, operating within territories covered by this Act, will be required to comply with these provisions.

In the case of transportation of CO_2 by ship, environmental and maritime health and safety legislation governing the transportation of substances, together with existing requirements for maritime operations, will all likely apply.

3.6.6.3. Authorisation of Storage Activities

CCS-specific legal and regulatory models, which establish a lifecycle permitting regime for conducting CCS activities, typically require a project operator to be granted a storage authorisation (e.g. a licence or permit) to begin CO_2 injection operations. Under many of these legal and regulatory frameworks, a storage authorisation may only be granted where the operator has identified and successfully characterised a suitable storage site, in accordance with the technical screening criteria established within legislation.

Under the Australian commonwealth's offshore Act, the operational phase of a CCS project is managed through the grant of a greenhouse gas (GHG) injection licence. The award of an injection licence entitles the holder to inject a GHG substance (in this instance a CO_2 stream), into an identified GHG storage formation within the licence area. Similar to all other forms of title under the Act, it is an offence to undertake injection and storage activities without first being granted the licence.

Similarly, under the EU CCS Directive, where a suitable storage site has been identified and successfully characterised, a potential operator may apply for a storage permit. A storage permit authorises the injection of CO_2 into geological formations for the purpose of permanent storage.

Currently, in the ASEAN region, separate pathways for permitting CO_2 storage activities have only been established in Indonesia and in the state of Sarawak in Malaysia. As discussed previously, in Indonesia, CO_2 storage is permitted under a Cooperation Contract, obtained from the Ministry of Energy and Mineral Resources. In Sarawak, in

Malaysia, CCS projects will be required to obtain a 'carbon storage license' to develop and operate a project. A carbon storage license may be obtained by any petroleum operator, any person undertaking any industrial activity or any storage user who desires to use the storage site, regardless of whether the CO_2 to be injected by the person is obtained within or outside Sarawak.

3.6.6.4. Development of Plans

When applying for a storage authorisation, applicants are required to prepare and submit a range of plans and information that details how they will manage their operations. These plans may address a range of issues relevant to the operation of a project, including monitoring arrangements, and details of the proposed corrective measures to be taken where there are risks posed to human health or the environment. Often, the plans submitted by applicants will be required to satisfy specified criteria, set-out in the relevant legislation. Regulatory frameworks will also require the relevant regulatory authority to approve the content of these plans, prior to the formal grant of a storage authorisation.

The preparation of a series of plans, which set out how an operator will manage the operation and eventual closure of a storage site, is an important element of the CCS Directive's permitting model. These plans will describe monitoring arrangements, as well as details of the proposed corrective measures to be taken in the event of a leakage, and the proposed course of action for the period following the closure of the storage site.

The Directive requires an iterative approach to regulation and operators will be required to review and update their plans and processes frequently, throughout the lifetime of a project. Operators will need to reflect relevant changes to the assessed risks to the environment and human health, new scientific knowledge, and improvements in best available technology in these plans.

Information Requirements in the Preparation of Plans: Regional Examples

A distinct feature of the Indonesian regime is the requirement that CCS activities can only be conducted pursuant to a Cooperation Contract. To obtain a Cooperation Contract, Contractors appointed by the Ministry of Energy and Mineral Resources must prepare a proposal and implementation plan in accordance with the requirements set out within MEMR No. 2 of 2023, which includes details relating to the implementation of:

- environmental and social impact assessments,
- engineering, procurement and construction processes,
- commissioning of CCS and CCUS operations,
- operation safety management,
- environmental management,
- emergency response activities,
- repair and maintenance,
- monitoring and verification and
- closure of a project.

In the Malaysian state of Sarawak, which has established the Sarawak CCS Rules, a storage user permit enables a storage user (an entity who is not the holder of a carbon storage license) to use the site.

The application for a storage user permit has detailed requirements, including a requirement to submit a storage development plan that includes various details about the stakeholders and nature of the project.

Source: Regulation No. 2 of 2023 on the Organization of Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS) for Upstream Oil-and-Gas Business Activities (MEMR 2/2023), Indonesia and Land (Carbon Storage) Rules 2022, Sarawak Government Gazette.

Source: GCCSI.

3.6.6.5. Monitoring, Reporting and Verification Requirements

Monitoring of the CO_2 storage site is a further important aspect of the operational phase of a CCS project. Regulatory requirements for conducting monitoring activities are aimed at ensuring that the behaviour of the CO_2 plume is in-line with predicted models and there is permanent containment of the injected CO_2, with minimal risk of leakage. An effective monitoring regime is also imperative for ensuring the climate change mitigation benefits of the CCS process are realised.

Many of the CCS-specific regulatory frameworks also require project operators to report the results of their monitoring activities. Reporting requirements are a means of managing the risks of geological storage, with operators obliged to report any incidents or imminent threats, of leakage or environmental harm. Some jurisdictions, however, have also established reporting requirements as a means of tracking and verifying greenhouse gas reductions that have been delivered through CO_2 storage activities.

An example of comprehensive monitoring and reporting requirements can be found within the US federal Underground Injection Control Program's requirements for Class VI Injection wells. The requirements include minimum technical criteria applicable to the monitoring of the CO_2 storage site. The purpose of these monitoring criteria is to ensure that CO_2 injection activities are operating as permitted and are not endangering underground sources of drinking water (USDWs). Project operators of Class VI wells are also required to comply with certain reporting requirements annually, when conducting CO_2 injection and sequestration activities under the federal Environmental Protection Agency's Greenhouse Gas Reporting Program (GHGRP).

The Storage Directive requires operators to undertake monitoring of their injection facilities, the storage complex, and where appropriate the surrounding environment. Monitoring is to be commenced on the basis of the operator's monitoring plan and is to be undertaken with a view to ascertaining:

- A comparison between actual and modelled behaviour of the CO_2
- 'Significant irregularities'
- Migration of the CO_2
- Leakage of CO_2
- Significant adverse effects upon the surrounding environment
- Effectiveness of any corrective measures undertaken
- Updating the assessment of the safety and integrity of the storage complex.

An operator will be required to submit to the national authority, on at least an annual basis, the results of its monitoring activities. As part of this reporting obligation, the operator will also provide details on the 'quantities and properties' of the injected CO_2 streams.

Within the ASEAN region, monitoring and verification requirements may be found in Indonesia's CCS-specific regulatory regime. Operators are required to prepare a monitoring, verification, and reporting plan at the pre-implementation phase of the project, covering all stages of the project, from planning through to post-closure. There are also requirements in relation to measuring, reporting, and verifying the emissions reduction contributions of projects and utilisation of the economic value of the carbon.

3.6.6.6. Corrective Measures and Remediation Measures

Scientific models of the CCS project risk profile, suggest that risk rises throughout a project's injection phase, before reducing considerably as pressure in the storage site reaches its maximum when injection stops. Consequently, the CCS-specific regimes developed to-date have incorporated a variety of measures aimed at managing and reducing risks throughout the project lifecycle.

The US federal UIC Class VI Injection Well Rule, includes provisions requiring owners or operators of Class VI wells to perform corrective action on all wells in the 'area of review'[7] that are determined to require corrective action. An owner or operator of a well is to submit a corrective action plan, which details how these activities will be conducted and the actions that will be undertaken prior to injection. Operators must also submit an emergency and remedial response plan describing actions that will be taken to address movement of the injection or formation fluids that may cause an endangerment to underground sources of drinking water (USDWs) during the construction, operation, and post-injection site care periods. In the event that CO_2 injection poses any threat of endangerment to USDWs, the rule requires operators to implement their response plan and notify the UIC Program Director within 24 hours.

The United Kingdom's regime, which implements the requirements of the EU CCS Directive, also requires an operator to take any necessary corrective measures, as well as those necessary for the protection of human health. These measures are to be undertaken in instances where a significant irregularity or leakage has been detected. The measures must include at least those set out in the corrective measures plan, which is to be submitted as part of the application for a storage permit.

In the ASEAN region, only Indonesia has introduced provisions aimed at addressing this issue. The nation's new Regulations require operators to consider mitigation and risk management responsibilities as part of their application process for a Cooperation Contract to conduct CCS activities. Once a Cooperation Contract has been awarded, a contractor is required to undertake a risk assessment to identify the risks that may arise from the failure of the injection and storage activities and determine how these risks will be mitigated.

In the absence of CCS-specific provisions, regulatory requirements applicable to oil and gas operations and environmental protection may be applicable to CCS projects. In many jurisdictions, operators of industrial operations may be required to take all reasonable measures to prevent pollution or damage to the environment, in the event of an incident.

3.6.6.7. Liability During the Project Period

Liabilities arising during the injection phase of a project are referred to as operational liabilities. During this phase, where storage activities are undertaken in accordance with a CCS-specific permit or license, operators will bear a liability in the form of compliance obligations that are imposed under these authorisations. In addition, and distinct from the enforcement powers to be exercised by an authority in instances of a breach of a permit or licence, administrative liabilities will be borne under a jurisdiction's wider environmental legislation. Where operating in a common law jurisdiction, operators will

[7] The region surrounding the geologic sequestration project where underground sources of drinking water may be endangered by the injection activity.

also be liable for any damages to the interests of third parties, that are the result of their operations.

The Australian commonwealth's offshore licensing regime imposes statutory liabilities upon an operator, where a GHG injection permit or licence is granted under the Act. Under these authorisations, an operator will be required to ensure that environmental protection and public health standards are maintained throughout the lifetime of a project. Operators will also be obligated to take action to prevent or remedy a serious situation.

Similar provisions are found in the United Kingdom's regulatory regime, where several duties are imposed upon a storage operator, when in possession of a valid storage licence. Once awarded, an operator will bear a number of obligations in relation to the injection of CO_2, including, monitoring, the reporting of leakages and significant irregularities and undertaking corrective measures where necessary.

In the ASEAN region, Indonesia's permitting process establishes clearly defined responsibilities for the project operator at each stage of the CCS project lifecycle. Proponents are required to prepare a proposal and implementation plan in accordance with the requirements set out in the regulations, which includes implementation of operation safety management, environmental management, emergency response activities, repair and maintenance and monitoring and verification. The operator is required to obtain approval on the management of these considerations from the Ministry of Energy and Mineral Resources. Once approved, these considerations are incorporated within the Cooperation Contract[8] that authorises CCS activities. Project operators are responsible for ensuring compliance with these requirements once they are part of the Cooperation Contract.

[8] As explained in Section 3.6.3, in the Indonesian regime, CCS activities can only be conducted pursuant to a Cooperation Contract that is to be obtained from the Ministry of Energy and Mineral Resources.

KEY MESSAGES

- The operational phase of a CCS project should be underpinned by a regulatory regime that governs CO_2 capture, transport, and storage activities.
- Examples from current regulatory frameworks demonstrate that countries have chosen to adapt or enhance a variety of existing regulatory regimes to regulate these activities. Legislation governing oil and gas and resources operations, environmental protection, property, planning, health and safety, and pollution control, may all have an impact upon CCS operations.
- Key issues to be prioritised during this phase of a CCS project, include the authorisation of injection activities, risk management measures such as the preparation of plans relating to monitoring and reporting, corrective action, and the allocation of liability during the operational phase.
- Existing regulatory frameworks, predominantly those facilitating other industrial activities, may serve as the basis for CCS regulation in the ASEAN region. Further amendment of these frameworks will be necessary to fully address the regulatory issues posed by CCS activities.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Develop a regulatory regime aimed at facilitating the operational phase of a CCS project, including technical requirements that ensure the safe operation of capture, transport and storage activities.
- Review existing regulatory frameworks and the extent to which they accommodate the regulatory issues associated with the technology and ensure that CCS activities are sufficiently integrated within wider legal frameworks that may also be applicable.
- Develop adequate risk mitigation measures that incorporate strategies and contingency plans to address potential CO_2 leakage during the operational phase and after the closure of a project.
- Clarify project operators' responsibilities during operation and ensure clarity as to the allocation of liabilities during this phase in instances of non-compliance with regulatory obligations or in the event of any accident or leakage.
- Establish adequate monitoring and reporting procedures to ensure robust accounting verification of the stored CO_2.
- Ensure there are adequate, formal opportunities for regulators to monitor activities and ensure compliance with the regulatory framework.

3.6.7. Closure

The cessation of injection operations and the closure a CO_2 storage site, triggers various obligations for the project operator. CCS-specific regulatory frameworks typically establish procedures for undertaking the closure a CO_2 storage site, as well as clarifying the responsibilities of both operators and regulators in the period immediately following its closure.

3.6.7.1. *Authorisation for Storage Site Closure*

Upon the completion of injection operations, regulatory frameworks typically require project operators to obtain a formal approval to close a CO_2 storage site. An approval for site closure will usually be conditional upon the operator fulfilling various obligations, including decommissioning activities, the removal of all injection well infrastructure, and land rehabilitation. Many of these activities will be undertaken in accordance with a site closure plan, that was approved by the regulator at the time of granting a storage authorisation (APEC Energy Working Group, 2012; International Energy Agency, 2022).

Under the provisions of the Australian commonwealth's offshore Act, an operator is required to apply to the Minister for a site closure certificate where injection operations under an injection license have been completed. Once an application has been made for a site closure certificate, the Minister may direct the holder of an injection license to carry out site closure activities, including the removal of all property from the relevant area, plugging, or closing off all wells, and the conservation and protection of the natural resources in the surrender area.

The EU's CCS Directive sets out the closure and post-closure obligations of an operator and competent authority, including the process and requirements for closing the site. A storage site will be closed once an operator has completed their obligations under a storage permit, including the storage of the total quantity of CO_2 authorised under the permit. The Directive requires that an operator fulfil their closure requirements based upon a final version of the post-closure plan, which is to be prepared by the operator and approved prior to the site's closure. As part of their closure obligations, an operator is required to seal the storage site and remove the injection facilities. Significantly, an operator shall continue to remain liable for monitoring, reporting and corrective measures, pursuant to the requirements of the Directive, and for all obligations under the EU Emissions Trading Scheme (EU ETS) and Environmental Liability Directive (ELD), once the site is closed.

Indonesia's MEMR 2/2023 provides a region-specific example of a comprehensive closure regime for CCS and CCUS projects. The regulations set out several conditions that will precipitate the closure of a project, these include, where the storage reservoir has reached its capacity, sources of captured CO_2 are no longer available, and the Cooperation Contact has expired. Contractors under a Cooperation Contract are required to submit a closure plan for approval to SKK Migas and the Director managing oil and gas activities. Closure plans must include strategies to prevent damage to the environment, human health, resources and the assets of the state(Ashurst, 2023).

3.6.7.2. *Well Plugging and Decommissioning Requirements*

Well plugging requirements for CO_2 storage wells vary from jurisdiction to jurisdiction; however, many of these regulatory requirements have evolved from legislation governing well abandonment in the hydrocarbon and petroleum extraction industries.

A 2011 report by the IEA Greenhouse Gas R&D Programme, which reviewed 11 different regulatory regimes in Europe, Australasia and North America, concluded:

'*Generally, the regulations in place provide guidance on abandonment methods for existing wells, and although the review shows that there is always a need for a cement plug, the length of cement plug varies greatly, from a minimum of 15m in Canada, to up to 100m in some European scenarios. Other areas where variation is apparent include verification of abandoned wells, provisions made for CO_2 storage, and data availability*.(IEA Greenhouse Gas R&D Programme, 2009)'

In the Canadian province of Alberta, the Alberta Energy Regulator regulates CO_2 storage activities through the issuance of directives. Well plugging requirements for CO_2 storage wells are set out in Directive 020, which distinguishes between routine and non-routine abandonments, and prescribes requirements for both instances.

Many of the ASEAN nations have not established CCS project-specific decommissioning requirements, however, existing oil and gas legislation will likely apply.

KEY MESSAGES

- During the closure phase of a CCS project, regulatory frameworks typically establish procedures for closing a CO_2 storage site. Regulation may also clarify obligations and allocate responsibilities between various stakeholders for overseeing the site after closure.
- The responsible and safe closure of a CO_2 storage site are the focus of regulatory requirements during the closure phase. Legislation will require project operators to seek authorisation to close a CO_2 storage site upon the fulfilment of prescribed criteria and may include well decommissioning and plugging requirements.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Develop a procedure within the regulatory framework to formally authorise site closure.
- Review existing legislation relating to oil and gas exploration and production for the purpose of enhancing or adapting provisions relating to well abandonment and site closure.

3.6.8. Post-Closure

Following the formal closure of a CO_2 storage site, project operators will still be required to comply with regulatory obligations that aim to ensure the long-term safety and security of any stored CO_2. In several jurisdictions operators will retain continuing legal responsibilities for the closed storage site and will be required to undertake post-injection site care and long-term monitoring for an extended period of time. In many instances, operators will also retain a variety of liabilities under wider legal regimes.

An important feature of several CCS-specific legal and regulatory frameworks, however, is the ability of operators to transfer their responsibility for the storage site to the state, where certain conditions are met (APEC Energy Working Group, 2012; Global CCS Institute, 2019; Global CCS Institute et al., 2014; International Energy Agency, 2022).

3.6.8.1. Post Closure Site Care and Monitoring Requirements

Prior to the closure of a site, project operators are typically required to submit a post-closure monitoring plan to be approved by the relevant regulatory authority. Regulatory frameworks also require that project operators continue to monitor the CO_2 storage site following its closure, pursuant to the post-closure monitoring plan and for a specified period of time.

In Indonesia, for example, MEMR 2/2023 requires that after the closure of the storage site the operator remains liable for any leakage at the site while also being responsible for conducting post-closure monitoring and reporting activities.

The Malaysian State of Sarawak's CCS Rules require project operators to comply with a range of post-closure obligations. Amongst these, a storage user is required to monitor the storage site post-closure, in accordance with a monitoring plan and comply with reporting and notification requirements and ensure corrective measures in the face of any risks, up until the storage permit applicable to the CO_2 storage site is cancelled.

3.6.8.2. Transfer of Liability and Stewardship

The novel risks and unique aspects associated with a CCS project gives rise to many different forms of liability that a project operator may incur during and after the completion of operations. These liabilities may be allocated through the design and implementation of new CCS-specific mechanisms, however in many instances far broader obligations are likely to be borne by operators through the implicit application of a wider body of legislation and case law.

However, the significant timeframes necessitated by the permanent geological storage of CO_2 have been raised as a concern for project operators. Liability for CO_2 storage operations extending into perpetuity, potentially beyond the lifetime of a traditional corporate entity, has been raised as particularly challenging. Regulators and the public, on the other hand, have sought to ensure that the process is comprehensively regulated and that solutions afforded high levels of protection to the environment and human health(Global CCS Institute, 2019).

One approach adopted by regulators has been to adopt regulatory provisions enabling the transfer of liability for a storage site or stored CO_2, from an operator to a state's competent authority. Examples of this approach have been implemented in frameworks in Canada, Australia, and under the European Union's CCS Directive. The operation of these transfer provisions varies between jurisdictions, but all require the satisfaction of specific performance criteria before a transfer may be affected. In many instances, the completion of a post-closure time limit will also be necessary, prior to a proposed transfer.

An example may be found in the EU CCS Directive, which provides the opportunity for operators to transfer their liabilities to the state following cessation of activities. Members States have subsequently transposed its provisions into national frameworks, resulting in a largely harmonised European approach to liability. In some Member States, notably those with strong commitments to deploying the technology, regulators have implemented models which go beyond the requirements of the Directive. The UK's transposition of the Directive is one example of this approach, with regulators adopting extensive transfer provisions that would encompass any sort of potential civil claim or administrative liability arising from a leakage, whether the leakage occurred before or after the transfer.

A critical issue in the development of any transfer regime, is determining precisely which liabilities and responsibilities are to be transferred. As highlighted in the preceding sections, an operator will bear a variety of different types of liability during the project lifecycle, and legislation will need to be clear as to which of these will be the subject of the transfer. In many instances, even following the transfer, an operator will remain liable for their operations in some form of liability.

The conditions necessary for enabling a transfer are a further significant consideration for policymakers and regulators. Many of the early regimes sets out a series of pre-conditions that have to be fulfilled by an operator and are intended to confirm the stability and integrity of the storage site. These conditions are ultimately designed to give the authorities confidence that the storage complex, including the sub-surface plume and related processes, will continue to behave in a predictable and safe manner.

Post-Closure Transfer of Liability: The Indonesian Model

Under Indonesia's MEMR No. 2 of 2023, following the satisfaction of responsibilities during the operational phase, there are certain conditions that, when satisfied, may lead to a Contractor's rights and responsibilities under a Cooperation Contract for CCS or CCUS project activities being transferred to the state. These conditions include that:

- the contractor has received a stipulation of verification results from the Director General of Oil and Gas for the completion of CCS closure activities,
- the monitoring results show no leakage,
- ground water contamination or other risks caused by CO_2 injection activities and
- the Cooperation Contract period has ended.

Following approval from the Ministry of Energy and Mineral Resources, provided in consultation with SKK Migas and BPMA, the contractor's rights and obligations for CCS or CCUS implementation in the Working Area will cease. Upon this cessation, responsibilities over the CO_2 storage site in relation to site care and supervision will transfer to the state.

Source: Regulation No. 2 of 2023 on the Organization of Carbon Capture and Storage (CCS) and Carbon Capture, Utilization and Storage (CCUS) for Upstream Oil-and-Gas Business Activities (MEMR 2/2023), Indonesia

Source: GCCSI.

3.6.8.3. Financial Security

In addition to transfer provisions, several CCS-specific regimes also include the requirement for operators to provide some form of financial security, aimed at addressing the various liabilities and anticipated costs that an operator may incur over the life of a project – including the post-closure period.

An example of an approach adopted to financial security can be found in Article 19 of the EU CCS Directive, which requires an applicant for a storage permit to provide proof by way of '*financial security or any other equivalent on the basis of arrangements to be decided by Member States*', to ensure that any obligations under the permit including closure and post-closure obligations can be met. The financial security is to be provided in advance of the grant of a permit and is to remain in place up until the point that responsibility for the storage site is transferred to the State in accordance with the Directive.

The European Commission's accompanying Guidance sets out the obligations that must be covered by the Article 19 financial security requirements. Clear from the Guidance is that the scope of financial security includes the costs of CO_2 leakage under the EU ETS, which would require an operator to provide an up-front payment for an ostensibly uncapped liability. The Guidance proposes that Member States should use current prices or estimates for near-term allowance prices over a 3-5 year period, making amendments to financial security periodically.

In the United States, in the State of North Dakota, the North Dakota Industrial Commission regulates/oversees CCS activities. The requirements for financial responsibility in North Dakota for permitting Class VI wells (CO_2 injection wells) are set out below:

- The storage operator is required to demonstrate and maintain financial responsibility as determined by the commission. The commission specifies the types of financial responsibility instruments that can be used and the CCS project activities that require coverage by the financial responsibility instrument. Activities covered include corrective action, injection well plugging, post-injection site care and emergency and remedial response measures. The provisions provide further detail as to the protective conditions of coverage that must be included in the financial responsibility instrument.
- The provisions establish a Carbon Dioxide Facility Administrative Fund and Carbon Dioxide Storage Facility Trust Fund to which operators are required to pay a fee for each ton of CO_2 injected for storage.

Regulators should also consider imposing requirements for project operators to obtain additional third-party financial assurance measures to ensure that projects are able to meet comply with regulatory obligations throughout the life of the project.

While the approach adopted to financial security varies between jurisdictions, the underlying rationale for the imposition of financial security requirements remains similar: a policy goal of reducing the exposure of the taxpayer and general government funds (Global CCS Institute, 2019).

KEY MESSAGES

- Regulatory obligations during the post-closure phase will include long-term monitoring and responsible site care, to ensure the safety and security of CO_2 storage sites. Regulatory frameworks may oblige project operators to provide post-closure monitoring plans to address potential risks, including leakage and site integrity concerns.
- Liability for stored CO_2 is a key issue that regulators and policymakers have attempted to address within early CCS-specific legal and regulatory frameworks.
- Regulatory provisions enabling the transfer of liability for a storage site or stored CO_2, from an operator to a state's competent authority, following the closure of the storage site is a key mechanism adopted across various regulatory frameworks.
- Regulatory frameworks also mandate financial security provisions to address the long-term liabilities associated with the closed CO_2 storage site, by requiring financial guarantees to cover closure, post-closure, and potential CO_2 leakage liabilities, to reduce the burden on public funds.

PRIORITY ACTIONS FOR POLICYMAKERS AND REGULATORS

- Develop regulatory provisions addressing long-term monitoring after site closure and require approval of these plans to ensure adherence to safety and reporting

Chapter 4

Study on Financial Framework for Deployment of CCUS in the Asian Region, including ASEAN

Eric Williams, Selim Cevikel, Bernardene Smith, Alex Zapantis, Matthew Loughrey, Joey Minervini, Ian Havercroft, Errol Pinto

4.1. Introduction

CCS and other climate mitigating technologies deliver a public good; a stable climate. The value they create for society is far greater than the value that can be captured by a private sector investor in an individual project. Thus any consideration of the financing of CCS, or any climate mitigation technology, necessarily requires a consideration of public policy to ensure that investment is sufficient to meet the needs of society. Public policy must create additional incentives for private sector investment beyond those that naturally exist in the market to secure the investment necessary to meet broader societal objectives (stable climate) that would otherwise not be made. These policies will generally require the allocation of public and private resources by governments on behalf of the communities they represent. However governments have many competing priorities to which they could allocate scarce resources including but not limited to health, education, infrastructure, defence etc.. The United Nations Sustainable Development Goals generally describe the objectives of governments.

The most fundamental question that must first be answered with respect to financial frameworks for the deployment of CCS is how much capital is required and when must the investments be made. Sound policy requires that governments optimise their use of resources to deliver on their priorities (eg, achievement of the UN Sustainable Development Goals). Put simply, governments should provide the most benefit for the least cost. Having set the achievement of net-zero emissions as one of many priorities or commitments, governments need to find the lowest cost solution. This can only be defined through the use of an appropriate model, such as the Global CCS Institute's Global Economic Net Zero Optimization (GENZO) model.

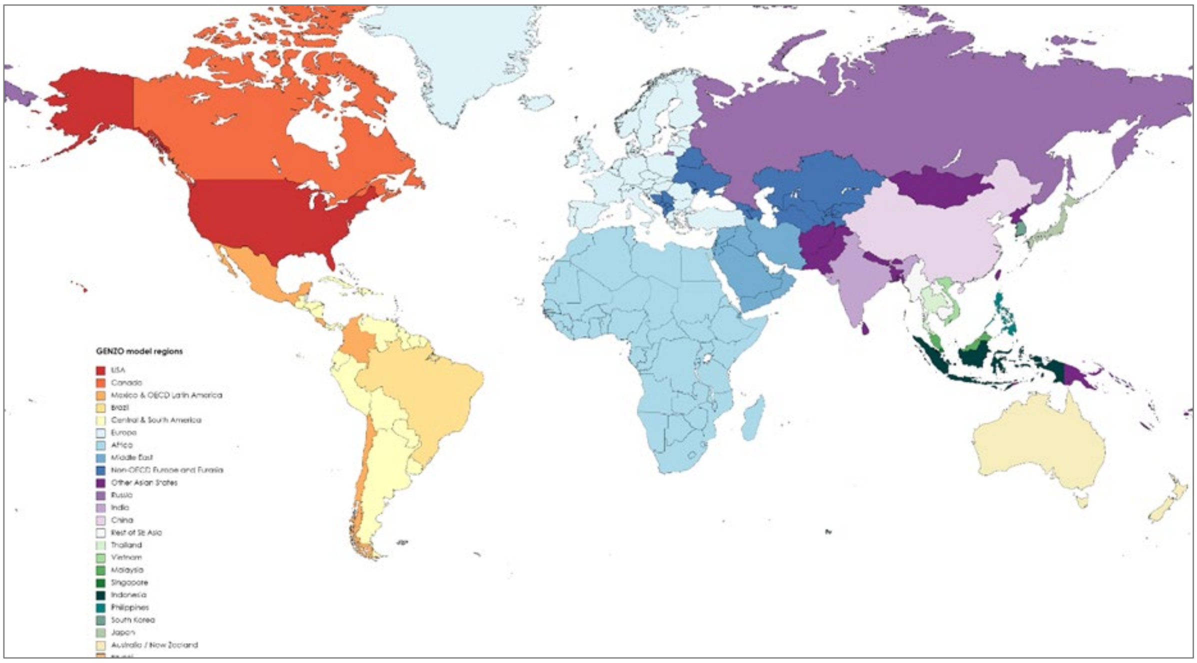
4.2. Global Economic Net Zero Optimization (GENZO) Model

The GENZO model is a bottom-up technology-focused model based on the Open Source Energy Modelling System (OSeMOSYS) framework. OSeMOSYS is similar to MARKAL and TIMES and is used widely in academia and in government for policy analysis and energy system planning (Gardumi et al. 2018; Howells et al. 2011; Löffler et al. 2017; Niet et al. 2021; Welsch et al. 2014).

GENZO consists of 24 regions as shown in Figure 4.1. Although we run GENZO with all 24 regions simultaneously to ensure that results reflect trade in energy and commodities across regions, we present results in this study for ASEAN countries based on the following model regions:

BRN: Brunei Darussalam
IDN: Indonesia
MYS: Malaysia
PHL: Philippines
RoSEA: Rest of South-East Asia
  Cambodia, Laos, Myanmar
SGP: Singapore
THA: Thailand
VNM: Viet Nam

Figure 4.1. GENZO Regions



Source: GCCSI.

GENZO solves for the lowest total cost whilst meeting emission trajectories and other constraints. GENZO is technologically rich and has good sectoral representation: 5 heavy industries + other industry, 4 modes of passenger travel, 7 modes of freight transport, Buildings, and agriculture. GENZO models trade in oil, LNG, coal, ammonia, Bio-LNG, synfuel, steel, aluminum, physical CO_2 for storage, and, optionally, CO_2 emission credits.

GENZO invests in and operates technologies over the entire energy system from energy resources to energy transformations to end-use technologies to satisfy final demands and to fall within constraints like net zero pathways.

In GENZO, future final energy service and commodity demands are exogenous, and everything else is endogenous. For example, we do not set oil prices or have an oil price forecast. GENZO models the supply of oil in each region, and the demand for oil that results from investment in technologies that require oil and the decision to operate those technologies. Oil prices result from the balance of supply and demand, along with trade of oil between regions. The same is true for all energy and commodity prices in GENZO.

