Carbon Capture, Utilisation and Storage: The Opportunity in Southeast Asia

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Abstract

Carbon capture, utilisation and storage (CCUS) technologies are set to play an important role in supporting clean energy transitions in Southeast Asia. CCUS can address emissions from the region's existing power and industrial assets while underpinning new economic opportunities associated with the production of low-carbon hydrogen and ammonia. Regional co-operation on the development of CO_2 transport and storage infrastructure can enable faster and more efficient deployment of CCUS. However, heightened efforts are needed to identify and develop the region's CO_2 storage resources, both on- and offshore. Future investment in CCUS in Southeast Asia will depend on the establishment of legal and regulatory frameworks and policy incentives, with an important role for international finance.

Acknowledgements, contributors and credits

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Executive summary

CCUS has vast potential to support clean energy transitions in Southeast Asia

Carbon capture, utilisation and storage (CCUS) can help to put the fast-growing economies of Southeast Asia on the path to net-zero emissions. Since 2000, almost 90% of Southeast Asia's energy demand growth has been met by fossil fuels and the region is home to major coal and liquefied natural gas (LNG) exporters. While the opportunity for CCUS goes beyond fossil fuel applications, the technology can be an important pillar for helping the region transition from its current energy mix to one that is aligned with future climate goals.

CCUS can contribute to emissions reductions in many parts of the region's energy systems. The deployment of CCUS can enable some of the more recently built power plants and industrial facilities in Southeast Asia to continue to operate with substantially reduced emissions, contributing to economic development and energy security objectives. CCUS is one of the few scalable solutions available for decarbonising heavy industries like cement and steel, and its deployment could also unlock new economic opportunities associated with low-carbon hydrogen or ammonia production. CCUS can also play a critical role in reducing emissions along the supply chain for natural gas.

Meeting climate goals will require countries to accelerate the deployment of CCUS technology. In pathways consistent with the Paris Agreement's temperature goals, CCUS would build from a limited base in the region today to 200 million tonnes (Mt) or more of CO_2 capture by 2050. Investment in carbon capture technologies in Southeast Asia would need to reach an average of almost USD 1 billion per year between 2025 and 2030.

Momentum for CCUS is growing in the region. Interest in CCUS in Southeast Asia has been growing in line with international trends. Worldwide, plans for more than 30 commercial CCUS facilities were announced in the first half of 2021 alone. In Southeast Asia, at least seven potential projects have been identified and are in early development – in Indonesia, Malaysia, Singapore and Timor-Leste. Singapore has identified an important role for CCUS in its long-term emissions-reduction strategy and is actively pursuing research and international partnerships, including with Australia. The establishment of the Asia CCUS

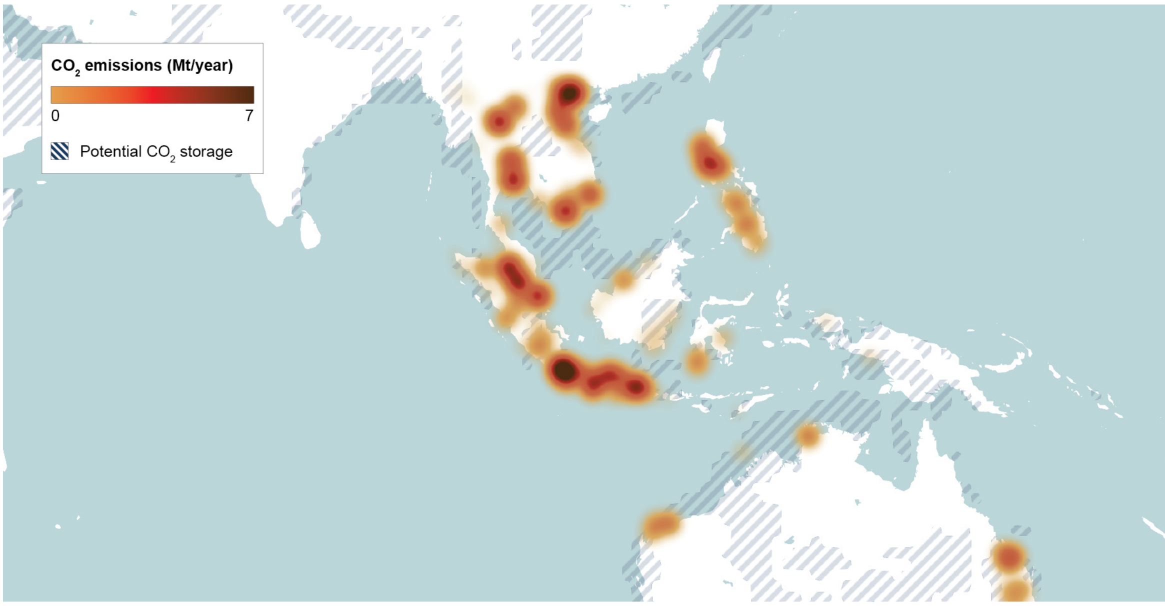
Network in June 2021, with the objective of facilitating collaboration and the deployment of CCUS, is another significant milestone and opportunity to advance CCUS in the region.

Regional co-operation and shared infrastructure can support faster deployment

Targeting industrial clusters will support economies of scale and kick-start deployment CCUS in the region. A hub approach can enable CO_2 capture from multiple industrial and power facilities and promote greater efficiencies in the planning and construction of capital-intensive transport and storage infrastructure. Separating capture from the transport and storage elements of the CCUS supply chain can also facilitate dedicated business models for transport and storage, recognising that the specific skills and expertise needed for large-scale carbon management may not be available in most emissions-intensive sectors. Globally, plans to develop CCUS hubs are progressing in more than 12 locations, with potential to capture more than 50 Mt CO_2 per year. In Southeast Asia, some of the largest industrial clusters can be found in Indonesia, Malaysia, Thailand and Viet Nam.

Regional approaches to CO_2 transport and storage infrastructure can build on international experience. Regional approaches to CO_2 transport and storage infrastructure could enable faster and more widespread uptake of CCUS 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 CCUS investment in locations where storage capacity is either limited or where its development faces delays. Such an approach could incorporate offshore CO_2 storage together with CO_2 shipping, providing additional flexibility and contingency in the CCUS value chain where several storage facilities are available. Efforts to develop shared infrastructure in Southeast Asia could be informed by international experience. For example, the Northern Lights CO_2 transport and storage project in Norway will accept CO_2 from facilities across Europe and has sparked plans for several new CCUS projects.

CO_2 sources and storage potential in Southeast Asia



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Notes: Sedimentary thickness serves as an indicator of the theoretical potential of CO_2 storage sites. The offshore capacity estimates exclude sites in water depths of more than 300 metres and more than 300 kilometres offshore.

Source: Storage assessment based on Kearns et al. (2017).

Efforts to prepare for CCUS must be accelerated

Identifying and developing CO_2 storage resources in Southeast Asia are key to unlocking the potential of CCUS. Estimates of CO_2 storage capacity in the region are highly uncertain but indicate that the theoretical capacity to store CO_2 would likely far exceed the region's needs. Most of this capacity is expected to be in deep saline formations. However, depleted oil and gas reservoirs will also provide large-scale storage opportunities. Significant further investigation will be required to adequately identify and assess the region's CO_2 storage resources, building on studies already undertaken by the Coordinating Committee on Geoscience Programmes (CCOP), the Asian Development Bank (ADB) and others. Given the potentially long lead-times associated with developing CO_2 storage resources, these initial efforts are critical.

Appropriate legal and regulatory frameworks are needed to underpin the safe and effective development of CCUS and to provide certainty for investors. Regulations to facilitate investment in CCUS, in particular CO_2 storage, have yet to be developed in the region, although Indonesia has made significant progress. In some countries, existing oil and gas regulations could serve as a starting point. Existing ISO standards and international examples can also inform the development of CCUS regulations. Key issues to be addressed in the regulations include site selection and permitting requirements, long-term ownership and liability for stored CO_2, property rights (including interactions with other resources) and requirements for financial securities.

Targeted policies and international financial support are essential for CCUS deployment. CCUS faces specific challenges in the early phase of deployment, including the need for co-ordination across multiple sectors and stakeholders, high capital investment requirements, and untested insurance and financial markets. Targeted policies and government leadership will be critical to successful deployment as will support from international finance entities. Increased access to grants and loans from institutions specialised in development and climate finance – such as the ADB and the Green Climate Fund – alongside sustainable debt and transition financing will be essential to secure the almost USD 1 billion in average annual CCUS investment needed by 2030.

Opportunity factors for CCUS in a selection of Southeast Asian countries

	Brunei Darussala	Indonesia	Malaysia	Philippines	Singapore	Thailand	Viet Nam
Domestic CO_2 storage potential	●	●	●			●	●
Potential to use CO_2 for EOR	●	●	●			●	
Legal and regulatory frameworks for CCUS in place	○*	○	○*	○*		○*	○*
Industrial clusters with CO_2 capture prospects	●	●	●	●	●	●	●
Recognition of CCUS in long-term strategies/goals	○	●	●		●		○
Targeted policies to support CCUS investment							
Active pilot or demonstration facilities							
Plans for commercial CCUS facilities		●	●				

Notes: ● = yes, ○ = possibly/partially; * = oil and gas regulations potentially applicable for CO_2 storage.

Strategic priorities for CCUS in Southeast Asia

Four high-level priorities for governments and industry would accelerate the progress of CCUS in the region over the next decade:

1. **Increase regional co-operation and collaboration**, including through the Asia CCUS Network, to identify and develop opportunities for shared infrastructure development and to build CCUS capabilities throughout the region.

2. **Identify and develop onshore and offshore CO_2 storage resources** in parallel with the establishment of robust legal and regulatory frameworks for the safe and secure storage of CO_2. Leverage international programmes to support these efforts, such as the ADB CCUS Trust Fund.

3. **Encourage early investment in CCUS projects**, including pilot demonstrations and industrial hubs, through targeted policies and integrating CCUS into national energy and climate strategies. Recognising a role for CCUS in energy and climate strategies can improve access to international finance.

4. **Build international support and financing for CCUS in the region**, particularly increased access to grants and loans from international development and climate finance institutions. Encourage international capital markets to fund a broader range of clean energy investment opportunities, including CCUS, in Southeast Asia.

Introduction

Carbon capture, utilisation and storage (CCUS) technologies can play important and diverse roles in supporting clean energy transitions in the dynamic and fast-growing region of Southeast Asia. CCUS can be deployed to tackle emissions from the region's existing power and industrial facilities – many of which were only built in the past decade. It can underpin new economic opportunities associated with the production of low-carbon hydrogen and ammonia while substantially reducing emissions from natural gas supply chains. CCUS provides solutions for heavy industry that are cost-competitive, readily scalable and secure, and it can help the region to meet its growing power needs while limiting emissions.

Interest in CCUS is expanding in Southeast Asia and globally. The renewed momentum for CCUS has been driven by strengthened climate commitments from governments and industry, including ambitious net-zero targets. The investment environment for CCUS has also improved: Since early 2020, governments and industry around the world have committed at least USD 12 billion in funding specifically for CCUS projects and programmes. CCUS projects are eligible for a further USD 20 billion in clean energy funding programmes established since early 2020.

The improved investment environment has seen more than 30 new commercial projects announced around the world in the first six months of 2021. Since 2018, a total of almost 60 projects have been announced globally with a potential capture capacity of around 145 million tonnes of carbon dioxide (Mt CO_2) a year. Today, 24 commercial CCUS facilities are in operation with a capture capacity of around 40 Mt CO_2 per year.

In Southeast Asia, at least seven large-scale CCUS projects have been identified and are in early stages of planning, including several linked to natural gas processing with offshore storage. Singapore and Indonesia have established leading CCUS-related research programmes, including the Institut Teknologi Bandung (ITB) Centre of Excellence for CCU and CCS in Indonesia. The November 2020 Association of Southeast Asian Nations (ASEAN) Plan of Action for Energy Cooperation (APAEC) recognises a role for CCUS in the region, particularly to reduce emissions from coal-fired power plants. In June 2021, the Asia CCUS Network was formally established by Japan's Ministry of Economy, Trade and Industry (METI) and the Economic Research Institute for ASEAN and East Asia (ERIA), with a mission to facilitate the deployment of CCUS in the region.

These recent developments can provide a foundation from which to grow CCUS capacity and facilitate widespread deployment of CCUS technologies in Southeast Asia. However, many economies in the region have limited experience and preparedness for CCUS: There are no operating commercial or demonstration projects in the region, for example. In most countries, the required legal and regulatory frameworks for CCUS have not yet been developed, nor have the potential resources for CO_2 storage been fully investigated. New investment incentives, an enhanced role for international finance and greater regional co-operation will be key to supporting CCUS and clean energy transitions in the region.

This report explores the opportunities for CCUS in Southeast Asia and identifies priorities to build CCUS capacity and accelerate its deployment. The countries included in this analysis are the ten member countries of ASEAN: Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic (PDR), Malaysia, Myanmar, Philippines, Singapore, Thailand and Viet Nam. A special case study on Indonesia is presented in the final section.

Recent CCUS developments in Southeast Asia

Government strategies	• **Asia CCUS Network** established to support collaboration and co-operation on the development and deployment of CCUS (June 2021). • **ASEAN** Ministers on Energy Joint Statement reference CCUS as a key technology for addressing emissions from coal (November 2020). • **ASEAN Plan of Action for Energy Cooperation (APAEC)** provides an overarching policy direction for CCUS deployment in the region (November 2020) • **Brunei Darussalam** announces it is investigating the role for CCUS in addressing industrial emissions (November 2020). • **Australia** and **Singapore** sign MoU to advance co-operation on low-emission technologies, including CCUS as a priority solution (October 2020). • **Singapore** recognises important role for CCUS in long-term strategy submitted to the UNFCCC (March 2020)
CCUS projects and investment	• Eni and Santos sign MoU to explore re-purposing the Bayu-Undan offshore gas facilities in **Timor-Leste** as well as broader CCUS opportunities in Darwin, **Australia** (May 2021). • Mitsubishi with JOGMEC, PAU and Bandung Institute of Technology commence a study on a project to produce low-emission ammonia in **Indonesia** (March 2021). • ExxonMobil announces plans for a CCS hub concept, with a plan to capture CO_2 emissions from **Singapore** manufacturing facilities for storage in the region (February 2021).

