Chapter 13

Latest Developments in Carbon Capture, Utilisation, and Storage and Hydrogen in ASEAN – Lessons for Lao PDR

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1. Introduction

1.1. Carbon Capture and Storage and Carbon Capture, Utilisation, and Storage

Carbon capture and storage (CCS) and carbon capture, utilisation, and storage (CCUS) involve the activities of capturing carbon dioxide and storing it underground in efforts to reduce emissions. The capture activity is generally done in large point sources, such as power generation or industrial processes that utilise the combustion of fossil fuels and produce emissions. Regarding storage, there are two types: (i) saline aquifers, which can be classified under CCS; and (ii) depleted oil and gas wells, which can be classified under CCUS. Depleted oil and gas wells are supported by technology to improve the production of oil and gas while storing carbon dioxide underground, which is termed 'enhanced oil recovery' or 'enhanced gas recovery'. The locations of emissions sources and storage are not normally in close proximity, so carbon dioxide transport is also an important part of CCS/CCUS technology. Transport can be done either via shipping or pipelines.

In the Association of Southeast Asian Nations (ASEAN) region and East Asia, fossil fuels still play a significant role in the energy mix. Regarding power generation in a business-as-usual scenario, coal and natural gas are predicted to remain dominant, contributing 39.5% and 20.8%, respectively, to the energy mix in 2050 (Kimura, Phoumin, Purwanto, 2023). Even under a carbon-neutral scenario, the combined coal and gas power generation would remain at over 40% of the power mix with CCS in 2050.

The high share of coal and gas in the energy mix could be attributed to the fact that South-east Asia has relatively new coal-fired power plants, with an average age of only 11 years. In India and China, these are about 13 years old. For Indonesia, 58% of coal-fired power plants are 10 years old and below; another 22% of them are 10 to 20 years. With such a high dependency on fossil fuels, ASEAN and East Asia must rely on CCS/CCUS in the future.

Lao People's Democratic Republic (Lao PDR) is also expected to keep using fossil fuels within its energy mix. In 2019, coal accounted for 38.4% thanks to the Hongsa coal-fired power plant; this share is expected remain at 30.0% in 2050 (Kimura, Phoumin, Purwanto, 2023). Looking at the high share of fossil fuels in electricity generation and its energy mix, CCUS will be crucial for Lao PDR to reach its carbon-neutrality targets.

1.2. Hydrogen

The ASEAN region has significant renewable energy resources that can be utilised for green hydrogen[1] generation, including solar, wind, hydropower, biomass, and geothermal energy. The region possesses vast potential for harnessing these renewable resources, which presents a highly attractive prospect for sustainable hydrogen production in the long run. The ASEAN Centre for Energy (2021) posited that ASEAN has a total of 229 gigawatts (GW) of wind energy resources, 158 GW of hydropower resources (including small hydro), 61 GW of biomass resources, and 200 GW of geothermal resources. Hydrogen presents a prospect for ASEAN Member States to broaden their energy portfolios, decreasing reliance on imported fossil fuels. Such diversification can improve energy security and increase resilience to global energy market fluctuations.

Hydrogen also serves as an energy storage medium, aiding in the equilibrium of supply and demand in power networks that have a significant presence of intermittent renewable energy sources such as solar and wind. It is an important and versatile technology with the potential to transform various sectors, including transport, power generation, and industry. There are numerous methods of producing hydrogen, each having various impacts on the environment and technological maturity levels. The primary methods for producing hydrogen are divided into groups based on the energy source and on the emissions that are released throughout the process:

(i) **Electrolysis**. Utilising electricity, electrolysis converts water into hydrogen and oxygen. The procedure takes place in an electrolyser, which can range in size from massive industrial facilities to small appliances.

(ii) **Steam methane reforming**. This is the most widely used technique, producing over 95% of the hydrogen made worldwide (Moore et al., 2022). To make hydrogen and carbon monoxide, fossil fuels – mostly natural gas – are reacted with steam at a high temperature.

(iii) **Coal gasification**. By burning coal with oxygen and steam at high temperatures and pressures, syngas – a mixture of hydrogen, carbon monoxide, and carbon dioxide – is produced. This technology is generally used in regions with large coal deposits and well-developed coal usage infrastructure. It is also employed in industries that need hydrogen for chemical operations like ammonia synthesis.