Further information about the GENZO model, its structure and key assumptions can be found in the Global Economic Net Zero Optimization (GENZO) model documentation.[9]

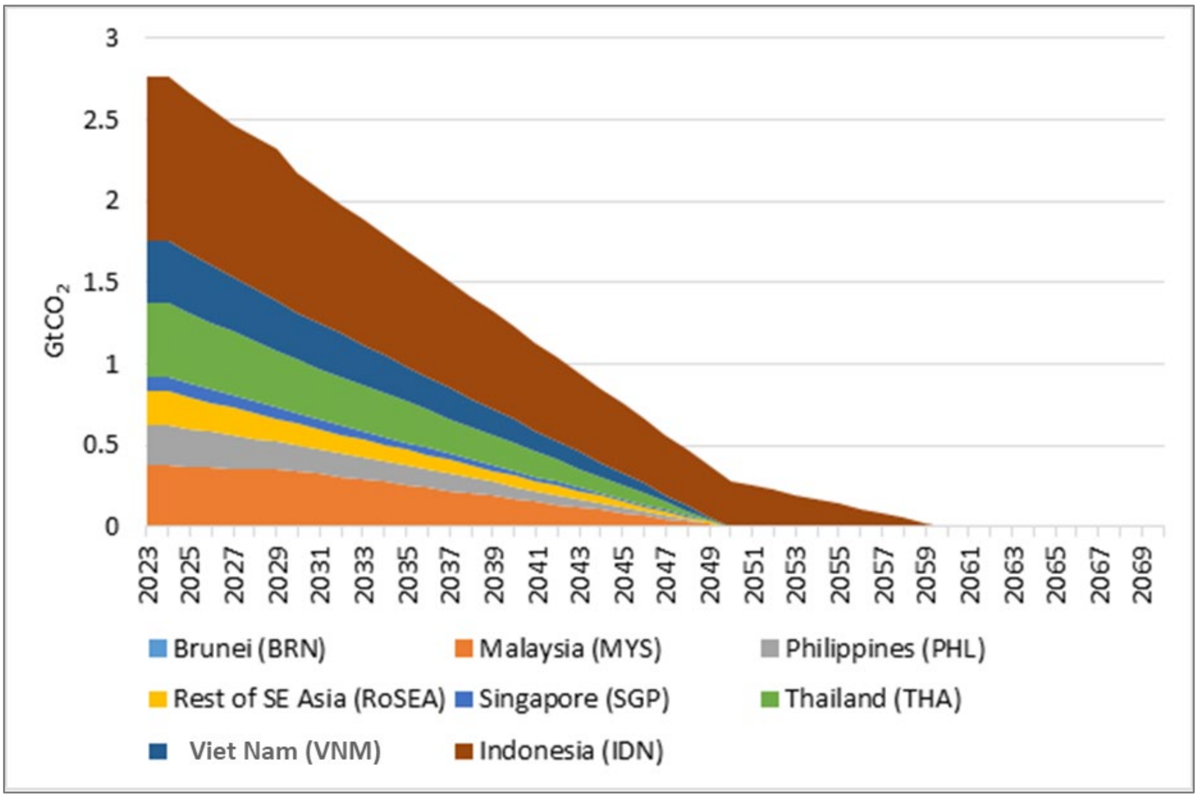
4.3. Scenarios

We run GENZO without net zero targets to establish a reference case by which to compare results of net zero scenarios. Unless specifically highlighted as a reference case result, the results shown and discussed in this report are all based on the net zero assumptions shown in Figure 4.2, which are linear reductions to a 2030 target if a particular country has one and to a 2050 net zero target for all of ASEAN except Indonesia, which has a 2060 net zero target.

---

[9] genzo1123.pdf; globalccsinstitute.com.

Figure 4.2. Net Zero Pathways for South-East Asia

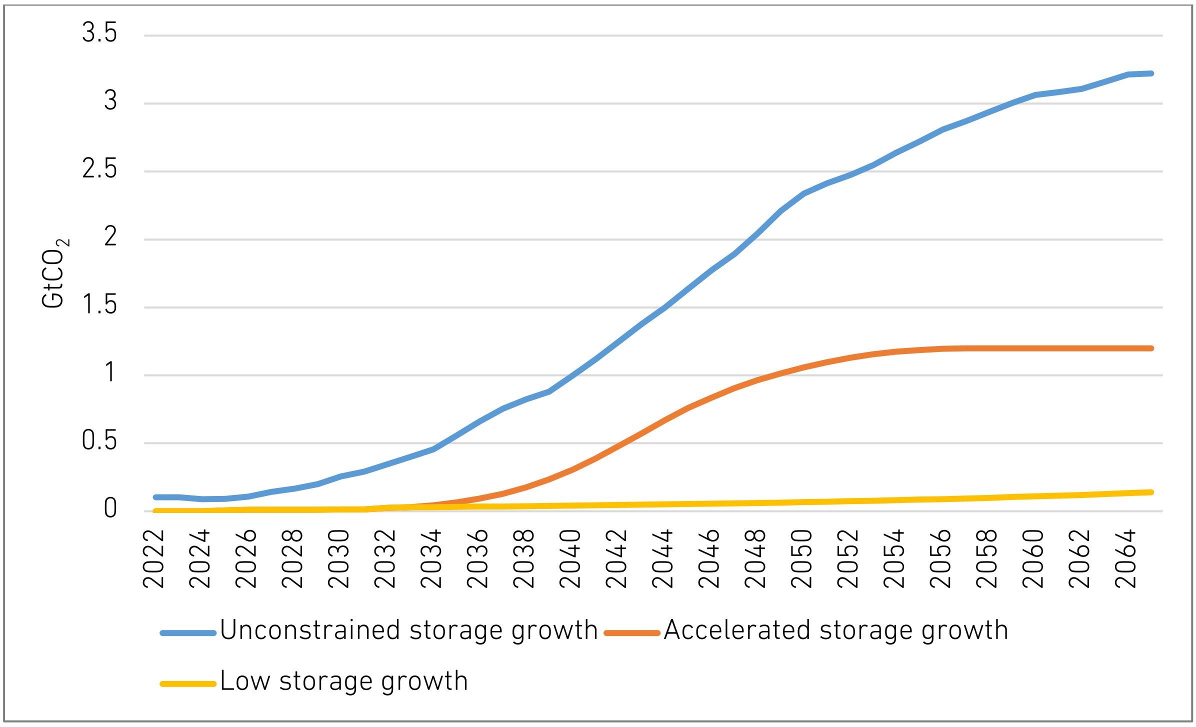


Source: GCCSI

What distinguishes the scenarios discussed and evaluated in this report is the assumption around the growth in storage capacity development. We distinguish the growth in development in storage capacity from the total evaluated storage resource available. Just like any resource, it must be developed to be used, and development of storage takes time and investment. Government policy can accelerate storage development. Based on what we know about the current project pipeline for storage development expected by 2032, we created storage development scenarios that apply to all regions in GENZO. Figure 4.3 shows the aggregation of each of the ASEAN countries/regions in GENZO for the three scenarios considered: a low storage growth scenario that grows at 5% per year beginning in 2032, an accelerated storage growth scenario that begins at 50% growth in 2032 with a declining growth rate through 2060 when the growth rate reaches 0%, and an unconstrained storage growth scenario.

The low storage growth and accelerated storage growth scenarios do not require that GENZO stores that level of CO_2, but places a limit on how much can be stored by when; GENZO can opt to store less if it is economic to do so. The Unconstrained scenario is a little different. The total storage capacities for each region are still in place – no region can store more than it has the capacity to store[10]. Unconstrained in this case is that we allow GENZO to store as much is it finds economic to store when it decides to store it while not exceeding the evaluated storage capacity in a region. The Unconstrained line in Figure 4.3 is the resulting storage GENZO opted for in the Unconstrained scenario model run. This scenario can be thought of as an optimal least-cost outcome; the average annual growth in storage development in the unconstrained scenario is about 15%. Sustained growth at this rate over 30+ years is not impossible but would depend on clear policy to drive the required investment.

Figure 4.3. South-East Asia Annual Potential Storage Development Scenarios



Source: GCCSI.

4.4. High-Level Results

Figure 4.4 shows at a high level how South-East Asia achieves net zero in each scenario. The black line in each figure shows the reference case emissions that would occur absent the net zero commitment. The red dotted line shows the aggregate net zero commitment for ASEAN. The blue area shows how much CO_2 is reduced from the

[10] GENZO can transport physical CO_2 by ship or by pipeline from one region to another, so if an opportunity to store in a neighboring or even more distant region is available in any scenario, and doing so lowers the total system cost, then GENZO will opt to transport CO_2 to other regions. Singapore, which has no storage capacity of its own, and the Philippines, which has very little storage capacity, can both still take advantage of carbon capture opportunities by transporting their captured CO_2 elsewhere.

reference case by direct carbon capture and storage applied to applications using fossil fuels. The green area shows the contribution of renewables, hydrogen, fuel switching, electrification, energy efficiency, and so on, toward meeting net zero targets. The dark green line shows the direct emissions in the scenario. The orange area shows bioenergy with CCS or BECCS as well as direct air carbon capture and storage (DACCS) – these technologies are carbon removals and are what enable a scenario to offset direct emissions to reach net zero.

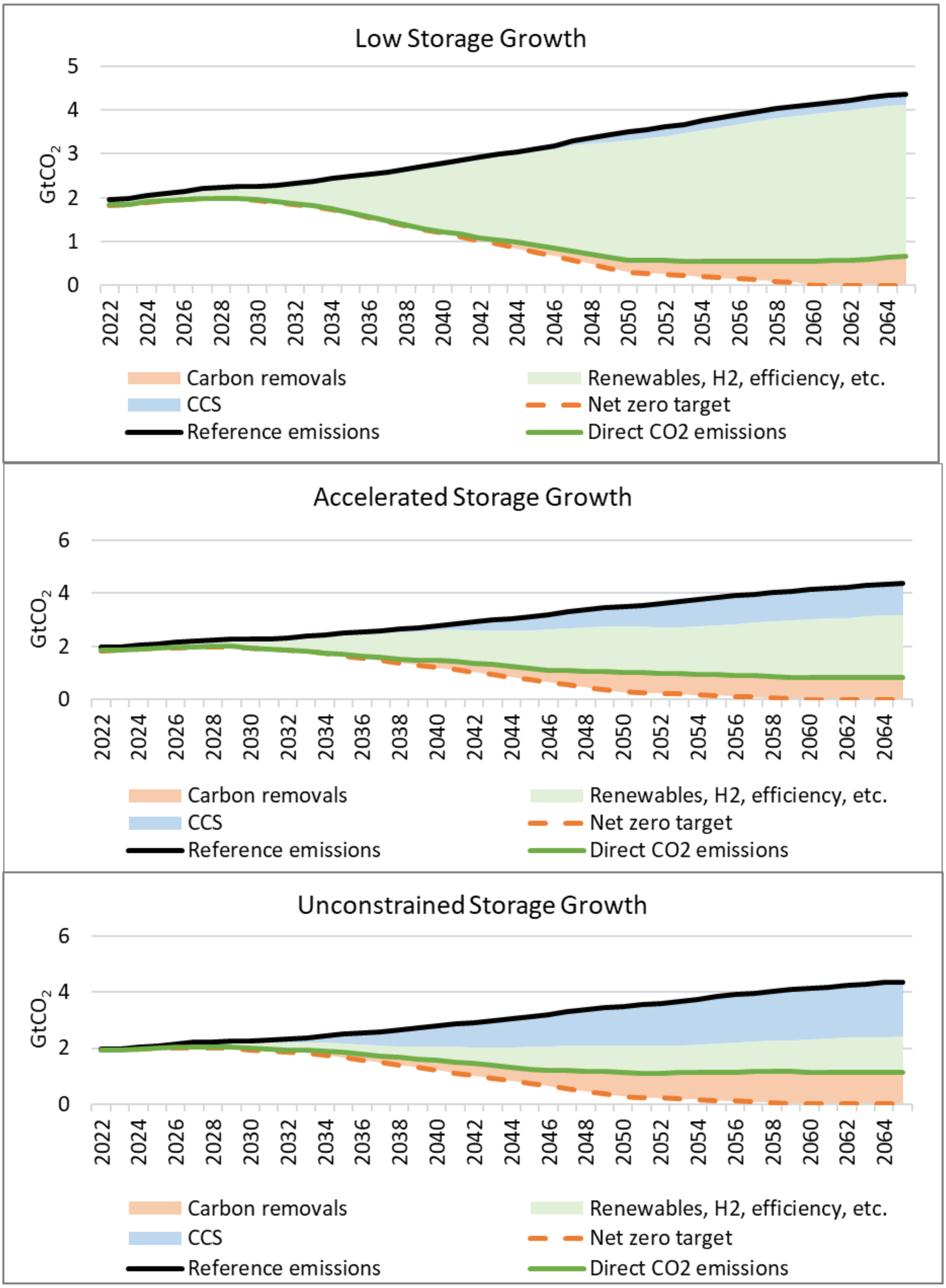
All three scenarios result in the same net zero emissions pathway.

The low storage growth scenario limits the development of CO_2 storage capacity, and with that limited available CO_2 storage GENZO finds that the optimal storage allocation is primarily to carbon removals and, in this case, almost all BECCS. BECCS serves two roles. BECCS provides useful energy while removing CO_2 from the atmosphere. A small amount of CCS is deployed with applications using fossil fuels. As discussed in more detail later, this CCS is primarily for natural gas combined cycles in the electricity sector. The low storage growth scenario relies overwhelmingly on renewable energy and hydrogen pathways to reduce CO_2 emissions.

The accelerated storage growth scenario enables a modest increase in BECCS, along with a very small amount of DACCS, but also enables a considerable increase in direct CCS. This scenario is less dependent on renewable energy and hydrogen pathways.

The unconstrained storage growth scenario allows for a significant increase in direct CCS while relying even less on renewable energy and hydrogen pathways. Although carbon removals go up compared to the accelerated scenario, what is not apparent here is that the increase is almost all from DACCS. The potential for BECCS is more or less maxed out in the accelerated scenario.

Figure 4.4. How Net Zero is Achieved

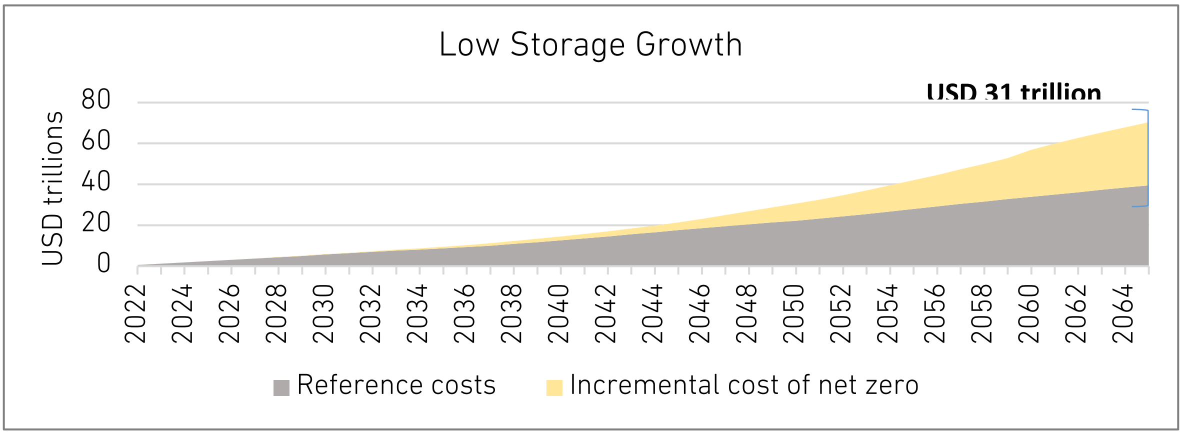


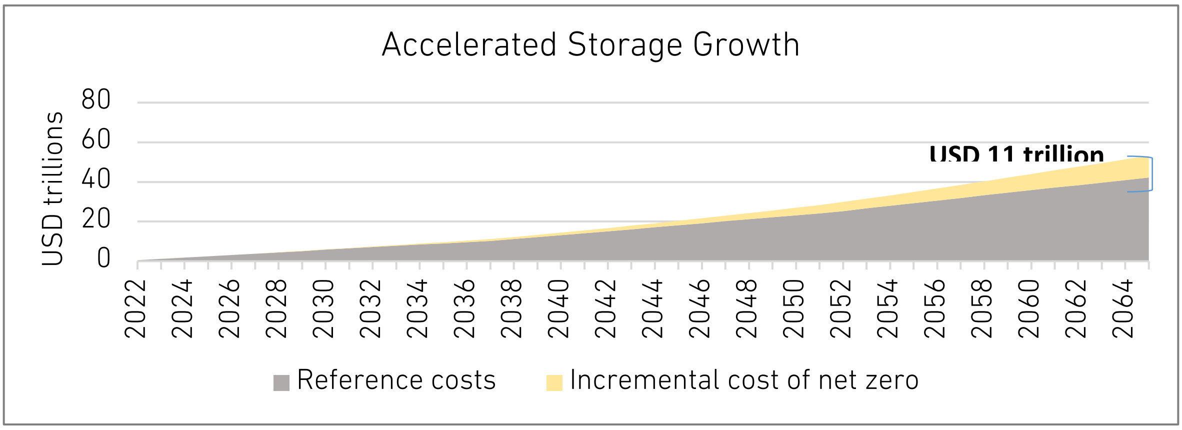
Source: GENZO result.

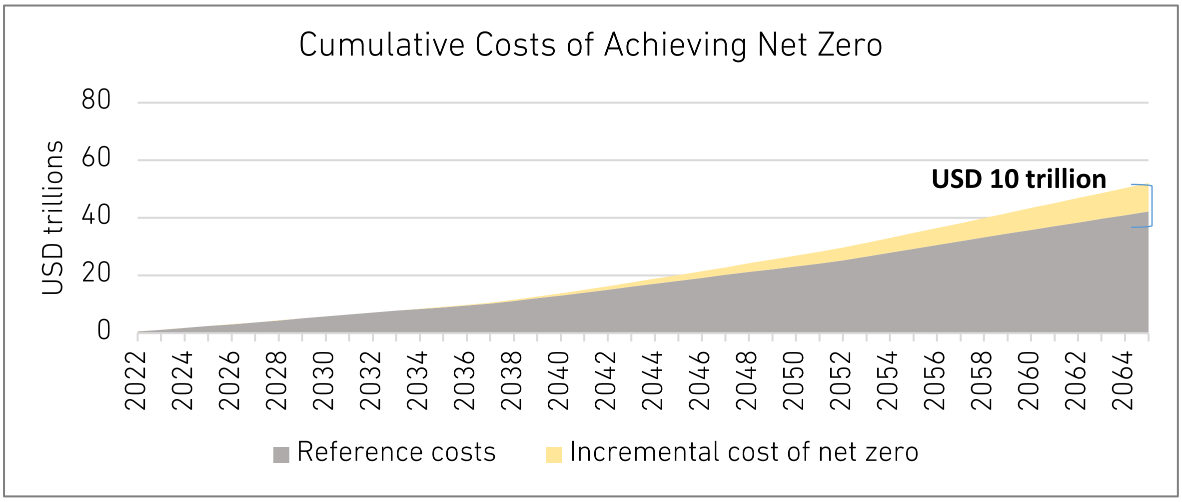
The scenarios have remarkably different incremental costs for meeting net zero (Figure 4.5). We define the incremental cost of meeting net zero as the total cost of the scenario minus the cost of the reference case scenario. The low storage growth scenario that relies so heavily on renewable energy and hydrogen pathways costs South-East Asia US$31 trillion through 2065 to reach net zero, an increase of 73% compared to the reference case. By contrast, the accelerated storage growth scenario costs only US$11 trillion (26% more than the reference case) – almost 1/3 the cost of the low storage scenario – to achieve the same net zero goal. The accelerated storage scenario shaves an additional US$1 trillion for a total cost of US$10 trillion. With many competing development priorities, a pathway to the same climate outcome that can save in excess of US$20 trillion is one that deserves consideration.

Another way to view it is that investing in CCS infrastructure, while costly, is far less costly than the alternative. The alternative may not simply be 3 times the cost but could be that we pay more while losing our political resolve due to the cost and, consequently, veer off the path, missing the net zero targets and facing potentially higher climate costs down the track.

Figure 4.5. Cumulative Costs of Achieving Net Zero



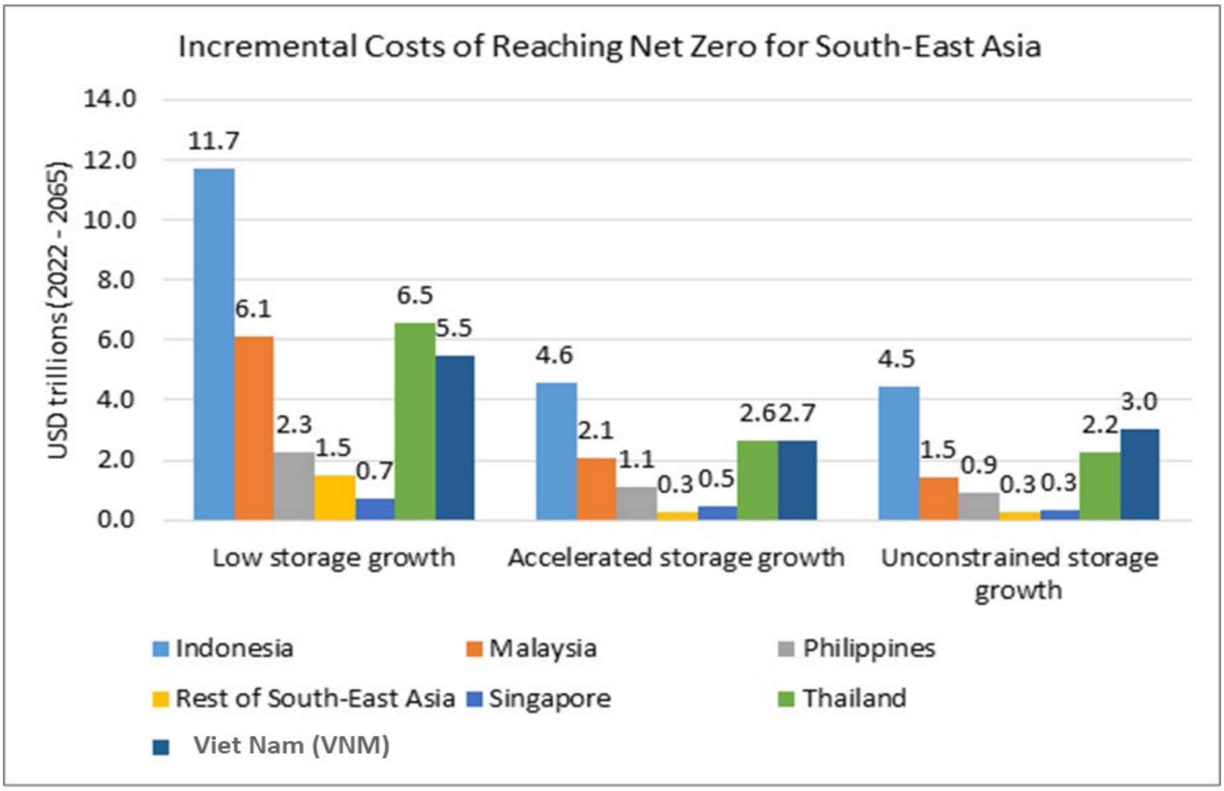




Source: GENZO result.

The cost of reaching net zero varies by country, with Indonesia facing the highest absolute cost in the region regardless of scenario, and Brunei, not shown, facing the lowest absolute cost.[11] Indonesia alone faces a higher cost in the low storage growth scenario than all of South-East Asia in the unconstrained storage growth scenario, and almost as much as the accelerated scenario for the whole region.

Figure 4.6. Incremental Costs of Reaching Net Zero by Country

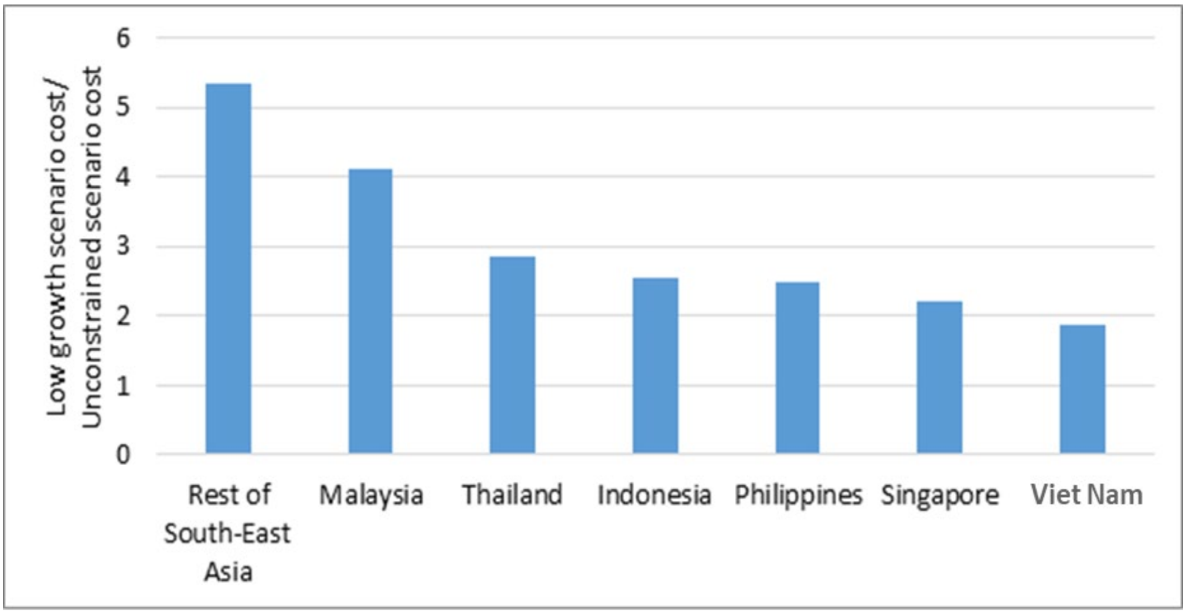


Source: GENZO result.

While all countries face lower costs with the accelerated and unconstrained scenarios, some countries gain more than others (Figure 4.7). The 'Rest of South-East Asia' region (Cambodia, Laos and Myanmar) faces costs in the low storage development scenario that are just over 5 times higher than its costs in the unconstrained scenario. Myanmar has low storage scenario costs that are 4 times its costs in the unconstrained scenario. Viet Nam, with the lowest cost multiple, still faces 1.8 times the cost in the low storage development scenario compared to the unconstrained scenario. Viet Nam has limited storage capacity, so its costs are high regardless of scenario and sees smaller, though still substantial, cost benefits from an unconstrained or accelerated scenario.

[11] Because the cost reflects net trade, Brunei's oil revenue more than compensates for the cost of the Brunei energy system. Therefore the cost is negative, but also so small compared to the scale of the other countries that it is not visible in a figure, so we have left it out.

Figure 4.7. Net Zero Cost Ratio: Low Storage Growth Scenario Cost to Unconstrained Storage Growth Cost



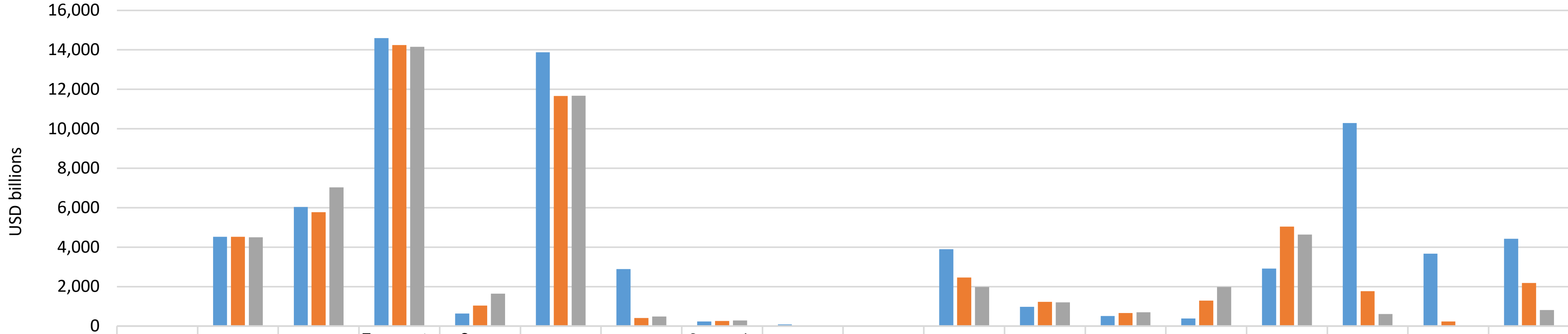
Source: GENZO result.

Breaking out the full cost of each scenario by key components reveals where the major cost differences are amongst the scenarios. shows the cost, through 2065, of CAPEX and OPEX in end-use and energy transformation sectors for South-East Asia plus the cost of energy production within the region, and the net cost of fuel imports. We can see that the non-energy costs in the buildings sector are almost identical across scenarios. The Accelerated storage scenario sees moderately lower non-energy costs in industry compared to the low growth scenario. The unconstrained storage scenario sees an additional US$1 trillion compared to the low growth scenario and 1.2 trillion compared to the accelerated scenario. The additional investment in CCS accounts for this added cost in the unconstrained scenario. The reliance on hydrogen infrastructure in the low growth scenario leads to moderately higher costs than the accelerated scenario, despite its having substantially more CCS. The low storage growth scenario has slightly more non-energy transportation costs than the other two scenarios.

Cross-sector CCS costs reflect the level of CCS deployment across the scenarios.[12]

[12] GENZO assumes that, once captured, CO_2 goes along a pipeline with a distance scaled based on the relative size of the country and the type of source (DACCS is assumed to be near CO_2 storage, for example) and either arrives at a storage location if capacity is available or a shipping terminal or inter-region pipeline or, if the source is bioenergy or direct air capture, to synfuel production if synfuel is needed. Once the CO_2 leaves the initial pipeline, its costs are no longer trackable directly to the source and are allocated in post-processing to cross-sector CCS. DACCS itself, since it is not within aparticular end-use sector, is also allocated to cross-sector CCS costs. Finally, for some industrial applications, particularly for 'other industry' that typically has smaller facilities, we assume that the thermal load for CCS would be met by a separate thermal supply akin to industrial hub district heating. For the purposes of the calculations in this figure, we have included the non-energy costs of the thermal supply for these CCS applications in cross-sector CCS costs.