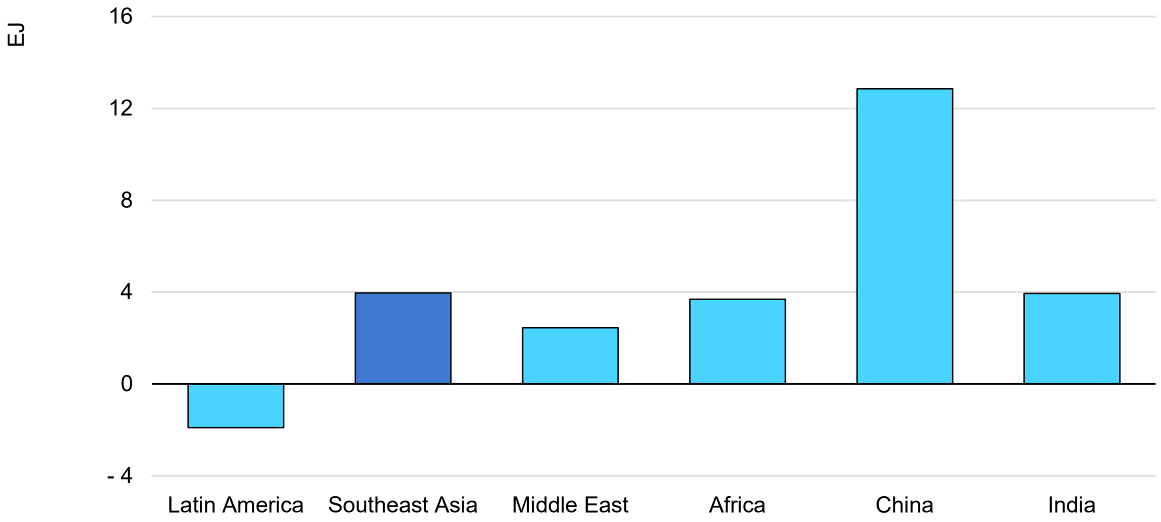
CCUS projects and investment (continue)	• Petronas is deploying CCUS technology at the Kasawari gas facility in **Malaysia**, with first injection into a depleted gas field planned in 2025 (February 2021). The project is aligned with Petronas' ambition to achieve net-zero carbon emissions by 2050, announced in November 2020. • Australian and Japanese energy and shipping companies and research organisations sign MoUs to consider the deepC Store Project, an offshore CCUS hub in **northern Australia** that could store CO_2 from around the region (December 2020). • J-POWER and Japan NUS Co, in co-operation with PT Pertamina are exploring a project to demonstrate CO_2 storage of up to 300 000 t CO_2/year at the Gundih gas field in Central Java, **Indonesia** (September 2020). The project builds on detailed studies conducted between 2012 and 2019. • Repsol SA indicates in 2020 Sustainability Plan for **Indonesia** that they will carry out a study for a large-scale CCUS project in their Sakakemang Block natural gas development in South Sumatra. • Petronas signed a MoU with Japan's JOGMEC and JX Nippon Oil and Gas Exploration in March 2020 to study the development of Malaysia's high-CO_2 content gas fields with CCUS and the possibility of exporting natural-gas based hydrogen to Japan. • Studies are underway for two projects in **Indonesia** related to enhanced gas recovery (EGR) at Sukowati and Tangguh
Research and innovation	• **Indonesia** - ITB National Centre of Excellence for CCU and CCS established in Indonesia in 2017, with support from ADB. • **Singapore** – Established a SGD 49 million (USD 37 million) Low-Carbon Energy Research Funding Initiative for RD&D projects in low-carbon energy technologies such as hydrogen and CCUS (October 2020). • **Singapore** - Keppel Data Centres, Chevron, Pan-United, and Surbana Jurong, with the support of Singapore's National Research Foundation, signed a MoU to develop the first end-to-end decarbonisation process and carbon capture system in Singapore (July 2020).
Financial support	• Japan's **Joint Crediting Mechanism** (JCM) scheme supported a feasibility study for the Gundih CCUS Project and Sukowati Field in Indonesia (2020). There is potential for the proposed CCUS project at the Gundih gas field to access JCM. • **ADB CCS Fund** supported updated feasibility study for Gundih pilot CCS project, including risk assessments and project management plans, as well as the development of CCUS legal and regulatory frameworks in Indonesia (2019). • **2019 Joint Report on Multilateral Development Banks' Climate Finance** confirms CCS (including related to fossil fuel use in power generation and process emissions in other industries) as eligible for classification as climate mitigation finance. • **GIC** (Singapore's sovereign wealth fund) has made a strategic investment in Storegga, an independent United Kingdom company pioneering low emission technologies including the Acorn CCUS project.

The opportunity for CCUS in Southeast Asia

A fast-growing region reliant on fossil fuels

Southeast Asia is one of the fastest growing regions of the world. Growth in energy demand from 2015 to 2019 was second only to that of the People's Republic of China ("China"). With per capita GDP and energy consumption at around 45% below the global averages, energy demand growth is likely to remain strong.

Energy demand growth in Southeast Asia and other selected regions, 2015-19



Energy demand growth in Southeast Asia has been heavily reliant on fossil fuels: 90% of the growth since 2000 has been fuelled by coal, natural gas or oil. Between 2000 and 2019, the use of fossil fuels more than doubled to 23 exajoules (EJ). Fossil fuels account now for around 80% of primary energy demand in the region, up from around two-thirds in 2000. As a result of the fossil-driven energy demand growth, CO_2 emissions increased from 0.7 gigatonnes (Gt) in 2000 to over 1.6 Gt in 2019, or an average annual growth rate of 3.8%. Emissions in Southeast Asia account for some 5% of the global total.

Fossil-fuel production in Southeast Asia has increased markedly since 2000, with coal and gas providing important export revenues for the region's economies. Before the onset of the Covid-19 pandemic, Indonesia was the world's largest exporter of coal; it is now the second-largest after Australia. Meanwhile, Malaysia (7% of global exports), Indonesia (4%) and Brunei Darussalam (2%) are all significant exporters of liquefied natural gas (LNG). However, a growing imbalance between rising demand, combined with stagnant or falling production, is gradually pushing Southeast Asia toward becoming a net importer of fossil fuels (IEA, 2019a).

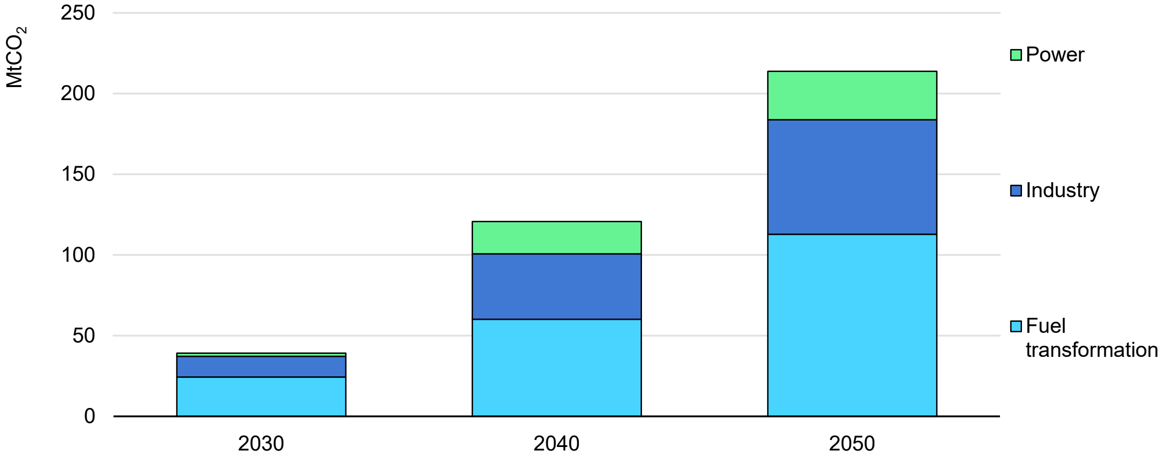
The role of CCUS in net-zero pathways

Reducing global CO_2 emissions to net zero will require a fundamental transformation of how we produce, transport and consume energy. The IEA Net Zero by 2050 Roadmap for the global energy sector highlights the scale of the challenge and the need for immediate and massive deployment of all available clean and efficient energy technologies. The analysis underscores the critical role that CCUS technologies will play in putting the world on a path to net-zero emissions, contributing more than 10% of cumulative emissions reductions globally to 2050. The role for CCUS spans virtually all parts of the global energy system, although to varying degrees – including heavy industry, low-carbon hydrogen production, power generation, carbon removal, and as a source of CO_2 for synthetic fuels.

For CCUS deployment to remain in line with the temperature objectives set out in the 2015 Paris Agreement, CO_2 capture in Southeast Asia will have to reach at least 35 Mt CO_2 in 2030.[1] This includes early and lower-cost retrofit opportunities in industry, capture opportunities in fuel supply sectors, as well as retrofitting of coal power plants. By 2050, CO_2 capture will need to exceed 200 Mt, with CCUS deployed at scale across the fuel transformation, industry and power generation sectors.

[1] Regional CCUS deployment figures are based on the IEA Sustainable Development Scenario, a pathway consistent with reaching net-zero emissions globally by 2070. The Net Zero by 2050 Scenario published in May 2021 suggests that these numbers represent the minimum CCUS deployment needed in Southeast Asia to remain on track to reach more ambitious global net-zero goals by 2050.

CCUS deployment in Southeast Asia in the Sustainable Development Scenario

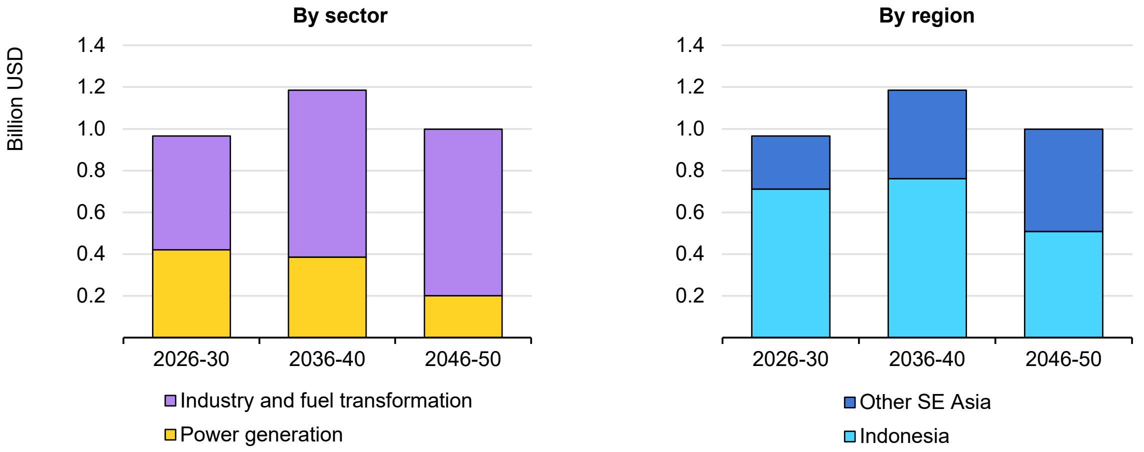


Note: Values shown are from the IEA Sustainable Development Scenario; corresponding CCUS deployment levels are generally higher in the Net Zero 2050 Roadmap.

Achieving this level of CCUS deployment in Southeast Asia will require considerable investment, growing to an average of almost USD 1 billion per year for CO_2 capture facilities by 2030. An increase in CCUS investment of this magnitude needs international support, significant private-sector investment and increased availability of debt finance.

Indonesia accounts for around 80% of Southeast Asia’s projected CCUS investment in 2030, reflecting the size of its economy and the relatively advanced state of CCUS development there. As other countries in the region develop CCUS capacity, Indonesia’s share declines to about 60% of investment in 2040. The share of investment in the power generation sector initially accounts for more than a third of total CO_2 capture investment, but declines over time, as more investment is directed to industrial applications. CCUS comprises less than 1% of Southeast Asia’s total energy-related investment needs, which equates to an average of more than USD 140 billion annually between 2026-30 under the Sustainable Development Scenario.

Average annual CO_2 capture investment by sector and region in the Sustainable Development Scenario



Notes: Values shown are from the Sustainable Development Scenario; investment needs in the Net Zero 2050 Roadmap are higher.

IEA climate-driven scenarios

The Net Zero Emissions by 2050 Scenario (NZE): this is an IEA Scenario that shows what is needed for the global energy sector to achieve net-zero CO2 emissions by 2050, with advanced economies reaching net zero emissions in advance of others. It also contains concrete action to reach energy-related United Nations Sustainable Development Goals (SDGs). The NZE does not rely on action in areas other than the energy sector to achieve net-zero emissions, but with corresponding reductions in emissions from outside the energy sector, it is consistent with limiting the global temperature rise to 1.5 °C without a temperature overshoot (with a 50% probability).

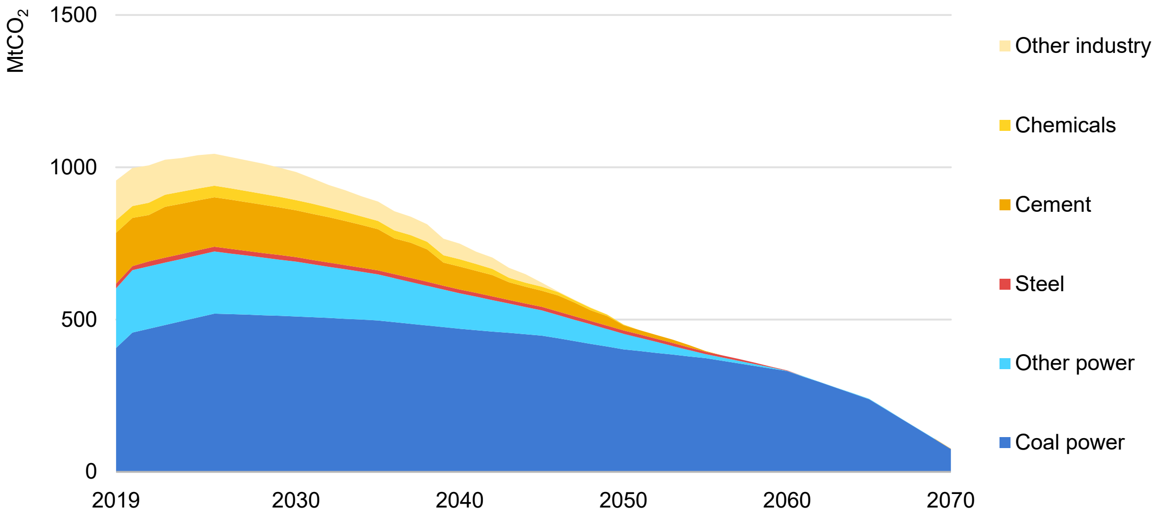
The Sustainable Development Scenario (SDS): the SDS is likewise based on a surge in clean energy policies and investment that puts the energy system on track to achieve key SDGs, including universal energy access by 2030, air quality goals, and reductions in emissions. In this scenario, advanced economies reach net-zero emissions by 2050, China around 2060, and all emerging market and developing economies by 2070 at the latest. This scenario is consistent with limiting the global temperature rise to 1.65 °C (with a 50% probability).