(iv) **Others**. Other hydrogen production includes biomass gasification, which involves utilising heat, steam, and oxygen without combustion.

[1] Green hydrogen is named as such since no greenhouse gases are released during the process in which electricity is obtained from renewable sources. Blue hydrogen is generated mainly from natural gas, and emissions are captured using CCS. Grey hydrogen is produced from natural gas without using CCS.

2. Carbon Capture, Utilisation, and Storage Implementation in ASEAN

ASEAN has focussed on CCS for over 1 decade, but its implementation has been slow compared to other parts of the world. Developments regarding regulations, policies, and cooperation on CCUS have recently arisen across the region.

2.1. Geological Storage Resource Potential

ASEAN has an estimated 200 gigatonnes of storage resources (ERIA and GCCSI, 2024). This estimation was done by assessing the storage data from six countries – Brunei Darussalam, Indonesia, Malaysia, Philippines, Thailand, and Viet Nam (Table 13.1).

Table 13.1. Estimated Storage Resources in ASEAN Member States

Country	Saline Formation – P50 Net Storage Resources ($MtCO_2$)	Depleted Field – P50 Net Storage Resources ($MtCO_2$) and Fields (number)	CO_2 Stored through EOR – P50 ($MtCO_2$) and Fields (number)
Indonesia	49,000	2,275 / 42	153 / 6
Malaysia	127,000	1,773 / 41	105 / 9
Brunei Darussalam	18,000	579 / 7	200 / 1
Thailand	15,000	1,024 / 27	0
Viet Nam	5,000	303 / 9	56 / 3
Philippines		67 / 1	0
Total	**214,000**	**6,021 / 127**	**514 / 19**

CO_2 = carbon dioxide, $MtCO_2$ = million tonnes of carbon dioxide.

Source: ERIA and GCCSI (2024).

Indonesia, Malaysia, and Thailand are the most advanced regarding suitable and highly suitable offshore and onshore basins, gigatonne storage resources, and active CCS facilities. However, only Indonesia has a national regulatory framework to enable CCS. Brunei Darussalam has a suitable offshore basin with gigatonne storage resources, but storage development and CCS deployment have not commenced; the nation also lacks a dedicated regulatory environment for storage exploration. Viet Nam and the Philippines have potential storage basins, but there is no storage development in key areas near strategic industrial emissions clusters.

For estimated storage resources, around 98% is in saline formations. This estimate is remarkable as only nine saline formations in nine basins were reviewed. Yet this estimate is uncertain since storage resources for saline formations are for theoretical storage, whereas the hydrocarbon field storage estimates use field data. In Indonesia alone, the storage resources were estimated up to 69 gigatonnes in the selected saline aquifers. Indonesia has significant storage potential in both deep saline aquifers and hydrocarbon fields.

The resources of Cambodia, Lao PDR, and Myanmar were not assessed in the study due to a lack of data; the storage potential of those countries has never been reviewed.[2] Lao PDR could move towards CCUS by conducting studies on this matter. Understanding potential storage is key for how the country could utilise CCUS in terms of emissions reduction, especially from coal-fired power plants.

2.2. Regulatory Frameworks and Policies

The approach to regulating CCS is an important consideration for governments seeking to develop a CCS-specific legal framework. Regulators and policymakers may decide to expand the focus of regulatory frameworks to include the broad suite of applications that constitute CCS technologies across the industrial and power sectors.

Within the region, the experiences of Indonesia and Thailand offer examples of the processes involved in developing regulatory frameworks for CCS. Both countries have undertaken collaborative, iterative processes that have engaged a diverse group of stakeholders across various levels of government. There is a risk of delay or a disconnect within the regulatory process, as stakeholders must take time to familiarise themselves with the technology and new regimes.

Activities involving the transport of carbon dioxide across international maritime zones and marine areas have implications under a broad range of international agreements, including those relating to the pollution of the marine environment, safety of maritime transport, transport of dangerous goods, and carriage of compressed gases. The London Protocol[3] removed barriers to the technology's deployment and provides a basis for the regulation of carbon sequestration in sub-seabed geological formations.

