Technology List and Perspectives for Transition Finance in Asia

Inclusive List of Green and Transition Technologies

2nd Version

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1. Introduction

1.1. Transition towards a low-carbon economy

Climate change is the most pressing challenge of our time. Its effects – rising global temperatures, increasing sea levels, and more frequent extreme weather events – are already having visible impacts on our environment, economy, and public health. A global transition towards a low-carbon economy is essential.

Transitioning from a predominantly fossil fuel-based energy system to one based on renewable and sustainable sources, such as wind, solar, hydro, geothermal power, hydrogen, and biofuels, requires significant changes in energy production, distribution, and consumption. Whilst the shift to renewable and sustainable sources is urgent, other lower-emission fuels and technologies that reduce greenhouse gas (GHG) emissions and improve energy efficiency will remain crucial during the transition. To accelerate the transition, we need technological innovation, financial investment, and policy frameworks that collectively drive the transition whilst ensuring energy security and affordability for all.

1.2. Challenges in transitioning towards a low-carbon economy in developing Asia

Developing Asia faces several challenges in transitioning towards a low-carbon economy:

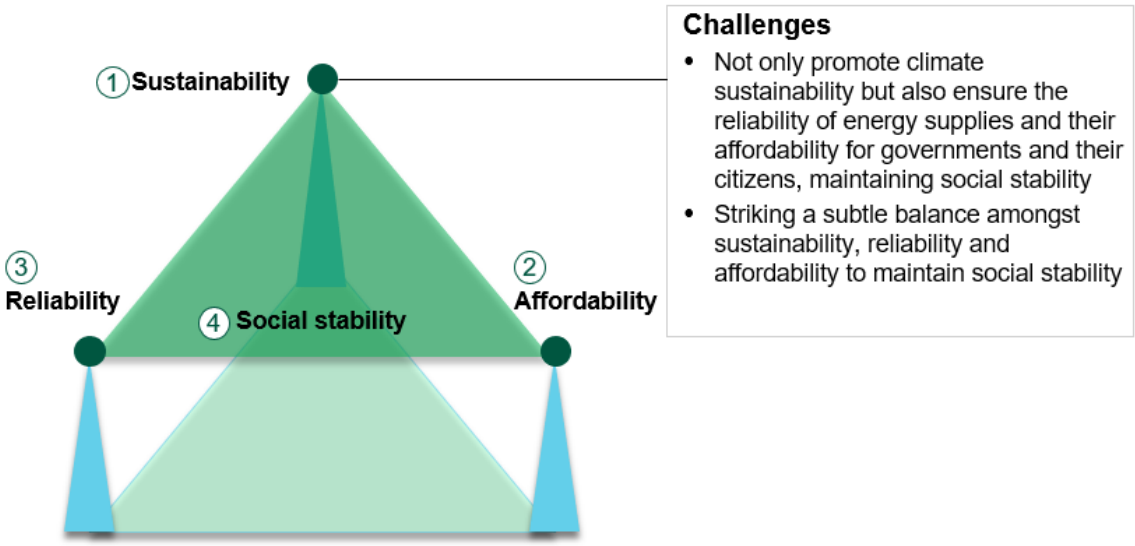
- **Infrastructure constraints.** The renewable energy sources with greater potential in the Association of Southeast Asian Nations (ASEAN) region are solar and wind (International Renewable Energy Agency [IRENA], 2022). These are classified as variable renewable energies (VRE), meaning their availability fluctuates with seasons and time of day. As a result, power systems face greater variability and uncertainty, which existing approaches of balancing supply and demand cannot adequately address. To accommodate higher levels of VRE, the power system requires deep structural changes to improve flexibility (ASEAN Centre for Energy, 2022). However, some Asian countries may lack the infrastructure necessary for renewable energy production and distribution, and building such infrastructure requires substantial investment and time.

- **Energy insecurity.** Many people in developing Asia still lack reliable access to electricity (Asia Development Bank, 2024). Balancing the need for rapid electrification with the imperative to reduce carbon emissions presents a significant challenge. Concerns about energy security and the uncertainties associated with transitioning to a different power model have slowed the adoption of renewable energy sources (IEA, 2023a).

- **Financial challenges.** High costs present a significant obstacle. Despite the sharp decline in global renewable energy technology costs in recent years, the capital expenditure required for utility-scale solar photovoltaic (PV) and wind projects in some Asian countries remains much higher than in other countries. Factors such as limited deployment scale, underdeveloped supply chains, and stringent domestic content requirements have all contributed to increased project costs.
- **Economic development.** Many countries in Asia are undergoing industrialisation and economic development, often relying on fossil fuels such as coal to power industries and meet growing energy demands. Transitioning from fossil fuels to cleaner energy sources requires significant investment.