Tackling emissions from existing energy infrastructure

A key opportunity for CCUS in Southeast Asia is to retrofit the region's existing energy infrastructure, which is still relatively new. Nearly half of the region's fleet of predominantly fossil-based power plants was built over the last decade, and there are still more than 20 GW of additional capacity under construction in the region. Industrial facilities in the steel and cement sectors are similarly young. If these facilities were to continue to operate until the end of their technical lives, emissions would amount to more than 33 Gt CO_2 over the next five decades – the equivalent to all energy-sector emissions worldwide in 2019. In the year 2050, close to 500 Mt CO_2 would still be emitted from these facilities.

The bulk of these cumulative emissions from existing infrastructure in Southeast Asia would come from the power sector (25 Gt), given its large share of emissions today and the long service lives of power plants. Around 80% of the potential cumulative emissions from today's power assets are from coal plants. By 2050, annual emissions from existing coal plants and plants under construction would still be around 400 Mt – only marginally below current levels – absent CCUS retrofitting, early retirements or other emission-reduction measures, such as co-firing with biomass, ammonia or hydrogen.

Potential emissions from existing power generation and industrial facilities in Southeast Asia



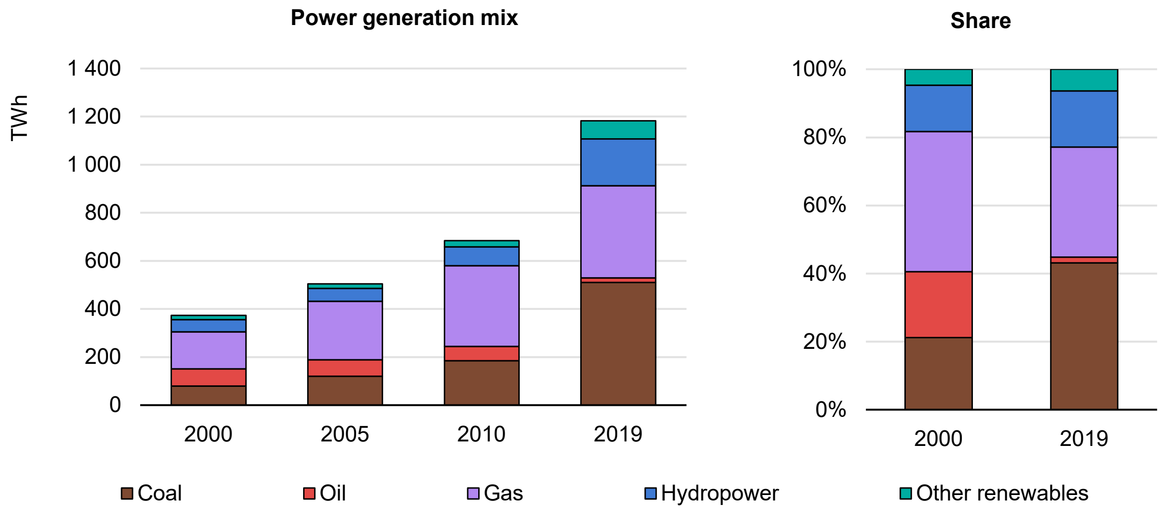
Contributing to stable, zero-emissions power systems

Power sector growth in Southeast Asia has been strong: In terms of electricity demand, Southeast Asia is one of the fastest-growing regions in the world. Driven by the growing ownership of household appliances and air conditioners, as well as increasing consumption of goods and services, demand has grown by an average of more than 6% per year over the past 20 years.

Southeast Asia has a unique geography, with islands, peninsulas and pockets of very densely populated regions separated by uplands and mountainous areas. Despite considerable electrification efforts, access to reliable and affordable energy remains beyond the reach of some remote communities. Consequently, around 37 million people (6% of the region's population) currently lack access to electricity.

Until now, coal and gas have played a central role. In fact, Southeast Asia is one of only a few regions in the world where coal's share in the power mix has increased in recent years – underscoring its exposure to the environmental costs of local air pollution, as well as its rising share in global CO_2 emissions. Spurred on by steadily growing demand and a heavy reliance on fossil fuels, the power sector is the region's largest emitter, accounting for more than 45% of emissions.

Power generation mix in Southeast Asia, 2000-2019



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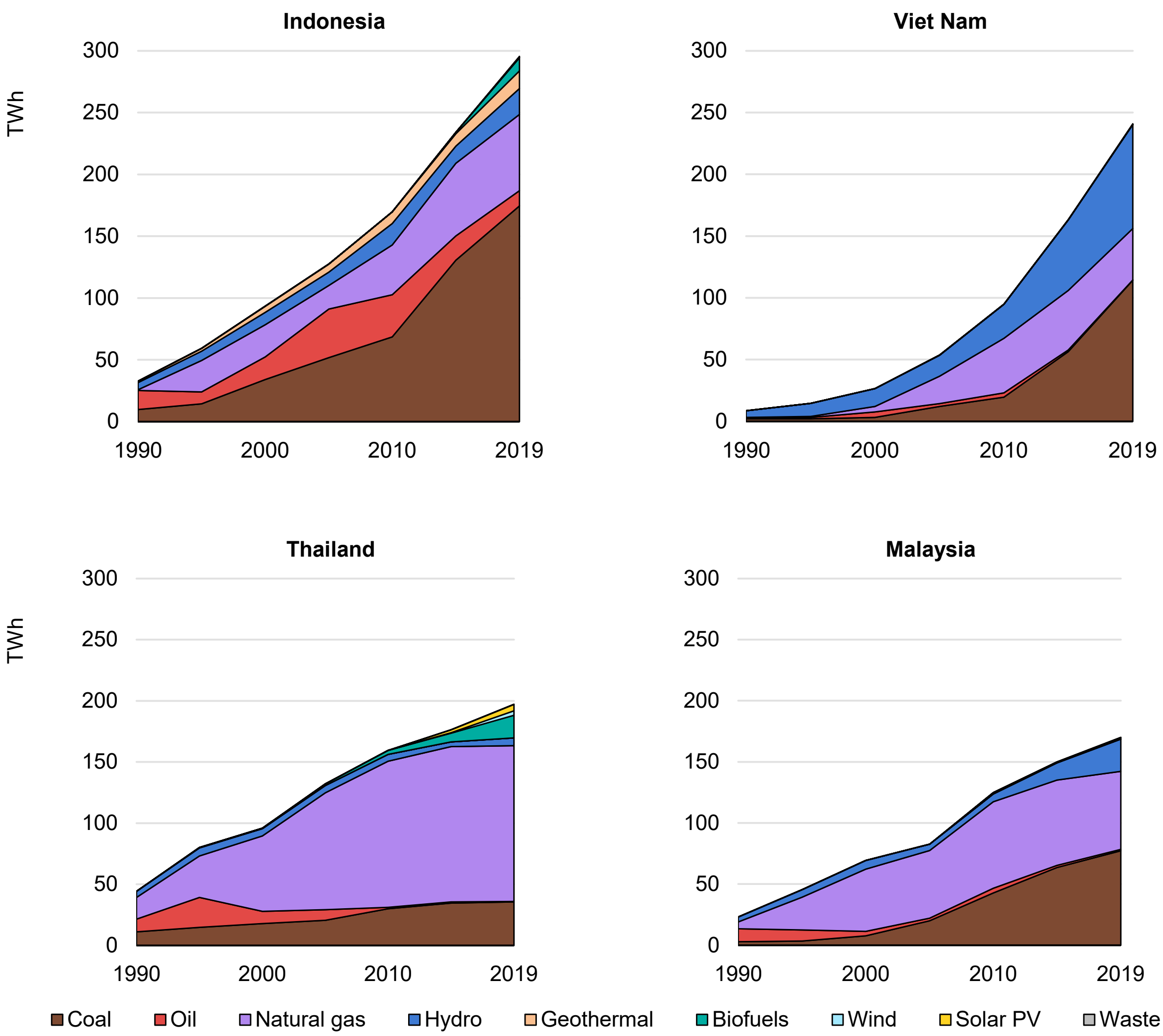
Of the region's ten countries, the four largest by electricity consumption – Indonesia (26%), Viet Nam (22%), Thailand (19%) and Malaysia (15%) – make up more than 80% of total demand. While the mix varies among individual countries, more than three-quarters of the region's power is generated from fossil fuels.

Power generation mix in Indonesia, Viet Nam, Thailand and Malaysia



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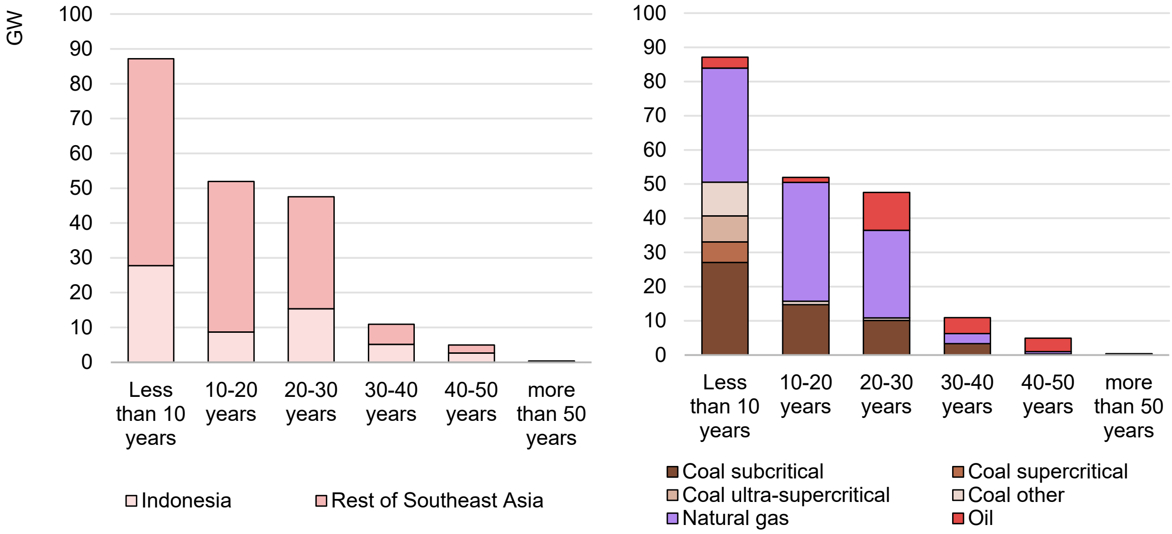
Around 25 GW of new coal-fired generating capacity is currently under construction in Southeast Asia, primarily in Indonesia (a major coal producer), Viet Nam and the Philippines. A significant amount of capacity remains at the pre-construction stage, but some plans are being reconsidered and greater emphasis is being placed on natural gas as well as the expansion of renewables. One example of this is in the Philippines, which at the IEA System Integration of Renewables Ministerial Conference in October 2020, announced a moratorium on the construction of new coal-fired power plants (IEA, 2020a). Indonesia also announced in May 2021 that it would halt approvals for new coal-fired power plants (Argus Media, 2021a).

Age of thermal power plants in Southeast Asia



As a result of recent investments, the fossil-based power plant fleet in Southeast Asia is one of the youngest in the world, averaging some 15 years for coal-fired power plants. CCUS retrofits can enable these plants to continue operating with substantially reduced emissions, allowing owners (often state-owned enterprises) to recoup their investments while still aligning plant operations with national and global climate targets. But each plant must first be assessed to establish its suitability for retrofit, according to a series of criteria. These factors include age, capacity, operating efficiency, availability of on-site space for carbon capture equipment and load factor, as well as the type, location and cost of fuel sources. Attributes such as cooling type and the steam cycle design of coal plants will have a significant impact on the cost of retrofitting (IEA, 2020b).

CCUS-equipped power plants can also enable the integration of growing shares of renewables (IEA, 2020b). Thermal plants are expected to be an important provider of flexibility (to manage both short-term and seasonal variations) to future power systems.

Co-firing biomass, including in combination with CCUS, can reduce the carbon footprint of existing coal or gas-fired power plants. A partial or full conversion to biomass can enable negative emissions when combined with CCUS. This is the ambition of the Drax BECCS plant in the United Kingdom, for example. Yet limits to the availability of sustainable biomass remain and the anticipated growth in bioenergy demand from other sectors, including for transport fuels, could ultimately constrain the potential to co-fire or fully convert existing thermal plants.

Interest in co-firing ammonia or hydrogen in existing thermal power plants is growing in the region, with potential to reduce emissions in the near-term. Possible pathways for low-emission ammonia or hydrogen production are either via renewables or from fossil fuels in combination with CCUS. Japan's roadmap for ammonia fuel estimates that ammonia demand from the Japanese power sector could reach 3 Mt per year by 2030. Japan is actively pursuing projects in Southeast Asia, including a renewables-based ammonia project in Thailand and a CCUS-based project in Indonesia (Argus Media, 2021b) to help to meet their domestic fuel needs. (See also the discussion below on hydrogen production in the region.)

A solution for heavy industry

CCUS provides a solution for one of the most challenging sources of emissions: heavy industry, which accounts for almost 20% of energy-sector emissions in Southeast Asia today.