Figure 4.8. Total Energy System Cost through 2065 Broken Out by End-Use and Transformation CAPEX and OPEX, Fuel Production Costs, and Net Cost of Fuel Imports

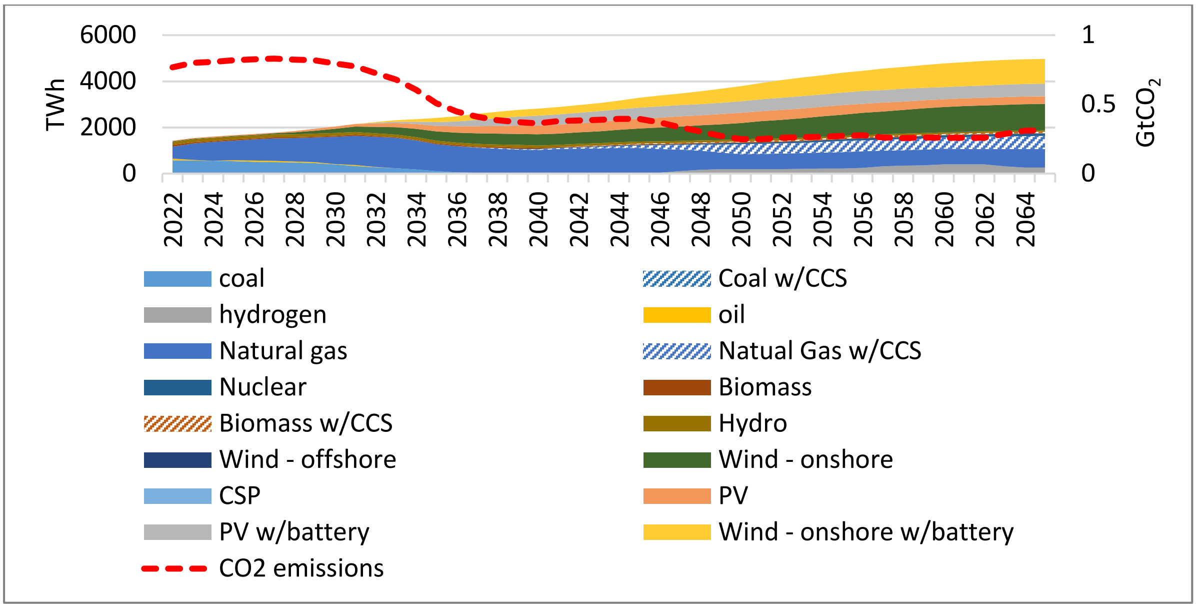


	Agriculture (CAPEX + OPEX)	Buildings (CAPEX + OPEX)	Industry (CAPEX + OPEX)	Transportation (CAPEX + OPEX)	Cross-sector CCS (CAPEX + OPEX)	Electricity (CAPEX + OPEX)	Hydrogen (CAPEX + OPEX)	Conventional fuels (CAPEX + OPEX)	Biofuels (CAPEX + OPEX)	Synfuels (CAPEX + OPEX)	Biomass production	Natural gas production	Oil production	Coal production	Conventional fuel imports	Biofuel imports	Synfuel imports	Ammonia imports
Low growth	21	4531	6041	14593	632	13884	2891	239	78	20	3897	975	504	383	2916	10292	3674	4424
Accelerated	21	4527	5771	14241	1045	11667	404	255	8	28	2460	1224	657	1288	5040	1767	238	2188
Unconstrained	21	4496	7027	14160	1643	11675	483	277	1	12	1989	1206	696	1983	4645	608	0	813

Source: GENZO result.

The low storage scenario sees a significant increase in CAPEX and OPEX in the electricity sector compared to the other two scenarios, owing in part to the necessity to use relatively poor wind resources in the region, but primarily for biomass and hydrogen-based generation for firm power – these lead to an additional US$2.3 trillion just in non-energy expenditures in the electricity sector.

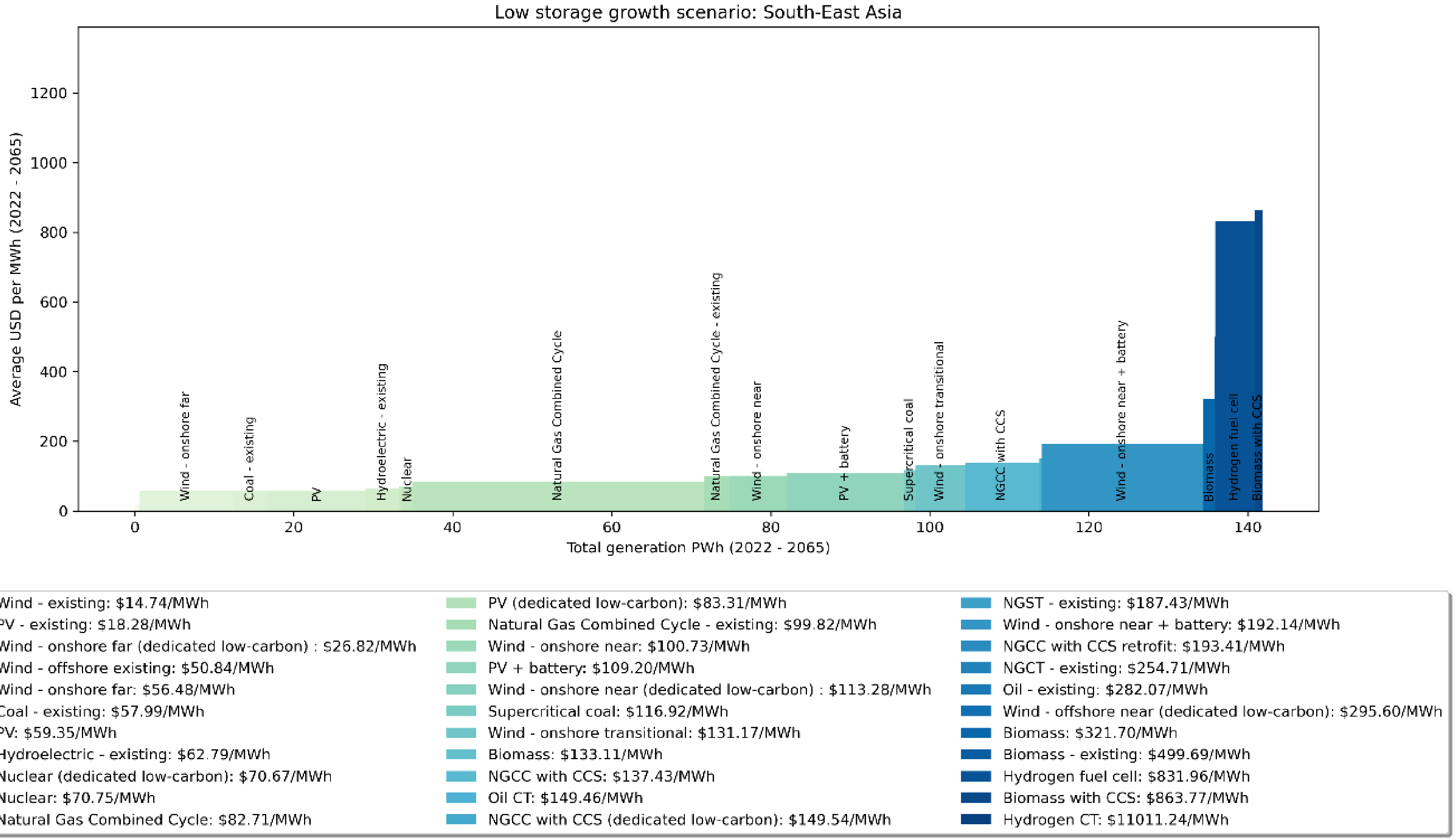
Figure 4.9. Electricity Generation and CO_2 Emissions through 2065: Low Storage Growth Scenario



Source: GENZO result.

Even though total hydrogen and biomass-based generation is not a large portion of the overall generation mix in the low storage growth scenario, the cost of that generation is quite high (Figure 4.10).

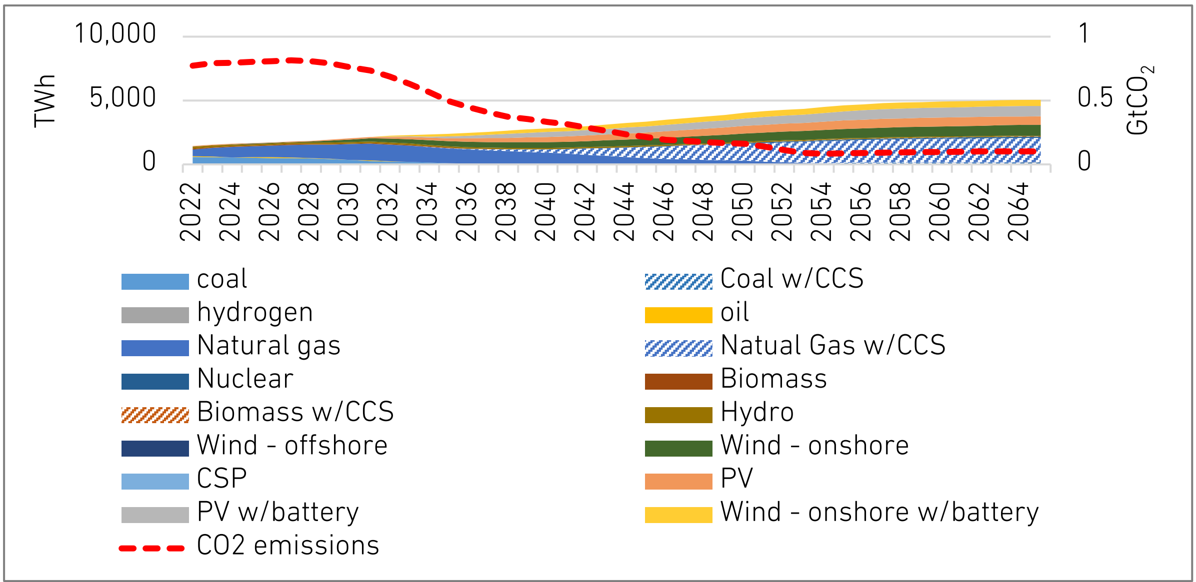
Figure 4.10. Cost of Electricity Generation: Low Storage Growth Scenario



Source: GENZO result.

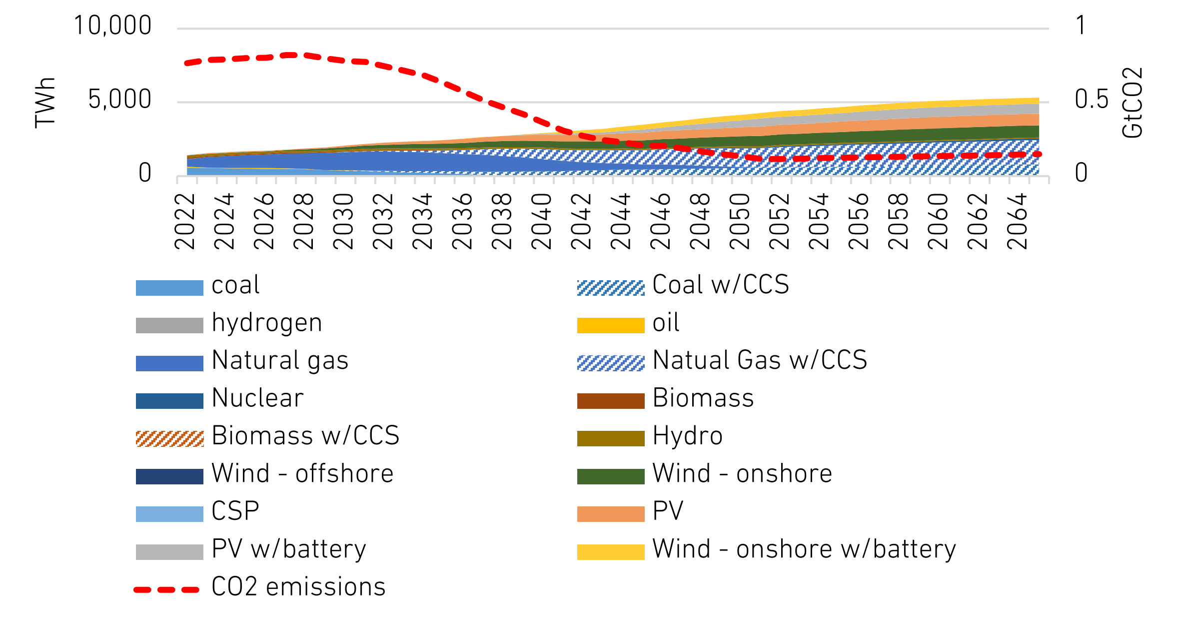
By comparison, the accelerated storage growth scenario has sufficient CO_2 storage to use natural gas combined cycle with carbon capture for firm power (Figure 4.11). The unconstrained storage growth scenario, with even more available CO_2 storage, also uses supercritical coal with post-combustion capture (Figure 4.12).

Figure 4.11. Electricity Generation and CO_2 Emissions through 2065: Accelerated Storage Growth Scenario



Source: GENZO result.

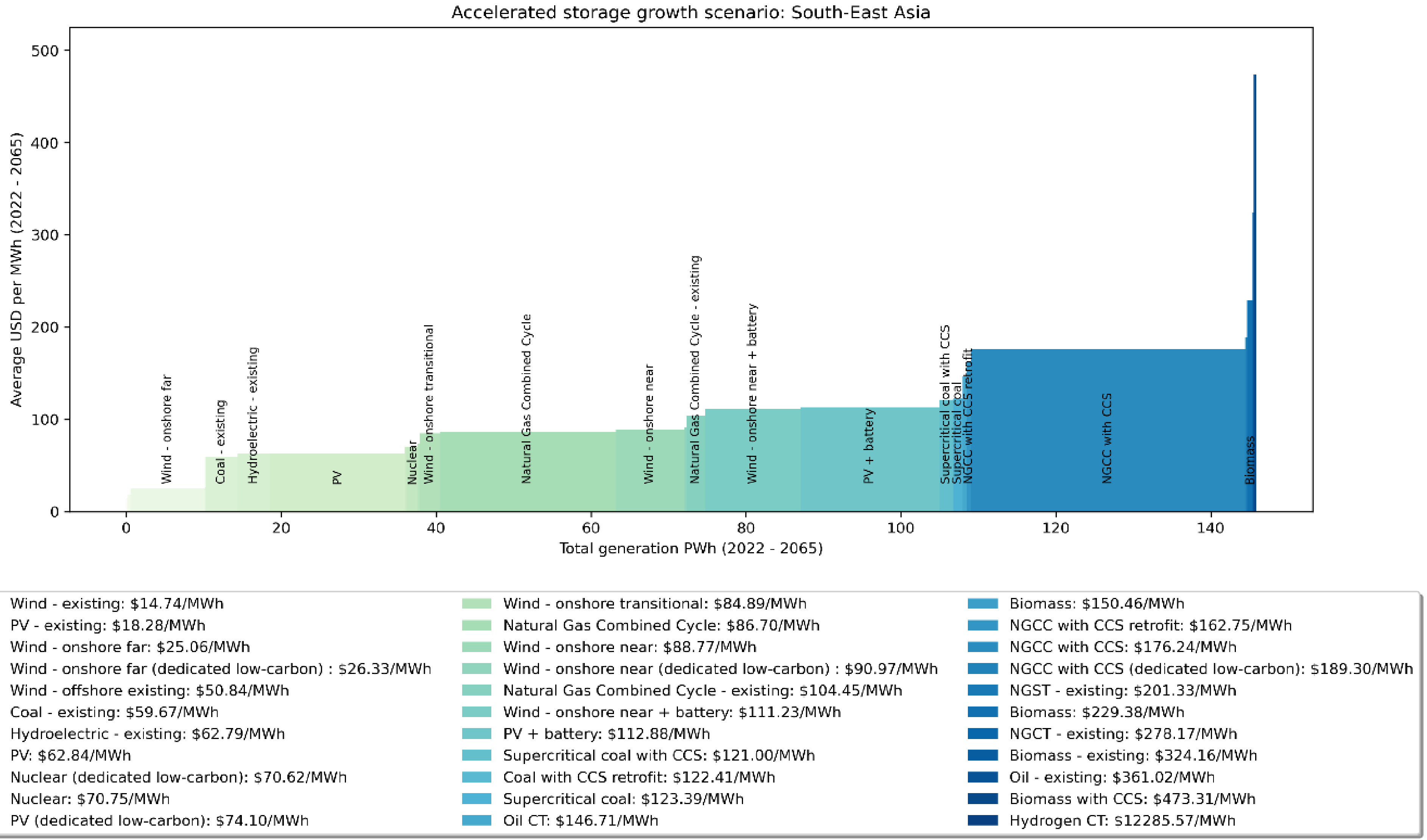
Figure 4.12. Electricity Generation and CO_2 Emissions: Unconstrained Storage Growth Scenario



Source: GENZO result.

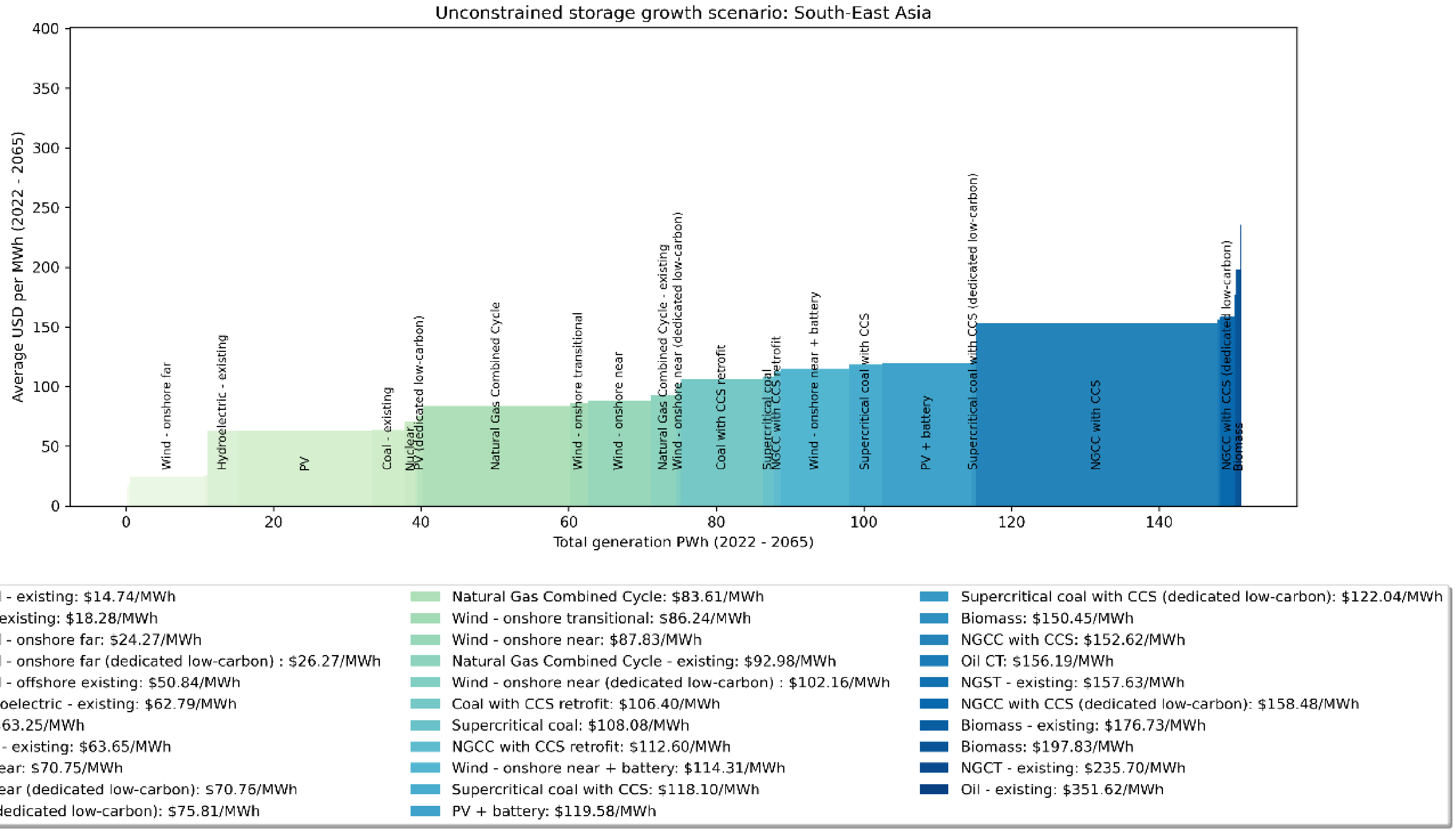
By avoiding the use of biomass and hydrogen-based generation, the cost of supplying electricity in the accelerated (Figure 4.13) and unconstrained (Figure 4.14) storage growth scenarios is significantly lower than in the low growth scenario, resulting in electricity prices that are also significantly lower. Many decarbonisation pathways, even if not directly achieved through electrification, depend in part on additional electricity consumption. For example, carbon capture requires both thermal energy and electricity. Electricity then drives the compression and pumps required to send CO_2 through pipelines and into geologic storage. Electricity also can provide a decarbonisation pathway itself. Electric heat pumps can offer low-carbon space heating and cooling in buildings. Electric vehicles, particularly for light-duty vehicles, offer a low-carbon alternative. Electrical heating for some industrial applications is also possible. Hydrogen, which offers its own decarbonisation options, especially in transportation, can be produced from electricity and must be produced from electricity if CO_2 storage availability is limited. The added cost of electricity generation and higher electricity prices in the low carbon storage scenario cascades throughout the energy system to contribute higher overall cost of net zero in the low carbon storage scenario than the other two scenarios.

Figure 4.13. Cost of Electricity Generation: Accelerated Storage Growth Scenario



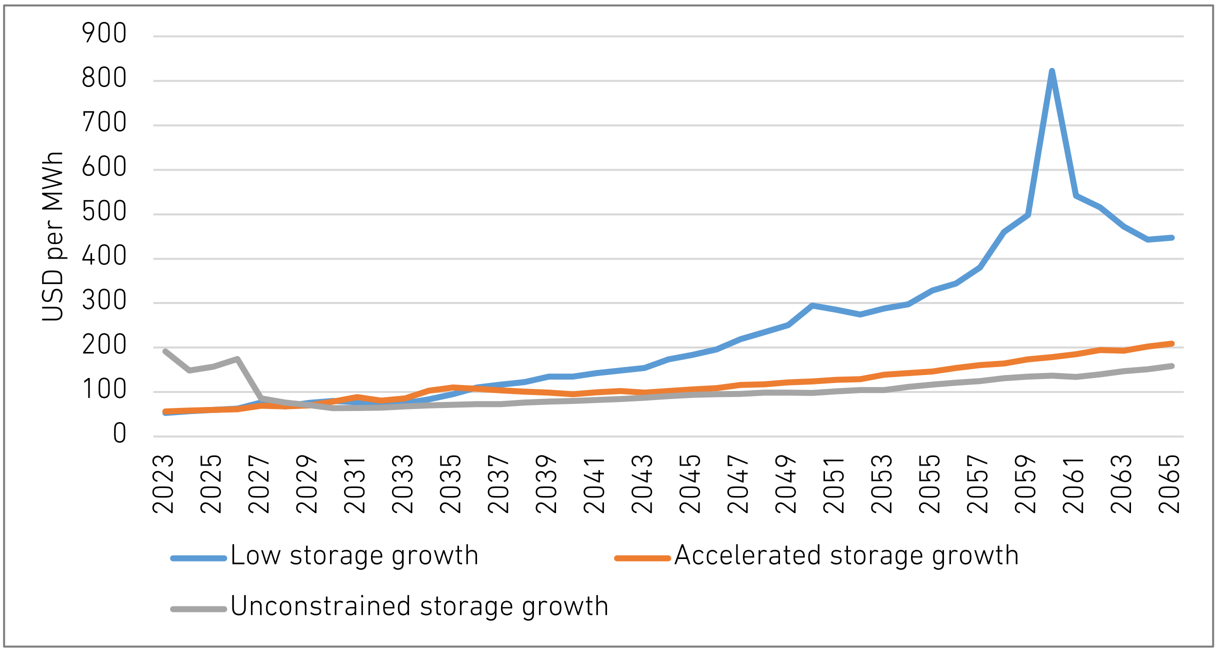
Source: GENZO result.

Figure 4.14. Cost of Electricity Generation: Unconstrained Storage Growth Scenario



Source: GENZO result.

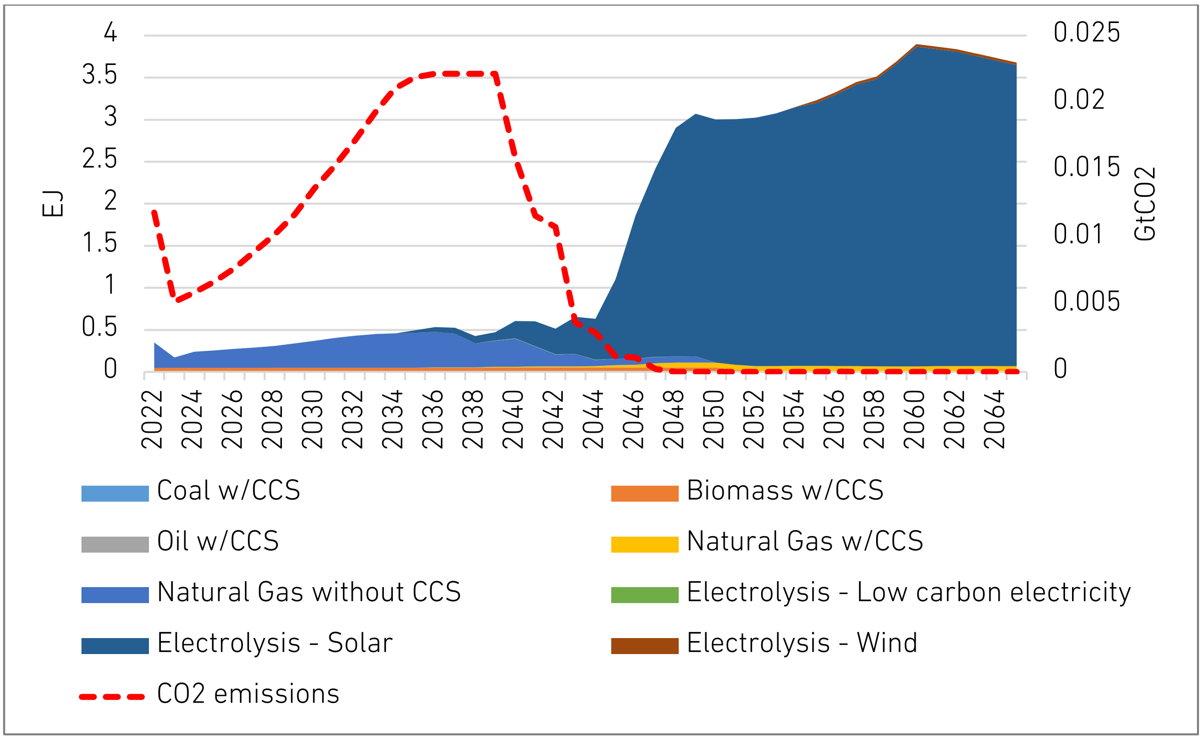
Figure 4.15. Electricity Prices Averaged Over All Countries in South-East Asia



Source: GENZO result.

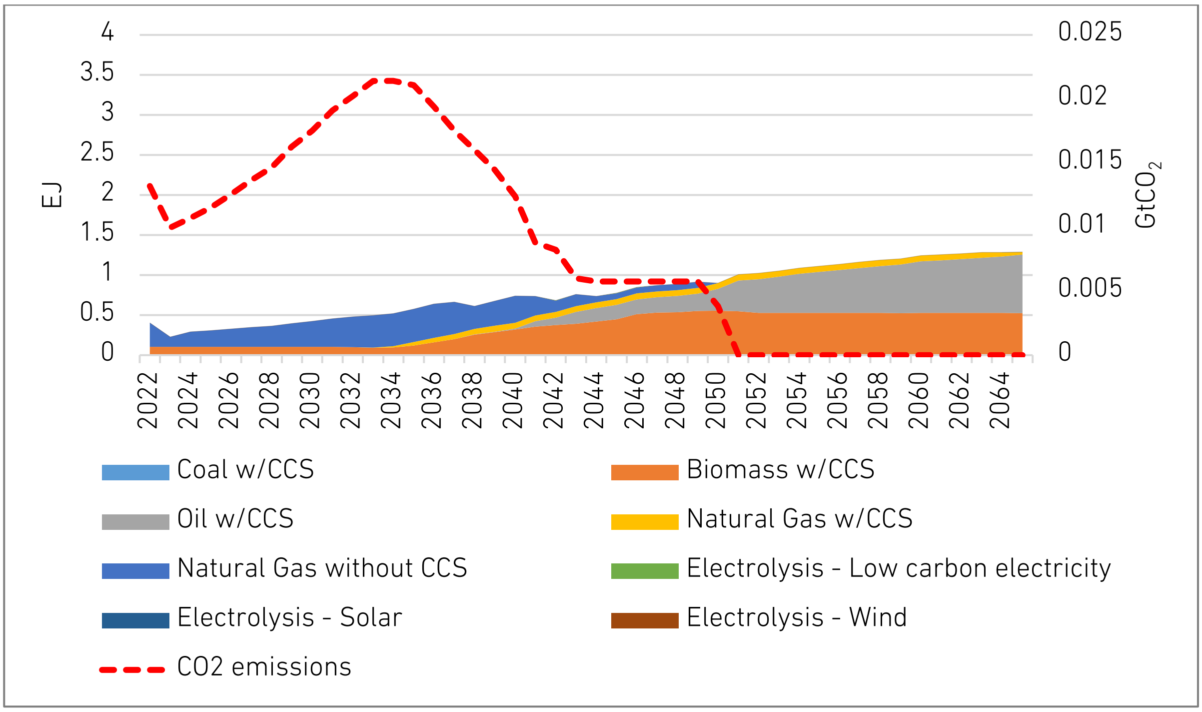
Because the low storage growth scenario has limited CO_2 storage availability, the hydrogen it generates is via electrolysis, primarily with dedicated solar (Figure 4.16). The low growth scenario also produces considerably more hydrogen than the accelerated (Figure 4.17) and unconstrained (Figure 4.18) scenarios because hydrogen is the primary method of decarbonisation in the low growth scenario. As a result, the CAPEX and OPEX needed for hydrogen in the low storage growth scenario is about US$2.5 trillion more than in the accelerated and unconstrained storage scenarios. The unconstrained storage scenario sees additional hydrogen production from coal gasification with CCS compared to the accelerated storage scenario because the greater availability of storage can accommodate coal gasification, which has a higher capture rate per kg of hydrogen production.

Figure 4.16. Hydrogen Production: Low Storage Growth Scenario



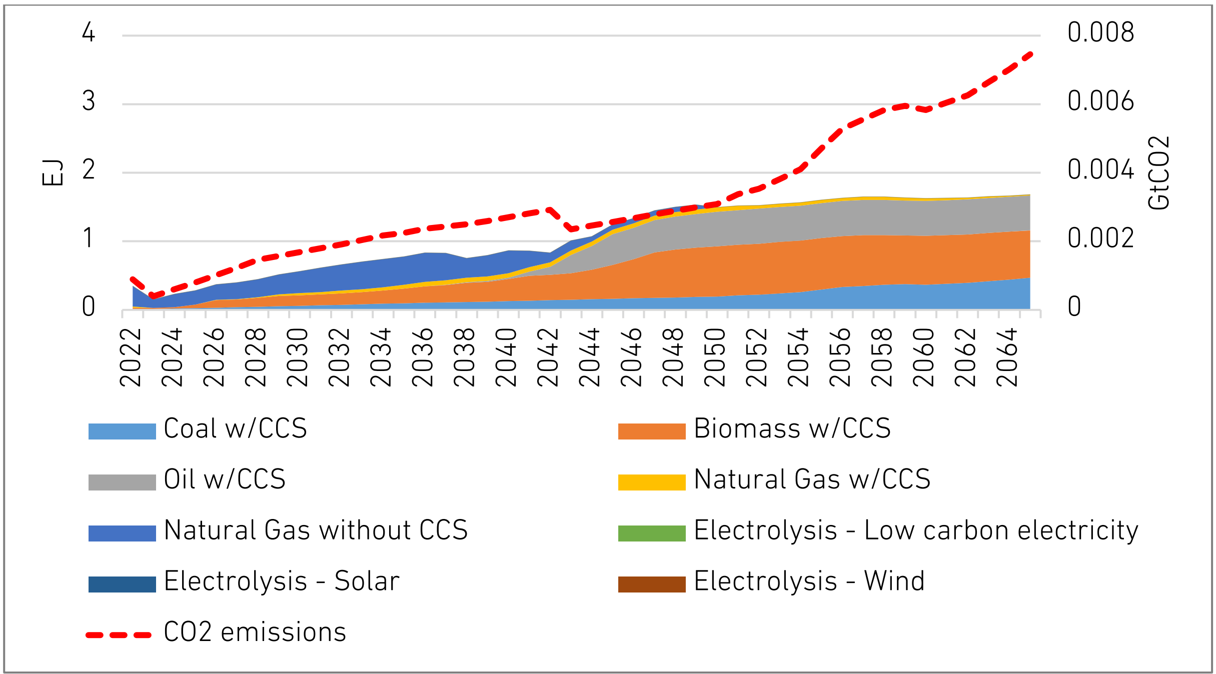
Source: GENZO result.