In transitioning to a low-carbon economy, energy security must be prioritised. Climate sustainability alone cannot dictate technology choices for emission reduction. Approaches to decarbonisation should be tailored to each nation's circumstances, ensuring that the transition is just and orderly and maintains sustainability, affordability, and reliability to prevent sudden disruptions and potential social unrest (Exhibit 1) (ERIA, 2024).

Exhibit 1. Important Factors for a Just and Orderly Transition



Source: Economic Research Institute for ASEAN and East Asia (2023).

1.3. Transition technologies in this document

Technologies that reduce but do not completely eliminate carbon emissions play a crucial role in facilitating a just and orderly transition. These are referred to as transition technologies and are the focus of this document. In addition, green technologies are defined as those with zero emissions throughout their operation and are key components of the broader technology solution package to achieve net-zero emissions.

1.4. The need for information and guidance on transition technologies for financial institutions

(1) Development of taxonomies

Governments and international organisations have established standards and guidelines to ensure financial flows align with a pathway to net-zero carbon dioxide (CO_2) emissions. One such effort is the development of taxonomy – a classification system that defines criteria for economic activities in line with sustainability goals.

For example, the European Union (EU) taxonomy for sustainable activities (EU taxonomy) defines green activities as those that make a substantial, rather than a marginal, contribution to achieving the EU's environmental objectives. It also recognises 'transitional activities' if they have plans to make a 'substantial contribution' soon, provided no other low-carbon alternatives are available (European Commission, 2021).

Similarly, ASEAN is developing its own regional taxonomy. The ASEAN Taxonomy Board (ATB) published its first version in 2021, recognising the criticality of a regionally harmonised taxonomy for sustainable finance (ATB, 2021). The ASEAN taxonomy uses a traffic light system, categorising activities as green, amber, or red. Green activities contribute substantially to environmental objectives, whilst amber activities are transitional, reflecting progress towards sustainability with practical considerations. The taxonomy includes clear numerical criteria – technical screening criteria (TSC) – to distinguish between green and transitional activities.

National efforts are also underway to develop taxonomies in Singapore, Malaysia, and Thailand. However, taxonomies alone do not provide specific information on the technologies or activities that need to be assessed.

(2) Development of technology lists and roadmaps

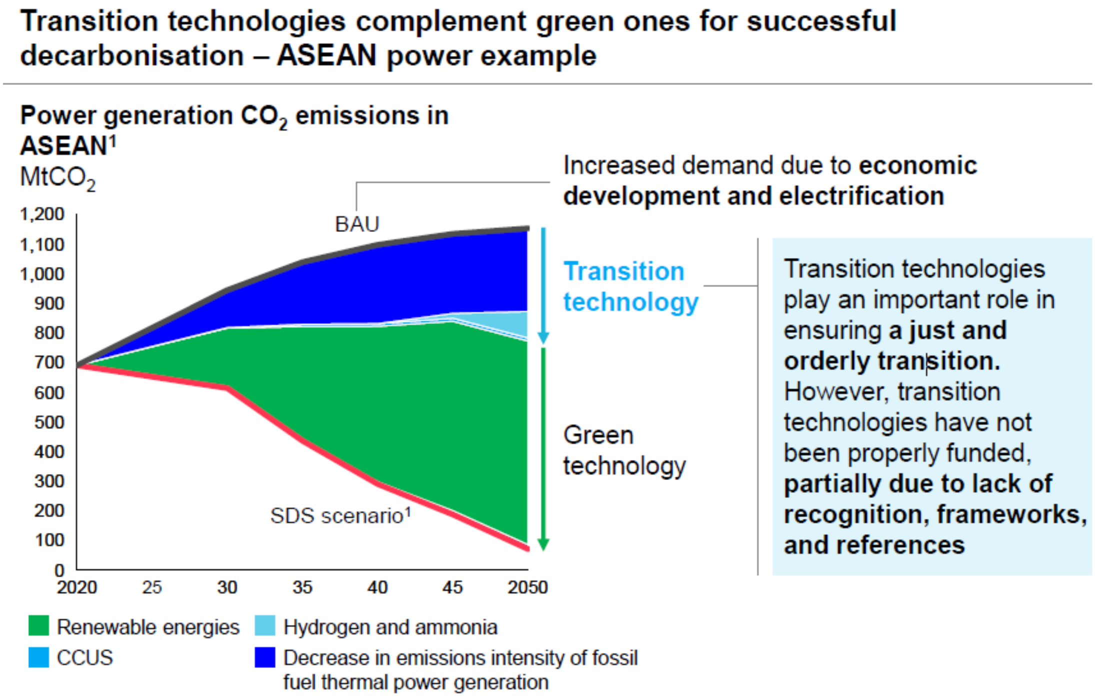
In addition to taxonomies, there has been significant effort to compile comprehensive lists of clean energy technologies and to develop detailed technology roadmaps. A notable example is the International Energy Agency (IEA) Energy Technology Perspective, which provides a comprehensive explanation of various technologies across the clean energy and technology supply chain. Japan has similarly developed sector-specific roadmaps aimed at promoting climate transition finance and supporting the decarbonisation transition. However, those documents often lack guidance on how to evaluate technologies when considering transition finance.