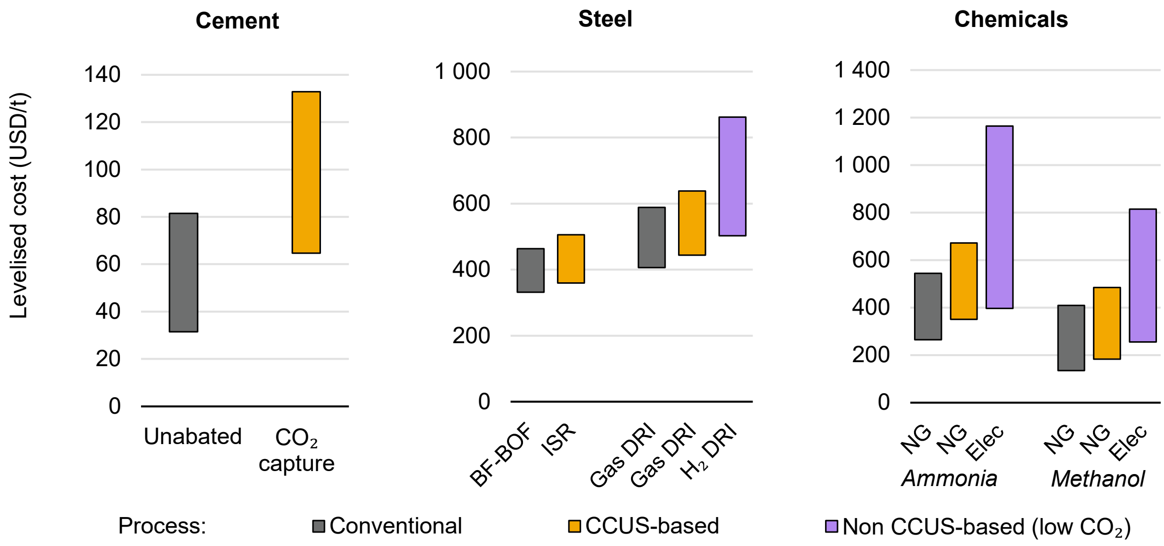
Cement production is the largest contributor of industrial emissions in Southeast Asia. Cement production stands at some 180 Mt per year (4% of global production), with Viet Nam and Indonesia being the world's third and fifth largest producers, respectively. Cement production generates significant process emissions, since it involves heating limestone (calcium carbonate) which breaks down into calcium oxide and CO_2. These process emissions – which are not associated with fossil-fuel use – account for around two-thirds of the emissions associated with cement production. With no demonstrated alternative way of producing cement, capturing and permanently storing these CO_2 emissions via CCUS is effectively the only option available to address them.

CCUS is often the most cost-effective approach to curb emissions from **iron and steel** manufacturing. Steel production amounts to about 40 Mt per year in Southeast Asia, predominantly from production in Viet Nam (20 Mt) and Indonesia (6 Mt). CCUS-based production pathways in the iron and steel sector tend to be at higher levels of technology maturity than hydrogen-based alternatives (IEA, 2020c). Based on expected costs once technologies are commercialised, producing one tonne of steel via CCUS-equipped production routes would be around 10% more expensive than today's main commercial production routes.

The hydrogen-based direct reduced iron (DRI) route for making steel, which also reduces emissions substantially, could emerge as a viable CO_2 mitigation option, although it requires access to very low-cost renewable electricity for hydrogen production via water electrolysis. Compared with CCUS, a hydrogen-based route would be considerably more expensive today. Producing 1 tonne of steel using a hydrogen-based route would increase costs by around 35-70% relative to today's commercial production routes, depending on regional electricity prices.

Similar comparisons hold true for the **chemicals** sector. Electrolytic hydrogen as a feedstock for ammonia and methanol production could become a viable CO_2 mitigation option for the chemical sector. But in most regions, this approach is more expensive than applying CCUS to existing or new plants, based on expected costs once commercialised. The cost of CCUS-equipped ammonia and methanol production is typically around 20-40% higher than for their unabated counterparts, while the cost of electrolytic hydrogen routes is today between 50-115% higher (IEA, 2020e).

Cost of CCUS compared to other decarbonisation options in heavy industry once they reach commercialisation



Notes: BF-BOF = blast furnace basic oxygen furnace; ISR = innovative smelting reduction; Gas DRI = natural gas-based direct reduced iron/electric arc furnace (EAF) route; H2 DRI = 100% electrolytic hydrogen-based; NG = natural gas; Elec = electrolytic; Indicative cost ranges are based on the technical and economic methodology and data in Chapter 4 of IEA's ETP2020, which reflects varying energy prices and technological uncertainty, and reflects expected costs for technologies once they reach commercialisation. In the SDS, for cement, the modern CO_2 capture methods become is expected to be commercially available in the mid-2020s; for steel, BF-BOF, Gas DRI, CCUS-based Gas DRI are commercial, while commercial scale is expected for ISR in 2028 and 100% H_2 DRI in 2035; for chemicals, CCUS NG routes are commercial for ammonia and methanol production, and at the pilot stage for other key chemical products, while electrolytic H2 routes for ammonia and methanol are expected to reach commercial scale in a few years. See the ETP 2020 Special Report on CCUS for additional figure notes.

Reducing emissions across the natural gas supply chain

Natural gas production in Southeast Asia amounts to around 200 billion cubic metres (bcm) or 5% of global production. Emissions related to gas production and processing in the region are estimated to be about 30 Mt CO_2. Indonesia, Malaysia and Brunei are important gas producers, operating six liquefaction facilities for LNG and together accounting for 13% of global LNG exports. In addition, Australia, the world's largest LNG exporter in 2020, operates ten facilities. Given the important role of gas production and exports in the region, and the continued use of natural gas across the energy system over the next decades, it is important to lower emissions from natural gas along the entire supply chain.

Natural gas deposits can contain CO_2 that, for technical and commercial reasons, must be removed before the gas is sold or processed for LNG. In most cases, the separated CO_2 is vented to the atmosphere – but an alternative is to reinject the CO_2 into geological formations. Globally, around 27 Mt CO_2 (two-thirds of operating CCUS capacity) are captured each year from 11 natural gas processing facilities, with the CO_2 either being injected for dedicated geological storage, or used for enhanced oil recovery (EOR).

Southeast Asia is home to gas fields with very high CO_2 content. For example, the K5 offshore gas field in Malaysia has a 70% CO_2 content and other (undeveloped) fields in Indonesia and Brunei have a CO_2 content exceeding 80% (APEC, 2020). Typically, the high CO_2 content of these fields presents technical, economic or environmental barriers to their development. However, Petronas is currently investigating the potential to develop the K5 field with CCUS, reflecting growing domestic demand for gas amid declining production that could see Malaysia shift from being a net exporter to a net importer of gas (IEA, 2019). Also in Malaysia, Petronas has announced that it will deploy CCUS at its Kasawari offshore gas development, with its first CO_2 injection planned for 2025 (Upstream, 2020; Energy Voice, 2021a).

The Spanish oil and gas company Repsol SA indicated in its 2020 Sustainability Plan for Indonesia that it would carry out a study to support the development of a large-scale CCUS project in their Sakakemang Block natural gas reserve in South Sumatra (Repsol SA, 2020). The Plan indicates that they are studying the potential to store the CO_2 generated by natural gas processing in this region. Recent reporting on the project indicates that the proposed facility could have the capacity to capture some 2 Mt CO_2 per year starting in 2026 (Insider Stories, 2021).

Though outside of the Southeast Asian region, developments in northern Australia could provide a case study for CCUS deployment associated with LNG facilities. Planned LNG developments in northern Australia are increasingly looking to deploy CCUS to address CO_2 emissions. For example, Woodside announced in 2020 that it would add a CCUS facility at the Browse gas project from the commencement of operation (The Chemical Engineer, 2020). The project is targeting Front-End Engineering Design (FEED) in 2023. The Browse project's gas reservoir contains between 7-12% CO_2 and would account for an average of 2.3-2.6 Mt CO_2 emissions per year (The West Australian, 2018; Woodside, 2019). Inpex's Ichthys LNG project is likewise exploring the feasibility of CCUS, with a CO_2 content of 8% in the project's reservoir gas, which would account for an average 2.4 Mt CO_2 emissions per year (Inpex, 2011).

Today the Gorgon CO_2 injection project in Western Australia – associated with the Gorgon LNG facility on Barrow Island – is the world's largest dedicated CO_2 storage project. Gorgon's reservoir gas has CO_2 content of up to 14% and a regulatory condition for the LNG facility was that some of this reservoir CO_2 would be permanently stored. The Gorgon facility started CCUS operations in August 2019 and will capture up to 4 Mt CO_2 per year from the raw natural gas stream, which is around 40% of the facility's emissions.

A further opportunity to reduce CO_2 emissions in the LNG supply chain arises from natural gas combustion in the gas turbines that drive the compressors needed for the refrigeration of LNG.[2] This can be either via direct mechanical drive of the compressors, or by generating electricity for electric motors. Application of CCUS to this part of the value chain can substantially reduce the carbon footprint of the supplied LNG. To date, no LNG facilities anywhere in the world have attempted to reduce emissions in this way, although there are now advanced plans in the United States at the Rio-Grande LNG project.

Supporting new opportunities for low-carbon hydrogen production

Hydrogen will play an important role in clean energy transitions globally as a versatile and emissions-free energy carrier. It can be used to address various energy challenges, including helping to store the variable output from renewables like solar photovoltaic (PV) and wind to better match demand. It offers ways to

[2] Use of renewable energy as the source of electricity is also possible for this part of the LNG value chain, but this has only been pursued in a small number of projects (such as the Snøhvit LNG facility in Norway).

decarbonise a range of sectors, including long-haul transport, chemicals, and iron and steel. It can also help to improve air quality and strengthen energy security (IEA, 2019b).

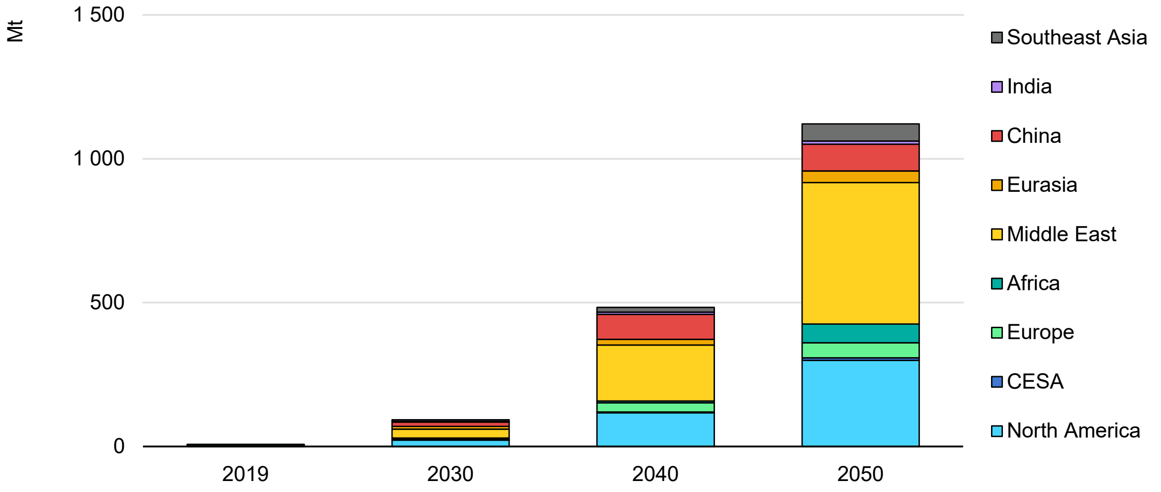
Global demand for hydrogen grows from around 75 MtH_2/year today to more than 500 MtH_2/year in 2050 in a net-zero compatible pathway. In Southeast Asia, the primary use of hydrogen today is in fertiliser production and oil refining, but demand is expected to expand and diversify in the future.

Virtually all hydrogen produced today is from fossil fuels – mainly natural gas and, to a lesser extent, coal – and this process is highly emissions-intensive. Future hydrogen demand can be met through alternative zero- or low-emission production pathways. The leading options are to apply CCUS to fossil-based production (including retrofitting CCUS to existing facilities) or to use renewable energy for water electrolysis. Today the cost of CCUS-equipped hydrogen production can be less than half the cost of electrolytic hydrogen in regions with access to low-cost fossil resources and CO_2 storage, although the cost of electrolytic hydrogen production is expected to fall significantly.

Capturing CO_2 from hydrogen production is a relatively low-cost CCUS application, due to the high concentration of CO_2. Hydrogen production facilities are also often located in ports or industrial zones, where shared CO_2 transport and storage infrastructure could be developed. In Southeast Asia, a significant share of hydrogen demand is met by fossil-based production equipped with CCUS in a net-zero pathway, reflecting the opportunity to use the region's coal and gas resources in a low-emission way. More than 60 Mt CO_2 are projected to be captured from hydrogen production in the region in 2050 in the Sustainable Development Scenario.

Plans for CCUS-equipped hydrogen production facilities are beginning to emerge in Southeast Asia, including a USD 100 million pilot project under construction in Brunei Darussalam that will produce 210 tonnes of hydrogen from natural gas for shipping to Japan for power sector use (Argus Media, 2017). Japan is also supporting the development of supply chains for CCUS-equipped hydrogen production in Australia, including through the AUD 500 million (USD 390 million) Hydrogen Energy Supply Chain (HESC) project in Victoria, During the pilot phase, HESC will use coal to produce between 1-3 tonnes of hydrogen for liquefaction and shipping to Japan, with plans to add CCUS if the project moves to commercial-scale operations. In November 2020, Malaysia's Petronas established a new business unit for hydrogen, with plans to scale up production of both CCUS-equipped and electrolytic hydrogen (IHS Markit, 2021). Petronas also signed a memorandum of understanding with Japan's JOGMEC and JX Nippon Oil and Gas Exploration in March 2020, to study the development of Malaysia's high-CO_2 content gas fields with CCUS and the possibility of exporting natural-gas based hydrogen to Japan (JOGMEC, 2019).

CO_2 capture at hydrogen production by region in the Sustainable Development Scenario



Note: CESA = Central and South America.

CCUS can also play an important role in low-carbon ammonia production in the region. Japan's JOGMEC and Mitsubishi Corporation, together with Indonesia's ITB and PT Panca Amara Utama (PAU), have agreed to conduct a joint study on carbon capture and storage and CO_2 utilisation for clean-fuel ammonia production in Central Sulawesi, Indonesia (Mitsubishi Corporation, 2021).

CO_2 use or carbon recycling opportunities in Southeast Asia

The use of CO_2 for industrial purposes can provide a potential revenue stream for CCUS facilities. Until now, the vast majority of CCUS projects have relied on revenue from the sale of CO_2 to oil companies for enhanced oil recovery (CO_2-EOR), but there are many other potential uses of the CO_2, including as a feedstock to produce synthetic fuels, chemicals and building materials.

CO_2 use, or carbon recycling, can support climate goals where the application is scalable, uses low-carbon energy and displaces a product with higher life-cycle emissions. Some CO_2-derived products also involve permanent carbon retention, in particular building materials (IEA, 2019c).