[2] Singapore does not have a storage basin within its borders.
[3] Protocol to the Convention of Marine Pollution by Dumping of Wastes and Other Matter from 1996.

Recent amendments to this agreement offer an important pathway for facilitating the transboundary transport of carbon for geological storage. For many ASEAN Member States, existing oil and gas operations will provide a good analogue for the various regimes that may also apply to CCS activities. Compliance with CCS-specific legal and regulatory regimes is an important feature of many carbon-crediting schemes that offer support for CCS activities.

The detailed reporting and accounting of stored carbon, as part of geological storage operations, is a key aspect of ensuring compliance with CCS-specific legislation and for ensuring the wider integrity of CCS operations. The 2006 IPCC guidelines demonstrate how national accounting schemes can manage the reporting of transboundary CCS operations (Eggleston et al., 2006). Legal and regulatory issues will arise in the context of transboundary project models, which will trigger obligations under international, regional, and national regimes. The absence of clear legal and regulatory frameworks for these operations within international and national law, however, suggests that this issue should be addressed in the pre-injection phase and prior to operation.

The responsible and safe closure of a carbon storage site is the focus of regulatory requirements during the closure phase. Legislation should require project operators to seek authorisation to close a storage site upon the fulfilment of prescribed criteria and may include well decommissioning and plugging requirements. Regulatory obligations during the post-closure phase should include long-term monitoring and responsible site care to ensure the safety and security of storage sites.

2.3. Value Chain Centre

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

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

The establishment of a centralised body, such as a CCS value chain centre (VCC), to coordinate and to administer regional efforts could accelerate CCS deployment in the region. The VCC could review and make recommendations on how existing national policies, legislation, and regulatory frameworks could be adapted to accommodate regional CCS activities, including identification of near- and mid-term activities to support national regulators and policymakers to align national CCS policies to enable collaboration in the region. With national policymakers and regulators, the VCC could implement the ASEAN CCS roadmap currently under development by the ASEAN Centre for Energy. As a regional body, the VCC could act as an advisory body, tasked with monitoring national CCS legislation and regulation development in the region, in line with the ASEAN CCS roadmap, and make recommendations to regulators as appropriate.

In addition, the VCC could coordinate the development of ASEAN CCS regulatory guidelines, based on the existing *ASEAN Guidelines on Good Regulatory Practices* to provide guidance on the approach to developing CCS-specific regulation for the region. The VCC could also play a role in the standardisation of CCS across the region, based on international standards and global best practices and through collaboration with other associations in the climate-change space. It could also become the official custodian of an ASEAN geological storage calculation engine and database, accessible to project proponents in the region, and coordinate the development of a regional framework for risk assessment and management of carbon storage in geological formations.

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

2.4. Financing Challenges

Using the Global Economic Net Zero Optimisation (GENZO) model, the capital investment required to establish CCS to transition towards carbon neutrality would be about US$880 billion to 2065, starting at US$420 million per year in the 2020s, rising to US$15.6 billion per year in the 2030s, and peaking at over US$40.0 billion per year in the 2040s. It would then decline to almost US$25.0 billion per year in the 2050s and to US$6.5 billion per year in the 2060s based on the GENZO Accelerated Storage Scenario (ERIA and GCCSI, 2024).

Mobilising the capital for CCS requires both public and private finance. However, the private sector can only invest where there is an appropriate risk-weighted return on investment. Private investment is incentivised by the expectation of future profits. Applied to CCS, this condition would only be met if the unit cost of CCS (per tonne of emissions avoided) is less than the cost of emissions plus the value of any revenue generated (e.g. in enhanced oil recovery) through CCS.

The unit cost of CCS varies considerably, depending on the capture source and scale, transport distance, and storage resource quality. The lowest cost applications may have a full value chain cost of less than US$25/tonne of carbon dioxide (tCO_2) including the cost of compression transport and storage. However, in most industrial applications, full value chain CCS will cost US$40–US$100/tCO_2; application in power generation, US$60–US$200/tCO_2; and over US$200/$tCO_2$ for direct air capture (ERIA and GCCSI, 2024). CCS is required to be applied across all of these applications to deliver net-zero emissions at the lowest overall cost. Private sector investment incentives are currently insufficient to mobilise the necessary capital, except in the lowest cost applications.