Figure 4.17. Hydrogen Production: Accelerated Storage Growth Scenario



Source: GENZO result.

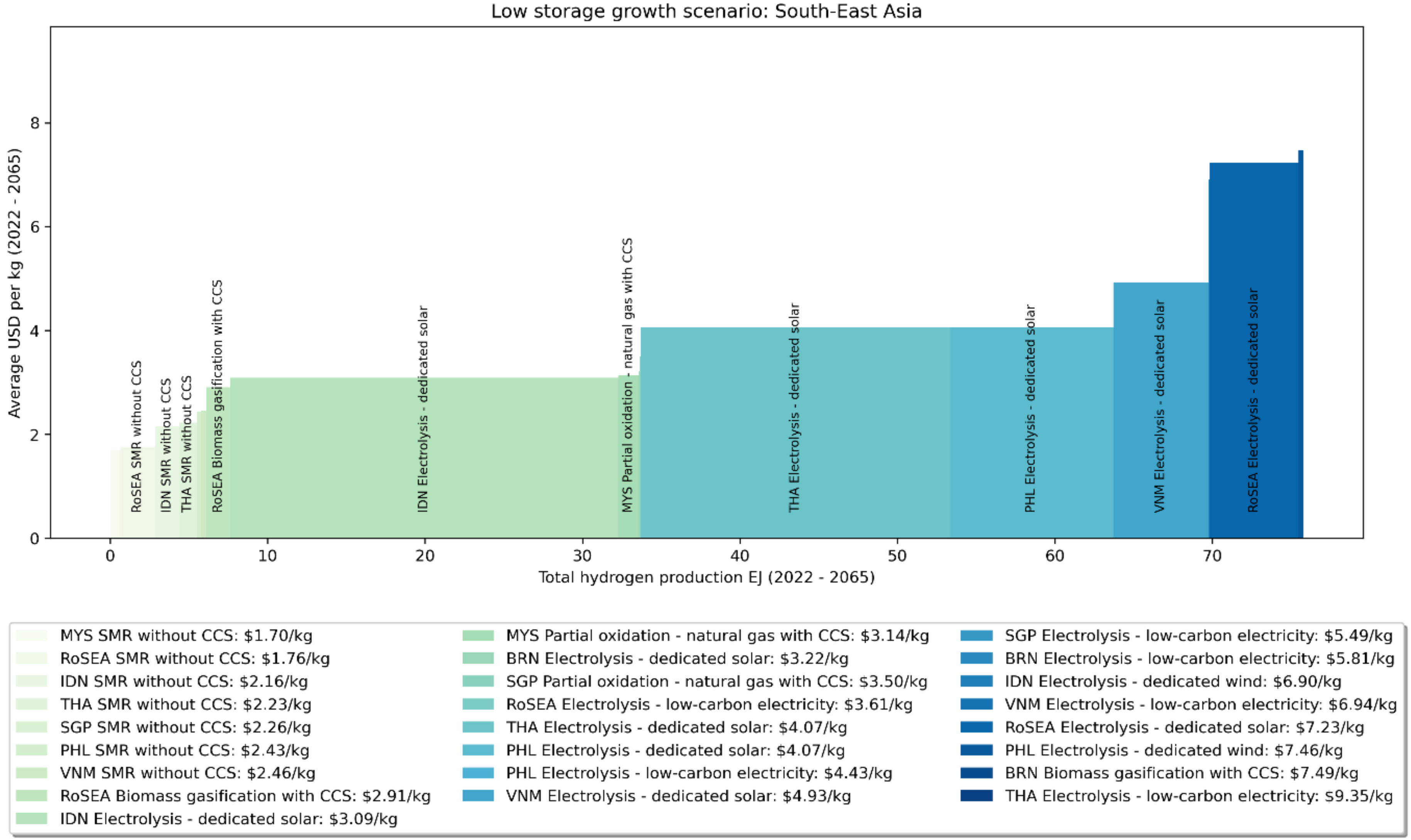
Figure 4.18. Hydrogen Production: Unconstrained Storage Growth Scenario



Source: GENZO result.

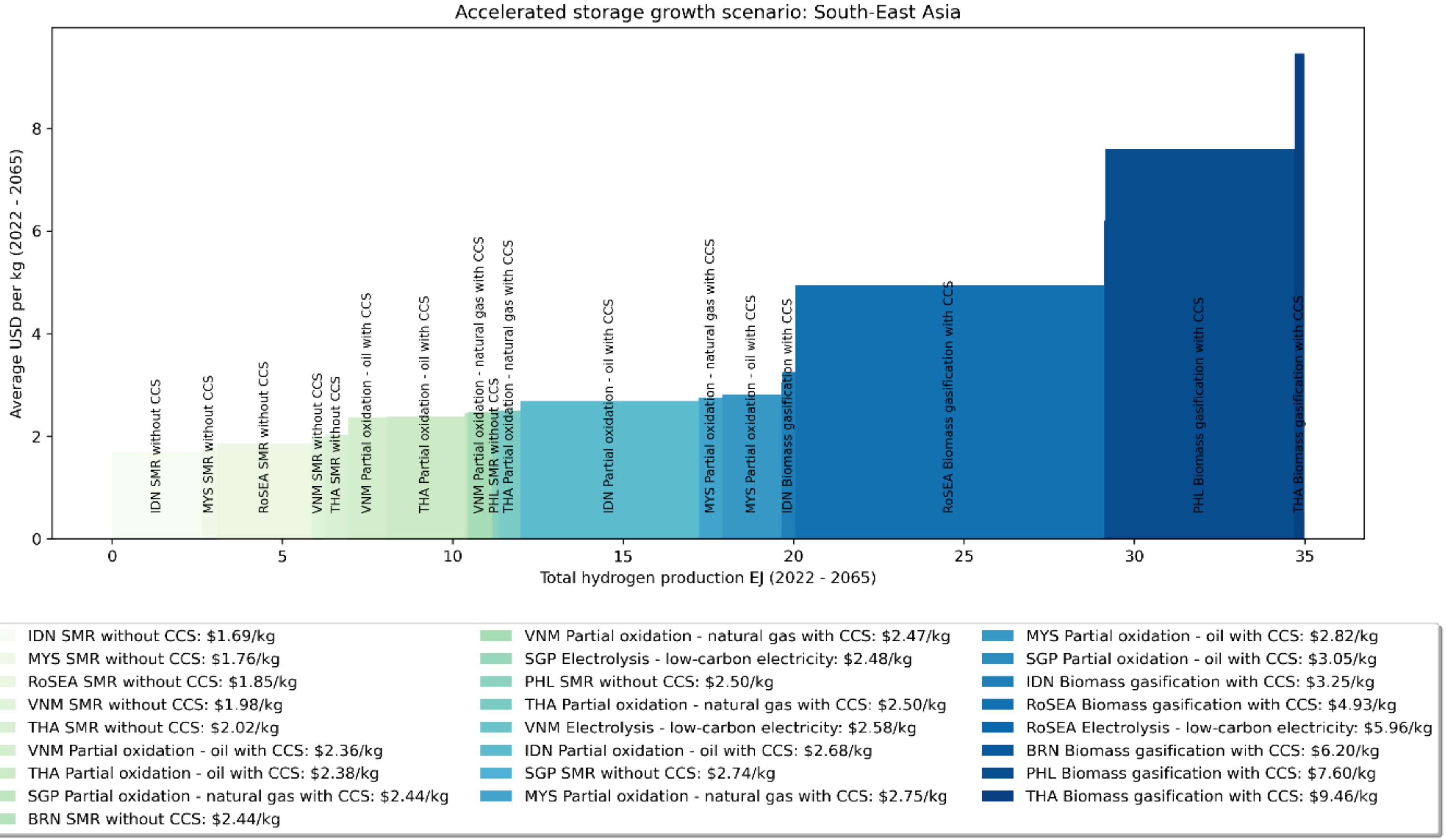
The total cost of producing hydrogen reveals some of the complexity of GENZO and the overall optimisation involved. The low storage growth scenario (Figure 4.19) has lower total cost of hydrogen production than the accelerated (Figure 4.20) and unconstrained (Figure 4.21) scenarios. Beyond around US$3 per kg, any meaningful level of production of hydrogen in the accelerated and unconstrained scenarios is from biogasification with CCS, which serves two purposes – providing low-carbon hydrogen for use in transportation and industry and carbon removals. The cost of producing hydrogen from biogasification with CCS is higher than most of the electrolysis based production costs in the low storage growth scenario, but the value in carbon removals more than compensates for the higher production costs for biogasification with CCS. If the low storage growth scenario had more available storage, it would opt for biogasification with CCS as well.

Figure 4.19. Hydrogen Production Cost: Low Storage Growth Scenario



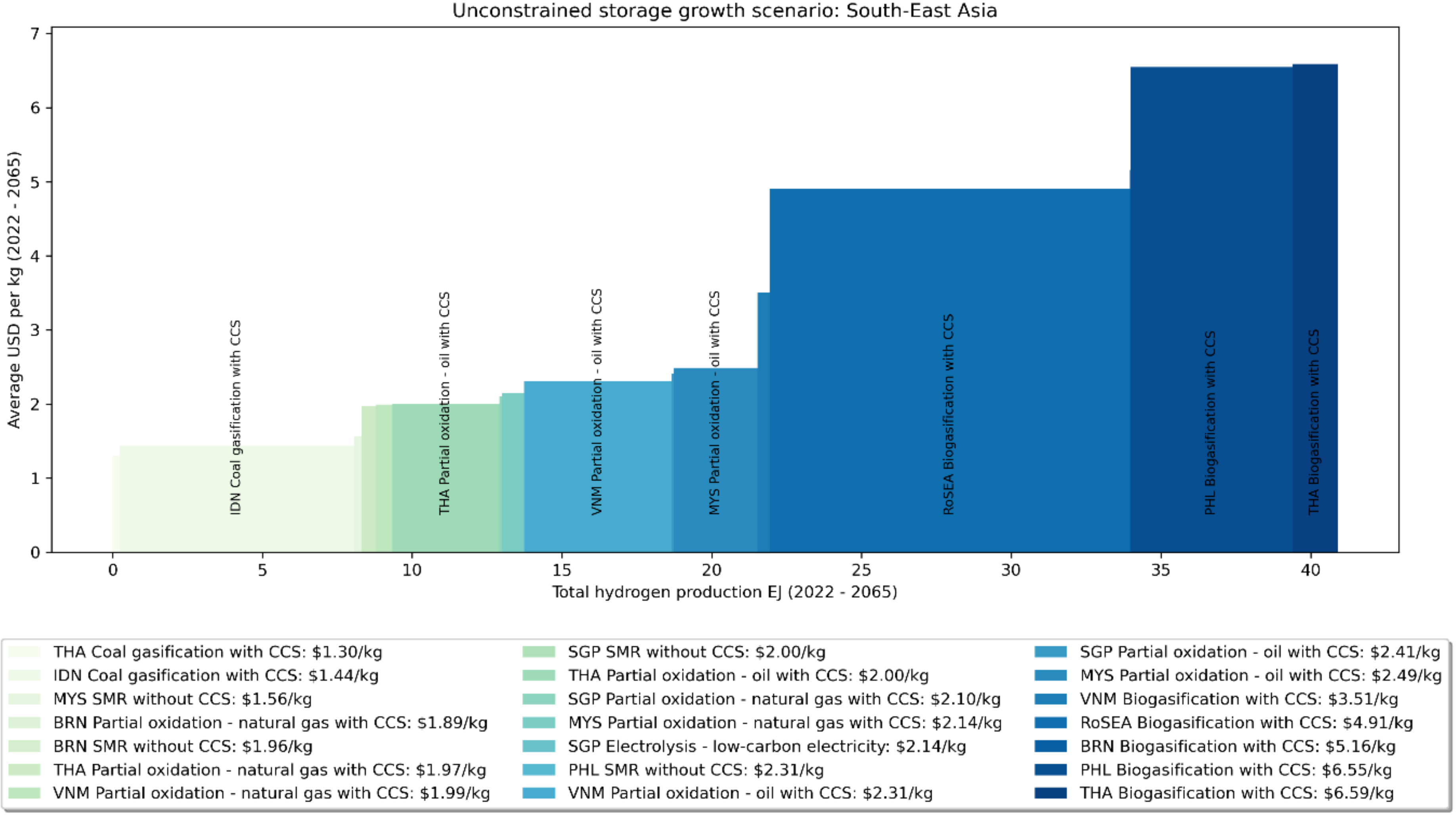
Source: GENZO result.

Figure 4.20. Hydrogen Production Cost: Accelerated Storage Growth Scenario



Source: GENZO result.

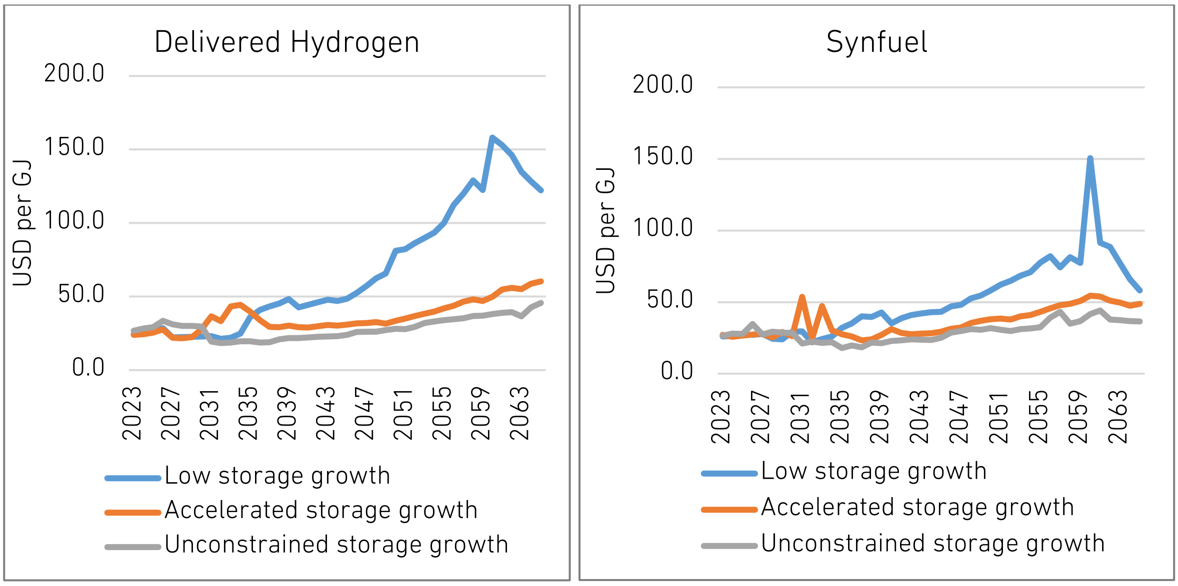
Figure 4.21. Hydrogen Production Cost: Unconstrained Storage Growth Scenario



Source: GENZO result.

The demand for hydrogen in the low storage growth scenario far outstrips the region's ability to produce it at a cost less than it can import ammonia – a hydrogen carrier – and synfuel, in which hydrogen can be a precursor. On the far right of Figure 4.8 we can see that the cost of synfuel dwarfs the import costs in the accelerated and unconstrained storage scenarios, costing more than an additional US$3 trillion. Ammonia imports also cost US$2.3 trillion more than the accelerated scenario and US$3.5 trillion more than the unconstrained scenario. Between the expensive ammonia and synfuel imports and the higher cost of domestic hydrogen production in the low carbon storage scenario, the prices of delivered hydrogen and synfuel are significantly higher than in the other two scenarios. Although hydrogen can be a precursor to synfuel, synfuel can also be produced via a process with biomass that does not require a separate production of hydrogen. Shipping and handling of synfuel, once created, is also far less costly than hydrogen or hydrogen-to-ammonia-to-hydrogen, which is why the delivered hydrogen prices in the region are generally higher than synfuel prices.

Figure 4.22. End-use Prices for Hydrogen and Synfuel Averaged Over the South-East Asia Region



Source: GENZO result.

Biofuel imports in the low storage growth scenario are even higher compared to the other scenarios than synfuel and ammonia imports. The cost of imported biofuels is US$8.5 trillion more in the low storage growth scenario compared to the accelerated scenario and a staggering US$9.3 trillion more than in the unconstrained scenario. Biomass production within the region is also significantly more costly in the low growth scenario – US$1.5 trillion more than accelerated and US$1.9 trillion more than unconstrained.

By contrast, the production of conventional fuels, especially coal, sees higher costs for the unconstrained scenario compared to the accelerated and low storage growth scenarios, but at a significantly smaller scale compared to the cost differences in imported advanced fuels. For example, the sum of conventional fuel production costs in the unconstrained scenario is only US$2 trillion more than in the low storage growth scenario. The cost of conventional fuel imports is also greater in the accelerated and unconstrained scenarios compared to the low storage scenario (accelerated is US$2.4 trillion more and unconstrained is US$1.7 trillion), but again far less than the additional cost for advanced fuel imports in the low storage growth scenario.

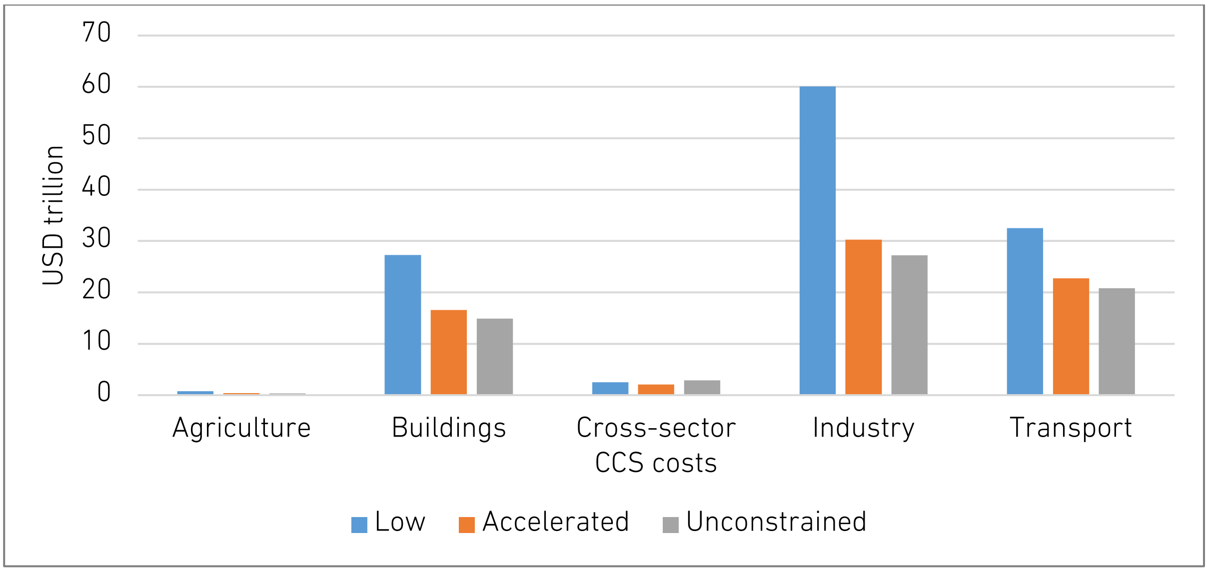
One implication for South-East Asia if it follows a low storage growth pathway is that a significant portion of its energy system costs will be dedicated to energy imports. If we add all of the CAPEX, OPEX and domestic energy production costs, the low storage growth scenario spends US$48.5 trillion, the accelerated storage growth scenario spends US$43.6 trillion, and the unconstrained scenario US$45.6 trillion. The net costs of all energy imports for the low storage growth scenario is US$20.7 trillion or 43% of its total energy system costs. Rather than spending those resources domestically in a way that supports the economy and contributes to additional jobs, 43% of the money entering the energy system will be transferred to other countries to use to develop their own advanced energy production for export. Producing the advanced fuels within the region would be even more costly, which is why GENZO opts to import. The accelerated scenario, on the other hand, spends US$9.1 trillion on imports or 21% of its total energy system spending. The unconstrained scenario spends US$6.2 trillion on energy imports for only 13.5% of total energy system spending. Both the accelerated and unconstrained scenarios allocate far greater shares of energy system spending to productive domestic resources than the low storage growth scenario. Because the total cost of the energy system is also substantially lower in these two scenarios, the additional resources that would have been used to buy imported energy in the low storage growth scenario could be used for other economic development needs like education and health care.

Up to this point in the report, we have considered costs for the entire energy system, but end-users do not face production costs for electricity and fuels. They face market-clearing prices. For example, oil production consists of some very low-cost wells followed by slightly higher cost wells and so on up to the point of demand for oil. All those buying oil are charged the marginal cost of the last well in that supply curve rather than some buyers being charged at the lowest cost production and some the next cost as so on. If we consider the consumption of energy and their marginal costs – or prices – faced by end-use sectors along with their end-use CAPEX and OPEX costs, we can see how the scenarios will fully impact end-use sectors (Figure 4.23).

The total cost to industry in the low carbon storage scenario is 2 times the cost of the accelerated scenario and 2.2 times the cost of the unconstrained scenario. Pursuing a net zero pathway within limited CO_2 storage development can double the total cost to industry – not the incremental cost over and above reference case, but the full cost to industry.

Although the quantitative assessment of the macroeconomic implications of the low carbon storage scenario are beyond the scope of this analysis, qualitatively, the result is clear. A low carbon storage scenario would significantly harm industry compared to either the accelerated or unconstrained scenario. If every other country in the world pursued the same strategy, then the export opportunities may remain unchanged, but if some countries rigorously pursue CO_2 storage, any country or region that does not will likely be at a competitive disadvantage.

Figure 4.23. Full Costs to End-Use Sectors in South-East Asia by Scenario



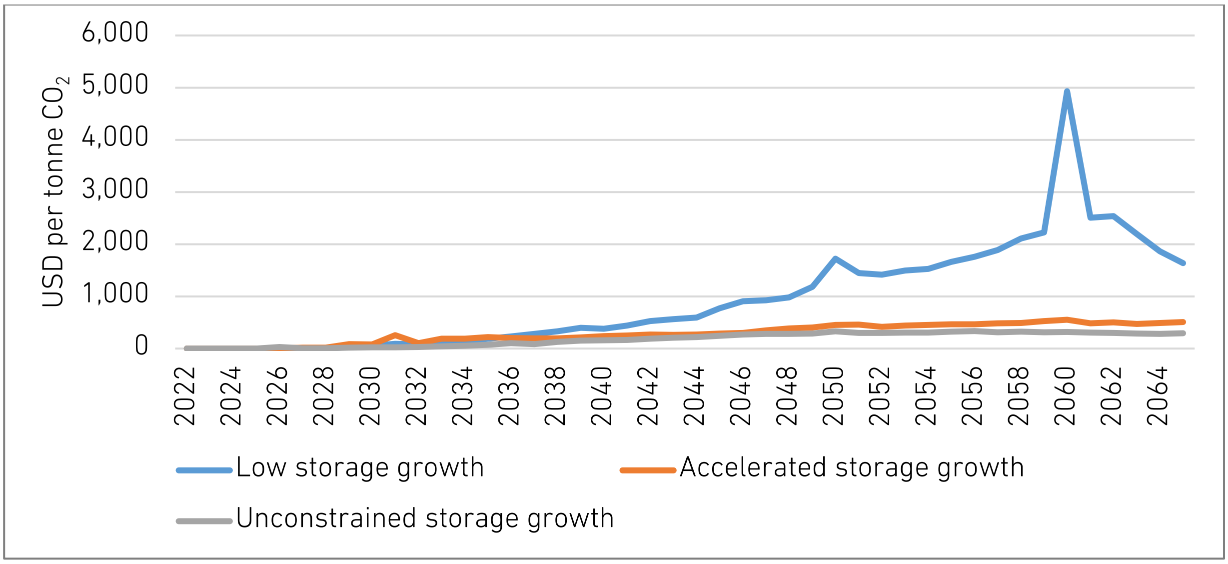
Source: GENZO result.

Buildings and transport do not face quite as stark cost increases in the low storage scenario as with industry, but nevertheless see substantially higher costs. The full energy costs of buildings, which disproportionately affects individuals and specifically low-income households, is 65% higher in the low storage scenario than the accelerated scenario and 83% higher than the unconstrained scenario. Similarly, transport costs – the majority of which is personal transport directly affecting households – are 43% higher in the low storage scenario than accelerated and 56% higher than the unconstrained scenario.

By applying a constraint on CO_2 emissions (net zero pathway) in GENZO, the model can generate the marginal cost of CO_2 emission reductions by country and scenario, which gives further insight into the relative costs across the scenarios. The marginal costs of CO_2 emission reductions mirror the total costs of the scenarios. The low storage growth scenario has significantly higher marginal CO_2 reduction costs compared to the accelerated and unconstrained storage growth scenarios (Figure 4.24). Setting aside the spike in 2060, the marginal costs in the low storage growth scenario are between

US$1500 and US$2500 per tCO_2 from 2050 onwards, after a steady rise from around US$200 per tCO_2 in the mid-2030s. The unconstrained storage growth scenario stays around US$300 per tCO_2, owing in large part to the availability to store additional CO_2 on the margin from DACCS, which acts as a backstop technology to keep CO_2 marginal costs contained. The accelerated scenario, while having significantly more development of CO_2 storage capacity than the low storage growth scenario, lacks the incremental capacity needed for sufficient DACCS to act as a backstop to keep marginal costs in line with the cost of DACCS. Nevertheless, the marginal CO_2 costs with the accelerated scenario are much lower than the low storage growth scenario and range between US$450 and US$500 per tCO_2 after 2050.

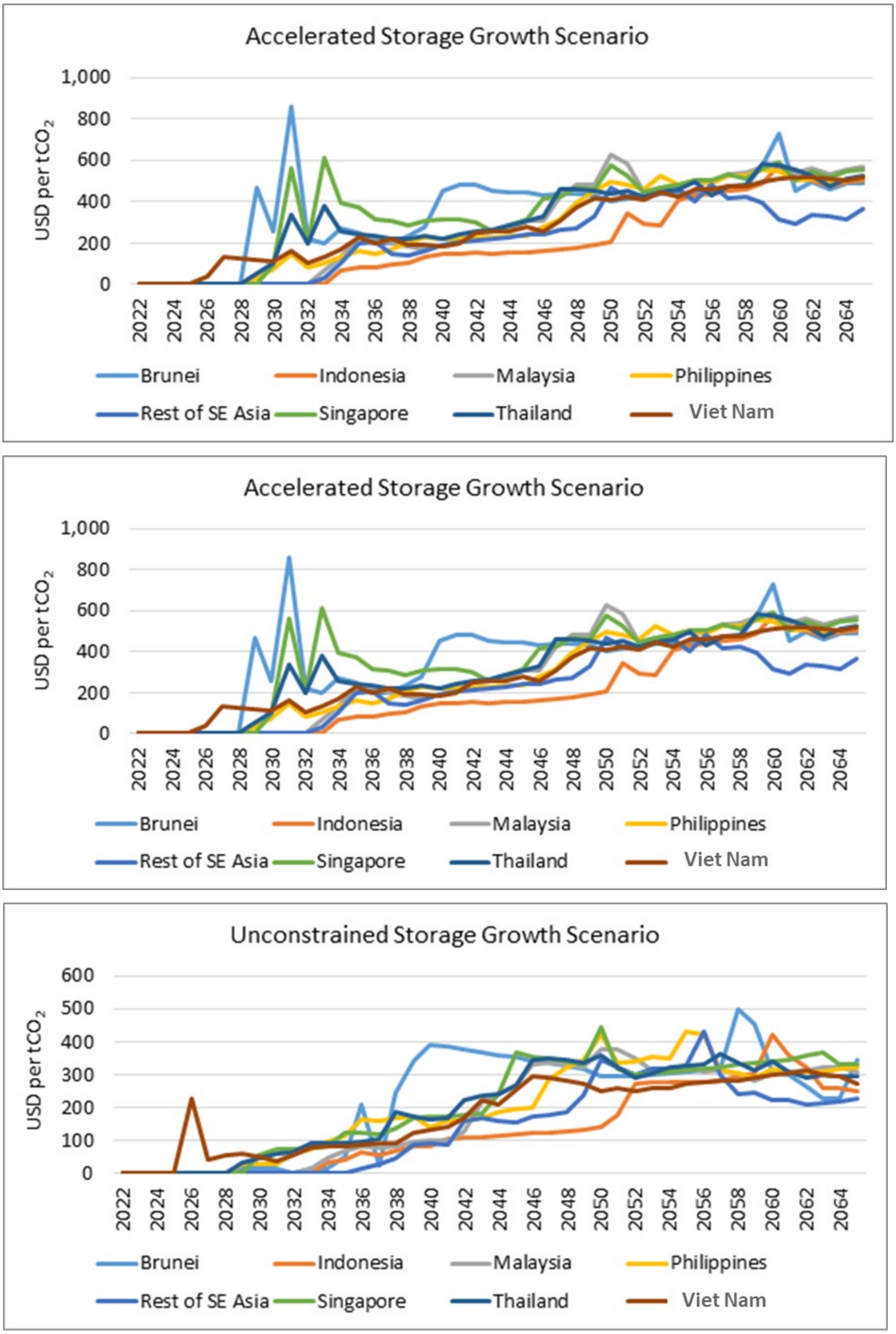
Figure 4.24. Marginal Cost of CO_2 Reductions, Averaged Across South-East Asia



Source: GENZO result.

Examining the marginal cost of CO_2 reductions by country (Figure 4.25) reveals the range of marginal costs in South-East Asia. Indonesia – with its later 2060 net zero target, relatively large CO_2 storage capacity for the region, and domestic energy resources – consistently has the lowest marginal CO_2 reduction cost in South-East Asia. At the other end of the range is Singapore, which consistently has one of the highest marginal costs of CO_2 reduction in the region. The low storage growth scenario sees the widest range between lowest and highest marginal cost in an absolute sense, with a spread of more than US$1000 per tCO_2 in some years.