Using CO_2 in building materials is less energy-intensive than some other CO_2 use applications and early commercial opportunities to use CO_2 to cure concrete or in the production of aggregates are already being realised – in some cases demonstrating improved cost and product performance relative to conventional production. Singapore is actively exploring the opportunity to use CO_2 in concrete manufacturing in a partnership between CarbonCure of Canada and Pan-United Corporation Ltd, a Singapore concrete innovator.

Using CO_2 for synthetic fuels – which require CO_2 and hydrogen – is another strategically important opportunity for CO_2 use. Synthetic fuels are one of a limited number of low-carbon options for long-distance transport, particularly aviation. The National University of Singapore and Shell have established a SGD 4.6 million (USD 3.5 million) research programme which aims to sustainably convert CO_2 into cleaner fuels and useful chemicals and A*STAR's Institute of Chemical and Engineering Sciences (ICES) has had a successful research collaboration with IHI on methanation of CO_2 (Carbon Capture Journal, 2021; A*STAR, 2019).

CO_2-EOR

Using CO_2 for EOR is a well-established technology that has been applied since the 1970s, primarily in the United States. The technology involves the injection of CO_2 into oilfields to enhance production. This increases the overall reservoir pressures and improves the mobility of the oil, resulting in a higher flow of oil towards the production wells.

Over the life of a CO_2-EOR project, it is estimated that 99% of the injected CO_2 is stored. During the CO_2-EOR operations, when the CO_2 is injected, a portion will remain in the reservoir while some will return to the surface with the oil. This CO_2 is typically separated and reinjected. Adapting conventional CO_2-EOR practices can enhance the potential climate benefits, particularly through maximising the amount of injected CO_2 (a "CO_2-EOR+" approach) (IEA, 2015).

CO_2-EOR practices can be modified to provide confidence and assurance for long-term CO_2 storage. The IEA has proposed that extending EOR to qualify as CO_2 storage can be achieved through a minimum of four main activities: *i*) additional site characterisation and risk assessment to evaluate the storage capability of a site; *ii*) additional monitoring of vented and fugitive emissions; *iii*) additional subsurface monitoring; and *iv*) changes to field abandonment practices.

CO_2-EOR and Enhanced Gas Recovery (EGR) can be an important pathway to commercialise CCUS in Southeast Asia, with opportunities already being explored. Studies underway in Indonesia include the Gundih project, with plans to start operation in 2024 (see box below), the Sukowati CO_2-EOR project that could reach pre-FEED status in 2021, and the Tangguh project that is undergoing feasibility studies. Interest in EOR applications is rapidly picking up in the major oil and gas producing countries in the region due to declining production from existing fields.

Despite the potential commercial and technical opportunity for CO_2-EOR and associated CO_2 storage in the region, CCUS projects linked to CO_2-EOR may be excluded from accessing international development or climate finance. For example, the ADB indicated in a 2021 consultation paper that it would not finance CCUS in the context of EOR, while acknowledging the importance of CCUS for power and industry.

Technology-based approaches to carbon removal

Carbon removal can play an important role in meeting the region's climate goals by balancing or offsetting emissions in sectors that are technologically challenging or prohibitively expensive to abate. The most mature technology-based approaches to carbon removal are underpinned by CCUS, namely bioenergy with CCS (BECCS) and Direct Air Capture (DAC) with CO_2 storage. These solutions can complement and enhance nature-based carbon removal solutions (such as afforestation and reforestation).

Biomass-based power generation in Southeast Asia amounted to nearly 35 terawatt-hours (2% of overall power generation; more than 50% in Thailand) in 2019. Equipping these plants with carbon capture could support negative emissions and help to offset emissions in other sectors. Bioenergy demand from industry amounts to 1 EJ (25% of overall bioenergy use in Southeast Asia), across a diverse set of industrial subsectors. Direct application of CCUS in some of these sectors, like pulp and paper, may prove to be cost-prohibitive. But if bioenergy use could be shifted across sectors, e.g. via the introduction of alternative bioenergy-based fuels, this could support carbon removal without raising bioenergy demand. The potential negative effects of reliance on bioenergy-based carbon removal approaches – including land use changes, food security and biodiversity losses – will need to be carefully evaluated in the Southeast Asian context.

There are no DAC plants currently operating in Southeast Asia, but global momentum for the technology is growing. DAC has the smallest land footprint among the most mature carbon removal options and offers flexibility in siting: DAC can be located close to CO_2 storage resources as well as renewable energy or other low-carbon energy sources, for example. The availability of geothermal power in the Southeast Asia region represents an excellent opportunity for powering DAC technology alongside electricity production. This approach is already being demonstrated in Iceland, where Climeworks and CarbFix are currently capturing 50 t CO_2 per year from the atmosphere and blending it with CO_2 captured from geothermal fluids for injection and underground storage in basalt rock formations. The project's proponents plan to expand capture capacity to as much as 4 000 t CO_2 per year by the end of 2021 (Climeworks, 2021). Similar applications could be explored in places like Indonesia, leveraging the country's leading role for geothermal energy as well as its existing collaborations with Iceland (Think Geoenergy, 2020).

Regional approaches to deployment: CCUS hubs and shared infrastructure

Regional approaches to CCUS deployment, including targeting industrial hubs with shared CO_2 transport and storage infrastructure, could support economies of scale and accelerated uptake of CCUS in Southeast Asia. With parallels to the approach currently being adopted in Europe, development of shared offshore storage could underpin a regional solution for countries that have limited onshore CO_2 storage potential.

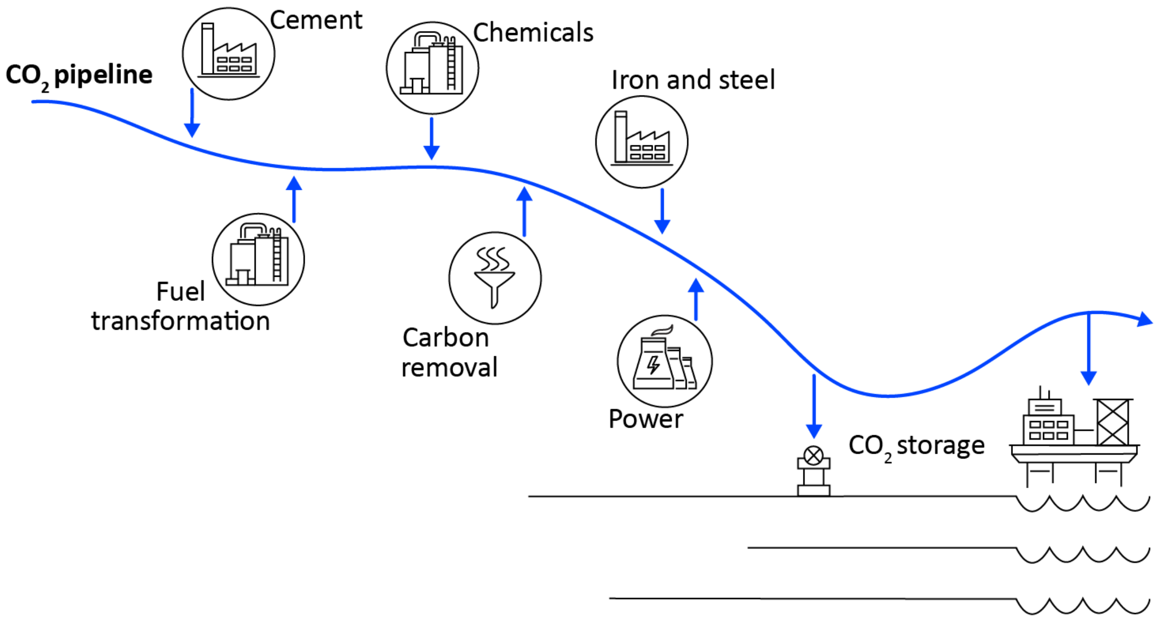
The benefits of targeting industrial CCUS hubs

In at least 12 locations around the world, efforts to develop CCUS hubs – that is, industrial centres with shared CO_2 transport and storage infrastructure – have begun. These hubs have an initial CO_2 capture capacity of around 25 Mt per year, but this could be expanded to more than 50 Mt per year.

The principal benefit of a hub approach is the potential for economies of scale to reduce unit costs for CO_2 transport and storage, including through greater efficiencies and reduced duplication in the planning and construction of CCUS infrastructure. Further, separating the capture, transport and storage elements of the CCUS value-chain can help to reduce commercial risks and financing costs.

Developing CCUS hubs with shared infrastructure can make it feasible to capture CO_2 at smaller industrial facilities, including cement plants, for which dedicated CO_2 transport and storage infrastructure may be impractical or uneconomical. Further, it can allow continued operation of existing infrastructure and supply chains in industrial regions, maintaining employment while still meeting emissions reduction targets. This approach also makes it easier to attract new investment, including in energy-intensive industries or low-carbon hydrogen or ammonia production.

Illustrative example of a shared CO_2 pipeline in an industrial cluster



Identifying CCUS hubs in Southeast Asia

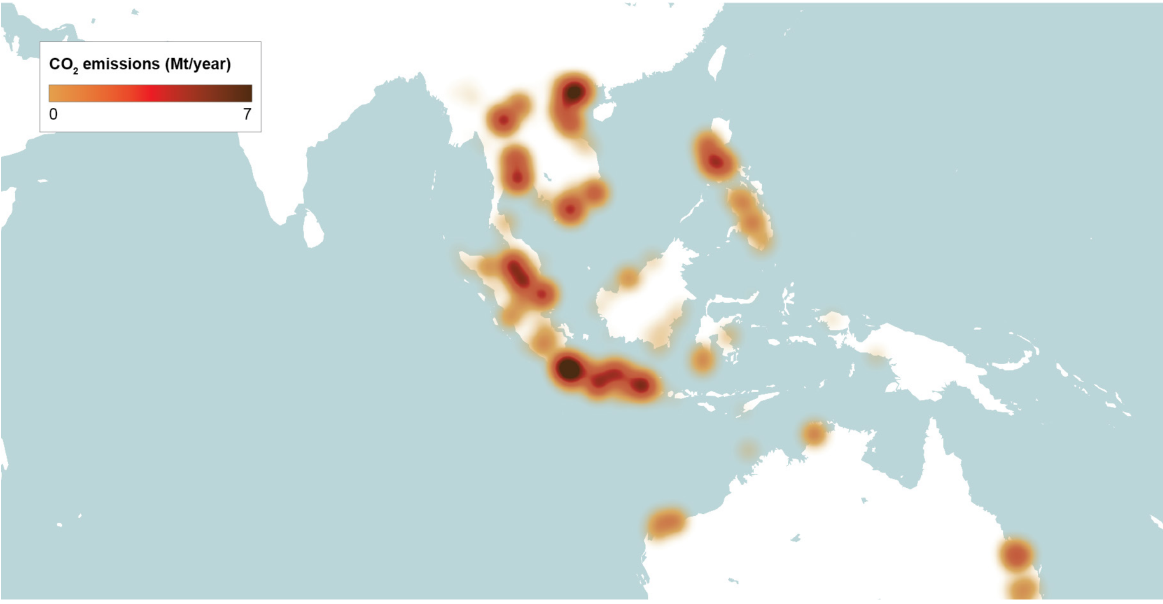
The IEA has mapped emissions from power and industrial facilities in Southeast Asia to identify key centres of industrial activity with high emissions. This detailed geospatial analysis reveals important emission clusters on Indonesia's main island of Java, as well as several industrial centres along the coast of Viet Nam, and on Luzon, the main island of the Philippines.

Emission sources in Indonesia are concentrated on Java, which is a densely populated and industrialised island. More than half of Indonesia's thermal-power plant fleet is installed on Java. There are many old gas fields and deep saline aquifers in the vicinity of the island, and the CO_2 storage potential is high. In addition to Java, there are large emission sites on Kalimantan Island and Sumatra Island. Indonesia could play a leading role for CCUS deployment in the region and is already exploring opportunities to advance CCUS technology across a broad range of sectors (power, industry, upstream oil and gas) and fuels (coal, biomass, oil). Indonesia has also undertaken detailed studies on the potential for CO_2-EOR at the Gundih gas field in central Java (see focus chapter below).

In the Philippines, the main emitters are concentrated near the capital, Manila. The potential for early large-scale CCUS projects outside Manila may be limited due to a lack of concentrated emission sources. In Viet Nam, many industrial emitters – including cement and steel manufacturing – are concentrated in the north. But assessments of CO_2 storage capacity in that area have been limited thus far. In Thailand, most industrial activity and emissions are concentrated around Bangkok, opening the potential for a CCUS capture cluster. Notably, many of the industrial clusters in Southeast Asia are located near the coast, opening the potential for offshore CO_2 storage.

The prospect of future offshore gas developments in Malaysia, Indonesia and northern Australia could also form the basis of new CCUS hubs involving both capture and CO_2 storage development.

CO_2 sources in Southeast Asia



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This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

The potential for regional CO_2 transport and storage

In addition to local CO_2 storage solutions, regional approaches to CO_2 transport and storage infrastructure could enable faster and widespread uptake of CCUS 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 CCUS investment in locations where storage capacity is either limited or where its development faces delays.

Regional approaches to CCUS deployment are currently being pursued in Europe. The Northern Lights project – a major CO_2 storage development in the North Sea

– will have capacity to store 1.5 Mt CO_2 per year beginning in 2024, when it starts operations, with plans to scale up to 5 Mt CO_2 per year as demand increases. The project is being developed by a consortium of Equinor, Shell and Total, with the support of the Norwegian Government, and has flexibility to accept CO_2 from industrial facilities across Europe. To date, the project has signed multiple MoUs with industrial companies that would have a combined CO_2 volume profile of more than 6 Mt CO_2 by 2030. Confidence in the availability of a CO_2 storage solution has contributed to a significant boost in CO_2 capture plans in Europe, with at least 9 capture projects now linked to the Northern Lights project. Several of the companies involved in these projects are also operating in Southeast Asia and could apply their CCUS technologies, expertise and experience to the region.

In northern Australia, the potential for shared offshore CO_2 storage is being considered by Transborders Energy in partnership with Australian and Japanese companies and researchers. The deepC Store project aims to store at least 1.5 Mt CO_2 per year with shipping of CO_2 from industrial facilities in Australia and the Asia-Pacific region to the injection site, with potential for expansion (Transborders Energy, 2021). The collaboration includes investors in LNG projects in the region, including Kyushu Electric Power, Osaka Gas, and Tokyo Gas Australia. It also includes Mitsui O.S.K Lines, a major shipping company.