This presents a fundamental problem for governments that are charged with achieving net-zero emissions to stabilise the global climate – a significant public good. The cost of emissions – climate change, surging insurance and disaster relief costs, and loss of life and property – are increasing rapidly. Yet these costs are dispersed, unevenly distributed, and back-ended, while abatement costs are front-ended. Governments face the classic economic problem of internalising negative externalities to incentivise removing emissions. Policies are thus required to align private investment incentives with public good investment incentives. This can be done through any combination of (i) increasing the cost of emissions (e.g. carbon taxes or emissions trading), (ii) instituting command and control mechanisms (e.g. prohibition or mandates through regulation), (iii) reducing the cost of CCS to private investors (e.g. through capital grants or concessional finance), and/or (iv) increasing the revenue created through CCS (e.g. through payments per tCO_2 stored or operational subsidies)

CCS has little economic value compared with freely emitting into the atmosphere, and that calculus can only change through policies and regulations. The challenge is how to reflect the cost of emissions in prices so that a low-carbon product is cheaper than its high-carbon substitute. This would drive the demand for abatement technologies and enable their applications to earn a profit. Policies on their own cannot tackle this financing challenge. Lao PDR can also find avenues to address the challenge, such as multi-lateral development banks, voluntary carbon markets, and sustainable financing such as green and climate bonds.

2.5. Asia Carbon Capture, Utilisation, and Storage Network

The Economic Research Institute for ASEAN and East Asia (ERIA) is the secretariat of the Asia CCUS Network (ACN), with a vision to contribute to the decarbonisation of the region through collaboration and cooperation on development and deployment of CCUS. The three main missions of ACN are (i) promoting knowledge sharing through annual fora, conferences, and workshops; (ii) conducting research studies and surveys on technical, economic, and legal standards, especially the common rules of CCUS in the region; and (iii) holding capacity-building workshops to bridge the knowledge gap on CCUS. ACN also supports various countries to identify the pilot CCUS projects until 2025 and is aiming to deploy and commercialise CCUS by 2030.

Necessary studies have been identified in collaboration with knowledge partners. In 2023, ACN commissioned four studies by the Global CCS Institute (GCCSI) and one study from *Bandan Reset dan Inovasi Nasional* (National Research and Innovation Agency, BRIN) (ERIA and GCCSI, 2024; ERIA and BRIN, 2024). Collectively, these studies assess the role of CCS in South-east Asia to support the achievement of net-zero emissions targets, review the policy and legal frameworks necessary to enable CCS, examine the need for collaboration amongst South-east Asian nations on institutional frameworks, and discuss options to facilitate the financing of CCS in the region. The five studies focussed on the geological storage potential in South-east Asia, establishment of an Asia CCS/CCUS value chain as a collective framework in the region, legal and policy framework for deployment of CCUS, financial framework for deployment of CCUS, and establishment of basin-scale storage in Indonesia.

3. Hydrogen Development across ASEAN

ERIA (forthcoming) conducted a study on the hydrogen demand and supply in the East Asia Summit region, taking into account government policies and patterns observed in national energy policies, particularly regarding the dependence on imported natural gas. Table 13.2 shows the projected demand and supply potential of hydrogen in the East Asia Summit region in 2040. In the ASEAN region, the biggest hydrogen demand potential comes from Indonesia, Malaysia, Singapore, and Thailand. ASEAN also lags behind in terms of its potential for hydrogen generation.

Table 13.2. Hydrogen-producing Potential from Unused Energies Compared to Hydrogen Demand Potential in the East Asia Summit Region in 2040
(million normal cubic metres)