Figure 4.25. Marginal Cost of CO_2 Reductions by Country



Source: GENZO result.

4.5. CCS

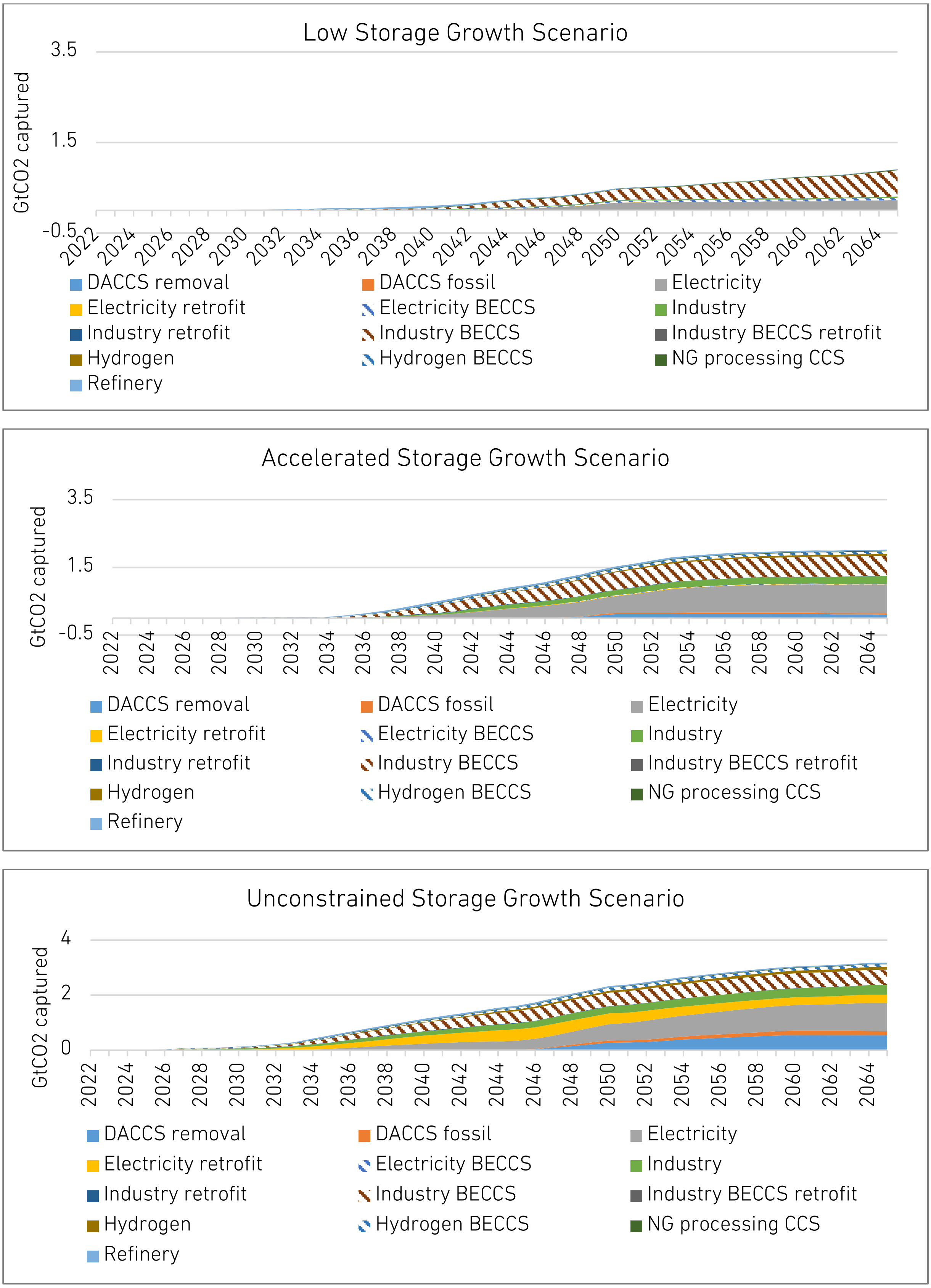
Delving into more details on the deployment of carbon capture in the scenarios (Figure 4.26), we can see that with limited storage availability in the low storage growth development scenario, most of the CCS is in the form of industrial BECCS, which provides carbon removals as well as direct decarbonisation within industry. Some BECCS in the electricity sector is also deployed, as well as some CCS in the electricity sector, specifically natural gas combined cycle with CCS. These CCS applications result in the lowest cost for the entire energy system given the availability of storage, energy prices and alternative decarbonisation options throughout the energy system.

The accelerated storage growth scenario's greater availability of CO_2 storage allows for other applications of carbon capture, including in refineries, natural gas processing, hydrogen production, industry, and direct air capture, as well as a significant expansion of carbon capture in the electricity sector. Compared to the accelerated scenario, the unconstrained storage growth scenario primarily expands direct air capture and CCS retrofits in the electricity sector. The tail end of the carbon capture supplied has lower costs in the accelerated and unconstrained scenarios than the low storage growth scenario because the low storage growth scenario must use electricity-based BECCS because it needs firm power supply options and carbon removals. The cost of biomass generating capacity is high, and the price of biomass itself in the low growth scenario is much higher than in the accelerated and unconstrained scenarios.

The supply curves presented are a modeling result and not a modeling input. What this means is that the cost and supply depend on many dynamic factors within the model, including energy prices, the cost of alternatives, which change as energy prices change, and the capacity factor or how much of a given capacity, once built, is used. The core inputs for technology costs and operating characteristics are identical, but if in one scenario the same amount of capacity is built, but that capacity operates 80% of the time, then the cost on a per tonne basis would be higher than an identical facility that operates at 90% of the time.

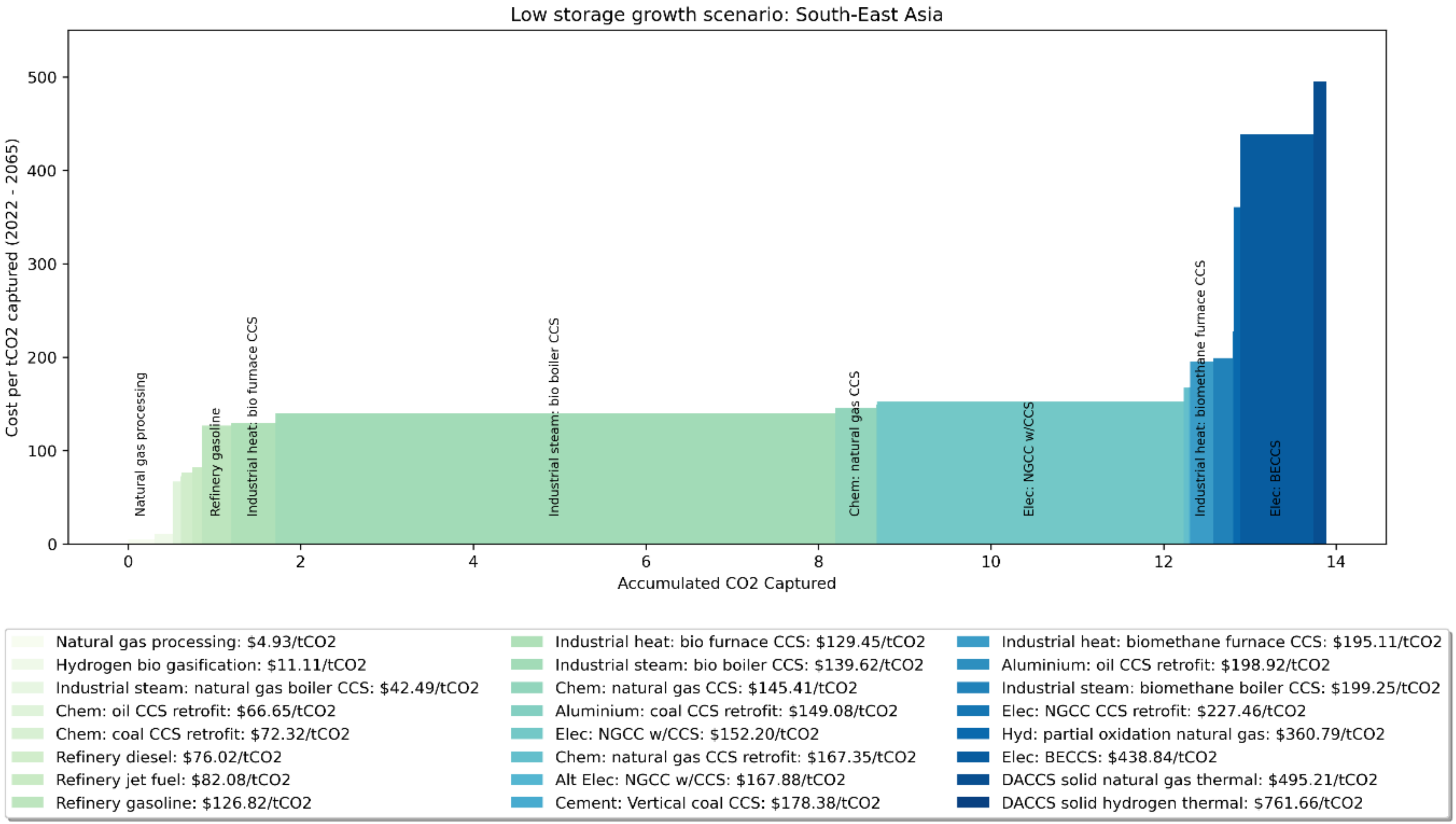
These costs also do not include the cost of transport and storage, which average over the period and the region to US$99 per tCO_2 in the low storage growth scenario. The average cost of transport and storage in the accelerated scenario is US$28 per tCO_2 and in the unconstrained scenario is US$8 per tCO_2. The widely diverging costs of transport and storage are directly related to the availability of storage in the scenarios. In all the scenarios, the same assumptions for storage development growth rates apply to all regions in the model, including those outside of South-East Asia. In the low growth scenario, CO_2 is shipped from South-East Asia to as far away as the USA and Canada because these regions have relatively greater storage availability – they are expected by 2032 to have already developed a significant storage capacity, and the low growth assumption is applied to that higher value in 2032. Shipping CO_2 that distance is costly, yet still cost-effective in the low growth scenario. In the accelerated scenario, Australia develops more capacity than it needs for its own use, so the CO_2 captured in South-East Asia that exceeds the locally developed storage capacity is primarily shipped to Australia. In the unconstrained scenario, all countries in South-East Asia that have sufficient storage capacity develop that capacity as needed so that the only countries shipping or piping CO_2 to another country are Singapore, the Philippines, and Viet Nam, which have from zero to limited CO_2 storage capacity.

Figure 4.26. CCS by Type and Sector



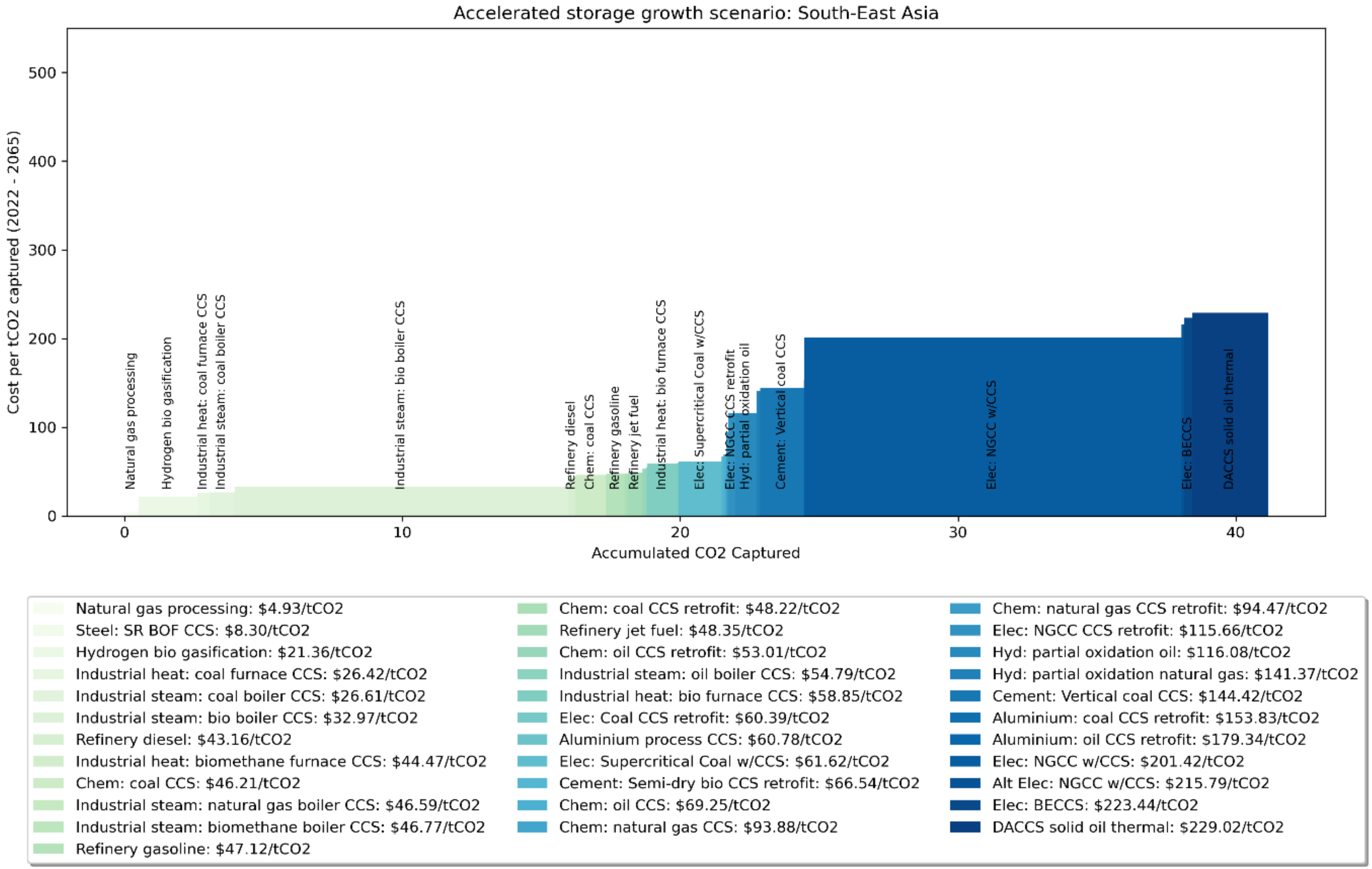
Source: GENZO result.

Figure 4.27. Average Cost of Carbon Capture in South-East Asia: Low Storage Growth Scenario



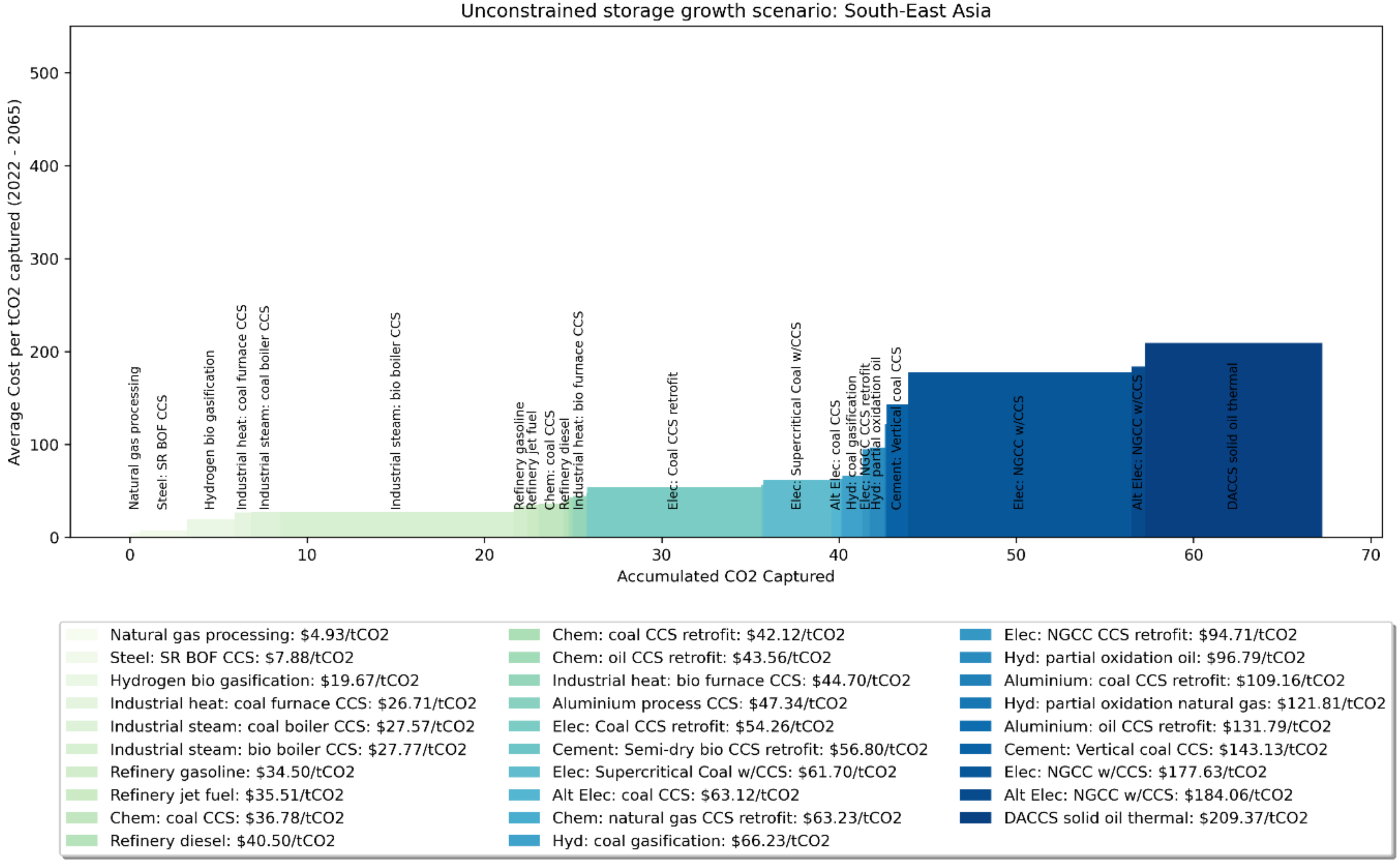
Source: GENZO result.

Figure 4.28. Average Cost of Carbon Capture in South-East Asia: Accelerated Storage Growth Scenario



Source: GENZO result

Figure 4.29. Average Cost of Carbon Capture in South-East Asia: Unconstrained Storage Growth Scenario



Source: GENZO result.

The benefits of pursuing a net zero pathway with an ample development of CCS infrastructure are clear. A savings in excess of US$20 trillion through 2065 is possible compared to a pathway with limited CCS infrastructure. Whatever technological pathway is chosen, countries in the region will need to make considerable investment and will likely need assistance from countries with developed economies. The potential for finance of CCS infrastructure is discussed in the next section. To get a sense for the scale of investment and finance needed, Table 4.1 shows the investment in CCS for the region by decade for the low storage growth scenario. Table 4.2 details the investment for the accelerated scenario, and table 4.3 the investment for the unconstrained scenario. While the accelerated and unconstrained scenarios obviously require greater investment in CCS, they avoid the high total cost of the low growth scenario and are thus remarkably cost-effective investments in the context of achieving net zero. However, the majority of investment in the low carbon storage scenario is in shipping rather than capture, underscoring just how cost-effective carbon capture is relative to other decarbonisation options that it is still pursued in the face of such high transport costs. The difference in total investment for CCS infrastructure between the low carbon and accelerated scenarios is surprisingly small. For an additional US$164 billion investment in CCS compared to the low storage scenario, in which resources are shifted toward capture rather than transport and storage is developed locally, the accelerated scenario saves US$20 trillion overall. What is not shown, but discussed more generally above, is that a greater level of investment is needed in the low storage growth scenario in other areas of the energy system while also resulting in significant outflows for purchasing low-carbon fuel imports.

Table 4.1. Investment (in US$ billions) for Each Decade by Type of CCS: Low Storage Growth Scenario

South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	4.30	2.93	0.00	*7.23*
Electricity	0.00	3.33	27.44	3.40	0.13	*34.31*
Electricity BECCS	0.00	0.00	6.91	3.59	1.49	*11.99*
Electricity retrofit	0.00	0.00	1.29	0.00	0.00	*1.29*
Hydrogen	0.01	0.17	1.02	0.18	0.06	*1.43*
Hydrogen BECCS	0.17	0.01	0.00	0.00	0.00	*0.18*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.08	0.10	0.01	0.01	0.00	*0.20*
Industry - cement	0.00	0.00	0.00	0.00	0.06	*0.06*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement retrofit	0.00	0.00	0.01	0.02	0.02	*0.05*
Industry - chemicals	0.00	2.12	1.94	1.71	0.93	*6.71*
Industry - chemicals retrofit	0.73	1.57	0.45	0.17	0.03	*2.95*
Industry - heat	0.00	0.00	0.00	0.00	0.02	*0.02*
Industry - heat BECCS	0.00	3.17	2.16	7.46	3.44	*16.24*
Industry - steam	0.00	0.00	0.00	0.00	0.96	*0.96*
Industry - steam BECCS	0.00	0.74	26.75	49.96	29.34	*106.79*
Industry - steel	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.00	0.02	0.09	0.04	0.00	*0.16*
Refinery	0.57	13.31	1.34	0.22	0.16	*15.59*
CO2 pipeline	0.00	0.94	0.45	0.65	0.57	*2.61*
CO2 shipping	1.13	20.10	114.33	228.90	125.91	*490.36*
CO2 domestic storage	0.08	1.37	0.58	0.83	1.07	*3.93*
CO2 international storage	0.54	0.92	1.74	1.26	6.37	*10.83*
Total	*3.30*	*47.89*	*190.82*	*301.32*	*170.57*	*713.90*

Source: GENZO result.

Table 4.2. Investment (US$ Billions) for Each Decade by Type of CCS: Accelerated Storage Growth Scenario

South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	77.88	25.53	0.00	*103.41*
Electricity	0.00	25.60	78.56	78.16	9.24	*191.55*
Electricity BECCS	0.00	0.00	3.22	0.00	0.87	*4.09*
Electricity retrofit	0.00	0.89	4.26	0.00	0.00	*5.16*
Hydrogen	0.00	1.25	3.55	7.11	2.22	*14.13*
Hydrogen BECCS	0.35	0.49	0.67	0.20	0.07	*1.79*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.07	0.15	0.07	0.04	0.01	*0.34*
Industry - cement	0.00	1.52	6.13	4.17	1.63	*13.46*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.00	0.08	0.14	0.15	0.09	*0.46*
Industry - cement retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - chemicals	0.00	1.60	4.96	3.58	0.97	*11.11*
Industry - chemicals retrofit	0.96	2.40	1.07	0.44	0.07	*4.95*
Industry - heat	0.00	0.00	4.32	0.27	0.00	*4.60*
Industry - heat BECCS	0.02	7.06	2.13	2.67	5.00	*16.88*
Industry - steam	0.00	0.30	7.00	0.80	0.57	*8.68*
Industry - steam BECCS	0.00	22.06	67.09	16.67	32.45	*138.27*
Industry - steel	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.00	0.16	0.00	0.00	0.00	*0.17*
Refinery	0.55	19.06	4.21	0.93	0.76	*25.51*
CO2 pipeline	0.00	1.63	7.46	0.82	0.04	*9.94*
CO2 shipping	0.37	60.29	101.50	95.82	8.52	*266.50*
CO2 domestic storage	0.07	8.24	24.18	6.47	0.45	*39.41*
CO2 international storage	0.56	2.99	9.60	2.43	2.18	*17.75*
Total	*2.95*	*155.79*	*408.00*	*246.27*	*65.14*	*878.15*

Source: GENZO result.

Table 4.3. Investment (US$ Billions) for Each Decade by Type of CCS: Unconstrained Storage Growth Scenario

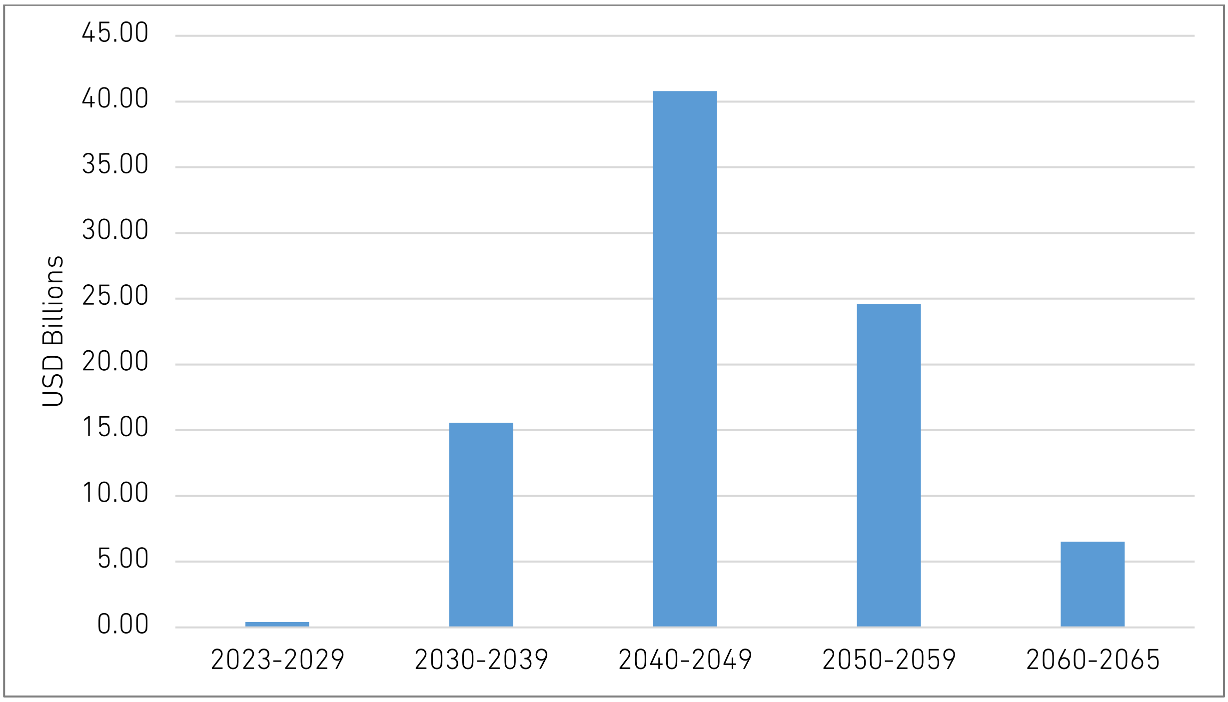
South-East Asia						
	2023 - 29	2030 - 39	2040 - 49	2050 - 59	2060 - 65	2023 - 65
DACCS	0.00	0.00	143.48	218.10	11.38	*372.96*
Electricity	0.11	57.34	73.58	70.12	23.90	*225.05*
Electricity BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Electricity retrofit	0.00	28.19	25.73	18.83	13.07	*85.83*
Hydrogen	4.86	5.57	10.04	15.37	9.07	*44.91*
Hydrogen BECCS	0.43	0.38	1.10	0.34	0.11	*2.36*
Industry - aluminum	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - aluminum retrofit	0.07	0.15	0.07	0.04	0.01	*0.34*
Industry - cement	0.00	2.13	6.16	2.97	0.91	*12.16*
Industry - cement BECCS	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - cement BECCS retrofit	0.08	0.17	0.15	0.15	0.09	*0.63*
Industry - cement retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
Industry - chemicals	0.00	3.74	3.72	3.00	1.13	*11.58*
Industry - chemicals retrofit	1.03	2.20	0.90	0.44	0.08	*4.65*
Industry - heat	0.05	5.06	1.21	2.30	3.28	*11.91*
Industry - heat BECCS	0.02	4.89	1.48	4.05	1.12	*11.56*
Industry - steam	5.57	3.20	1.45	6.98	2.04	*19.25*
Industry - steam BECCS	0.00	42.47	47.48	25.30	36.65	*151.90*
Industry - steel	0.36	0.00	1.04	0.52	0.39	*2.31*
Industry - steel retrofit	0.00	0.00	0.00	0.00	0.00	*0.00*
NG processing	0.01	0.15	0.00	0.00	0.00	*0.17*
Refinery	2.12	19.10	2.74	1.84	5.30	*31.10*
CO2 pipeline	0.00	2.64	2.47	0.84	0.12	*6.06*
CO2 shipping	0.23	10.21	11.10	5.28	0.42	*27.25*
CO2 domestic storage	3.12	31.54	44.85	35.78	7.72	*123.01*
CO2 international storage	0.09	5.34	5.72	2.40	0.24	*13.78*
Total	*18.18*	*224.44*	*384.48*	*414.63*	*117.04*	*1,158.77*

Source: GENZO result.

4.6. The CCS Financing Challenge

Assuming the central scenario modelled in this report (Accelerated Storage Scenario), almost US$880 billion must be invested in CCS between now and 2065 across southeast Asia, peaking at over USD40 billion per year, on average, in the 2040s.

Figure 4.30. Average Annual Investment (US$ Billions) for Each Decade: Accelerated Storage Growth Scenario



Source: GENZO result.

Mobilising this quantum of capital for CCS will require both public and private finance. The private sector has enormous financial resources, human capital and capabilities necessary for the development and operation of CCS projects. However, the private sector can only invest where there is an appropriate risk weighted return on that investment. Private investment is incentivised by the expectation of future profits. Applied to CCS, this condition will only be met if the unit cost of CCS (per tonne of CO_2 emissions avoided) is less than the cost of emitting CO_2 plus the value of any revenue generated (e.g. in enhanced oil recovery) through CCS.

The unit cost of CCS (full value chain) varies considerably depending on the capture source and scale, CO_2 transport distance and storage resource quality. The lowest cost applications may have a full value chain cost of less than USD25/tonne CO_2 including the cost of compression transport and storage. However, in most industrial applications, full value chain CCS will cost in the range of USD40-USD100 per tonne CO_2, application in power generation between USD60 and USD200 per tonne CO_2 and over USD200 per tonne

CO_2 for direct air capture. As shown previously using GENZO, CCS is required to be applied across all of these applications to deliver net zero emissions at lowest overall cost. However private sector investment incentives are currently insufficient to mobilise the necessary capital except in the lowest cost applications.

This presents a fundamental problem for governments that are charged with achieving net-zero emissions to stabilise the global climate – a significant public good. The cost of GHG emissions – climate change, surging insurance and disaster relief costs, loss of life and property – are increasing rapidly, becoming visible and felt by every society. Yet the emissions costs are dispersed, unevenly distributed, and back-ended, while abatement costs are front-ended. Governments face the classic economic problem of internalising negative externalities to incentivise removing emissions. Policies are required that align private investment incentives with public good investment incentives. This can be done through any combination of:

- Increasing the cost of emitting CO_2 (e.g. carbon taxes or emissions trading)
- Command and control mechanisms (e.g or prohibition or mandates through regulation)
- Reducing the cost to private sector investors of CCS (e.g. through capital grants or concessional finance)
- Increasing the revenue created through CCS (e.g. through payments per tonne of CO_2 stored or operational subsidies)

CCS has little economic value compared with freely emitting CO_2 into the atmosphere, and that calculus can only change with policy and regulation.