(3) Need for a list of transition technology information and assessment framework

Despite the progress made in creating taxonomies, technology lists, and assessment frameworks for green and transition activities, financial institutions still face significant challenges in gathering the necessary information to evaluate transition technologies. This document provides a fact-based overview of each selected transition technology, helping financial institutions and other stakeholders better understand their suitability for transition finance. It is intended to catalyse the release of funding for these technologies, thereby supporting a just and orderly pathway to achieving net-zero emissions. Additionally, it will offer a framework to provide an overview of potential transition technologies.

Exhibit 2 shows how transition technologies can support a just and orderly transition in the ASEAN power generation sector. Under the business-as-usual (BAU) scenario, CO_2 emissions from power generation in ASEAN are estimated to reach 1,200 $MtCO_2$ in 2050, which is 70% higher than the 2020 level of 700 $MtCO_2$. This increase is due to the growing electricity demand driven by economic development and electrification. In contrast, the sustainable development scenario (SDS) shows that achieving net-zero emissions solely through renewable energies would require ASEAN countries to reduce emissions from 700 $MtCO_2$ in 2020 to 600 $MtCO_2$ by 2030, and maintain a rapid reduction rate of approximately 30 $MtCO_2$ per year from 2030 to 2050. On the other hand, adopting transition technologies such as carbon capture utilisation and storage (CCUS), along with hydrogen and ammonia could also reduce emissions below the BAU level. Although less aggressive, this approach allows ASEAN countries time to develop the necessary infrastructure whilst transitioning to a net-zero emission energy mix.

Exhibit 2. Role of Transition Technologies in Successful Decarbonisation in ASEAN Power Generation



BAU = business as usual; CCUS = carbon capture, utilisation, and storage; CO2 = carbon dioxide; $MtCO_2$ = metric tonne of carbon dioxide; RE = renewable energy; SDS = sustainable development scenario.
Sources: Economic Research Institute for ASEAN and East Asia (2022), International Energy Agency (2021).

1.5. The structure of this report

This report is organised into six key sections to provide a comprehensive overview of transition technologies and their role in facilitating a low-carbon economy in ASEAN. Each section is structured to guide readers through the development, assessment, and application of these technologies within the framework of transition finance.

2. **How to use the document.** This section provides practical guidance on using the TLP for assessing transition technologies across various sectors. It explains the framework's role in aiding stakeholders in decision-making.
3. **The first version of TLP.** An overview of the technologies and criteria considered in the first version of TLP.
4. **The second version of TLP.** Expands the scope to include additional sectors and technologies, with updated methodologies for assessing green and transition technologies across industries.
5. **Sector-specific needs.** This section identifies the unique challenges and technology needs for different sectors such as upstream, power, midstream, downstream, and the end-use and industries sectors offering insights into key technologies for emissions reduction.

6. **Summary and next phases.** The final section summarises key findings and outlines future steps for expanding and refining the Technology List to support Asia's transition to a low-carbon economy.

2. How to Use the Document

2.1. Development of the Technology List and Perspectives for Transition Finance in Asia

The first version of the Technology List and Perspectives for Transition Finance in Asia (TLP) was launched in September 2022 to support just and orderly energy transitions in developing Asia. This initiative adopts realistic approaches, enabling countries to pursue carbon neutrality whilst considering key factors such as energy security, affordability, accessibility, and environmental protection (Exhibit 1). TLP achieves this by providing a fact-based overview and a framework for assessing the suitability of transition technologies for financing.

In TLP, sectors are categorised into five groups based on energy-related activities: upstream, power, midstream, downstream, and end-use and industry sectors. These sectors are defined as follows:

Upstream sector:	The production of fuels for direct combustion and power generation.
Power sector:	The generation of power utilising renewable sources and/or the combustion of renewable or non-renewable fuels.
Midstream sector:	The transmission, transport, storage, and distribution of electricity and fuels.
Downstream sector:	The provision of electricity and fuels to end-users.
End-use and industry sector:	The use of electricity and fuels to provide services and produce goods.