Santos and Eni have signed a MoU to co-operate on opportunities in northern Australia and Timor-Leste. The areas of co-operation include assessing the potential to share infrastructure and the creation of a storage hub (Santos, 2021). CCUS deployment at Petronas Kasawari development is part of a greater strategic plan for CCUS across depleted gas fields in Malaysia (Energy Voice, 2021a).

Regional CO_2 storage solutions could be of particular benefit to Singapore, which has no known geological storage resources and an industrial sector that accounts for 46% of the country's emissions. In its Long-Term Low-Emission Development Strategy (LEDS) submitted to the UNFCCC, Singapore identified significant potential for CCUS to contribute to emissions reductions and highlighted the need for partnerships with companies and countries for CO_2 storage opportunities.

Regional approaches to CO_2 infrastructure in Southeast Asia would likely incorporate CO_2 transport by ship, which can be a lower-cost option for longer distances and smaller quantities of CO_2. Shipping CO_2 also offers greater flexibility and contingency in the CCUS value chain, particularly where there are numerous storage facilities able to accept shipped CO_2. In Europe, projects including Northern Lights in Norway, the Coda Terminal in Iceland and the Antwerp@C hub in Belgium will rely on shipping as a means of CO_2 transport.

Legal considerations for regional infrastructure: the London Protocol

A major international legal hurdle to the development of regional CO_2 transport infrastructure was removed in 2019, when the Parties to the London Protocol – part of the International Maritime Organization (IMO) London Convention, an international agreement on preventing marine pollution – approved a resolution to establish conditions allowing countries to export and receive CO_2 for offshore geological storage.

The London Protocol effectively prohibits the transport of CO_2 across national boundaries for the purposes of sub-seabed storage. The Protocol was amended in 2009 to remove this barrier, but for the amendment to come into force, it must be ratified by two-thirds of the Parties. There has been little progress in reaching this threshold. In October 2019, Norway and the Netherlands, with the endorsement of the United Kingdom, secured the IMO's approval of an interim solution in the form of a Resolution for Provisional Application of the 2009 CCS Export Amendment. The resolution highlights the role of CCUS technology to reduce atmospheric concentrations of CO_2 and provides for its provisional adoption in the absence of full ratification (IEAGHG, 2021). With the support of several countries, the proposal was accepted (IMO, 2019a).

The conditional approach to developing shared offshore storage outlined by the Resolution for Provisional Application and in the 2009 Export Amendment require the use of bilateral (or multilateral) agreements or arrangements, in which countries must deposit formal declarations to the IMO. Agreements must declare to meet the same environmental conditions related to CO_2 composition and CO_2 storage as in the 2006 CO_2 Amendment (guidance documents outlining conditions for sending and receiving parties were revised/finalised in IMO (2012, 2013).

In Southeast Asia, most countries are not Contracting Parties to the London Protocol/London Convention (notable exceptions being the Philippines and Papua New Guinea) (IMO, 2019b; UN, 2021). Australia is also a Contracting Party. Contracting status can give rise to four specific cases of maritime CO_2 export that may be relevant to project developers in the region, based on the status of the country of origin and/or destination of CO_2 captured for cross-border maritime transport. The 2009 Amendment provides some clarity regarding these cases, and the resolution allowing provisional application is not intended to limit the application of the 2009 Amendment.

Cross-border maritime CO_2 transport under the 2009 Amendment and 2019 Resolution for Provisional Application of the London Protocol

		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).

For States that are not Parties to the London Protocol, the United Nations Convention on the Law of the Sea (UNCLOS) establishes an overarching framework for the governance, management and protection of the world's oceans and the marine environment, including the seabed and subsoil. Articles 205 and 206 of UNCLOS set out the basic obligations of parties to UNCLOS to monitor activities and undertake environmental impact assessment of activities (UNFCCC, 2012). Although the provisions are somewhat general, it is arguable that there is an obligation on parties to UNCLOS to consider the environmental impacts of CCS project activities on the marine environment, and the provisions of and application of the London Protocol would be regarded as the best practice in doing so.

CO_2 storage capacity in Southeast Asia

As in many parts of the world, estimates of CO_2 storage capacity in Southeast Asia are highly uncertain. Based on methodology applied by Kearns and others, some 170 Gt of potential storage capacity is estimated to be available in the region. It should be noted that only a fraction will ever be economically and technically viable. But in a net zero-compatible pathway, storage capacity still likely exceeds storage needs by an order of magnitude.

Most of the storage in Southeast Asia is expected to be in saline aquifers, but depleted oil and gas fields can also provide important storage opportunities. As mentioned above, oil and gas production in the region has been declining for years and CO_2-EOR and EGR are being explored – notably in Indonesia – as a way to increase production from existing sites while reducing emissions.

Despite work by the ADB and others, there is still limited information on the storage capacity in individual countries in Southeast Asia. In its 2013 CCUS report, the ADB has established estimates on CO_2 storage for Viet Nam, Indonesia (South Sumatra), Thailand and the Philippines. The ADB estimates storage capacity in saline aquifers amounts to some 50 Gt. METI similarly conducted a study on storage potential and assessed the potential for its utilisation in Indonesia, Thailand, and Viet Nam based on existing information. Further, Indonesia and Malaysia have been included in the 2021 update of the CO_2 Storage Resource Catalogue, which shows some 165 Gt CO_2 in storage potential.

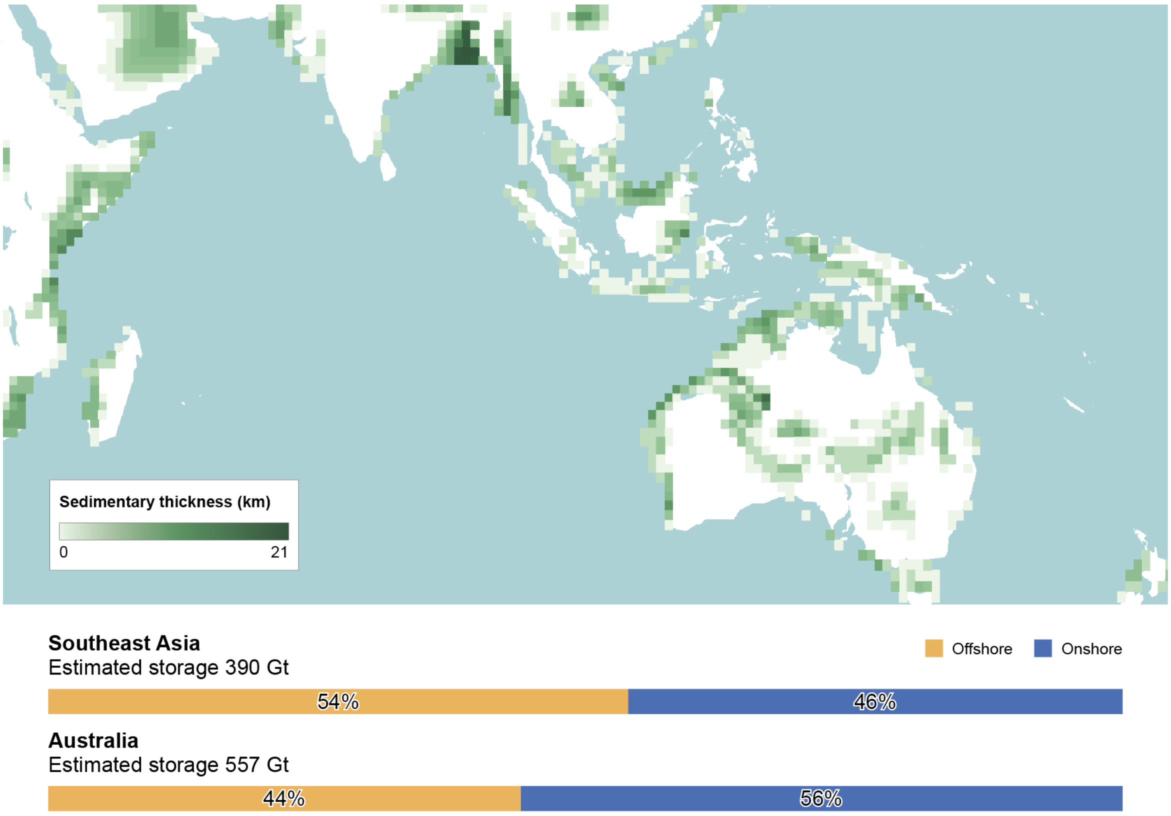
Storage estimates for countries in Southeast Asia

Country	Type of storage	Estimated volume	Total volume
Brunei	Oil and gas fields	0.6 Gt CO_2	0.6 Gt CO_2
Indonesia	South Sumatra Basin	7.65 Gt CO_2	8.4 Gt CO_2
	Java Basin (deep saline layers)	386 Mt CO_2	
	Tarakan Basin	130 Mt CO_2	
	Central Sumatra Basin	229 Mt CO_2	
Malaysia	Malay Basin	80 Gt CO_2	80 Gt CO_2
Philippines	Saline Aquifers	22 Gt CO_2	22.3 Gt CO_2
	Gas fields	0.3 Gt CO_2	
Thailand	Saline formation in the Greater Thai Basin and Pattani Basin	8.9 Gt CO_2	10.3 Gt CO_2
	Gas and oil fields	1.4 Gt CO_2	
Viet Nam	Deep saline reservoirs	10.4 Gt CO_2	11.8 Gt CO_2
	Depleted oil and gas fields	1.4 Gt CO_2	

Sources: Based on ADB (2013); METI (2020b); ERIA (2021).

Large parts of Southeast Asia are within the so-called Ring of Fire, a region around much of the rim of the Pacific Ocean known for frequent earthquakes and volcano eruptions. This does not rule out geological storage in the region – but robust site selection will be important, in addition to ongoing measurement, monitoring and verification during and after operations. Oil and gas reservoirs frequently experience minor tremors, with no detected escape of oil and gas. Since CO_2 is physically trapped within reservoirs the same way oil and gas is, this provides an analogous example of reservoir security. In addition, a magnitude 6.7 earthquake – completely unrelated to CO_2 injection – occurred in September 2018 near the Tomakomai project in Japan. The project itself experienced a seismic intensity of lower than magnitude 5, with no leakage or impact on the CO_2 storage (METI, 2020a).

CO_2 storage potential in Southeast Asia and Australia



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Notes: Sedimentary thickness serves as an indicator of the theoretical potential of CO_2 storage sites. The offshore capacity estimates exclude sites in water depths of more than 300 metres and more than 300 kilometres offshore.

Source: Storage assessment based on Kearns et al. (2017).

Building CCUS capacity in the region

While there is considerable opportunity for CCUS to play an important role in meeting energy and climate goals in Southeast Asia, unlocking this potential will require advances across four key areas. Governments and industry in the region, and in some cases international institutions, have vital roles to play in:

- Identifying and developing CO_2 storage resources.
- Establishing legal and regulatory frameworks for CCUS activities.
- Implementing targeted policies for CCUS, including CO_2 infrastructure investment.
- Accessing international finance to build capacity, unlock capital and encourage investment.

Near-term opportunities for CCUS vary among countries in Southeast Asia based on policy, industrial and geological factors. For example, although several countries have CO_2 storage and EOR potential, only a few offer supportive policy environments or recognise these technologies in their long-term energy and climate plans.

Opportunity factors for CCUS in a selection of Southeast Asian countries

	Brunei Darussalam	Indonesia	Malaysia	Philippine	Singapore	Thailand	Viet Nam
Domestic CO_2 storage potential	●	●	●			●	●
Potential to use CO_2 for EOR	●	●	●			●	
Legal and regulatory frameworks for CCUS in place	○*	○	○*	○*		○*	○*
Industrial clusters with CO_2 capture prospects	●	●	●	●	●	●	●
Recognition of CCUS in long-term strategies/goals	○	●	●		●		○

	Brunei Darussalam	Indonesia	Malaysia	Philippine	Singapore	Thailand	Viet Nam
Targeted policies to support CCUS investment							
Active pilot or demonstration facilities							
Plans for commercial CCUS facilities		●	●				

Notes: ● = yes, ○ = possibly/partially; * = oil and gas regulations potentially applicable for CO_2 storage.

Identification and development of CO_2 storage resources

Confidence in the availability of safe and secure CO_2 storage is a prerequisite for investment in both transport and storage infrastructure and capture facilities. CO_2 storage resources in Southeast Asia are considered to be well in excess of likely future requirements (including northern Australia, which could be part of regional approaches for CO_2 storage infrastructure). But for some locations, significant further assessment by project developers is required to convert theoretical capacity into "bankable" storage. For depleted oil and gas reservoirs, the availability of existing geological data (associated with the oil and gas production) could enable a faster pathway to developing CO_2 storage in some cases.

The process of characterising and assessing CO_2 storage can be very time consuming – up to ten years, depending on existing data – underscoring the need for early action. Governmental agencies including geological surveys, as well as authorities overseeing mineral and underground petroleum resources, all have key roles to play in undertaking pre-commercial CO_2 storage assessments in order to develop an atlas of CO_2 storage resources. (As with other natural resources, the knowledge obtained can be considered a public good). Oil and gas companies in Southeast Asia will likely be important partners, as they will already hold large amounts of data, notably on depleted oil and gas reservoirs. Information sharing between oil companies and national geological survey authorities is critical.

Support from government or international financial institutions is particularly important to bolster national governmental agencies in their efforts to map CO_2 storage potential. For four years, the Coordinating Committee on Geoscience Programmes (CCOP) supported storage identification and development in the region through its CO_2 Storage Mapping Programme (CCS-M). The programme included participation from institutions in countries including Viet Nam, Malaysia, Thailand and Indonesia. Current opportunities for regional co-operation to support storage capacity building in Southeast Asia include the ADB Trust Fund, and the recently launched Asia CCUS Network. Initiatives such as the OGCI's CO_2 Storage Resource Catalogue, which provides an evaluation of geologic CO_2 storage assessments worldwide, are also important for building industry confidence in the availability of storage resources.

Establishing legal and regulatory frameworks for CCUS

Robust legal and regulatory frameworks are needed to facilitate the development of CCUS and to provide project developers and financiers with certainty and confidence to invest in CCUS projects. They will also play a key role in ensuring the protection of public health and the environment. As in many regions today, CCUS regulation is largely absent in Southeast Asia.

Storage of CO_2 will be a key focus of legal and regulatory frameworks for CCUS. Regulations must ensure appropriate site selection and safe operations, providing a framework to mitigate and manage risks across all stages of site development, operation and closure. Regulations should also provide a legal basis for CO_2 storage, allocating property rights, managing competition for resources (for example, with oil and gas development), and defining roles and responsibilities, including ownership and liability for stored CO_2. International standards for CO_2 storage (e.g. ISO/TC 265, ISO 27914), as well as approaches that have been implemented in other regions, can inform efforts to establish such frameworks.