In simple terms, the challenge is how to reflect the cost of GHG emissions in prices so a low-carbon product is cheaper than its high-carbon substitute. This would drive the demand for abatement technologies and enable its applications to earn a profit – a powerful incentive.

Current experience from around the world demonstrates that significant public finance is necessary to leverage the private finance required to accelerate CCS investment. Whilst the private sector is investing to receive a financial return, governments are investing to deliver public goods – a stable climate. It is appropriate for governments to fail to achieve a financial return on investments as long as they are efficiently contributing towards the delivery of public goods. It is in this context that government support of CCS and other climate mitigating technologies is justified.

Governments, policymakers, and regulators have accelerated the design and implementation of these policy tools in the past two years, especially in developed economies. In the US, the policy choice is skewed towards direct and indirect subsidies for CCS and producing clean energy; in European countries, it can be a combination of carbon pricing and production subsidies; and in Japan, it is a mix of demand subsidies for clean energy and early phases of carbon pricing.

Financial institutions, whether commercial banks, pension funds, or infrastructure funds, consider the potential risks and returns of a project. The elimination or reduction of a risk factor is converted to a higher value for the project, or vice versa.

Hence, a policy designed to incentivise investment should consider not only rates of return but also the associated risks. This is especially true for capital-intensive long-term infrastructure projects. Some risks include the viability and durability of a long-term demand driver, cost and time overruns, execution, permitting, political, and liability risks.

The US, European Union, and Japan have devoted significant financial resources to support the development of a low carbon economy and to make CCS applications commercially viable, which in turn can be leveraged with private sources of capital. According to the Congressional Budget Office, the Inflation Reduction Act (IRA) in the USA will inject a total of $394 billion into clean energy and climate funding to leverage private capital. To finance this, the government proposed a 15% minimum corporate tax and a 1% excise tax on share buybacks.

The European Union is leveraging the Emissions Trading System and carbon taxes to raise an annual $40 billion to finance its public funding available for climate finance and CCS. Japan and South Korea have prioritised demand subsidies for clean energy and devoted significant financial resources.

4.7. Policies to Incentivise Investment in CCS

The following sections present a brief description of key policies in leading jurisdictions that have been successful in incentivising significant private sector investment in CCS.

4.7.1. USA

Infrastructure Investment & Jobs Act and the Inflation Reduction Act

In 2021, the Infrastructure Investment and Jobs Act (IIJA) authorised $12 billion in grants, loans, and loan guarantees for industrial emissions reduction, carbon capture, transport, and storage permitting, Direct Air Capture (DAC) and $8 billion for hydrogen hub development.

These developments were dwarfed by the Inflation Reduction Act of 2022 (IRA), ambitious legislation that aims to decrease GHG emissions by 50% to 52% below 2005 levels by 2030, in line with the country's nationally determined contribution (NDC). The IRA relies heavily on investment and production tax credits and low-cost government loans. Tax credits can be subtracted from corporate income taxes and are effectively a subsidy. The tax credits relevant to CCS are known as 45Q, 45Z, and 45V, after the section of the US tax code under which they are established.

The 45Q Tax Credit

The IRA boosted the 45Q tax credit for the capture, geological storage, and utilisation of CO_2. Companies capturing and geologically storing CO_2 are eligible for USD85/tCO_2 captured from a power or industrial source and USD180/tCO_2 captured from the atmosphere.

Table 4.4. Increases to the 45Q tax credit from the Inflation Reduction Act of 2022

Activity		Before IRA (in US$ per tonne of CO_2)	After IRA (in US$ per tonne of CO_2)
Geological storage of CO_2	From power generation and industrial facilities	50	85
	From direct air capture (DAC) facilities	50	180
Utilisation of CO_2	From power generation and industrial facilities	35	60
	From DAC facilities	35	130

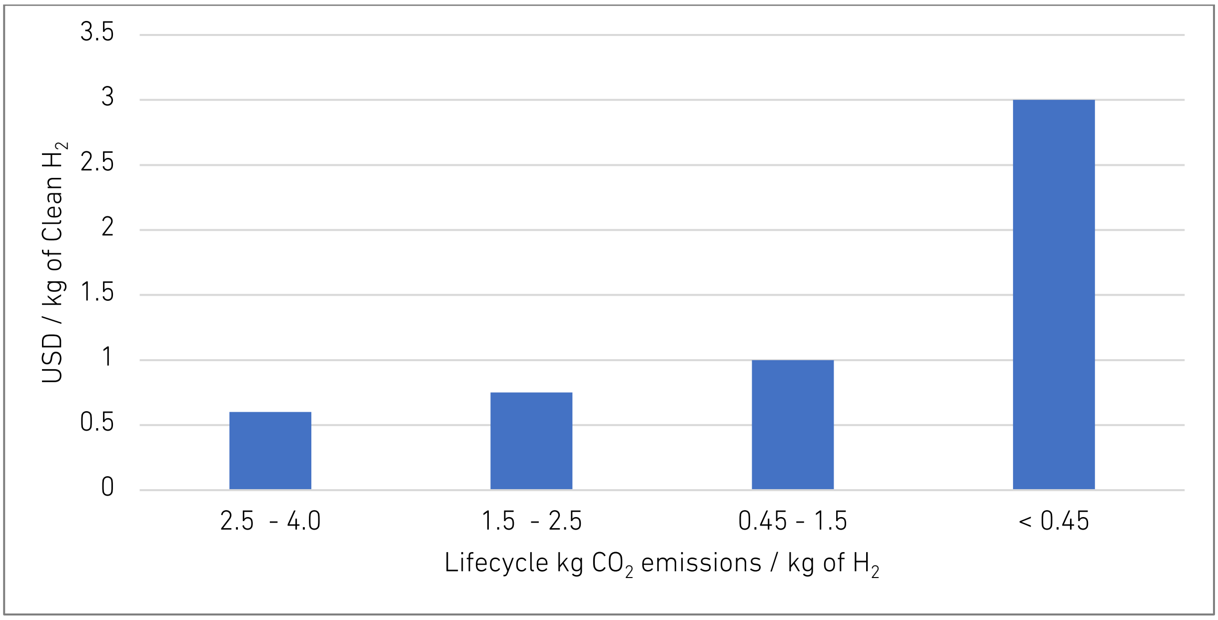
Source: GCCSI.

The tax credit for CO_2 which is utilised (as opposed to geologically stored) is lower at USD60/tCO_2 captured from a power or industrial source and USD130/tCO_2 captured from the atmosphere.

The 45V Tax Credit

The IRA introduced the 45V tax credit, paid per kg of clean hydrogen production. The value depends on its lifecycle production emissions intensity, with the highest value being $3 per kg of hydrogen for emissions intensities of less than 0.45 kgCO_2e/kg H_2 over 10 years. The maximum emissions intensity is 4 kgCO_2e/kg H_2 for eligibility. A project can claim 45Q or 45V but not both.

Figure 4.31. The Value of 45V Tax Credit Depending on The Carbon Intensity of Clean Hydrogen



Source: GCCSI.

The 45Z Tax Credit

The IRA expanded the scope of the 45Z tax credit for clean transportation fuels, mainly ethanol. 45Z is $0.02 per gallon of clean transportation fuel for each reduction point in the carbon intensity score below 50, as measured by CO_2kg per gallon. The carbon intensity of ethanol production can be reduced through the application of CCS at ethanol production plants. 45Z has strict time limits and is available for three years, from 2025 to 2027. Unlike 45Q and 45X, 45Z does not have direct pay optionality.

Title 17 Clean Energy Financing

The IRA has increased the financing capacity of the Title 17 Clean Energy Financing Program to $300 billion in loan guarantees and up to 80% of project costs. The cost of the loan guarantee is a 10-year treasury interest rate plus 0.375%.

The programme is managed by the Department of Energy's (DOE) Loan Programs Office (LPO). It has two sections: Section 1703, with some $40 billion capacity, includes projects under the Innovative Energy, Innovative Supply Chain, and State Energy Financing Institution categories, and Section 1706, which covers Energy Infrastructure Reinvestment projects and can provide loan guarantees of up to $250 billion. CCS, as a versatile technology with many applications, is eligible for loan guarantees under either section.

Low Carbon Fuel Standards and State-based Cap and Trade Programs

The Low Carbon Fuel Standard (LCFS) is a compliance baseline carbon market in California. Oregon, Washington State, and British Columbia (Canada) have similar legislation, and other states are expected to launch their LCFS programs. The LCFS encourages the use of transportation fuels with a lower carbon intensity based on the fuel's lifecycle emissions intensity. This includes fuel production, transportation, and combustion. The emissions intensity of each fuel is compared to an annually declining benchmark. Fuels with an emissions intensity below the benchmark generate credits, while those with emission intensities above the benchmark generate deficits. Credits created under the scheme are tradeable. Fuel wholesalers with deficits are required purchase and surrender an equivalent number of credits. California has a CCS Protocol under its LCFS, which allows for emission reductions through CCS that can be outside the state if the fuel is used in California.

California also has a compliance cap and trade programme, a vital element of the state's strategy to reduce emissions. The programme establishes a declining limit (cap) on GHG emissions, covering approximately 80% of the state's GHG emissions. The California Air Resources Board (CARB) creates allowances (a tonne of CO_2 emission) equal to the cap and auctions at an increasing floor price: the declining cap and the floor price aim to create a stable price to incentivise emissions reduction.

4.7.2. European Union and the United Kingdom

The EU's decarbonisation effort has several pillars: The Emission Trading Scheme (EU ETS), a compliance cap and trade carbon market, newly developed mechanisms like Carbon Contracts for Differences (CCfD), the EU Innovation Fund -- mainly funded by the auctioning of EU ETS allowances -- and the Carbon Border Adjustment Mechanism, effectively a carbon duty for imports from countries that lack a carbon pricing or tax mechanism.

Individual countries also have separate and additional mechanisms to support emission reductions and CCS investments.

EU Emissions Trading System

Dating back to 2005, Europe's climate policy cornerstone is the EU ETS, the world's first and largest carbon market covering the EU and Norway, Iceland and Liechtenstein. It is based on a cap-and-trade principle, which sets a cap for the covered GHG emissions and lets operators trade the allowances. The cap is reduced over time to reduce emissions, and participation is mandatory for covered sectors. The EU ETS covers about 40% of total emissions. CCS is included in the EU ETS; captured and permanently sequestered CO_2 in line with the European Commission's CCS Directive is considered not emitted.

The allowances are either auctioned or allocated for free. The free allocation is meant to protect the competitiveness of regulated sectors and to safeguard against carbon leakage -- the migration of production to other countries with no or less stringent emissions reduction requirements.

Until the recent reform of the EU ETS, there were too many free allowances resulting in a low EU ETS carbon price, and thus, the impact on emission reductions has been limited.

The presentation of the European Green Deal in December 2019, a package of policy initiatives aimed at reaching carbon neutrality by 2050 framed as a new economic growth policy, signaled the EU's more robust policy response. The proposal and then passage of the European Climate Law and Fit for 55 package (13 legislative proposals except for REDII, Revision of Gas Directive and Regulation) significantly reduced free allowances, leading to a fourfold increase in the carbon price and stabilisation despite major geopolitical shocks like the Russia-Ukraine war and Covid-19 pandemic. As a consequence of these reforms, the price of EU Carbon Permits increased from around 25 Euro/t to peak at over 100 Euro per tonne in March 2023 (*Trading Economics*, 2023).

Fit for 55

Released in July 2021, the Fit for 55 package aimed at updating European climate and energy policies to align them with the EU's new target of reducing GHG emissions by at least 55% by 2030, as defined under the European Climate Law. Amongst the 13 legislative proposals submitted were a revision of the EU ETS Directive and establishing a carbon border adjustment mechanism.

In April 2023, the EU adopted a reform of the package. The most important features include:

- Tightening of the EU ETS by increasing the emissions reduction target to 62% of 2005 levels from 43%
- Increasing the annual reduction of allowances from 2.2% to 4.3% for 2024-2027 and 4.4% for 2028-2030 in addition to one-off absolute cap reductions of 90 million and 27 million allowances in 2024 and 2027, respectively
- Coverage of maritime shipping in EU ETS starting 2024 and complete phase-out of free allowances in 2026
- Phase-out of free allowances for aviation by 2027
- A new ETS for buildings, road transport, and small industries and allocation of revenues to fund Social Climate Fund to support affected parties
- Implementing the carbon border adjustment mechanism (CBAM)

Whilst these measures do not specifically target CCS, they serve to increase the value of EU Carbon Permits, which strengthens the business case for investing in CCS to avoid the carbon liability.

The EU Innovation Fund

The EU ETS funds the EU Innovation Fund and provides financial support through grants for deploying innovative technologies, including CCS facilities, to meet net-zero commitments and the energy transition. The EU Innovation Fund supports various EU commitments like the Hydrogen Bank, the REPowerEU Plan, the Net-Zero Industry Act, and the Green Deal Industrial Plan.

In 2023, the EU increased the size of the ETS allowances from Eur450 million to Eur530 million. At current EU ETS prices, the total size of the EU Innovation Fund for the 2020-2030 period could be Eur40 billion.

Carbon Border Adjustment Mechanism (CBAM)

The EU parliament in April 2023 passed the CBAM to reduce the impact of European climate policy on the international competitiveness of European industry. It is effectively a carbon duty on imports from countries without an equivalent carbon tax or price. As free allowances under the EUETS phase out, CBAM will kick in to protect domestic industry from import competition.

The transitional phase, i.e. the reporting requirement, for importers commenced in October 2023 and ends in January 2024. It will initially apply to carbon-intensive goods like steel and cement and expand to 50% of the ETS-covered sectors. The permanent phase, i.e. the surrender of CBAM certificates based on the EU ETS price, will start in 2026.

CBAM creates a policy question for the EU's main trading partners: Whether to pay the carbon tax on products exported to Europe to the European Commission or to introduce their own carbon tax or carbon price generating domestic revenue.

European Country Initiatives

In addition to the EU-level policy and regulation, member states have developed policies and regulations to reach emission reduction targets. For instance, Denmark and the Netherlands pledged EUR 3.6 billion (over 15 years) and EUR 2.1 billion in state aid for CCS projects, respectively.

Germany announced the launch of Carbon Contracts for Difference (CCfD), a 15-year subsidy programme to increase carbon price visibility. The German government plans to support the programme with a budget in line with estimates of around EUR50 billion.

Norway has a carbon tax equivalent of NOK 761 ($71) per tonne of CO_2 for 2023, and the country introduced a plan to increase the tax to EUR200 ($220) by 2030. Norway is a leader in the CCS with the Longship CCS project to which it has committed USD2.3 billion in support.

United Kingdom

In March 2023 the UK Government committed 20 billion pounds to support CCS. The UK government has also allocated 1 billion pounds to support the establishment of 4 CCS networks by 2030, with the objective of capturing 20-30Mtpa CO_2.

4.7.3. Japan

The Japanese Ministry of Economy Trade and Industry (METI), announced its CCS Long Term Roadmap in January 2023, setting a target for the commencement of operations of Japan's first commercial CCS facility by 2030. METI has since announced capital support for feasibility studies for seven CCS networks.

4.7.4. Effective Policies – Observations

Of the 376 commercial CCS facilities in development, construction or operation in the Global CCS Institute's database, 254 are in the USA, Europe, the United Kingdom or Japan(Global CCS Institute, 2023b). Most CCS projects are being developed in advanced economies, especially North America and Europe where strong policy and existing CCS regulation supports a business case for investment. These jurisdictions have demonstrated how strong supportive policy can rapidly attract private investment in CCS.

A common factor across these leading jurisdictions is that public finance, whether through capital grants or operational subsidies or tax credits, is a critical enabler of the rapid growth in the CCS project pipeline. Nations mentioned in the previous section are all providing significant financial resources to CCS project developers, even in Europe which has the world's highest carbon price. Whilst the avoidance of a carbon liability certainly supports the business case for investment, it is the bankability or certainty of robust future revenues and/or the provision of free capital to reduce private sector capital-at-risk, that has proven most effective.

Whilst CCS technologies are mature and commercially available, the business models, norms and commercial experience that build confidence in investments in well established industries are still developing. Even where clear regulation for CCS exists, this results in uncertainties or risks that are significant barriers to investment. These risks relate to uncertainties in future revenues and costs and therefore return on investment, the risk that expenditure on exploration for storage resources will not yield a suitable resource as well as the normal project development and operational risks that apply to any large industrial facility.

CCS projects require the coordination of multiple investment decisions, each with long lead times, leading to cross chain risk. This arises as the decisions to develop each element of the CCS chain may be required before there is full certainty about the entire value chain. For example, capture plant developers may not have secured access to transport and storage infrastructure. Transport and storage infrastructure developers may not have secured contracts from capture sources to provide transport and storage services creating uncertainty regarding whether their assets will be sufficiently utilised. These uncertainties delay or may even prevent FID and put expenditure on studies at risk. Once projects are operational the interdependency remains, as the failure of one of the components to deliver on their obligations may affect the costs and revenues of others and prevent the value chain performing as a whole.

Put simply, businesses prefer not to be the first investor in a new CCS hub and cluster; they prefer to invest in a mature network. This is a significant barrier to initial investments, unless guarantees are provided for revenue during the early stages of development. This is where governments can play a significant role.

In summary, the role of public finance in this phase of CCS deployment, where there is a requirement to accelerate investment well beyond what the market would deliver without intervention, is to de-risk private investment in CCS.

4.8. Public Finance for CCS in ASEAN

There are significant differences between the developed economies of the USA, Europe and Japan and the developing economies of Southeast Asia. There are important differences in the CO_2 emission levels, income levels, state capacity, and existing infrastructure of the ASEAN Member States. For instance, Indonesia ranks first in CO_2 emissions (on a production basis) with 625 million tonnes in 2019 (IRENA, 2022) with a 2022 GDP per capita of $4,788 (at Purchasing Power Parity of $14,652) versus Singapore with 53 million tonnes in 2019 (IRENA, 2022) but with a GDP per capita of $82,807 (at Purchasing Power parity $108,036). The following table presents the CO_2 emissions of the ASEAN countries and their economic output as a proxy of state capacity to mobilise resources to decarbonise their economies.

Table 4.5. Economic and Emissions Metrics for ASEAN Member States

	CO_2 Emissions Mtpa	Per capita CO_2 Emissions Mtpa/Capita	GDP per capita Thousand USD/Capita	GDP per capita PPP Thousand USD/Capita
Laos	20.8	2.8	2.1	2.5
Viet Nam	326.0	3.3	4.1	13.2
Philippines	144.0	1.3	3.6	10.5
Singapore *	32.5	5.5	82.8	127.6
Malaysia	256.1	7.6	12.5	34.8
Indonesia	619.3	2.3	4.8	14.6
Thailand	278.5	3.9	7.1	21.2
Myanmar	36.3	0.7	1.2	4.9
Brunei *	10.5	23.5	37.9	70.8
Cambodia	19.0	1.1	2.8	5.6

Source: the IMF, Global Carbon Budget. Emissions data is 2021, GDP data is 2022.

By comparison, the United States' GHG emissions per capita in 2021 was 17.6 tonnes, and GDP per capita in 2022 was US$77,469 (*United States GDP*, n.d.). With the exception of Singapore, the GDP per capita of ASEAN Member States are very significantly less than developed economies. The governments of developing economies have far fewer resources making public financing for CCS at the scale available in the USA or Europe extremely difficult.

However, this is not to say that public finance for CCS is completely ruled out for ASEAN Member States. Considering that CCS reduces the total cost of achieving net zero commitments, carefully targeted public finance and policy that leverages private sector capacity and investment will ultimately reduce the total cost of climate action to these governments and to their economies. A key strategy for developing economies in ASEAN is to identify international sources of public and private finance or aid to support CCS deployment, in addition to public finance they can provide themselves. The provision of aid by developed economies to support the deployment of CCS in southeast Asia serves the interests of all nations. To meet global climate objectives, net zero emissions must be achieved everywhere and without CCS that will be impossible especially in the rapidly growing economies of southeast Asia.

As noted above, the ASEAN countries' economic and political structure differs significantly from the US and the EU. Infrastructure investments are generally financed by public funds through taxation and borrowing. The ASEAN country's debt-to-GDP and revenue-to-GDP ratios are favorable to finance infrastructure investments for years to come; in some cases, they fare better than the developed countries. The following table presents the data for 2022.

Table 4.6. Fiscal Capacity Indicators for ASEAN Member States

	Public Debt /GDP %	Revenue/GDP %	Current Account/GDP %	Exports /GDP %
Laos	68.0	14.9	(2.6)	33.2
Viet Nam	36.1	19.0	0.2	93.3
Philippines	60.9	20.4	(3.0)	28.4
Singapore *	135.9	17.3	16.6	186.6
Malaysia	60.4	19.5	2.7	73.8
Indonesia	39.5	15.2	(0.3)	24.5
Thailand	53.6	20.1	(0.2)	65.8
Myanmar	63.9	13.3	(1.6)	37.0
Brunei	2.1	28.9	10.6	86.4
Cambodia	37.0	24.0	(11.0)	77.6

*Note: Singapore's high debt-to-GDP ratio is misleading as it is gross. On a net basis, the country is a creditor.
Source: the IMF.

A high-level analysis shows that the wealthy ASEAN nations of Singapore and Brunei have ample fiscal capacity to finance energy and climate policies. Their economies also have the ability to raise funds through borrowing or taxation. Such public funding can then be leveraged with private sources of capital. For instance, just like its transition from coal to natural gas, Singapore can make the shift from natural gas to hydrogen. Malaysia, too, has the fiscal capacity to gradually phase out its unabated carbonisation through financing its government-controlled emitters like Petronas. These countries' high export and current account surplus ratios provide necessary incentives for decarbonisation.

Even though the ASEAN countries show very significant differences in the levels of development, fiscal capacity, and resources, the majority have low debt and revenue ratios. The pressing question is prioritisation: the developing countries need to balance their development needs to meet the demand of their populace with the need to decarbonise.

4.9. Potential Sources of External Finance

4.9.1. Multilateral Development Banks

Financing transformative climate action is vital for the development and support of the poorest people who are most affected by climate change. However, the fiscal constraints countries face today make it more challenging to find the necessary resources. Multilateral Development Banks (MDBs) provide grants and loans to support economic development in developing economies.

A multilateral development bank (MDB) is an international financial institution chartered by two or more countries to encourage economic development in poorer nations. Multilateral development banks consist of member nations from developed and developing countries. Five major MDBs are the World Bank and four regional development banks: the African Development Bank, the Asian Development Bank, the European Bank for Reconstruction and Development, and the Inter-American Development Bank (IDB).

For ASEAN countries, the sources of Finance would be the World Bank Group and Asian Development Bank. The World Bank provided $31.7 billion, and Asian Development Bank $6.7 billion in 2022 to address climate change. These figures include adaptation, resilience, renewables, the grid, EVs, and batteries. Both the World Bank and the Asian Development Bank have active programs to support CCS in ASEAN. Grants may be provided to support feasibility studies or capacity building activities and low-cost loans may be available to support projects. These are unlikely to be sufficiently large to finance a commercial CCS project on their own, but can make a material contribution together with other sources of finance.

The World Bank Group

Established in 1946 in the post-World War II global order, The World Bank Group is the oldest and the largest MDB. The World Bank Group has three lending facilities. The first, the International Bank for Reconstruction and Development (IBRD), provides primarily market-based loans to the governments of middle-income countries. The IBRD, with a membership of 144 countries, focuses on financing large infrastructure projects and broadened efforts to include social projects and policy-based loans. A second lending facility, the International Finance Corporation (IFC), was established in 1955 to extend loans and equity investments to private firms in developing countries. The International Development Association (IDA) was created to make concessional loans (with low-interest rates and long repayment periods) to the poorest countries. IDA also now provides grants to these countries. (*Multilateral Development Banks: Overview and Issues for Congress*, n.d.)

The World Bank Group is the most significant multilateral financier of climate action in developing countries. The Group, as part of the Climate Change Action Plan, targets deploying an average of 35% of the institution's financing for climate action in the 2021-2025 period. In 2022, this target was exceeded to reach 36%. As a result, the World Bank Group provided a record of $31.7 billion in fiscal year 2022 to help countries address climate change. The Bank Group's climate finance is calculated based on the agreed joint Multilateral Development Bank methodology (*Climate Finance 2020*, n.d.). It counts the share of financing directly tied to climate action across all Bank Group projects. The breakdown of this financing is provided below: (*10 Things You Should Know about the World Bank's Climate Finance*, n.d.)

- IBRD and IDA delivered $26.2 billion in FY22 in climate finance.
- Building resilience to climate shocks is a priority. Nearly half of the Bank's finance—$12.9 billion—supported investments in adaptation and resilience.
- IFC, the private sector arm of the World Bank Group, delivered $4.4 billion in climate finance and mobilised an additional $3.3 billion from other sources.
- MIGA, the World Bank Group's political risk insurance and credit enhancement arm, delivered $1.1 billion in climate finance in FY22.

As can be observed from the breakdown, nearly half of the funding provided by the World Bank Group was destined towards adaptation and resilience instead of mitigation, of which CCS is a part. Of the total funding, very little, if any, was provided directly or indirectly for the funding of the CCS projects globally.

The World Bank has a CCS trust fund under the Energy Sector Management Assistance Program (ESMAP), which provided a few million dollars in projects in Mexico, Botswana, and Nigeria. This facility will shut down in December 2023. Even though the bank says it will support it through other means, it is unlikely to reach even $1bn globally.

For the World Bank Group to increase financing for CCS-related projects, there needs to be support from the member countries. The Carbon Challenge initiative led by the US plans to form a global consensus that includes CCS as an integral part of the mitigation plan to address climate change. If the US succeeds in gathering support for CCS investments, the financial resources allocated for CCS investments by the World Bank Group can be expected to increase significantly.

Even then, the CCS investment needs of the ASEAN countries dwarf the funds that can be provided using the World Bank Group's balance sheet. In a best-case scenario, such funds would help to finance activities such as studies to help write legislation, pay for consultancy reports, techno-economic optimisation modeling, feasibility studies, and a small number of small-scale demonstration or pilot projects.

The Asian Development Bank

The Asian Development Bank (ADB) is a regional multilateral development bank established to promote economic and social progress in Asia and the Pacific. It was founded in 1966 and is headquartered in Manila, Philippines. ADB is an essential institution in the region, and its primary mission is to reduce poverty, foster economic growth, and improve the quality of life for people in its member countries.

ADB's membership consists of 68 member countries, of which 49 are from Asia and the Pacific, and 19 are from outside the region, including the United States and several European countries. ADB's membership is open to countries within and outside Asia and the Pacific. ADB is governed by its Board of Governors, which comprises representatives from each member country. ADB provides financial resources, technical assistance, and policy advice to its member countries. It supports various development initiatives, including infrastructure development, poverty reduction, education, healthcare, environmental protection, and regional cooperation.

ADB raises funds from international capital markets and its member countries. It provides loans, grants, and technical assistance to its member countries for development projects and programs. ADB's financing helps member countries implement projects and policies that promote sustainable economic growth and social development. It places a particular emphasis on addressing poverty, inequality, and climate change in the Asia-Pacific region. ADB collaborates with various partners, including other international organisations, governments, private sector entities, and civil society organisations, to maximise its impact and leverage resources for development projects and initiatives.

ADB is committed to promoting environmentally sustainable development practices and integrating climate change mitigation and adaptation into its projects and policies. Overall, the Asian Development Bank is crucial in facilitating economic development and poverty reduction across the Asia-Pacific region.

An operational priority of ADB's Strategy 2030 is tackling climate change, building climate and disaster resilience, and enhancing environmental sustainability. ADB committed to ensuring that 75% of operations on a 3-year rolling average will support climate change mitigation and adaptation by 2030. In October 2021, ADB announced that it would be increasing its climate finance ambition by 25% to $100 billion in the 2019-2030 period from $80 billion. (Asian Development Bank, n.d.-a)

In 2022, ADB committed $7.1 billion in climate finance, 60% of which was towards mitigation and 40% for climate change adaptation. The amount committed for adaptation is the highest adaptation finance committed since 2011, showing the complex nature of climate finance. (Asian Development Bank, n.d.-b)

Like the World Bank Group, the ADB's commitment to finance CCS-related projects depends on the demand from its member states. So far, such demand has not been sufficient to prioritise CCS amongst its financing activities allocated to address climate change, although discussions with ADB indicate that CCS is rising in priority. Even in the most positive scenario, due to resource limitations, such funding would be limited to funding research studies, feasibility reports, mapping storage capacity, and small-scale demonstration and pilot projects. Large-scale deployment will depend on ASEAN countries fiscal support and ability to create business models to mobilise private capital.

4.9.2. Voluntary Carbon Markets

A Voluntary Carbon Market, in its broadest definition, is a marketplace that allows its participants to buy and sell carbon credits or carbon offsets voluntarily. A carbon offset is the removal of GHGs from the atmosphere, and a carbon credit is reducing GHGs released into the atmosphere. The conventional unit is a tonne of CO_2 in both. Its origins date back to the 1990s.

The global voluntary market is a noncentralised, fragmented, and emergent global industry ecosystem. The carbon credits in these markets are usually unregulated and non-standardised and generated by various types of projects such as forestry, biomass, etc., and certified by various independent organisations. Buyers purchase credits to offset emissions and meet internally set voluntary goals. A second kind is organised voluntary carbon market initiatives. These markets try to differentiate themselves with attempts to create regulated and centralised marketplaces with standards. (Center for Strategic & International Studies, 2023) The most prominent standards include Verra (The Verified Carbon Standard), Plan Viv, The Gold Standard, The American Carbon Registry, and the Climate Action Reserve

Paris Article 6 confirmed their role in achieving global emissions reduction targets of countries' NDCs, focusing on country-to-country transfers of carbon credits. These credits can then be used to meet NDCs. Implementation of Article 6 requires establishing standards, a registry, and a market for transfers. Such consolidation could streamline the fractured global market that exists today. Advocates argue that such a development would accelerate the growth of carbon markets, helping commercial returns and financing and deploying technologies like CCS.

However since then, the enthusiasm has been curbed with inconclusive negotiations over implementation. The uncertainty over Article 6 accounting and interaction with voluntary markets remains.

With the question marks increasing over the quality of carbon offsets, the credibility of the voluntary carbon markets has taken a hit. The industry continues to expect exponential growth in the voluntary markets, but so far, voluntary markets failed to live up to the expectations.

The total size of the voluntary carbon markets can vary from year to year and is influenced by various factors, including global demand for carbon offsets, regulatory changes, and the overall state of the global economy. Estimates of the size of the voluntary carbon market ranges from several hundred million to a couple of billion dollars.