It is important to note that the framework is not intended as a definitive tool for deciding whether to provide transition finance. For instance, it does not assess a particular technology's suitability in specific contexts or predicts its financial performance. Instead, the framework offers stakeholders an overview of potential transition technologies, functioning as an interim reference until more comprehensive technology roadmaps or taxonomies are published by Asian governments (Exhibit 3). Although the framework is primarily designed for financial institutions, it may also be useful for other public and private organisations. For example, it can assist corporations in decarbonising their operations or identify new business opportunities, and assist policymakers in understanding the technology landscape in Asia to inform their technology roadmaps, taxonomies, and decarbonisation policies.

Exhibit 3. How to Use the TLP

✓	✗
The document • Provides **a framework** for assessing a potential transition technology • Provides **relevant, practical information** on various potential transition technologies in **a fact-based manner** • Focuses upon major potential transition technologies, initially in a limited number of sectors. (Other sectors will be addressed in future updates.)	The document • Does **not** provide **absolute criteria** for what constitutes a transition technology. • Is **not restricted to** offering a set of **principles**; it provides example information on individual technologies • Is **not an exhaustive list** of potential transition technologies in Asia

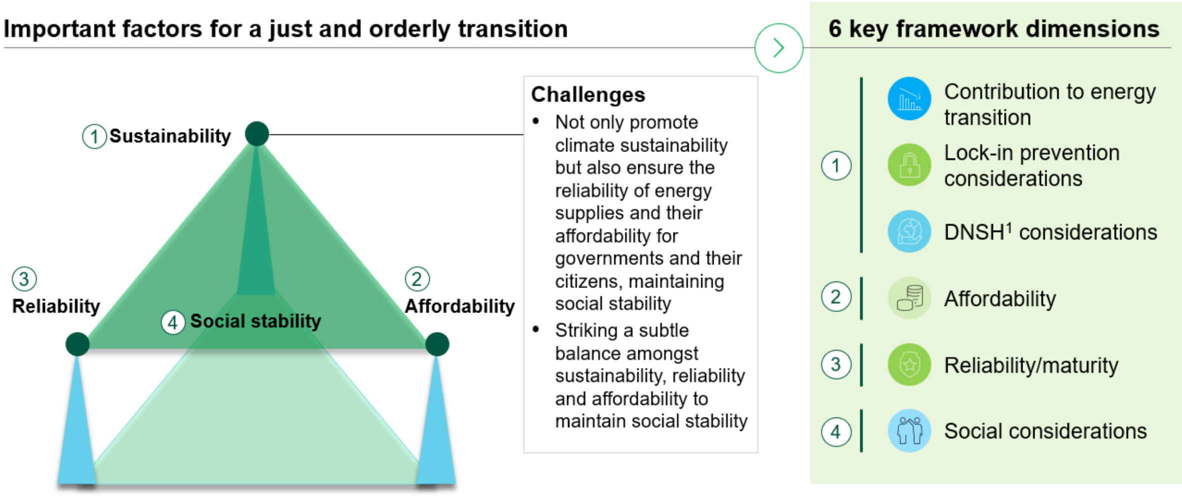
TLP = Technology List and Perspectives for Transition Finance in Asia.
Source: Economic Research Institute for ASEAN and East Asia (2022).

2.2. Assessments and considerations in TLP

(1) Elements assessed in TLP

TLP provides guidance on assessing a technology's suitability as a transition technology based on six dimensions that reflect a just and orderly transition to net-zero emissions. These are divided into two categories: three pertaining to the technology itself and three involving broader considerations linked to climate change mitigation and the three essential criteria (ECs) of the ASEAN taxonomy (Exhibit 5).

Exhibit 4. Six Framework Dimensions Addressing Important Factors for a Just and Orderly Transition



DNSH = do no significant harm.
Source: Economic Research Institute for ASEAN and East Asia (2022).

(2) Technology characteristics

The following characteristics determine how a technology contributes to a just and orderly transition to net-zero emissions.

- **Contribution to energy transition:** This assesses the sustainability of the technology, measuring how effectively it directly reduces emissions or enables others to do so, thereby contributing to the decarbonisation of projects, companies, and countries.
- **Reliability:** This assesses the maturity of a technology. A commercially available technology at scale is considered more reliable than one still in the pilot phase.
- **Cost:** The cost of the technology influences the affordability of the transition, whether it be the cost of abatement for upstream technologies or the lifetime cost of energy for power sector technologies.