Key issues relating to CCUS regulatory frameworks

Issue categories	Key issues
Regulatory scope and definitions	• classification of CO_2 • composition of CO_2 streams • geographic coverage, exclusions and prohibitions
Property rights	• property rights • competition with other interests • preferential rights between CCUS operators • third-party access to storage sites
CO_2 storage exploration and development	• permitting exploration activities • controls on site selection and characterisation • environmental protection and impact assessment • permitting CO_2 injection and storage

Issue categories	Key issues
CO_2 injection and site operation	• monitoring, reporting and verification • corrective and remedial measures • site inspections • operational liabilities • financial security • enforcement
CO_2 storage site closure	• authorisation for site closure • allocation of long-term responsibilities and liabilities • financial contributions to long-term security
Transboundary movement of CO_2	• cross-border land and maritime transport
Other issues	• enhanced oil and gas recovery • public participation • CCUS ready conditions • protecting human health
Emerging issues	• industrial hubs (ownership of CO_2 when shared storage/transportation, network issues) • accounting for removals in existing frameworks • regulating demonstrations or first-mover projects

Indonesia has made significant progress in the development of a CCUS legal and regulatory framework (see the country case study on Indonesia). For other countries in Southeast Asia that have established oil and gas industries, such as Malaysia and Brunei Darussalam, existing oil and gas regulations may have potential to serve as the basis for CCUS regulations. Malaysia has conducted scoping studies that have explored legal and regulatory aspects of implementing CCUS and has identified insufficiencies in its existing system. In Thailand, existing regulatory frameworks can support pilot projects, but would require modifications to support full-scale or commercial investments. Legislation such as Australia's 2006 Offshore Petroleum and Greenhouse Gas Storage Act provides a useful example of the development of legislation for offshore storage that builds on existing oil and gas regulations, incorporating CCUS provisions into the primary regulation.

Developing comprehensive legal and regulatory frameworks for CCUS can be a lengthy process, with potential to delay investments or impede early demonstrations. Countries may therefore consider approaches to accommodate regulatory approvals for early commercial or research projects in parallel with the development of comprehensive regimes. Such approaches can include adaptation of existing frameworks (notably oil and gas regulations), exemptions for research or pilot projects, or special-purpose/project-specific legislation.

In Australia, the first commercial CCUS project, the Gorgon CO_2 injection project, was the subject of project-specific legislation, the Barrow Island Act. The legislation also provided a mechanism for transferring the long-term liability for the stored CO_2 to the Commonwealth post-closure, subject to specific conditions. In the United States and Canada, CCUS research projects have received specific exemptions or exclusions through the Underground Injection Control Program for Carbon Dioxide in the United States and through Ministerial letters of consent under Alberta's Mines and Minerals Act. This reflects the reduced risks associated with pilot demonstrations and the value of these projects for building CCUS capacity. Notably, early commercial and demonstration projects can also be an important means of testing and identifying gaps in legal and regulatory frameworks.

Targeted policy support for CCUS projects

Targeted policy support will be critical to facilitate commercial deployment of CCUS technologies, and particularly to support early investment in CO_2 transport and storage infrastructure. In the initial scaling-up phase, CCUS faces some specific challenges, including: the need for co-ordination across multiple sectors and stakeholders; high capital investment requirements; uncertainty surrounding long-term ownership and liability for stored CO_2; and untested insurance and financial markets. Government leadership and policy support will be needed to address these challenges and facilitate investment. The November 2020 ASEAN Plan of Action for Energy Cooperation (APAEC) is an important step in that direction, recognising an important role for CCUS in Southeast Asia.

Although there is no one-size-fits-all policy for CCUS, several options are available to policy makers to encourage investment in CCUS. The appropriate policy mix will depend on local market conditions and institutional factors, as well as the stage of technology development in the sector or application. As deployment increases, the market for CCUS should become progressively more independent, requiring less government intervention. Targeted subsidies could be phased out, and economy-wide measures such as carbon pricing could become the primary means to support investment.

Main policy instruments for incentivising CCUS development and deployment

Category	Types	Examples
Grant support	• Capital funding provided directly to targeted projects or through competitive programmes to overcome high upfront costs	• UK CCUS infrastructure fund • EU Innovation Fund
Operational subsidies	• **Tax credits** based on CO_2 captured/stored/used • **Contracts-for-difference** (CfD) mechanisms covering the cost differentials between production costs and a market price	• US 45Q and 48A tax credits • Netherlands' SDE++ scheme • UK power sector CfD arrangements
Carbon pricing	• **Carbon taxes** which impose a financial penalty on emissions • **ETSs** involving a cap on emissions from large stationary sources and trading of emissions certificates • **Credit trading systems**, where carbon credits generated from emissions reduction projects are valued via market mechanisms	• Carbon taxes in Singapore and Norway (offshore oil/gas) • ETS in Europe, China, or under consideration in Viet Nam, Thailand, Indonesia • Canada federal Output-Based Pricing System • Australian Emissions Reduction Fund
Demand-side measures	• **Public procurement** of low-CO_2 building materials, transport fuels and power, including those produced with CCUS • **Border adjustments**, adding a carbon tariff on imported goods to prevent competition from those with higher CO_2 and a lower price	• Canada and the Netherlands' rules favouring low-CO_2 material inputs for construction projects • Various countries purchasing concrete cured using CO_2
Regulatory standards and obligations	• **Mandates** on manufacturers to meet emissions criteria, or oblige firms to purchase a minimum share of products with low life-cycle CO_2 emissions • **Emissions standards** establishing limits on unabated CO_2 emissions	• Australia – Gorgon LNG project CCS requirement • Limits on allowable CO_2 intensity from coal and natural gas power generation in Canada

Policy support for CCUS has expanded in many regions in recent years. Examples include the enhanced 45Q tax credit in the United States, the GBP 1 billion (USD 1.4 billion) CCUS Infrastructure Fund in the United Kingdom, and the NOK 16.8 billion (USD 1.8 billion) commitment of the Norwegian government to support the Longship integrated CCUS project. The Australian government has announced an AUD 264 million (USD 203 million) fund to support CCUS hubs and technology, which includes support for multilateral engagement on CCUS and low emissions technologies. Although targeted policy support for CCUS in Southeast Asia is limited today, there are notable developments. For example, Singapore has established a SDG 49 million (USD 37 million) research programme for low carbon energy solutions to support near-term CCUS demonstration. Meanwhile, carbon pricing systems in Singapore, and those in development in Viet Nam, Indonesia and Thailand, could play key roles in increasing the attractiveness of equipping industrial and power generation facilities with CO_2 capture.

Of potential interest for Southeast Asia is the emergence of business models for industrial CCUS hubs in Europe and other regions. Virtually all involve the CO_2 transport and storage infrastructure being owned and operated by a dedicated entity that is publicly owned (wholly or partly) and regulated. An exception involves hubs built around an "anchor" capture facility (often a power plant) providing sufficient scale for the initial transport and storage infrastructure development, with third-party access being granted to neighbouring CO_2 capture sources.

Integration of CCUS into national energy and climate strategies can serve as an important policy signal. The recognition of CCUS in Nationally Determined Contributions (NDCs) is especially significant since multilateral climate finance can look to this when assessing funding requests. Globally, few countries explicitly mention CCUS in their NDCs, but most recognise a role for CCUS in meeting long-term (mid-century) climate goals. For example, Singapore's Long-Term Low-Emissions Development Strategy (LEDS), which builds on the country's NDC target, notably specifies CCUS as an important advanced technology for enabling the low-carbon transition.

Accessing international finance for CCUS

CCUS deployment in line with the temperature objectives of the Paris Agreement will require investment in CCUS in Southeast Asia to grow from a negligible base today to more than USD 1.2 billion a year in 2030. Achieving this level of investment will rest critically on strengthened support from international finance, recognising that many governments in the region will have limited capacity to provide direct public funding for early CCUS projects. With the appropriate policy incentives, governments can work together with international finance entities to create strong business cases for CCUS investment.

Grants and loans from development and climate finance institutions, emissions-credit mechanisms and climate-related debt financing could all be applied to CCUS projects. However, to date there are no examples of these measures being successfully accessed to support commercial or large-scale CCUS projects. Increased engagement between CCUS stakeholders in Southeast Asia and the development- and climate-finance community will be important for building understanding and generating support for future projects.

CCUS eligibility among selected international finance mechanisms

		Pilot and demonstration projects	Capacity building*	Capital support	Operating or revenue support
Development finance institutions, MDBs	CCUS trust funds (ADB, World Bank)	●	●		
	Concessional loans from MDBs	●		●	O
	IFC-leveraged investment	O		●	O
Climate finance / multilateral climate funds	Green Climate Fund	●		●	O
	Global Environment Facility	●		●	O
	Climate Technology Centre and Network	●	●		
Carbon markets	Joint Crediting Mechanism	O		O	O
	Clean Development Mechanism	O		O	O
	Voluntary carbon markets				●
Sustainable debt securities	Green/sustainability bonds	O		●	●
	Transition bonds	O	O	●	●
	Bank loans	O		●	●
Potential instruments	Storage certificates and credits	O		O	●
	Article 6 (Paris Agreement)	O		O	O

Notes: ● = eligible, O = may be eligible; *: including legal and regulatory development and technology assistance.
ADB = Asian Development Bank. MDB = Multilateral Development Bank. IFC = International Finance Corporation.

Blended finance and co-finance approaches could be especially useful to de-risk longer-lived loans for potential investors, given the long project timelines and large capital expenditures for CCUS developments. The International Finance Corporation (IFC) – part of the World Bank Group – formed an internal Carbon Capture Interest Group in 2019 that is currently exploring potential investment opportunities, including in heavy industry, and in collaboration with various groups such as the World Bank CCS Trust Fund, which could provide risk-sharing opportunities.

Voluntary carbon markets and UNFCCC trading mechanisms that value emissions reductions could provide crucial revenue streams for CCUS projects – although these too, have yet to be tested in practice. CCUS was approved to be eligible for the UN-led Clean Development Mechanism (CDM) in 2011 and, although two projects in Southeast Asia (from Viet Nam and Malaysia) applied, the projects were withdrawn and no CCUS projects were ultimately included in the CDM.

Resolution on the operation of international carbon markets (as per Article 6 of the Paris Agreement) could support new approaches to CCUS financing and cost-sharing. These approaches could include tradeable international mechanisms for CCUS such as storage certificates, but would require assurance measures and verification. The Joint Crediting Mechanism, a project-based bilateral offset scheme initiated by the Government of Japan, could become a source of climate finance to support CCUS development in Southeast Asia, subject to feasibility studies currently underway.

Sustainable debt could also play an important role in unlocking CCUS investment. “Labelled” green bonds may not be available to all CCUS projects (eligibility can be limited to specific clean energy technologies, and some explicitly exclude heavy industries or oil and gas companies), but bonds with broader definitions could apply to climate-focused investments. China notably updated its green bond standards to include CCUS in 2020. A new category of transition bonds could also assist companies in emissions-intensive industries to fund improvements. Direct bank loans, including risk-tolerant financing and co-financing approaches, can provide substantial capital support and bolster the confidence of potential equity investors.

Several investment funds in Southeast Asia could be potential sources of financing for CCUS projects. Singapore’s Temasek investment fund, alongside BlackRock recently formed a low-carbon investment partnership called Decarbonisation Partners, which could emerge as a valuable source of capital for project developers. As well, the developer of the Acorn Project in the United Kingdom, Storegga, has attracted funding from GIC, Singapore’s sovereign wealth fund (Storegga Geotechnologies, 2021). Japan is also considering investment to support emissions reductions from LNG facilities in Asia, including plants in Indonesia and Malaysia.

CCUS facilities linked to fossil fuels may face restrictions in accessing some sources of financing, in particular from entities that that have prohibited new investments in fossil fuels, including upstream developments or EOR. Some commitments distinguish between abated and unabated fossil fuel investments – for example, the European Investment Bank announced that it will cease financing unabated fossil fuels by the end of 2021 and specifies CCUS as an eligible technology in its lending policy – but in other cases there is a lack of clarity on the eligibility of CCUS. It is important that investment and financing policies recognise the critical role that CCUS plays in meeting climate goals and in supporting the transition to net-zero emissions (IEA, 2021b). Investment bans that apply to CCUS could negatively impact the cost and speed of emissions reductions.

CCUS Trust Funds

The Asian Development Bank and World Bank have CCUS-specific trust funds to support capacity building. These have supported a range of CCUS assessment and capacity building activities, including ongoing help to establish pilot projects (e.g. via the World Bank in South Africa and Mexico) and to support the development of legal and regulatory frameworks (e.g. via the ADB in Indonesia, and via the World Bank in South Africa and Mexico). These funds could be an important source of support for countries in Southeast Asia:

- The **Asian Development Bank CCS Fund** is a multi-partner trust fund, initially established with the support of Australia under the Clean Energy Financing Partnership Facility in July 2009. The United Kingdom joined in December 2012. The fund aims to help recipient countries address a range of issues related to capacity building, public consultation and education, and technology demonstration. All ADB developing member countries are eligible for funding, with initial priority given to the People's Republic of China, India, Indonesia, and Viet Nam.

- Established in 2009, the **World Bank CCS Trust Fund** is backed by the governments of the United Kingdom and Norway. It is available to support CCUS capacity-building activities in emerging economies. This includes funding for pilot projects, CO_2 storage assessments and the development of legal and regulatory frameworks. To date, the fund has allocated more than USD 55 million to national and regional CCUS programs, including ongoing support for the development of CCUS pilot projects in South Africa and Mexico. The World Bank also provided capacity building support to Indonesia and held a knowledge exchange between South Africa and Indonesia on the implementation of pilot projects.

Country case study: Indonesia

Indonesia is among the most advanced countries in Southeast Asia for CCUS. It has gained early experience through the Gundih project, as well as through ongoing studies at the Sukowati and Tangguh projects. Further, the launch of the ITB National Centre of Excellence for CCS and CCU by the Ministry of Energy and Mineral Resources of Indonesia in 2017 and ITB joining the GHG Technology Collaboration Programme (IEAGHG) demonstrates Indonesia's strategic interest and its commitment to CCUS development.