Apart from the issues surrounding quality, standardisation, and lack of transparency, the fundamental problem with the voluntary carbon markets is the fact that they are voluntary. There is no obligation for the corporates or state actors to adhere to the aspirational targets. The mechanism is, to a large extent, limited in quantity. The price, quantity, conditionality, and maturity of the transactions are not transparent.

Furthermore, in the current legal system, the purchase of carbon offsets at scale can be in direct conflict with the fiduciary duty of the corporations to provide a return to their shareholders.

At the scale needed, the VCMs are unlikely to provide a reliable and durable source of revenue that against which the banks can provide credit. Indeed, the institute's engagement with the financial sector confirms this assessment.

The potential positive contributions of VCMs:

1) When executed and administered correctly, they help provide the know-how of carbon accounting and resources for the certifiers and evaluators of projects with the necessary experience and a platform to learn from mistakes. As such, they can be seen as a dress rehearsal for the compliance markets.
2) They potentially provide additional revenue streams for CCS even if such revenue streams are not yet at scale and the durability remains a concern.

The one major downside of VCMs is that due to a lack of standards, transparency, and issues related to measurability, they may create a false sense of a solution.

In summary, while VCMs can provide a marginal return for decarbonisation in general and CCS in particular, they cannot be relied upon as a base for a bankable business model.

4.9.3. Sustainable Finance – Green and Climate Bonds

Sustainable finance refers to financing available for investments that aim to increase clean energy and processes. Sustainable finance aims to increase funding and decrease the cost of capital for sustainable investments.

However, green and climate bond certification is not a transparent and standardised process. There are several certifiers to evaluate the marginal impact of a project. The certifiers typically rely on the GHG emission profile of a company or issuer rather than emissions reductions. The lower the emissions, the greener or the more sustainable the issuer. In that sense, sustainable finance can potentially divert funds from high emitters to already low emitters, for instance, from energy producers to information technology companies.

Second, even when sustainable finance pays attention to emission reductions, the focus is generally on percentage emission reductions, not absolute reductions. Such a bias also potentially diverts funds away from high-emitting firms, which could deliver a much higher absolute impact on the emissions with a slight percentage decrease compared with an already low-emitting issuer, which can deliver a higher percentage decrease but an immaterial absolute emission reduction. (Hartzmark et al., 2023)

CCS is an emissions abatement technology mainly utilised by high-emitting sectors and, therefore, potentially could suffer from the selection bias that is discussed above. Green and climate bond standards and certificates have historically omitted CCS technologies.

There are signs of more resources being allocated to examining the eligibility of CCS; however, those efforts are attempting to limit the eligibility of CCS to hard-to-abate sectors like cement and steel. Such limitations decrease the potential significant emission reductions that CCS can deliver in power and heating.

Even if CCS is increasingly admitted as eligible for sustainable finance, it does not ensure that it will be instrumental in filling the funding gap at the scale needed. The lower cost of debt that green bonds offer is found to be a meager 8 basis points (0.08%) (Board of Governors of the Federal Reserve System, 2022). Considering a selection bias given that, on average, companies with high investment grades qualify for green bonds, the difference is due to the quality of the borrower. One advantage of sustainable finance would be access to funds that would not be available but with the caveats detailed above.

4.9.4. The Loss and Damage Fund

The 'loss and damage' fund refers to a financial mechanism designed to assist developing countries that are disproportionately affected by the impacts of climate change and are unable to cope with the associated losses and damages. This fund is part of international climate negotiations and agreements, particularly under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement. Developing countries argue they bear a disproportionate burden of these impacts despite contributing less to global greenhouse gas emissions. The loss and damage fund intends to provide financial support for developing countries to address these losses and damages, as well as to enhance their capacity to adapt to future climate-related risks.

There are significant disagreements between the developed countries and developing countries' positions. The most important disagreement is over how to finance the loss and damage fund. Developing countries demand contributions from developed countries, given their wealth and historical responsibility for emissions. Developed countries, on the other hand, resist financial commitments due to the cost and their economic priorities.

The second most important disagreement is governance and accountability: There are concerns about how the fund would be governed, how funds would be allocated, and how accountability and transparency would be ensured. The developed nations prefer the funds to be governed by the World Bank, where they have a higher influence, and the developing countries prefer oversight by the UN.

There is also concern as to whether loss and damage should imply legal liability or compensation. Developed countries resist acknowledging legal responsibility.

Finally, defining what constitutes 'loss and damage' is another contentious issue. Some argue for a narrow definition to limit the financial burden, while others advocate for a broader one.

The first and second points continue to be contentious ahead of the COP28. The loss and damage fund at a size of $100 billion per year commitment was affirmed and agreed upon in the Paris Agreement at COP 21 in 2015. This commitment would start in 2020 and continue through 2025. It was a crucial element of the Paris Agreement to help address the needs of developing countries in their climate action and adaptation efforts.

Despite these concerns, the Loss and Damage Fund was formally established at COP 28 in December 2023. In total, USD700 million has been pledged, less than 1% of the annual commitment first agreed in Paris in 2015.

How much of these funds will be available to ASEAN countries, which are relatively wealthy compared with poorer African nations is yet to be determined. Further, of that amount, how much will be available for CCS technologies looms as a question.

In summary, like the MDB funding, Voluntary carbon markets, or Sustainable Funds, the Loss and Damage Fund in its current form, while providing marginal support for feasibility studies and pilot studies, is very unlikely to be material for large-scale deployment of CCS for the ASEAN region.

4.10.The Role of Carbon Pricing

There is no doubt that carbon pricing is an efficient mechanism for aligning private investment incentives with the need to reduce emissions. But to be effective, the price of carbon must be high enough to drive changes in behaviour and capital flows, must be broadly applied across all sectors, and there must be confidence in the long-term resilience of the carbon market and the carbon price. This is particularly important with respect to investments in capital intensive, long lived assets such as CCS facilities.

To achieve net-zero targets, modelling from Genzo illustrates that the marginal cost of abatement across ASEAN nations will be around USD100/tonne in the mid 2030s, rising to around 400-500 per tonne in the mid 2050s (see figure 4.24) if CCS is deployed (higher if it is not). To achieve the emissions reduction trajectory assumed in the model, which is derived from ASEAN member state net zero commitments, without any supportive policies, a comprehensive carbon price at least equal to this marginal cost of abatement would be required. Further, the market would need perfect foresight and must act rationally, investing without hesitation when it is economic to do so. If that were the case, then the private sector would invest in CCS, and all other necessary climate mitigation technologies at the appropriate time. Whilst this applies within a model, it does not apply in reality. Carbon pricing schemes are not comprehensive. The market does not have perfect foresight, nor does it invest without hesitation. Other non-economic factors (e.g. geopolitical) also disrupt or distort markets and the investment behaviour of market actors.

As noted previously, even in Europe where carbon prices have approached and even exceeded Euro100 per tonne, CCS has required significant policy support including public financing to attract private sector investment. Given time, experience and the confidence in business models etc that will develop over time, the effectiveness of carbon pricing alone in driving investments in CCS in Europe is expected to increase and at some point, the need for additional supportive policies or public finance will diminish. If there were no time constraint on achieving net zero emissions, then simply pricing carbon and letting the market respond would be an appropriate strategy. However there is a very significant time constraint – net zero emissions within the next 30 years. Supportive policies including public finance are essential to deploy CCS at an accelerated rate, faster than the market would otherwise achieve.

Considering ASEAN specifically, whilst carbon pricing is the most efficient mechanism for driving emissions reduction, a material carbon price also introduces additional costs across the economy, which may be opposed by some sectors, especially those that are energy or emissions intense. Perhaps with the exception of Singapore, a comprehensive and material carbon price, exceeding USD100/tonne, is unlikely to be in place in ASEAN nations for some time.

However, some ASEAN industries that export into Europe will be exposed to European carbon pricing through the European Carbon Border Adjustment Mechanism from 2026. It is possible that other nations may follow Europe's example and introduce their own carbon border taxes on imports to protect their import-exposed industries whilst they decarbonise. This may bring forward ASEAN firms' exposure to material carbon prices for exports into these markets. This future risk to the competitiveness of ASEAN exports supports a case for the introduction of carbon pricing sooner to collect revenue domestically (rather than pay the carbon tariff imposed by the importer), and to accelerate reductions in emissions intensity of production (to reduce the impact of any carbon tariff). It also supports the implementation of other policies to drive deployment of lower emission production processes, including CCS, to protect the competitiveness of exports into these markets.

Carbon pricing should be pursued as quickly as possible, in line with other priorities of government, but it is very unlikely to be sufficient to drive the rapid ramp-up in investment in CCS in ASEAN necessary to support the achievement of net zero targets. Other policies, including public finance will need to do the heavy lifting, at least in the short term.

4.11. Policy Recommendations

Achieving net zero emission commitments made by ASEAN Member States by the middle of this century requires the deployment of a comprehensive range of low emission and energy efficiency technologies. Carbon capture and storage is essential to reduce emissions in the power sector, across hard to abate industries, to support the production of clean hydrogen, and to deliver carbon dioxide removals through bioenergy with CCS and direct air capture with CCS.

If deployed at optimal or near optimal levels, CCS can reduce the overall cost of achieving net zero targets in ASEAN by more than USD20 trillion between 2023 and 2065. At these levels, at least 2Gtpa of CO_2 will be captured in southeast Asia by 2060. The capital investment required to establish CCS at this scale sums to almost US$880 billion to 2065 starting at USD420 million per year in the 2020s, rising rapidly to USD15.6 billion per year in the 2030s and peaking at over USD40 billion per year in the 2040s before declining to almost USD25 billion per year in the 2050s and USD6.5 billion per year in the 2060s (GENZO Accelerated Storage Scenario).

A phased approach to driving investment in CCS is recommended.

4.11.1. Phase 1 – First Projects; 2020s

ASEAN members benefit from the considerable resources, experience and expertise of national and international oil companies that are active in the region. This industry has some of the lowest cost opportunities for very significant emissions reductions in their production value chain. For example, reservoir CO_2 which is currently vented to atmosphere, may instead be compressed ready for transport and geological storage after minimal clean up (eg dehydration).

The oil and gas industry also holds subsurface data from oil or gas exploration and production necessary to identify, appraise and develop pore space for the geological storage of CO_2 and has the technical expertise and knowledge necessary to establish and operate CO_2 transport and injection infrastructure. In some cases, existing infrastructure such as pipelines or offshore platforms may be utilised or re-tasked to support CCS operations, very significantly reducing the necessary capital investment.

The oil and gas industry is studying several CCS projects in the ASEAN region that share a common strategy; establish CCS infrastructure to enable the reinjection of their own reservoir CO_2, and explore opportunities to receive third party CO_2 for storage for a fee.

These first projects are likely to be the lowest cost opportunities for CCS projects and may also be the anchor projects for the establishment of CCS networks that will serve the broader needs of industry in the region seeking a carbon management solution. Establishing these first projects and their infrastructure to kickstart CCS deployment in the region this decade and lay the foundations for broader CCS deployment should be a priority for government climate policy in the region.

In the absence of a material carbon price, these first CCS projects in the region will likely require capital investment support to reach FID. Where the developer is a National Oil Company, government should consider supporting the financing of the CCS project off the company's balance sheet. This will necessarily require government to accept a reduced return from the NOC for a period. This represents, in effect, government investment in the establishment of CCS infrastructure that will deliver a return in the future.

Government should put in place a proactive strategy to identify and obtain sources of external finance that could support these first CCS projects. This could be provided in the form of grants or concessional loans or loan guarantees. Sources to consider include the World Bank Group, the Asian Development Bank, the Green Climate Fund and developed countries with climate aid programmes or climate -related investments in the ASEAN region such as Japan, Australia, and the USA. Multilateral initiatives focused on CCS such as the Carbon Management Challenge which has an explicit objective of supporting carbon management efforts in the Global South (Clean Air Taskforce, 2023) should also be actively engaged.

If necessary, Government should consider the provision of targeted low-cost loans, capital grants or operational subsidies to CCS projects to bridge any remaining finance gap and allow developers to reach FID. Public finance could be awarded on a competitive basis to ensure funds are allocated and utilised efficiently.

Governments should commence the development and implementation of carbon pricing schemes, starting at low prices for the least developed ASEAN economies, but with announced plans to increase the price in the future. Even at low prices of a few dollars per tonne of CO_2, carbon pricing, if applied broadly across the economy, could generate hundreds of millions of dollars of revenue for each government which could then be used to support climate mitigation initiatives, including CCS. These schemes will also set a clear expectation in the market of more stringent future climate policies and higher carbon prices that will incentivise increased analysis of CCS opportunities, entrepreneurial activity and CCS project development.

4.11.2. Phase 2 – CCS Network Establishment and Deployment Ramp-up; 2030s

Investment in CCS in the 2030s must ramp up significantly to stay on track to achieve net-zero emissions targets, reaching an average of USD15.6 billion per year (Accelerated Storage Scenario) during this decade in southeast Asia. By this time, the global CCS industry will have accrued another decade of operational and commercial experience. Business models, risk mitigation strategies, and commercial confidence will have matured. More providers of CCS technologies and services will have entered the market and the policy and regulatory environments in developed economies will probably have strengthened the business case for CCS. The European Carbon Border Adjustment Mechanism will be in force, effectively exposing exports to Europe to the ETS carbon price. Private sector finance will likely be more accessible and attract a much lower risk premium (if any) as the finance sector becomes familiar with CCS. The first CCS projects in southeast Asia will have commenced operations.

In this decade, Governments should aim to facilitate investment in the next wave of CCS projects especially where they leverage the infrastructure developed by the first wave of CCS projects. Governments should prioritise investment in additional CO_2 transport and storage infrastructure, including shipping necessary to establish CCS networks that will reduce the overall cost of CCS, and emissions mitigation, in the region. This will require continued development of carbon pricing programs (carbon price should continue to rise), continued engagement with multilateral development banks and other potential sources of external finance, and continued provision of targeted capital support.

The top three sectors which must host capture projects in the 2030s include, in decreasing order of investment, bioenergy with CCS in industry, electricity generation, and refining. These capture projects will require access to CO_2 transport and storage infrastructure which will likely be provided, in the majority of cases through networks. The importance of investment in networks this decade is clear from the GENZO model (Accelerated Storage Scenario). From GENZO, of the USD155 billion required to be invested in CCS in the region in the 2030s, over USD73 billion is required for CO_2 transport and storage including shipping, pipelines and geological storage development. This infrastructure is essential to enable the region to reach its net zero targets.

Governments should increase international collaboration and regional cooperation and proactively seek to facilitate investment in geological storage resource development and CCS networks. In addition to leveraging CO_2 transport and storage infrastructure that has been constructed in the 2020s to service the first CCS projects, Governments should deliberately target specific opportunities to create CO_2 collection hubs to service regions with significant emissions intense industry, to support the next wave of investment in CO_2 capture projects.

To illustrate this opportunity, consider the port of Singapore. The port of Singapore hosts a large petrochemical industry including refineries with a capacity of 1.5 million barrels per day and accounts for a significant portion of Singapore's total emissions. The port, together with the port of Rotterdam, is aiming to decrease emissions from shipping between them by 20-30% by 2030 through the use of low emission fuels. (Bovenizer, 2023). Singapore has also announced plans to capture 2Mtpa CO_2 by 2030, and to produce biofuels and other low emission products to deliver total emissions abatement of 6Mtpa by 2050. (Nair, 2021). The government of Singapore is actively seeking to access geological storage resources in other countries, which will require the establishment of CCS networks. Singapore also has the highest GDP/capita in the region and so would be expected to have greater capacity to provide public finance to support CCS and network development. In addition, Singapore has the region's highest carbon tax. The carbon tax will rise from S$5/t CO_2 in 2023 to S$25/t CO_2 in 2024, S$45/t CO_2 in 2026 and between S$50 and S$80/t CO_2 by 2030. The government of Singapore plans to use revenue generated by the carbon tax to support decarbonisation efforts (National Climate Change Secretariat Singapore, 2023). These conditions make Singapore highly prospective with respect to both public and private finance of CCS.

Further, there are similarities between the Port of Singapore and the Port of Rotterdam which is already hosting a major CCS network development; the Porthos project. The Porthos project, which includes 4 refinery and petrochemical customers capturing CO_2 and then shipping it to the LongShip project in Norway has taken a final investment decision.

Porthos provides a good example of international cooperation to enable CCS network development. For the Porthos Project to be realised, it took two governments, the

Netherlands and Norway, to provide subsidies for the transportation of CO_2 and guarantees for the clients. The Dutch government set aside EUR 2.1 billion for the four clients (capture projects) at the Port of Rotterdam (Air Liquide, Air Products, ExxonMobil, and Shell), and the government of Norway also indirectly provided in excess of Eur 3 billion support for the project.

A similar partnership between Singapore and other nations in the region with geological storage resources and available infrastructure should be amongst the first to be vigorously explored and developed as a priority. Governments should also collaborate to proactively identify other potential hubs and CCS networks for development in the region.

4.11.3. Phase 3 - CCS Industry Maturity: 2040s and beyond

First-mover projects are the riskiest for the private sector to finance, so the first CCS projects in the region in the 2020s and 2030s will need public finance to bridge the funding gap. By the 2040s, if the region has been successful in maintaining its emissions reduction trajectory consistent with net zero targets, it is likely that a mature CCS Industry in the region will require significantly less public finance as private investors enter the market. As operational experience accumulates and networks are established in the region, government can shift from a capital subsidy policy model toward supplemental loan guarantees to lower the cost of private finance as the private sector takes a more active role. Government can gradually remove loan guarantees as the private sector gains confidence in lending for CCS projects and as the CO_2 price signal goes higher, making CCS projects more and more cost-effective.

During this decade, governments should achieve material carbon prices that are sufficient to drive investment in CCS, and all other climate mitigating technologies, with little or in some cases no public finance or policy support. The capital investment required for CCS in the region peaks in the 2040s at an average on over USD40 billion per year. Investment at this scale will only be possible with full private sector engagement.

In the 2040s Governments should look for opportunities to facilitate private sector investment in CCS investments that are commercially viable without significant public finance. One potential opportunity will likely be the production of low carbon hydrogen and its derivatives.

Hydrogen and its derivatives, the most prominent of which is ammonia, is gaining traction as an energy carrier. The research on applications is wide-ranging, including power generation with hydrogen and ammonia turbines, fuel cells, and the use of ammonia as a maritime fuel. Global CCS Institute's Investment Case for CCS details how blue hydrogen and ammonia production with Autothermal Reforming of methane with CCS is developing as one of the main investment themes in the US, enabled by strong policy support (production subsidy for clean hydrogen). Japan and Korea are actively looking for off-take agreements for coal cofiring and other applications using a hypothetical CO_2 price of $130-150. The total amount to be produced, according to recent announcements amount to close to 40 million tonnes of low carbon ammonia in the US Gulf Coast alone – with a potential to sequester 60 million tonnes of CO_2 per annum. (Cevikel & Thomas, 2023). Southeast Asia has the opportunity to also develop a clean hydrogen production industry.

By the 2040s the production of clean hydrogen or ammonia with CCS may require very little if any subsidy, especially if carbon prices have reached material levels and global demand for clean hydrogen, particularly in developed economies, grows to hundreds of millions of tonnes per year, as projected by the IEA and others.

Malaysia and Indonesian both have significant natural gas resources, and natural gas prices are similar to US prices (around $3 per MMBtu) (Indexmundi, 2023). Southeast Asian nations are well positioned to take advantage of the shorter distance to the centers of demand for hydrogen like Japan, South Korea, Taiwan and potentially Singapore's refining petrochemical and maritime industries. Using LNG shipping as a proxy, Southeast Asia would have a freight advantage of USD70 per tonne of ammonia compared with the US Gulf Coast. Lower labor costs and lower capital expenses in ASEAN countries, if maintained through to the 2040s as expected, would add to the region's competitiveness as a supplier of clean hydrogen or ammonia.

Furthermore, Malaysia and Indonesia have existing natural gas pipelines connecting them to Singapore. These pipelines can be complemented by hydrogen pipelines to Singapore, creating a virtual loop of carbon sequestration in Malaysia and Indonesia while utilising natural gas resources in these countries and using clean hydrogen in Singapore's refining and petrochemical sectors.

References

Singapore's update of its first Nationally Determined Contribution (NDC) and accompanying information. (2022).

10 Things You Should Know about the World Bank's Climate Finance. (n.d.). Retrieved December 12, 2023, from https://www.worldbank.org/en/news/factsheet/2022/09/30/10-things-you-should-know-about-the-world-bank-group-s-climate-finance

12 Projects Awarded $55 Million to Accelerate Decarbonisation in Singapore. (2021).

ADB. (2013). *Prospects for carbon capture and storage in Southeast Asia*.

APEC. (2005). CO2 Storage Prospectivity of Selected Sedimentary Basins in the Region of China and South East Asia. In *Asia-Pacific Economic Cooperation* (Issue June).

APEC Energy Working Group. (2012). *Permitting Issues Related to Carbon Capture and Storage for Coal-Based Power Plant Projects in Developing APEC Economies,*. www.apec.org

ASEAN. (n.d.). *ASEAN Strategy for Carbon Neutrality*.

ASEAN. (2023, August). *ASEAN charts course for a sustainable future with ambitious ASEAN Strategy for Carbon Neutrality*. https://asean.org/asean-charts-course-for-a-sustainable-future-with-ambitious-asean-strategy-for-carbon-neutrality/

Ashurst. (2023). *Indonesia Regulates CCS and CCUS-MEMR Regulation 2/2023*.

Asia Zero Emission Community. (2022, November). *Joint announcement on Asia Zero Emission Community (AZEC) concept*.

Asia Zero Emission Community (AZEC). (2023a). *AZEC Ministerial Meeting – Chair's Summary*. https://www.meti.go.jp/press/2022/03/20230306005/20230306005-26.pdf

Asia Zero Emission Community (AZEC). (2023b, March 4). *AZEC Ministerial Meeting – Joint Statement*. https://www.meti.go.jp/press/2022/03/20230306005/20230306005-24.pdf

Asian Development Bank. (n.d.-a). *ADB Raises 2019-2030 Climate Finance Ambition to $100 Billion*. Retrieved December 12, 2023, from https://www.adb.org/news/adb-raises-2019-2030-climate-finance-ambition-100-billion

Asian Development Bank. (n.d.-b). *Climate Finance in 2022*. Retrieved December 12, 2023, from https://www.adb.org/news/infographics/climate-finance-2022#:~:text=In%202022%2C%20ADB%20committed%20%247%2C110,since%20reporting%20began%20in%202011

Asian Development Bank. (2013). *Prospects for carbon capture and storage in Southeast Asia*.

Asian Development Bank. (2019). *Indonesia: Pilot Carbon Capture and Storage Activity in the Natural Gas Processing Sector For Directorate General of Oil and Gas, Ministry of Energy and Mineral Resources, Republic of Indonesia (DG MIGAS)*.

Bain & Company. (2021). *Southeast Asia's USD$10 billion carbon markets opportunity and the race to net zero*. https://www.bain.com/about/media-center/press-releases/sea/sea-carbon-markets-2021/

Baker McKenzie. (2023). *Indonesia: New OJK Rule on carbon trading on carbon exchange*. https://insightplus.bakermckenzie.com/bm/capital-markets/indonesia-new-ojk-rule-on-carbon-trading-on-carbon-exchange

Bishop, M. G. (2002). *Petroleum systems of the Malay Basin Province, Malaysia*.

Board of Governors of the Federal Reserve System. (2022, June 1). *International Finance Discussion Papers*. https://www.federalreserve.gov/econres/ifdp/the-green-corporate-bond-issuance-premium.htm

Boston Consulting Group. (2022). *Companies need to explicitly integrate climate into their strategies*. https://www.bcg.com/publications/2022/why-australian-companies-need-integrated-esg-investment-frameworks

Bovenizer, N. (2023). Singapore and Rotterdam aim for 30% emissions reduction by 2030. *Ship Technology*. https://www.ship-technology.com/news/mpa-singapore-port-of-rotterdam-30-emissions-reduction-2030/?cf-view

Braun, C. (2017). Not in My Backyard: CCS Sites and Public Perception of CCS. *Risk Analysis*, *37*(12), 2264–2275. https://doi.org/10.1111/RISA.12793

Brennan, S. T., Burruss, R. C., Merrill, M. D., Freeman, P. A., & Ruppert, L. F. (2010). A Probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage. In *U.S. Geological Survey Open-File Report 2010–1127*. https://pubs.usgs.gov/of/2010/1127/

Brunei banks on technology to preserve its economic lifeline. (2021). *Eco-Business*.

Brunei Darussalam Nationally Determined Contribution (NDC). (2020).

Bureau des Recherches Géologiques et Minières. (2009). *Où sont les capacités de stockage du CO2 au Viet Nam ?' In Forum Économique et Financier, Huitième Session, Énergie et Développement Durable*.

Byers et al. (2022). Global Power Plant Database. In *World Resources Institute*.

C. Caughey, & T. C. Cavanagh. (1994). *The Central Sumatra Basin Geologic Setting*.

Carbon Capture Utilization and Storage (CCUS): A Key Decarbonization Technology for Thailand and the Region. (2023).

CCS Development in Thailand. (2022).

Center for Strategic & International Studies. (2023, May 31). *Voluntary Carbon Markets: A Review of Global Initiatives and Evolving Models*. https://www.csis.org/analysis/voluntary-carbon-markets-review-global-initiatives-and-evolving-models

Cevikel, S., & Thomas, J. (2023). *THE INVESTMENT CASE FOR CCS: POLICY DRIVE AND CASE STUDIES THE INVESTMENT CASE FOR CCS: POLICY DRIVE AND CASE STUDIES 2*.

Choomkong, A., Sirikunpitak, S., Darnsawasdi, R., & Yordkayhun, S. (2017). A study of CO 2 Emission Sources and Sinks in Thailand. *Energy Procedia*, *138*, 452–457. https://doi.org/10.1016/j.egypro.2017.10.198

Clean Air Taskforce. (2023, October 10). *A Pledge with a plan: How the Carbon Management Challenge can accelerate climate action*. https://www.catf.us/2023/10/how-the-carbon-management-challenge-can-accelerate-climate-action/

Clean Energy Regulator. (2022). *About the National Greenhouse and Energy Reporting scheme*. https://www.cleanenergyregulator.gov.au/NGER/About-the-National-Greenhouse-and-Energy-Reporting-scheme

Climate Finance 2020. (n.d.). Retrieved December 12, 2023, from https://thedocs.worldbank.org/en/doc/9234bfc633439d0172f6a6eb8df1b881-0020012021/original/2020-Joint-MDB-report-on-climate-finance-Report-final-web.pdf

CO2CRC. (2010). *Assessment of the capture and storage potential of CO2 co-produced with natural gas in South-East Asia*.

CO2CRC, & Gamma Energy Technology. (2015). *Australian Power Generation Technology Report*.

Comprehensive Investment and Policy Plan 2023. (2023). https://jetp-id.org/storage/official-jetp-cipp-2023-vshare_f_en-1700532655.pdf

Cuong, T. X., & Warren, J. K. (2009). Bach Ho Field, A fractured granite basement, Offshore SE Viet Nam. *Journal of Petroleum Geology*, *32*(2), 129–156. https://doi.org/10.1111/j.1747-5457.2009.00440.x

Department of Industry, S. and R. (n.d.). *Offshore Greenhouse Gas Storage*. Retrieved November 9, 2023, from https://www.industry.gov.au/mining-oil-and-gas/offshore-greenhouse-gas-storage

Dien, P. T., Tai, P. S., & Dung, N. V. (1997). Basin Analysis and Petroleum System of the Cuu Long Basin on the Continental Shelf of Viet Nam. *Indonesian Petroleum Association, Proceedings of the Petroleum Systems of SE Asia and Australasia Conference, May 1997.*

DNV GL. (2012). *Recommended Practice DNV-RP-J203 Geological Storage of Carbon Dioxide*.

Emissions Trading Worldwide: Status Report 2023. (2023).

Enhanced Nationally Determined Contribution. (2022).

ENI S.p.A. (2018). *Offshore Western Australia & Northern Territory Northern Australia CO_2 Store: Petrel sub-Basin Facilities Description*.

ERIA. (2023, June 24). ERIA supports first Asia Zero Emission Community (AZEC) Senior Official Meeting (ASOM). *News and Views: ERIA*. https://www.eria.org/news-and-views/eria-supports-first-asia-zero-emission-community-azec-senior-official-meeting-asom/

European Commission. (2021a). *Effort sharing 2021 – 2030: targets and flexibilities*.

European Commission. (2021b). *Monitoring, Reporting and Verification of EU ETS emissions*.

European Commission. (2022a). *The EU legal framework for cross-border CO2 transport and storage in the context of the requirements of the London Protocol, Commission services analysis paper for the Information Exchange Group (IEG) under Directive 2009/31/EC – 30.09.2022*. EU-London_Protocol_Analysis_paper_final0930.pdf (climate.ec.europa.eu)

European Commission. (2022b). *Consolidated version of the Treaty on the Functioning of the European Union - PART THREE: UNION POLICIES AND INTERNAL ACTIONS - TITLE XVIII: ECONOMIC, SOCIAL AND TERRITORIAL COHESION - Article 174 (ex Article 158 TEC)*. EUR-Lex - 12008E174 - EN - EUR-Lex (eur-lex.europa.eu)

European Commission. (2023). *Implementation of the CCS Directive*. https://climate.ec.europa.eu/eu-action/carbon-capture-use-and-storage/implementation-ccs-directive_en#documentation

Directive 2009/31/EC Of The European Parliament and of the Council, (2009).

Fahmi, F. (2007). Jerneh Full Field Studies - An Integrated Approach to the Identification of New Development Opportunities. . . *Proceedings of the Indonesian Petroleum Association, Thirty-First Annula Convention and Exhibition.*

Fournier, F., & Borgomano, J. (2007). Geological significance of seismic reflections and imaging of the reservoir architecture in the Malampaya gas field (Philippines). *AAPG Bulletin*, *91*(2), 235–258. https://doi.org/10.1306/10160606043

GCCSI. (2021). *Technology Readiness and Costs of CCS The Circular Carbon Economy*. *March*.

Global CCS Institute. (2018). *CCS Readiness Index 2018*.

Global CCS Institute. (2019). *Lessons and Perceptions: Adopting a Commercial Approach to CCS Liability*.

Global CCS Institute. (2023a). *CO2RE*. Co2re.Co.

Global CCS Institute. (2023b). *CO2RE*. Co2re.Co. https://co2re.co/FacilityData

Global CCS Institute, ASEAN Center for Energy, & ASEAN Forum on Coal. (2014). *ASEAN CCS Strategic Considerations*.

Global Energy Monitor. (2022). Global Steel Plant Tracker. In *Global Energy Monitor*.

GlobalData. (2022). Oil and Gas Database. In *GlobalData*.