(3) Additional considerations

Three additional factors help financial institutions determine the suitability of a technology as a transition technology.

- **Lock-in prevention considerations:** In the ASEAN taxonomy, this factor is part of the risk management tool (RMT). It examines potential paths for a technology to transition towards zero emission or net-zero emission when there is a remaining emission that cannot be completely eliminated by the technology.

- **Do no significant harm (DNSH) considerations**: This evaluates whether the technology could negatively impact other environmental objectives, such as ecosystem health, biodiversity, resource resilience, or the circular economy. It also assesses possible preventative measures, which are part of the RMT requirements in the ASEAN taxonomy.
- **Social considerations:** This assesses whether the technology could negatively impact society, such as by reducing employment opportunities.

Exhibit 5. Assessments Along the Six Framework Dimensions

	Framework dimensions	Description
Technology characteristics	**Contribution to energy transition**	GHG emissions intensity and/or reduction impact required to contribute to decarbonisation of a country or company
	Affordability	Estimated cost for technology
	Reliability/ maturity	Readiness for technology (e.g. commercial at scale, pilot, etc.).
Additional considerations	**Lock-in prevention considerations**	Eventual emissions reduction plan to reach zero or near-zero emissions.
	DNSH considerations	'Do No Significant Harm' to environmental objectives other than GHG emissions.
	Social considerations	Mitigate the negative effects of transition activities to the society, e.g. unemployment

1. All the environmental objectives in EU taxonomy are covered in the six framework dimensions. All environmental objectives and essential criteria in ASEAN Taxonomy for Sustainable Finance are similarly covered in the six framework dimensions.

DNSH = do no significant harm, GHG = greenhouse gas.
Source: Economic Research Institute for ASEAN and East Asia (2022).

When examining the DNSH and social considerations dimensions, the following key questions are addressed (Exhibit 6).

Exhibit 6. Key Considerations for the DNSH and Social Dimensions

Framework dimensions	Considerations/Key questions	
DNSH considerations	**Protecting healthy ecosystems and biodiversity**	• Would the technology be detrimental to the health and resilience of ecosystems and biodiversity? What preventative measures should be implemented? • Beside GHG, would the technology lead to a significant increase in the emissions of pollutants into the air, water, or land? What preventative measures should be implemented?
	Promotion of transition to circular economy	• Would the technology run on sustainably-sourced raw materials? • Would the technology increase the generation, incineration, or disposal of waste? What measures should be taken to avoid or minimise waste?
Social considerations	**Are there plans to mitigate the negative social impacts of the technology?**	• Would the technology lead to negative changes in job opportunities?
		• Would the technology lead to negative changes in working environments?

DNSH = do no significant harm, GHG = greenhouse gas.
Source: Economic Research Institute for ASEAN and East Asia (2022).

(4) Links between TLP and the ASEAN taxonomy

TLP provides guidance on assessing of suitability of each technology for transition finance, closely aligning with the ASEAN taxonomy. The ASEAN taxonomy defines four environmental objectives (EOs):

EO1: Climate change mitigation

EO2: Climate change adaptation

EO3: Protection of healthy ecosystems and biodiversity

EO4: Resource resilience and transition to a circular economy.

For an activity to be classified under the ASEAN taxonomy, it must contribute to at least one of these EOs. Amongst these, EO1 is the most relevant to TLP, as the focus is on energy transition. To meet EO1 criteria, an activity must show its contribution to one or more of the following:

1) avoiding GHG emissions;
2) reducing GHG emissions; and
3) enabling others to avoid or reduce GHG emissions.

Additionally, activities must meet the following three ECs:

EC1: Do no significant harm (DNSH). Activities must not cause significant harm to any EO. This includes ensuring that contributing to one EO does not detract from another.

EC2: Remedial measures to transition. Activities must have plans and measures in place to mitigate any potential significant harm within 5 years (see ASEAN Taxonomy Board [ATB], 2024) for more details).

EC3: Social aspects: Activities must adhere to social safeguards, including human rights, labour rights, and minimising impacts on vulnerable communities.

The three framework dimensions of TLP provide useful information and insights to assess an activity's suitability against EO1, EC1, and EC2 under the ASEAN taxonomy criteria.