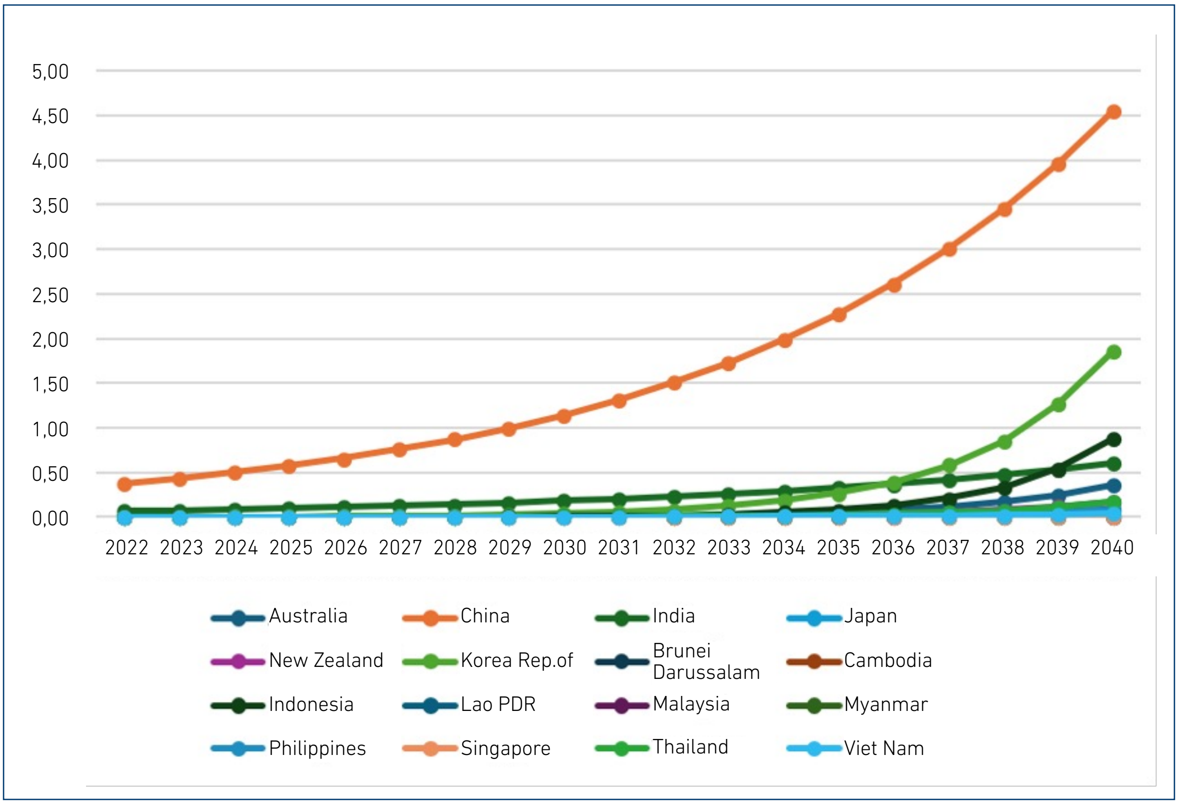
	Production Potential		Demand Potential	Self-sufficiency Rate from Previous ERIA Study		Self-sufficiency Assumptions in the Study
	Max	Min		Max	Min	
Australia	21,502	7,169	13,974	154%	51%	154%
Brunei Darussalam	1	1	1,775	0%	0%	0%
Cambodia	5	1	352	1%	0%	100%
China	1,204	395	163,408	1%	0%	95%
India	1,057	352	11,990	9%	3%	100%
Indonesia	1,501	500	44,807	3%	1%	100%
Japan			29,252	0%	0%	5%
Korea, Republic of			41,558	0%	0%	76%
Lao PDR	13	3	9	137%	34%	137%
Malaysia	42	16	24,034	0%	0%	100%
Myanmar	49	12	1,263	4%	1%	100%
New Zealand	3,370	1,123	1,065	317%	106%	317%
Philippines	49	16	4,551	1%	0%	100%
Singapore			15,098	0%	0%	1%
Thailand	192	63	12,993	1%	0%	70%
Viet Nam	85	29	3,668	2%	1%	100%
Total	**29,070**	**9,681**	**369,796**	**8%**	**3%**	

ERIA = Economic Research Institute for ASEAN and East Asia, Lao PDR = Lao People's Democratic Republic.

Source: ERIA (forthcoming).

The study also estimated the green and blue hydrogen production outlook by country in the East Asia Summit region (ERIA, forthcoming). Green and blue hydrogen are expected to see exponential growth until 2040 (Figures 13.1 and 13.2). These patterns have been noted due to the advancement of renewable energy during the last few decades. By 2040, the production of blue hydrogen is expected to be nearly double that of green hydrogen.