Government of Alberta. (2023). *Fact Sheet Storage Hub Development*. https://www.alberta.ca/carbon-capture-

Government of Japan (METI). (2022, November). *Asia Energy Transition Initiative (AETI)*. https://www.meti.go.jp/english/press/2021/pdf/20210528001_aetieng.pdf

Government of the United Kingdom. (2009). *TSO, AMENDMENT TO ARTICLE 6 OF THE 1996 PROTOCOL TO THE CONVENTION ON THE PREVENTION OF MARINE POLLUTION BY DUMPING OF WASTES AND OTHER MATTER 1972*. Amendment to Article 6 of the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter 1972 CM 8046 (publishing.service.gov.uk)

Ha-Duong, M., & Nguyen-Trinh, H. A. (2017). Two scenarios for carbon capture and storage in Viet Nam. *Energy Policy*, *110*, 559–569. https://doi.org/10.1016/j.enpol.2017.08.040

Harinderan, K. (2023, October 1). NETR, A Commitment To Just Energy Transition For The Rakyat In A Whole-Of-Nation Approach . *Business Today*.

Hartzmark, S. M., Shue, K., Giglio, S., Gormsen, N., Hebert, B., Howard, A., Krüger, P., Levine, M., Liang, H., Pontiff, J., Rampini, A., Shleifer, A., So, E., Solomon, D., Sufi, A., Taylor, L., Wang, N., & Yasuda, A. (2023). *COUNTERPRODUCTIVE SUSTAINABLE INVESTING: THE IMPACT ELASTICITY OF BROWN AND GREEN FIRMS **. https://ssrn.com/abstract=4359282

Hedriana, O., Sugihardjo, & Usman. (2017). Assessment of CO2- EOR and Storage Capacity in South Sumatera and West Java Basins. *Energy Procedia*, *114*(November 2016), 4666–4678. https://doi.org/10.1016/j.egypro.2017.03.1598

Hester, T. (2018). *Legal Pathways to Negative Emissions Technologies and Direct Air Capture of Greenhouse Gases*. https://doi.org/10.5194/esd-8-577-2017

Hieu, H. H. (2016). The Potential for CCS in the Red River Delta Basin, Viet Nam. *CCOP CCS-M S6: Workshop on CO2 Geological Storage and CO2 for EOR*.

IEA. (2021a). *Carbon capture, utilisation and storage: the opportunity in Southeast Asia*.

IEA. (2021b). *Carbon capture, utilisation and storage: the opportunity in Southeast Asia*. 60.

IEA GHG. (2009). *Development of Storage Coefficients for Carbon Dioxide Storage in Deep Saline Formations: Report No. 2009/13*. https://ieaghg.org/docs/General_Docs/Reports/2009-13.pdf

IEA Greenhouse Gas R&D Programme. (2009). *Long Term Integrity of CO2 Storage – Well Abandonment: Technical Study*. www.ieagreen.org.uk

IEAGHG. (2000). *Barriers to overcome in implementation of CO2 capture and storage (1)- Storage in disused oil and gas fields* (Issue February). https://doi.org/PH3/22

IEAGHG. (2009). *CO2 Storage in Depleted Gas Fields* (2009/01).

IEAGHG. (2020). *The Status and Challenges of CO_2 Shipping Infrastructures. July*.

IEAGHG. (2023). *IEAGHG Technical Report 2023-01, Integrating CCS in international cooperation and carbon markets under Article 6 of the Paris Agreement*.

Resolution LP-3(4), (2009).

IMO Document LC 41/17/Add.1. (2019). *Resolution LP.5(14) on the Provisional Application of the 2009 Amendment to Article 6 of the London Protocol (2019), Annex 2, Report of The Forty-First Consultative Meeting and The Fourteenth Meeting of Contracting Parties; LC 41/17*.

Indexmundi. (2023, December 12). *Natural gas Monthl Price - Malaysian Ringgit pe MMBTU*. Indexmundi.

Indonesia launches emissions trading system for power generation sector. (2023, February 27). International Carbon Action Partnership. https://icapcarbonaction.com/en/news/indonesia-launches-emissions-trading-system-power-generation-sector

Intergovernmental Panel on Climate Change. (2006a). *2006 IPCC - Guidelines for National Greenhouse Gas Inventories*. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html

Intergovernmental Panel on Climate Change. (2006b). *Carbon Dioxide Transport, Injection and Geological Storage: 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

International Energy Agency. (2022). *Legal and Regulatory Frameworks for CCUS - An IEA CCUS Handbook*. https://www.iea.org/reports/legal-and-regulatory-frameworks-for-ccus

International Maritime Organisation. (2013). *Guidance on the Implementation of Article 6.2 on the Export of CO2 Streams for Disposal in Sub-Seabed Geological Formations for the Purpose of Sequestration, Annex 6, Report of the Thirty-Fifth Consultative Meeting and the Eighth Meeting of Contracting Parties, LC 35/1*. http://www.imo.org/MediaCentre/SecretaryGeneral/Secretary-

International Maritime Organisation. (2018). *Resolution LP.3(4) On the Amendment to Article 6 of the London Protocol*.

IOGP. (2022). *Carbon Capture, Transportation and Storage Committee*. https://www.iogp.org/workstreams/energy-transition/energy-transition-committee-overview/carbon-capture-transportation-and-storage-committee/

Iskandar, U. P., & Sofyan, S. (2013). Ranking of Indonesia sedimentary basin and storage capacity estimates for CO 2 geological storage. *Energy Procedia*, *37*, 5172–5180. https://doi.org/10.1016/j.egypro.2013.06.433

Jacobs, W. B., & Craig, M. (2017). *Legal Pathways to Widespread Carbon Capture and Sequestration*. http://www.eli.org

JBIC Signs MOU with National Oil Company of Indonesia, Pertamina. (2022). JBIC. https://www.jbic.go.jp/en/information/press/press-2022/1115-016992.html

JETP Secretariat. (2023). *Just Energy Transition Partnership Indonesia - Comprehensive Investment and Policy Plan 2023*. official-jetp-cipp-2023-vshare_f_en-1700532655.pdf (jetp-id.org)

JOGMEC. (2023). *Handbook for CCS Carbon Credits – Workshop report of 'Global Carbon Markets and CCS: Towards ASEAN Decarbonisation*.

Junin, R., & Hasbollah, D. Z. A. (2016). *CO2 Storage Capacity Assessment of Deep Saline Aquifers in Malaysia CO 2 Storage Capacity Assessment of Deep Saline Aquifers in Malaysia*. *September*.

Krause, R. M., Carley, S. R., Warren, D. C., Rupp, J. A., & Graham, J. D. (2014). 'Not in (or Under) My Backyard': Geographic Proximity and Public Acceptance of Carbon Capture and Storage Facilities. *Risk Analysis*, *34*(3), 529–540. https://doi.org/10.1111/RISA.12119

Madon, M., & Council, N. S. (2016). *Penyu Basin*. *January 1999*.

McCarten et al. (2022). Global Database of Cement Production Assets. In *Global Database of Cement Production Assets*. Spatial Finance Initiative.

Mccollum, D. L., & Ogden, J. M. (2006). *Techno-Economic Models for Carbon Dioxide Compression, Transport, and Storage Correlations for Estimating Carbon Dioxide Density and Viscosity*. *530*, 87.

McKinsey & Company. (2023). *Unlocking Asia-Pacific's vast carbon capture potential*. https://www.mckinsey.com/industries/oil-and-gas/our-insights/unlocking-asia-pacifics-vast-carbon-capture-potential#/

Ministerial Council on Mineral and Petroleum Resources (MCMPR). (2005). *Australian Regulatory Guiding Principles for Carbon Dioxide Capture and Geological Storage*. (industry.gov.au)

Minister of Energy and Mineral Resources Regulation Number 2 of 2023 concerning Implementation of Carbon Capture and Storage, as well as Carbon Capture, Utilization and Storage in Upstream Oil and Gas Business Activities, (2023). https://jdih.esdm.go.id/index.php/web/result/2371/detail

Multilateral Development Banks: Overview and Issues for Congress. (n.d.). https://crsreports.congress.gov

Nair, P. (2021, November 24). Singapore targerts 2mn t of carbon capture by 2030. *Argus*. https://www.argusmedia.com/en/news/2276796-singapore-targets-2mn-t-of-carbon-capture-by-2030

National Climate Change Secretariat, S. G. P. M. O. S. (2022). *Addendum to Singapore's Long-Term Low-Emissions Development Strategy*. nccsleds_addendum_2022.pdf

National Climate Change Secretariat Singapore. (2023). *Carbon Tax*. Carbon Tax. https://www.nccs.gov.sg/singapores-climate-action/mitigation-efforts/carbontax/

Nationally Determined Contribution,. (2021).

Nationally Determined Contribution. (2022).

NETL. (2017). *Best Practices: Site Screening, Site Selection, and Site Characterization for Geologic Storage Projects*.

Neuhaus, D., Borgomano, J., Jauffred, J.-C., Mercadier, C., Olotu, S., & Grotsch, J. (2004). Quantitative Seismic Reservoir Characterization of an Oligocene– Miocene Carbonate Buildup: Malampaya Field, Philippines. *Seismic Imaging of Carbonate Reservoirs and Systems: AAPG Memoir*, *81*, 169–183.

NOAA. (2007). *London Protocol: Specific Guidelines for Assessment of Carbon Dioxide Streams for Disposal into Sub-Seabed Geological Formations*. Microsoft Word - 9 - CO2 Sequestration.doc (noaa.gov)

Odeh, N., & Haydock, H. (2009). *International CCS Policies and Regulations WP5.1a/WP5.4 Report*.

Pertamina Cooperates with ExxonMobil to Study CCUS Technology Application in Three Oil and Gas Field Areas. (2022, May 14). Pertamina. https://www.pertamina.com/en/news-room/news-release/pertamina-cooperates-with-exxonmobil-to-study-ccus-technology-application-in-three-oil-and-gas-field-areas

Petronas. (2022, August 2). *PETRONAS Signs MoU with Six South Korean Companies to Explore Opportunities in CCS Value Chain*. https://www.petronas.com/media/media-releases/petronas-signs-mou-six-south-korean-companies-explore-opportunities-ccs-value

Phase two of NETR to focus on biomass, waste-to-energy, carbon capture. (2023, August 23). Malaysia Investment Development Authority. https://www.mida.gov.my/mida-news/phase-two-of-netr-to-focus-on-biomass-waste-to-energy-carbon-capture/

Philippine Energy Plan 2020 – 2040, 2023 update. (2023).

Publications Office of the European Union. (2012). *Implementation of directive 2009/31/EC on the geological storage of carbon dioxide: guidance document 2, characterisation of the storage complex, CO2 stream composition, monitoring and corrective measures.* https://doi.org/10.2834/98293

Ramli, N. (1988). Characteristics of J Sandstone (Tapis Formation) Reservoirs in the Southeastern Part of the Malay Basin, Offshore West Malaysia. *Proceedings of the South East Asia Petroleum Exploration Society, Volume VIII*, 239–248.

Raza, A., Gholami, R., Rezaee, R., Bing, C. H., Nagarajan, R., & Hamid, M. A. (2017). Preliminary assessments of CO 2 storage in carbonate formations: a case study from. *Journal of Geophysics and Engineering*, *14*(3), 535–556. https://doi.org/10.1088/1742-2140/aa5e71

Raza, A., Gholami, R., Rezaee, R., Rasouli, V., Bhatti, A. A., & Bing, C. H. (2018). Suitability of depleted gas reservoirs for geological CO2 storage: A simulation study. *Greenhouse Gases: Science and Technology*, *8*(5), 876–897. https://doi.org/10.1002/ghg.1802

Rijks, E. J. H. (2014). Baram Delta Geology and Hydrocarbon Occurrence. *Geological Society of Malaysia Bulletin*, *1*, 1–18.

Roussanaly, S., Deng, H., Skaugen, G., and Gundersen, T. (2021). 'At what Pressure Shall CO_2 Be Transported by Ship? An in-Depth Cost Comparison of 7 and 15 Barg Shipping'. *Energies* 14, no. 18: 5635. https://doi.org/10.3390/en14185635

Sanguinito, S., Hanson, A., Haeri, F., Myshakin, E., Moore, J., & Crandall, D. (2022). *CO2 Storage prospeCtive Resource Estimation Excel aNalysis (CO2-SCREEN) User's Manual: Python_V4.1*. https://doi.org/10.2172/1862020

SETIS. (2020). *Set Plan Information System, European CO2 storage database*. https://setis.ec.europa.eu/european-co2-storage-database_en

Shell signs MoU to explore carbon transport, storage options in Brunei and Singapore. (2022, October 26). Alarabiya News. https://english.alarabiya.net/business/energy/2022/10/26/Shell-signs-MoU-to-explore-carbon-transport-storage-options-in-Brunei-and-Singapore

Shell to explore carbon transport and storage in Brunei and Singapore. (2022). *Shell Singapore*.

Shell to explore carbon transport and storage in Brunei and Singapore. (2022).

Smith, S. M. , Geden, O. , Nemet, G. , Gidden, M. , Lamb, W. F. , Powis, C. , Bellamy, R. , Callaghan, M. , Cowie, A. , Cox, E. , Fuss, S. , Gasser, T. , Grassi, G. , Greene, J. , Lück, S. , Mohan, A. , Müller-Hansen, F. , Peters, G. , Pratama, Y. , … Minx, J. C. (2023). *The State of Carbon Dioxide Removal - 1st Edition*. https://doi.org/10.17605/OSF.IO/W3B4Z

Society of Petroleum Engineers (SPE). (2018). *CO2 Storage Resources Management System*.

Sukor, N. R., Shamsuddin, A. H., Meurah, T., Mahlia, I., & Isa, F. M. (2020). *Techno-Economic Analysis of CO 2 Capture Technologies in O ff shore Natural Gas Field:*

Thailand's 2nd Updated Nationally Determined Contribution. (2022).

Thanh, H. V., Sugai, Y., Nguele, R., & Sasaki, K. (2019). Integrated workflow in 3D geological model construction for evaluation of CO 2 storage capacity of a fractured basement reservoir in Cuu Long Basin, Viet Nam. *International Journal of Greenhouse Gas Control*, *90*(April), 102826. https://doi.org/10.1016/j.ijggc.2019.102826

The ASEAN Secretariat. (2019). *ASEAN-Guidelines-on-Good-Regulatory-Practices-2019-1*. https://asean.org/wp-content/uploads/2021/01/ASEAN-Guidelines-on-Good-Regulatory-Practices-2019-1.pdf

The government of Singapore. (2023). *Singapore Green Plan*. https://www.greenplan.gov.sg/

The White House. (2022). *CEQ Issues New Guidance to Responsibly Develop Carbon Capture, Utilization, and Sequestration*. https://www.whitehouse.gov/ceq/news-updates/2022/02/15/ceq-issues-new-guidance-to-responsibly-develop-carbon-capture-utilization-and-sequestration/

The World Bank Group. (2022). *State and trends of carbon pricing, 2022*. https://openknowledge.worldbank.org/handle/10986/37455

Trading Economics. (2023). EU Carbon Permits. https://tradingeconomics.com/commodity/carbon

UNFCCC Subsidiary Body for Scientific and Technological Advice. (2012). *Transboundary Carbon Capture and Storage project activities - Technical Paper*. http://unfccc.int/parties_observers/ngo/submissions/items/3689.php

United States GDP. (n.d.). Countryeconomy.Com. Retrieved December 12, 2023, from https://countryeconomy.com/gdp/usa?year=2022

US Environmental Protection Agency. (2023). *Class II Oil and Gas Related Injection Wells*. https://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells

US EPA, 40 CFR § 144.3, 75 FR 77287 (2010).

US Federal Register. (2022). *Carbon Capture, Utilization, and Sequestration Guidance*. https://www.federalregister.gov/documents/2022/02/16/2022-03205/carbon-capture-utilization-and-sequestration-guidance

Viet Nam Briefing – Viet Nam's National Energy Master Plan: Key Takeaways. (2023).

World Bank. (2015). *The Indonesia Carbon Capture Storage (CCS) Capacity Building Program*.

World Economic Forum. (2023). *How carbon capture, usage and storage could get us to net zero*. https://www.weforum.org/agenda/2023/08/carbon-capture-usage-and-storage-net-zero/

World Resources Institute. (2008). *CCS Guidelines: Guidelines for Carbon Dioxide Capture, Transport, and Storage*. http://www.wristore.com/.

Appendices

Appendix A

CO_2 Storage Suitability Methodology and Categories

The suitability of basins in Southeast Asia uses publicly available data and the expert opinion of the Institute. Over 70 basins were reviewed using the Institute's storage basin assessment tool. The assessment tool is a quantitative and qualitative criteria-based approach to define a basin's potential to store CO_2. The criteria incorporate best practice guidelines on storage site selection by IEAGHG (IEAGHG, 2000), NETL Best Practice manual (NETL, 2017) and DNV (DNV GL, 2012).

Each basin is assessed using 23 criteria. Broadly, these criteria include:

- Geology – tectonics, basin size, depth, water depth, reservoir-seal potential, depositional environment and geothermal history
- Hydrocarbon maturity and prospectivity – multiple factors, including the hydrocarbon potential, exploration and production history, presence of giant fields (3 TCF), and CO_2-EOR potential
- Storage assessment maturity – scale (region, national basin, formation, site) and the comprehensiveness of the basin's storage assessment published in English-speaking publications
- Storage resource maturity – confidence and comprehensiveness of published English-speaking resource estimates guided by categorisation according to the Storage Resource Management Scheme (Society of Petroleum Engineers (SPE), 2018)
- Storage operation maturity – the scale of CO_2 injection and storage, ranging from test injection to pilot, through to multiple commercial operations
- Subsurface data and transport infrastructure – the density of hydrocarbon wells, platforms, and pipelines
- Accessibility – based on environmental, social and cultural constraints, regulatory frameworks, potential sources conflicts (e.g. potable water), and density of CO_2 sources near the basin.

Based on the criteria and their total score, each basin is categorised as follows:

- Highly-suitable (dark green in maps). These basins have most, if not all, the following factors:
  - Completed multiple detailed assessments of its storage characterisation and resource estimates by multiple parties with consensus on results
  - In most instances, the injectivity and storage of CO_2 have been tested, undertaken (pilot/EOR) or modelled
  - The basin hosts a commercial-scale storage operation or advanced planning

    - The basin is (or has been) a mature and major oil and gas producer
    - The basin is accessible to CO_2 storage operations
- Suitable (light green). These basins meet many properties of a highly suitable basin, but generally:
    - Storage assessments have been more localised on particular parts of the basin
    - Do not host active or completed storage operations (commercial or pilot)
    - CO_2 storage operations may have accessibility issues
- Possible (orange). These basins have the following:
    - Prominent indicators of viable storage geology, such as oil and gas operations suggesting viable reservoirs and seals for CO_2
    - Storage analysis is limited to only broad, regional assessments, generally focusing on the oil and gas fields
    - Can have significant accessibility issues for CO_2 storage operations
- Unlikely (red). These basins generally have either:
    - Obstructing accessibility issues for CO_2 storage operations
    - The geology is currently defined as unsuitable for CO_2 storage, for example, a shallow (<800 m) basin.

Appendix B

Pipeline and Compression Cost Estimate Methodology

Capital Cost Estimating of Compression Facilities:

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

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

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

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

Equation 2 – Capital cost of compression system (US$2005)

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

Where:

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

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

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

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

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

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

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

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

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

Work of compression was calculated using the following assumptions:

- Aftercooling to 50°C after each stage.
- 75% adiabatic efficiency for each compression stage and for pumping.
- 90% drive (motor & gearbox) efficiency (i.e. 90% of energy fed to the motor is transferred to the compressor shaft). This makes electricity consumption 1/0.9 = 1.11 times higher than the compression energy.
- Pressure ratio of each stage is the same
- Aspen HYSYS (by AspenTech) was used to estimate work of compression and pumping for all compression/pumping systems in this report.
- The location, currency and inflation conversions were based on:
- Malaysia location factor: 1.16 (Richardson)
- Japan location factor: 1.25 (Richardson)
- Singapore location factor: 1.16 (Richardson)
- Producer Price Index 2005 USA: 81.3
- Producer Price Index 2022 USA: 131.5

Annualised Capital Costs

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

Operating Cost of Compression Systems

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

Energy Operating Cost

An electricity price of USD70/MWh was assumed for energy. Energy price was estimated by multiplying this price by MWh for the year for each compression system, in turn assuming 24/7/365 operation. In practice this will be a slight overestimate as most compression facilities will have some planned downtime.

Other Operating Costs

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

Capital Cost Estimating of Pipelines

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

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

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

Pipe weights were obtained online for all pipes ('Steel pipes schedule 40 chart: wall thickness and weight' 2020; 'Steel pipes schedule 160 chart: wall thickness and weight' 2020). This enabled steel pipe cost per metre to be estimated for all line sizes.

Surface area was calculated based on outside diameter of each pipe, as obtained from online charts mentioned above. This enabled coating cost to be estimated for all line sizes.

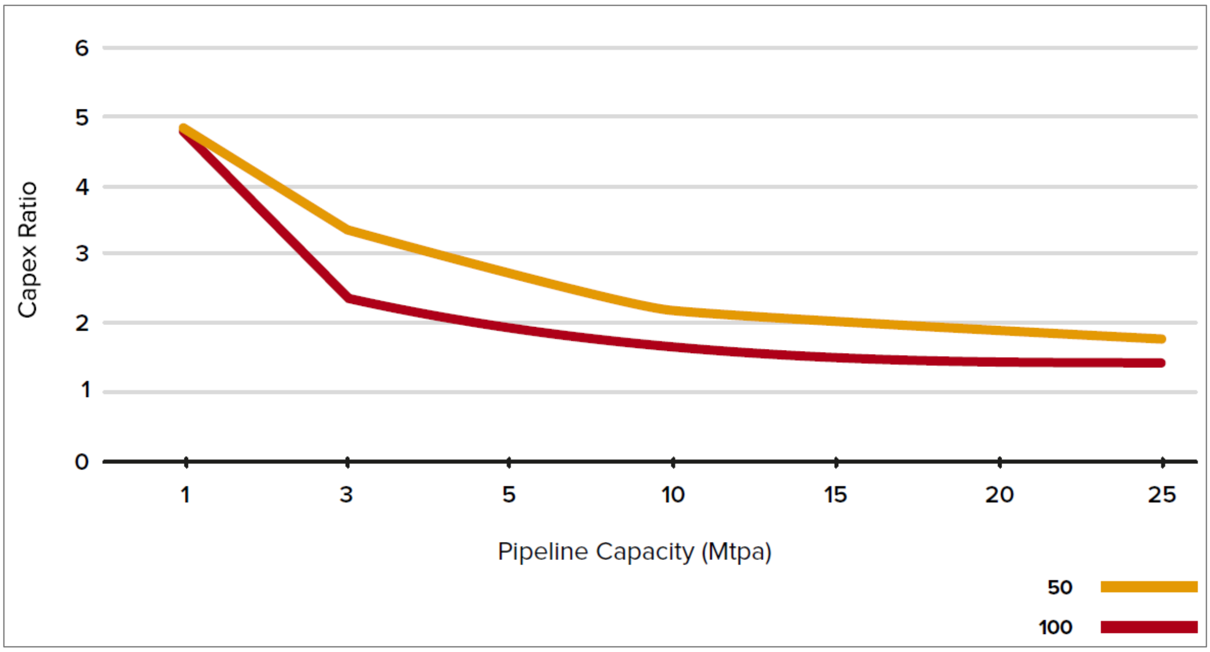
Inch-kilometres are simply nominal pipe sizes in inches (mm size divided by 25) multiplied by pipe length. This enabled construction cost to be estimated.

Other and Contingencies are simple percentages based on the sum of piping, coating and construction costs.

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

One comparative source of data on offshore piping costs is from the Australian Power Generation Technology Report (Gamma Energy Technology, 2015). This report gave pipeline cost estimates for onshore and offshore lines of various flow capacities and lengths. Figure A.1, derived from this report, shows the ratio of offshore to onshore capital costs (per km) for pipelines across a range of capacities. The Yellow line represents a pipe length of 50 km, and the Red line a length of 100 km.

Figure A.1. Offshore to Onshore Capital Cost Ratio for Pipelines.



Source: GCCSI.

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

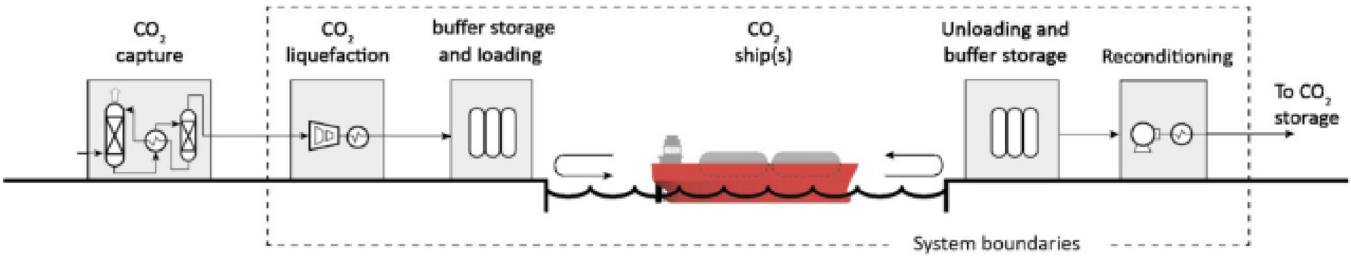
Operating Cost of Pipelines

A straightforward estimate of 1% of capex was used as the annual fixed operations and maintenance (O&M) operating cost for all pipelines in this study (Gamma Energy Technology, 2015, CO2CRC & Gamma Energy Technology, 2015). Pipelines have little or no variable O&M operating costs, so these were taken to be zero.

Shipping Infrastructure Cost Estimate Methodology

The following lists the key assumptions, parameters and methodologies for the techno-economic analysis for the elements of the shipping value chain defined in the system boundaries in Figure A.2.

Figure A.2. Main Components for Shipping Logistics for CCS



Source: Roussanaly et al., 2021.

CO_2 Liquefaction

The CO_2 liquefaction costs for this study are based on costs presented by Roussanaly et al., (2021) The costs assume the base case pure CO_2 conditions and costs for both 15 bar or 7 bar transport pressure for 1 Mtpa CO_2. The liquefaction process modelled is an external closed system using an ammonia refrigeration circuit.

Table A.1. CO_2 Liquefaction Cost Factors

Shipping Transport Pressure (bar abs)	Capex (Million USD)	Specific Energy Consumption (kWh/tCO_2)	Other Opex (USD/tCO_2)
Low Pressure	22.3	104.2	2.22
Medium Pressure	17.3	83.1	1.73

Source: GCCSI.

Capex scaling for CO_2 liquefaction is based on the rule of six tenths. Energy Opex is a function of the electricity price and the specific energy consumption for compression and pumping. Other Opex covers items such as personnel, maintenance, and administration is scaled linearly with the flow required for liquefaction.

CO_2 Storage

The storage costs for this study are based on costs presented by (Roussanaly et al., 2021). Storage costs are scaled linearly with the CO_2 capacity required for storage.

Table A.2. Storage Costs

Shipping Transport Pressure (bar abs)	Capex (USD/tCO_2)
Low Pressure	590
Medium Pressure	909

Source: GCCSI.

CO_2 Loading and Unloading

The investment costs of loading and unloading facilities are scaled linearly from a reference case, assuming a capacity of 3 Mtpa CO_2 for each facility from (Roussanaly et al., 2021). The annual operating cost of these facilities is assumed to represent 2% of investment costs.

Table A.3. Loading and Unloading Cost Factors

Shipping Transport Pressure (bar abs)	Capex (USD/tCO_2)	Annual Opex (USD/tCO_2)
All pressures	1.6	0.05

Source: GCCSI.

CO_2 Shipping Costs

CO_2 shipping at scale for CCS is still a new and emerging means for CO_2 transport. There are a number of sources in literature for costs of concepts for CO_2 shipping, however as no large-scale CO_2 ship has been built to date the costs can only be deemed indicative which is sufficient for a concept or high-level costing study such as this.

CO_2 shipping costs for this study are taken from (Roussanaly et al., 2021) which leverages existing work undertaken in (BEIS, 2018). It is assumed that shipping is limited to 10,000 tonne capacity for medium pressure transport based on the range if ship sizes for medium pressure based in literature. For low pressure transport, ship capacity increases up to 50,000 tonnes.

Table A.4. Ship Cost Factors

Shipping	Capital (Million USD/tCO_2)		Fixed Opex (Million USD/Ship/Year)		Fuel Consumption ($gfuel/tCO_2/km$)
Capacity (tCO_2)	*Low Pressure*	*Medium Pressure*	*Low Pressure*	*Medium Pressure*	*All pressures*
2,500	9	21	0.5	1.06	7.07
5,000	13	30	0.7	1.49	6.97
7,500	20	42	1.0	2.11	6.87
8,000	25	52	1.2	2.58	6.85
10,000	29	59	1.4	2.97	6.77
12,500	32		1.6	3.32	6.67
15,000	37		1.8		6.58
20,000	41		2.0		6.38
25,000	48		2.4		6.18
30,000	54		2.7		5.98
35,000	60		3.0		5.78
40,000	65		3.2		5.59
45,000	70		3.5		5.39
50,000	74		3.7		5.19

Source: GCCSI.

Traditional fuels that are typically used for shipping include marine fuel oil (MFO) and marine gas oil (MGO). The recent International Maritime Organisation's sulphur cap on fuels has seen a shift from traditional MFO to very low sulphur MFO, or VLSFO. However, this does not assist with managing ship CO_2 emissions. More recently LNG has been considered to assist in reducing emissions in shipping (ZEP 2011). LNG has been the assumed ship fuel for this study.

Table A.5. Ship Fuels

Ship Fuel	Cost (USD/tonne)
LNG	202

Source: GCCSI.

CO_2 Conditioning

CO_2 conditioning is a relatively small cost compared to the other elements in the shipping value chain, however it is worth ensuring it is still covered. Conditioning costs are taken from (BEIS 2018) for this study.

Table A.6. Conditioning Cost Factors

Shipping Transport Pressure (bar abs)	Capex (Million USD)	Specific Energy Consumption (kWh/tCO_2)	Other Opex (USD/tCO_2)
Low Pressure	0.9	0.289	0.05
Medium Pressure	0.9	0.271	0.05

Source: GCCSI.

Additional design parameters used in the development of the design and costs for shipping transport of CO_2 are given in Table A.7.

Table 5.7. Design Parameters for Shipping

Design Parameters	
Location	Japan, Singapore and Malayisa
Present Value	2022 US$cost escalated from 2015 EUR cost basis for CO_2 liquefaction, storage, loading/unloading and ship costs 2022 US$cost escalated from 2018 GBP cost basis for conditioning costs
Exchange Rates	0.97 GBP/USD 0.82 EUR/USD
Japan, Singapore, Malaysia: United Kingdom Location Factor Japan, Singapore, Malaysia: Norway Location Factor	0.80 0.80
Cost Recovery Factor (CRF)	8.55% based on a Weighted Average Cost of Capital (WACC) of 7.6%
Operating life	30 years
Capacity factor	90 %
Utility Cost	
Electricity	AUD70/MWh

Source: GCCSI.