Exhibit 7. Links Between Framework Dimensions of TLP and Relevant ASEAN Taxonomy Criteria

Framework dimensions of the TLP		Relevant ASEAN Taxonomy criteria
Contribution to energy transition		EO1: Climate Change Mitigation 1) Avoids GHG emissions 2) Reduces GHG emissions 3) Enables others to avoid or reduce GHG emissions
Lock-in prevention considerations		
DNSH considerations	Potential negative impacts	EC1: DNSH
	Mitigation measures	EC2: Remedial Measures to Transition (RMT)

ASEAN = Association of Southeast Asian Nations, DNSH = do no significant harm, EC = essential criteria, GHG = greenhouse gas, TLP = Technology List and Perspectives for Transition Finance in Asia.
Source: Author.

EC3, which focuses on a company's compliance with relevant social regulations and legislation within the ASEAN Member States (AMS), is primarily concerned with policies at the company level rather than the activity level.

However, whilst the ASEAN taxonomy does not require a social impact assessment at the activity level, TLP examines the social aspects of each transition technology. For potential users of TLP, such as financial institutions, policymakers, and corporations, understanding the positive or negative impacts of a technology on workers, communities, and the environment is crucial when assessing its suitability for transition finance.

3. The First Version of TLP

3.1. Coverage of technologies in the first version of TLP

The first version of TLP focused on technologies that met two criteria, described below, and provided guidance on how to assess their suitability for transition technology using six elements of a just and orderly transition to net-zero emissions.

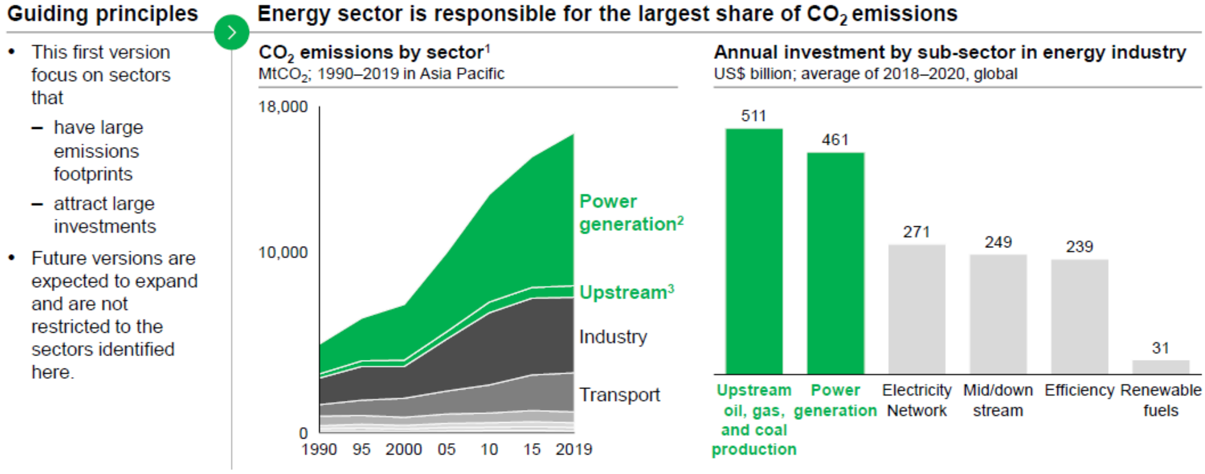
Exhibit 8. Focus of the First Version of TLP

Applicable sectors		Features of technology
In this first edition, the document covers technologies applicable to **the power (electricity generation) and its upstream (fuel production),** which together accounts for more than 50% of CO_2 emissions in Asia	×	The document covers technologies that: • Have **direct impact to carbon emissions reduction** • Are **not green/zero emissions technology** (those with zero carbon emissions through operation)

Source: Economic Research Institute for ASEAN and East Asia (2022).

Not all potential transition technologies were examined in the first version of TLP. The focus was on technologies with the most impact on reducing emissions, particularly in the power sector and related upstream activities, which together account for more than 50% of the region's CO_2 emissions (Exhibit 9). As a result, the first version examined 10 different technologies that could address emissions from these sectors (Exhibit 11). This list is not exhaustive, and the omission of a technology from this document does not disqualify it from being considered a transition technology.

Exhibit 9. Focus of the First Version of TLP



1. IEA data excludes non-fuel emissions, such as land-use change and forestry.
2. Includes emissions from electricity production, combined heat and power plants, and heat plants.
3. Includes emissions from fuel combustion in oil refineries, solid fuel production, coal mining, oil and gas extraction, and other energy-producing industries.

CO_2 = carbon dioxide, $MtCO_2$ = metric tonnes of carbon dioxide, TLP = Technology List and Perspectives for Transition Finance in Asia.
Source: Economic Research Institute for ASEAN and East Asia (2022).