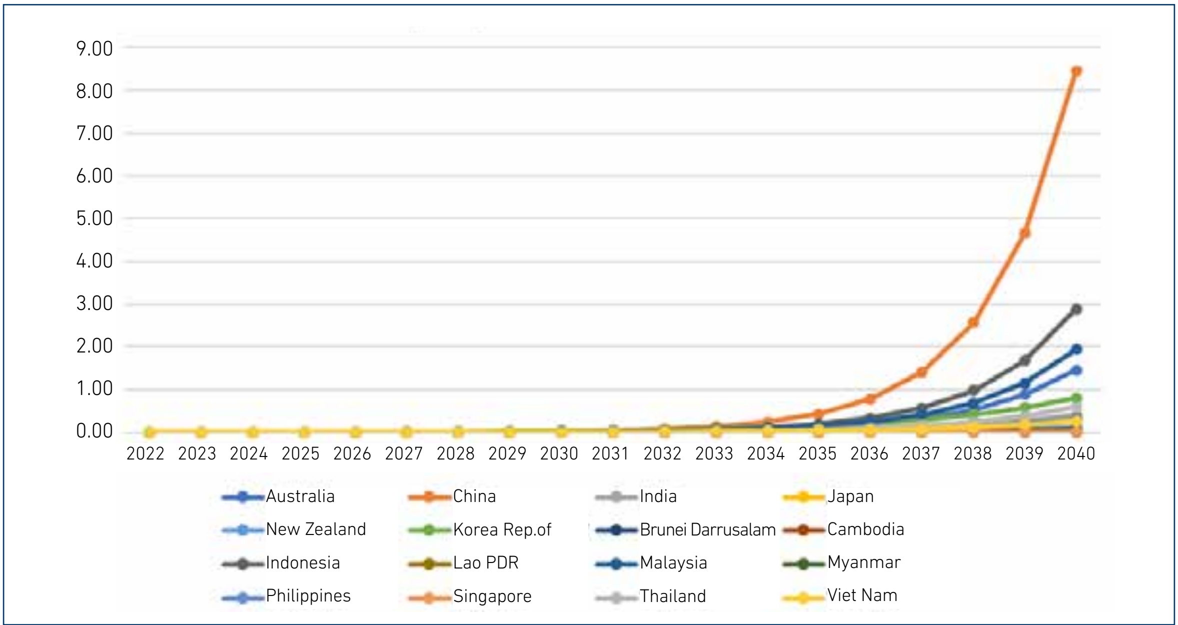
Figure 13.1. Green Hydrogen Production Outlook by Country
(million tonnes)



Lao PDR = Lao People's Democratic Republic.

Source: ERIA (forthcoming).

Figure 13.2. Blue Hydrogen Production Outlook by Country
(million tonnes)



Lao PDR = Lao People's Democratic Republic.

Source: ERIA (forthcoming).

Referring to ERIA (2022; forthcoming), the ASEAN region possesses significant potential for the production of green, blue, and grey hydrogen. However, the current capital expenditure for hydrogen production, transport technology, and fuel cells – along with the relatively high levelised cost of electricity for renewables – makes it uneconomical to utilise hydrogen energy in the power and transport sectors (ACE, 2021). Thus, enabling a hydrogen economy entails implementing several strategies and initiatives to foster the production, shipping, and use of hydrogen as a clean and sustainable energy carrier.

Hydrogen energy is becoming an important part of ASEAN's plan to improve energy security and shift towards cleaner energy sources, but hydrogen in ASEAN is at an initial stage of development. ACE has presented a systematic and gradual strategy for the implementation of hydrogen utilisation (ACE, 2021):

(i) **Phase I (2020–2025)**. The primary objective is to generate and to distribute grey hydrogen by utilising current fossil fuel resources and infrastructure for exportation purposes.

(ii) **Phase II (2026–2030)**. The objective is to shift towards the production of blue hydrogen using CCS technology.

(iii) **Phase III (post-2030)**. Here, there will be a notable transition towards green hydrogen as the costs of renewable energy decrease and infrastructure becomes more developed.