CCUS deployment in line with the temperature objectives of the Paris Agreement requires an increase in CO_2 capture to around 12 Mt in 2030 and 90 Mt in 2050, capturing cumulatively over 1.0 Gt CO_2. Over that time horizon, there is a near-even split in capture volumes among power generation, industry and fuel transformation.

Overview

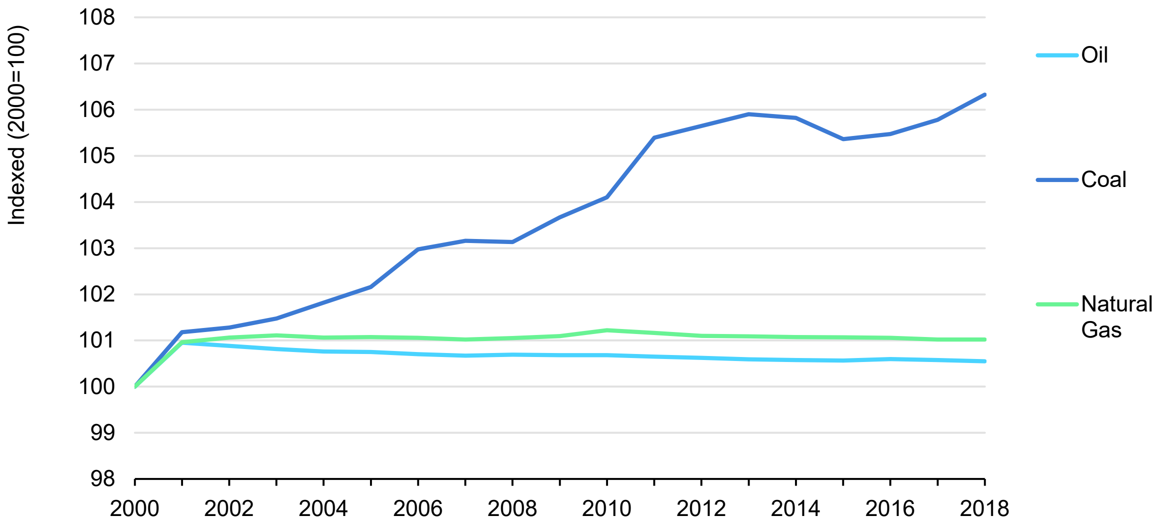
Indonesia is expected to become the fourth-largest economy in the world by mid-century. With a population of over 260 million people, Indonesia has seen energy demand grow by 2.3% per year since 2000. A major producer of oil, natural gas and coal, Indonesia is one of the largest energy exporters in the world. Rising domestic energy demand combined, in part, with diminishing resources, have increased the domestic claims on Indonesia's production, thereby lowering its energy export potential. Energy security and affordability remain priorities in Indonesia: CCUS is therefore an important pillar in the country's strategy to keep emissions growth in check while also meeting growing energy demand from its rapidly expanding economy.

Oil production in Indonesia has been declining gradually in recent years, as new investment and field developments have not kept pace with natural production decline from more mature producing areas. While almost 40% of all offshore producing fields in Southeast Asia have been in operation for more than 20 years, in Indonesia the level is 55%. Combined with rising demand, this is pushing net import needs up. EOR, and in particular CO_2-EOR, is being explored as a way to slow production declines and to lower the carbon footprint of oil production.

Indonesia is a significant exporter of LNG, with a global market share of around 4%. However, with gas production at roughly the same level today as it was in

2000, the increase in domestic demand has dragged down the gas export surplus. On the production side, overall gas output is expected to increase as development of new resources broadly keeps pace with rising demand. CCUS can help reduce emissions along the gas value chain in Indonesia, from gas processing to operations at LNG facilities and in end-use applications.

Development of oil, natural gas and coal production in Indonesia since 2000



Indonesia was the largest coal exporter in the world (by volume) in 2019 – before the Covid-19 pandemic. Going forward, coal production is expected to remain robust. Coal serves as a primary export good that helps to ease the country's widening current-account deficit. However, there are considerable uncertainties over future export opportunities, and Indonesia's rising domestic demand is gradually creating a wider gap between the pace of growth in production and export surplus.

Coal dominates the Indonesian power mix, supplying around 60% of its electricity in 2019. Natural gas and oil together account for around a quarter of the supply. The remainder comes from renewables, mostly hydro and geothermal. Indonesia is one of the world's leading markets for geothermal energy today. The potential of solar PV and wind is only starting to be tapped. Opportunities for deploying CCUS at coal-fired power plants are being explored in Indonesia to reduce emissions from power generation. In addition, there is a growing interest in exploring opportunities for CCUS associated with geothermal energy, building on Indonesia's leading role in geothermal energy worldwide.

In some areas (e.g. Central and East Java) high reserve margins for power are indicative of capacity that is more than ample to serve demand and to provide energy security. In remote locations, however, there remains a lack of access to power for serving even basic needs. CCUS can further help integrate renewables and facilitate energy-access efforts in Indonesia.

CO_2 sources in Indonesia

Indonesia's energy-sector emissions have more than doubled over the past two decades, to around 520 Mt CO_2 in 2019 from 255 Mt CO_2 in 2000. Many of the power plants and industrial facilities built during that period could continue to operate for decades to come. Those plants, and others under construction or planned, could cumulatively emit an additional 15 Gt CO_2 between 2021 and 2070 unless they are retrofitted with CCUS, repurposed to use alternative fuels, or retired early.

Power generation is by far the largest source of CO_2 emissions in Indonesia, accounting for about 44% of emissions. The cement (8% of CO_2 emissions) and iron and steel (2%) industries are also large stationary sources of emissions that could be suitable for CCUS. Some of the least-cost opportunities to capture CO_2 in Indonesia are to be found along the natural gas and oil supply chains, particularly natural gas processing, as well as in the petrochemical and fertiliser sectors. The availability of CO_2 from gas processing is likely to grow as several of the gas fields that are expected to come online in the coming years have particularly high CO_2 content.

Stationary sources of energy sector CO_2 emissions in Indonesia, 2000 and 2019, in Mt CO_2

Sources	2000	2019
Power and heat generation	62	230
Chemicals	3	9
Iron and steel	4	12
Cement	9	43
Fuel refining	27	26
Total	**255**	**520**

Note: *Fuel refining* includes emissions from oil and gas extraction and emissions from LNG facilities.

Indonesia is actively exploring CCUS to decarbonise its energy system

Indonesia has gained early experience with CCUS through the Gundih project, as well as ongoing studies at the Sukewati and Tangguh projects (all linked to EOR or EGR). These studies are paving the way for planned commercial projects associated with low-carbon ammonia production (with Mitsubishi, JOGMEC, PAU and ITB), and two projects targeting CO_2 capture from natural gas processing (Repsol SA in South Sumatra and a consortium of J-POWER, Japan NUS Co, with support of Indonesia's PT Pertamina at the Gundih gas development).

Indonesia's Gundih CCUS Study

Since 2012, detailed studies have been undertaken to assess the feasibility of CCUS, including a pilot project, at the Gundih gas field in Central Java. The studies assessed the feasibility of capturing around 30 tonnes of CO_2 per day from the processing of natural gas extracted from the Gundih field, which has a CO_2 content of around 20%. The studies were supported by the ADB's CCS trust fund and the Norwegian Government.

These studies have provided an important foundation for the development of a proposed commercial project, the Gundih CCUS Project, which has a planned capture capacity of 0.3 Mt CO_2 per year from natural gas processing, to be geologically stored in conjunction with enhanced gas recovery. Operations are expected to start in late 2024. The project is led by the ITB Indonesia Centre of Excellence for CCS and CCUS in collaboration with J-POWER (Electric Power Development Co), Japan NUS Co. and PT Pertamina. It is supported by the Japanese government and with the anticipated application of the Joint Crediting Mechanism.

Several studies have been conducted to further evaluate the potential of CCUS in Indonesia and to identify potential storage sites, linking sources of CO_2 to specific oilfields and other sinks. An initial study by the ITB Centre for Excellence highlighted the scope for CCUS, notably CO_2-EOR+, in Indonesia, given the potential availability of low-cost energy-sector CO_2 emissions from industrial processes. EOR, and potentially CO_2-EOR+, could prove to be a low-cost climate mitigation option, in particular where the revenues from EOR are sufficient to cover the cost of capturing and transporting CO_2 to oilfields. Potential new pilot projects have been identified and several studies are ongoing.

CCUS activities in Indonesia

Study/project	Proponents
FS JCM CCUS/CO_2-EGR Gundih	CoE CCS/CCUS ITB, J-POWER & JANUS
CO_2-EOR Sukowati Field	Pertamina EP CCUS Study Supported by Japex & CoE CCS/CCUS LEMIGAS
CO_2-EOR Limau Niru Field	Japex & CoE CCS/CCUS LEMIGAS
MRV Methodology for CCUS/CO_2-EOR	Japex & CoE CCS/CCUS LEMIGAS
CO_2 Source-Sink Match	CoE CCS/CCUS ITB & JANUS
FS Tangguh CCUS/CO_2-EGR	BP Berau Ltd. & ITB

Notable studies include a source sink mapping for CO_2-EOR+ candidate fields by the Indonesian Research and Development Centre for Oil and Gas Technology (LEMIGAS) in 2016, which ranked candidate fields by proximity to promising sources and by their infrastructure. The study found that close to 1 billion barrels could be recovered from 22 fields using CO_2-EOR Plus, with around 50 Mt CO_2 injected and stored each year. Most of the CO_2 would come from coal-fired power stations, including up to 11 Mt CO_2 per year from the Bangko Tengah Power Plant in South Sumatra, which is commonly viewed as the most promising region for EOR in Indonesia. The large East Natuna gas field could supply up to 40 Mt CO_2 per year. The primary candidate for the CO_2 is the Seria field in onshore Brunei Darussalam. In a further study in 2017, the Centre of Excellence and LEMIGAS evaluated Indonesian sedimentary basins for their suitability of deploying CO_2-EOR+, showing the potential to boost oil production while storing large amounts of CO_2 in the reservoirs (see detailed discussion in ADB, 2019).

CCUS opportunities in Indonesia's coal sector

Coal mining and coal-based power generation play important roles in Indonesia. The government has brought forward clean coal implementation strategies to help the country achieve its decarbonisation goals. The strategy includes:

- Encouraging gradual use of clean and high-efficiency coal technology in coal-fired power plants.
- Deploying CCUS in downstream processes such as coal gasification, underground coal gasification (UCG), coal liquefaction, coke making, coal slurry and coal briquetting.
- Utilising CCUS in the industry sector, especially iron and steel.

By supporting high-efficiency coal technology, Indonesia could bring nearly 30 GW of additional capacity online. Roughly 12 GW of that new coal capacity will use ultra-supercritical (USC) firing technologies, while another 12 GW will come from supercritical (SC) plants. Subcritical plants will provide a further 6 GW. All new USC coal plant development is expected to be in Java. However, some of these projects could be challenged by a May 2021 announcement, that Indonesia would halt approvals for new coal-fired power plants, a further sign of increasing scrutiny towards coal-fired power plant developments across Southeast Asia (Argus Media, 2021a).

Co-firing low carbon fuels like ammonia or hydrogen could be a further pathway for decarbonising the power fleet. Ammonia or hydrogen from fossil fuels with CCUS could be produced locally in Indonesia while at the same time enable emissions reductions in the power sector or even provide new export opportunities. Notable industry initiatives include Mitsubishi Power's agreements with Indonesia's ITB to test new fuel technologies using ammonia and hydrogen to reduce greenhouse gas emission.

CO_2 storage opportunities in Indonesia

There is significant potential for CCUS deployment in Indonesia, and CO_2-EOR could be an initial step. Dedicated CO_2 storage opportunities in Indonesia are expected to be found in saline aquifers, for instance in the Natuna region. Moreover, there are coal seams scattered among Indonesia's many islands that could be investigated for CO_2 storage. The feasibility of coal seam storage has yet to be demonstrated. However, it could provide an additional opportunity for Indonesia given its abundant coal seam reserves – particularly low-rank deposits that are distributed across eleven identified onshore basins.

The bulk of Indonesia's energy sector emissions are from sources located in proximity to potential storage sites. Around 85% of all the emissions from power plants and factories in Indonesia are located within 150 km of a potential storage site. Indonesia could further provide storage solutions for neighbouring countries with limited CO_2 storage resources, such as Singapore. It could also be part of regional hubs where CO_2 captured in Indonesia could be transported by ship to storage sites – off the north coast of Australia, for instance, where early plans to create regional storage hubs are already being explored.

Policy framework in Indonesia

CCUS has not yet been formally incorporated into Indonesia's National Energy Plan. However, the potential of CCUS – to help mitigate the climate impacts of energy consumption and production, to mitigate CO_2 emissions, and to strengthen energy security – has long been recognised in Indonesia. Any future CCUS policy framework must be seen in the context of an overall national ambition to achieve an electrification level of 99.7% by 2025 and to achieve Indonesia's NDC target of reducing greenhouse gas emissions by 29% from business-as-usual levels by 2030, or by as much as 41% with international support.

An important step was taken by a 2015 study by the Ministry of Finance of Indonesia. The study evaluated the prospects of CCUS deployment in Indonesia, highlighting the opportunity to leverage global CCUS expertise. It recommended pilot testing to confirm the feasibility of storing CO_2, stressing the importance of gaining experience and expertise in operating a CCUS project. Such tests were seen as a way for Indonesia to better learn about the technical challenges, risks, costs, and funding requirements for CCUS projects. The study also called for an improved understanding of the changes to the regulatory and fiscal framework that will be required in Indonesia to promote large-scale deployment of CCUS (see also discussion in ADB, 2019).

To facilitate the deployment of CCUS, the Directorate General of Oil and Gas within the Ministry of Energy and Mineral Resources (MEMR) of Indonesia established the Centre of Excellence for CCS and CCUS in 2017. The Centre promotes collaboration on research and development, particularly between ITB and the Indonesian Research and Development Centre for Oil and Gas Technology (LEMIGAS).

In March 2019 a draft presidential decree provided the first regulation specifically covering CCUS in any developing country. ADB provided assistance on the development of the framework, which was carried out in parallel with work on identifying pilot and demonstration projects. The framework builds on existing regulations for the upstream sector in Indonesia. It incorporates permitting requirements and covers all aspects of CO_2-EOR projects, including CO_2 capture, transport and storage, as well as the measurement, reporting, and verification of CO_2 storage. The framework is intended to cover pilot and large-scale, commercial CCUS projects. It will provide important learnings and serve as the basis for developing a more comprehensive CCUS regulatory framework at a later stage.

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