Exhibit 10. Coverage of Technologies in the First Version of TLP

Classification of technologies/solutions relative to fulfilling decarbonisation goals

Green technologies Zero or near-zero emissions	• Renewable energy (solar, wind, biomass, small hydro, geothermal…) • Battery storage & other storage solutions • Grid interconnections, grid flexibility • BECCS • Direct air carbon capture • Large hydro and nuclear (subject to DNSH considerations)	Focus of green finance taxonomies
Transition technologies Significantly lower emissions	• Coal avoidance by early retirement and/or gas power generation • Inefficient plant phase out or upgrade (e.g. OCGT to CCGT) • Co-firing of low-carbon fuels • Venting and fugitive emissions reduction by leak detection and repair • Process electrification in gas production and processing • Low-carbon fuels production (ammonia, hydrogen) • CCUS	Focus of this document
Brown technologies	• Unabated coal-fired power generation[1] • Unabated oil (including diesel)-fired power generation	Progressively restricted from financing

BECCS = bioenergy with carbon capture and storage; CCGT = combined-cycle gas turbine; CCUS = carbon capture, utilisation, and storage; DNSH = do no significant harm; OCGT = open cycle gas turbine; TLP = Technology List and Perspectives for Transition Finance in Asia.
1In line with the Glasgow climate pact, this document assumes any coal-fired plants without co-firing or CCUS is classified as unabated, regardless of its efficiency (e.g. subcritical, supercritical, ultra supercritical, integrated gasification combined cycle, etc.)
Source: Economic Research Institute for ASEAN and East Asia (2022).

(1) Technologies included in the first version of TLP

The first version of TLP focused on technologies that met two key criteria:

- They are related to the power sector and upstream activities, such as gas production and treatment.

- They drive decarbonisation by directly reducing CO_2 emissions, though they are not zero-emission technologies. Zero-emission technologies, such as renewable energy or green hydrogen production, are classified as green technologies, and there are already clear guidelines in place to help financial institutions assess their suitability for funding. As a result, zero-emission technologies are excluded from consideration here. Also excluded are technologies that may be part of the value chain of a transition technology but do not themselves reduce CO_2 emissions. For example, whilst the use of low-carbon fuels such as hydrogen and ammonia is within the scope of the analysis due to their direct impact on emissions, the transport of these fuels is not.

Ten technologies were selected for close examination in the first version (Exhibit 11) based on the criteria mentioned above. It is not an exhaustive list of potential transition technologies. The exclusion of a technology from this document does not disqualify it from being considered a transition technology.

Exhibit 11. Ten Technologies Examined in the First Version of TLP

NON EXHAUSTIVE

Included in the first version (blue) | Not included in the first version (grey)

	Energy sector activities				Other sectors
	Upstream (fuel production)	**Power (electricity generation)**	**Mid-stream**	**Downstream**	**End-use**
Green/ zero emissions technology	Green hydrogen/ ammonia production Biogas production	Hydro, Solar, Wind, Geothermal, Biomass, BECCS, Nuclear, green fuel etc.	**Power transmission and distribution** • Storage system • Grid interconnectors, smart grid **Fuel transport** • Pipeline • Low-carbon fuel shipping and storage • LNG terminals to promote electrification or fuel switching	**Retail** • EV charging • Low-carbon hydrogen fuel station **Services to end users** • Provision of energy efficiency services to end users (e.g. ESCO)	**Industry** • Cogeneration/CHP[1] • Electrification **Transport** • EVs, FCVs • Sustainable fuels (biofuels), e.g. • Hybrid **Buildings** • Smart metering • Insulation • Heat pumps **Agriculture** • Electrification of machines
Transition technology	Fugitive emissions reduction (LDAR) Process electrification Blue ammonia/hydrogen production CCUS in gas production	CCGT (for coal avoidance or higher efficiency conversion) Waste to energy power plant Biomass or low-carbon fuels (ammonia, hydrogen) co-firing CCUS in coal/gas power plant			
Brown technology	Coal mining Oil extraction	Unabated coal-fired[2] Unabated oil-fired (incl. diesel)			

Note that the distinction between green/zero emissions and transition technology becomes blur after mid-stream

BECCS = bioenergy with carbon capture and storage; CCGT = combined-cycle gas turbine; CCUS = carbon capture, utilisation, and storage; CHP = combined heat and power; ESCO = energy service company; EV = electric vehicle; FCV = fuel cell vehicle; LDAR = leak detection and repair; LNG = liquefied natural gas.

1. In the majority of cogeneration and CHP cases, heat generated during electricity production is transferred to neighbouring industries or buildings, reducing their heat consumption. As a result, emission reductions occur in the industrial or building sectors, where this technology is categorised.