There are multiple initiatives underway to investigate the potential for hydrogen advancement in the region. Brunei Darussalam is at the forefront of exporting hydrogen to Japan. The process is made possible by a cutting-edge technology, liquid organic hydrogen carriers, which offers a practical solution for storing and transporting hydrogen.

Only three ASEAN Member States have hydrogen national strategies – Singapore, Malaysia, and Indonesia, outlined below.

3.1. Singapore

In 2022, Singapore implemented a national hydrogen strategy to accelerate the shift towards achieving net-zero emissions and enhancing energy security. Hydrogen can enhance the country power combination in conjunction with solar energy, imported electricity, and other possible sources of low-carbon energy, such as geothermal energy. By 2050, hydrogen has the potential to meet up to 50% of Singapore's power requirements, contingent upon advancements in technology and the emergence of alternative energy sources (EMA, 2022).

Singapore is actively engaging in partnerships with Japanese companies to investigate the potential of hydrogen as a clean fuel alternative. The primary objectives are to reduce emissions in the economy and to foster the development of new industries. Through its national hydrogen strategy, Singapore is aiming to produce 50% of its energy from low-carbon hydrogen by 2050.

Singapore will prioritise the development of expertise in industry, human resources, and the government in areas that are crucial for promoting the use of hydrogen. Based on Singapore's national strategy, the efforts will be centred around five main areas: (i) conducting trials of cutting-edge hydrogen technologies that are on the verge of being commercially viable through pilot projects, (ii) allocating resources to research and development to overcome significant technological obstacles, (iii) engaging in international partnerships to establish efficient networks for the production and distribution of low-carbon hydrogen, (iv) engaging in extensive land and infrastructure planning for the long term, and (v) providing assistance for workforce training and the growth of Singapore's overall hydrogen industry.

3.2. Malaysia

Malaysia is implementing a thorough plan to advance its hydrogen economy, as detailed in the *Hydrogen Economy and Technology Roadmap* (MOSTI, 2023). The main objectives of this plan are to integrate hydrogen into Malaysia's emerging energy sector, encourage a sustainable energy mix, and allocate resources towards hydrogen technologies to enhance both domestic and international energy stability and to reduce emissions.

Malaysia's objective is to establish a robust hydrogen supply chain, intending to export to China, Japan, Republic of Korea, and Singapore. As mentioned in the *Hydrogen Economy and Technology Roadmap*, the country is expected to become a prominent exporter in the region, with a predicted income of RM400 billion by 2050 (MOSTI, 2023). The funds generated will contribute to the advancement of infrastructure for both export and domestic sectors as well as creating new opportunities for job growth.

The roadmap is based on five major objectives with the goal of establishing hydrogen as a feasible energy source: advancement of infrastructure, promotion of technological innovation, generation of market demand, establishment of regulatory frameworks, and improvement of international cooperation. Sarawak State is leading this initiative with the H2biscus project in Bintulu. The project aims to generate an annual production of 220,000 tonnes of green hydrogen, principally intended for sale to the Republic of Korea, while also allocating a portion for domestic consumption. Sarawak is making progress in developing its hydrogen infrastructure, which includes the establishment of multi-fuel stations and hydrogen production facilities for public transport (Lye, 2022).

3.3. Indonesia

In late 2023, Indonesia established a national hydrogen strategy based on three principles – diminishing dependence on fossil fuels to guarantee energy security, fostering the growth of the domestic hydrogen market, and exporting hydrogen and its byproducts to the international market (MEMR, 2023). Presently, the development of hydrogen technology in Indonesia is limited to research and pilot projects. It is, however, expected to experience significant growth after 2030 (MEMR, 2023). Its applications will expand to include hydrogen vehicles (powered by fuel cells or synthetic fuels); electricity generation; energy storage; and decarbonisation of sectors such as shipping, aviation, steel production, manufacturing, and long-distance transport.

4. Lessons Learned and Key Directions for Lao PDR

4.1. Enabling Carbon Capture, Utilisation, and Storage

CCUS will be an avenue for Lao PDR to reach a carbon-neutral future. Several key directions could be adopted to realise the enablement of CCUS technologies:

(i) **Conduct a national storage resources assessment**. To understand the total potential amount of carbon that can be stored in Lao PDR, an assessment should be conducted. Due to currently limited data on storage resources, Lao PDR will be overlooked in providing potential storage. This study will require a substantial amount of investment; hence, cooperation schemes and international support are required.

(ii) **Develop regulatory frameworks for CCS/CCUS activities**. Regulating CCS/CCUS projects and activities will be the next key step to help diminish uncertainties and attract more investment to enable the development of CCS/CCUS projects. Indonesia's example can be adopted, where regulations began regulating enhanced oil recovery and enhanced gas recovery activities (i.e. CCUS), which then expanded towards storage in saline aquifers (i.e. CCS). Specific regulations on capture; transport; storage; measurement, reporting, and validation; and post-closure should be addressed in later stages of regulatory frameworks development.

(iii) **Pilot project development**. CCUS pilot projects are crucial to demonstrate economic viability and to improve the effective and efficient technology in terms of storage. Pilot projects also showcase and inform the community regarding the environmental benefits of carbon injections. The successful implementation of such projects encourages investors to develop and to fund more CCUS projects in the country.

(iv) **Financing CCUS**. To fully develop CCUS as a viable business, the price of emitting needs to be higher than capturing and storing carbon. This can be done by increasing the price of emitting (i.e. carbon pricing), instituting prohibition or mandating mechanisms, reducing the cost to private sector investors of CCS (e.g. through capital grants or concessional finance), and/or increasing the revenue created through CCS (e.g. through payments per tCO_2 stored or operational subsidies). In terms of financing CCUS technology deployment, Lao PDR can request the assistance of multi-lateral development banks, create a voluntary carbon market, and use sustainable financing such as green and climate bonds.

(v) **Develop interconnected CCUS networks**. Connecting with ASEAN Member States to develop a regional CCUS network would be beneficial, especially for countries with limited amount of storage. Lao PDR, in the long term, should aim to tap into this to gain access to lower-cost storage options. Cross-border mechanisms should be addressed at the national, bilateral, and regional level to enable the option. This option, however, will need high-level coordination in terms of planning and development.

4.2. Hydrogen Potential for Lao PDR

To make hydrogen a feasible alternative, it is imperative to implement specific policies such as subsidies, tax incentives, and international collaboration for infrastructure development. Implementing these methods will effectively reduce the financial disparity and improve the competitiveness of hydrogen technologies, especially during the initial phases of implementation.

Lao PDR is aggressively investigating the potential of hydrogen energy as a key component of its renewable energy plan. The country possesses substantial capacity for renewable energy, particularly hydropower, which can be used to generate hydrogen. Indeed, Lao PDR has the potential to become a significant participant in the regional hydrogen economy by exporting hydrogen generated from the country's renewable resources.

Multiple endeavours are in progress to foster the growth of the hydrogen industry in Lao PDR. For instance, the government is currently collaborating with international partners such as the Asian Development Bank and Global Environment Centre Foundation to develop a power-to-gas master plan. This strategy's purpose is to delineate the necessary procedures for implementing hydrogen production and utilisation on a large-scale commercial level. This involves the implementation of regulations, infrastructure, and business plans to facilitate the growth of the hydrogen economy, as recommended by the Asian Development Bank and the Climate Technology Centre and Network.[4]

In addition, collaborations with the Electricity Generating Authority of Thailand and Mitsubishi are being pursued to investigate the establishment of green hydrogen and ammonia production plants in collaboration with the Government of Thailand. These facilities will harness Lao PDR renewable energy potential to produce hydrogen. This programme is a component of a wider plan aimed at augmenting the proportion of renewable energy sources in energy composition and diminishing dependence on imported fossil fuels (EGAT, 2024).

To conclude, Lao PDR has significant potential to develop green hydrogen in the future, as its hydropower potential capacity is predicted to be approximately 26.5 GW, which is far more than its present energy requirements (UNESCAP, 2022). The country can leverage this excess to generate hydrogen, establishing itself as a prominent player in the hydrogen supply chain.

[4] CTCN, 'Developing a Power to Gas Masterplan in Lao PDR', https://www.ctc-n.org/technical-assistance/projects/developing-power-gas-masterplan-lao-pdr

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