2. In line with the Glasgow climate pact's stipulation on the phase-down of unabated coal power, this document assumes any coal-fired plants without co-firing or CCUS fall under the category of unabated, regardless of their efficiency (subcritical, supercritical, ultra supercritical, integrated gasification combined cycle, etc.).

Source: Economic Research Institute for ASEAN and East Asia (2022).

The ten major technologies may vary in their emission intensity, influencing their suitability for deployment at different stages of decarbonisation.

They are categorised into the following groups:

- **Early decarbonisation technologies.** These have lower emissions than legacy technologies but still emit GHGs. They are suited for the early phases of a country's transition pathway and may be phased out before reaching net-zero emissions.
- **Partial emissions reduction technologies.** These have lower emissions than early decarbonisation technologies but still emit some GHGs. They can be deployed in the early and middle phases of a country's transition pathway.
- **Deep decarbonisation technologies.** These have near-zero or zero emissions and are essential for achieving net-zero targets. They can be deployed throughout a country's transition pathway.

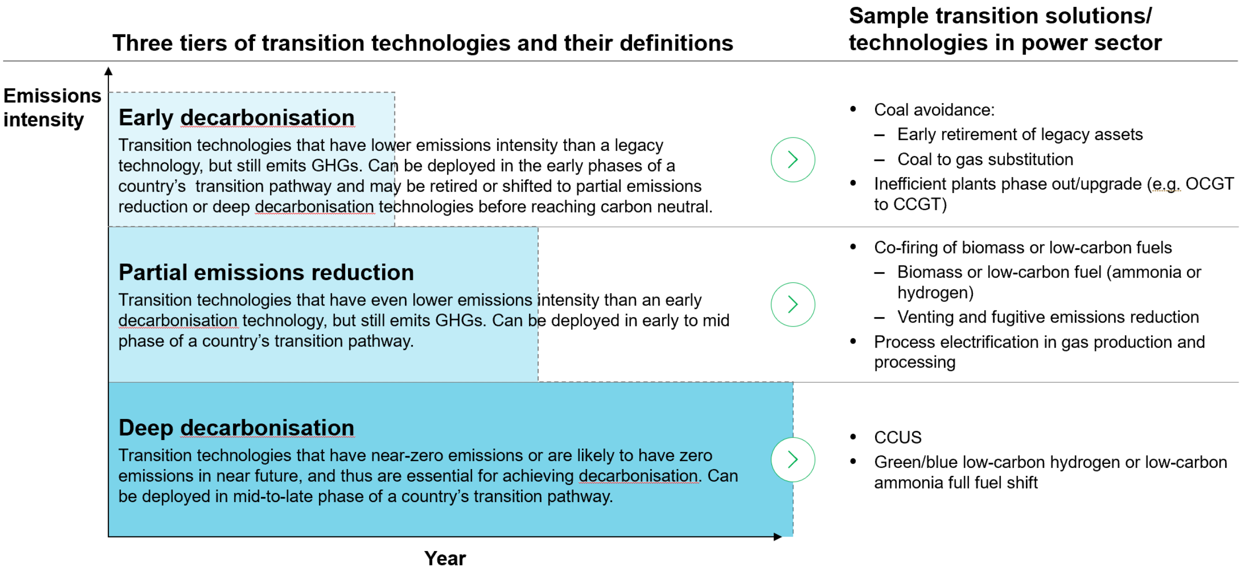
Exhibit 12. Technology Tiers of the Ten Technologies Covered in the First Version

The first version of the document prioritises technologies based on
- Direct and sizable impact on emissions reduction
- Neither zero emissions/green, nor brown
- Involving sizable deployment scale or investments

	Sector	
Technology tier	Power (Electricity generation)	Upstream (Fuel production)
Early decarbonisation	①CCGT (coal avoidance, higher efficiency conversion) ②Waste to energy power plant	⑥Leak detection and repair (LDAR) for fugitive emissions reduction
Partial emissions reduction	③Biomass co-firing ④Low-carbon ammonia co-firing ⑤Low-carbon hydrogen co-firing	⑦Process electrification in gas production and processing
Deep decarbonisation	⑧CCUS in coal/gas power plant	⑨Blue hydrogen & blue ammonia production ⑩CCUS in gas processing

CCGT = combined-cycle gas turbine; CCUS = carbon capture, utilisation, and storage.
Source: Economic Research Institute for ASEAN and East Asia (2022).

Exhibit 13. Three Tiers of Transition Technologies and their Definitions



CCGT = combined-cycle gas turbine; CCUS = carbon capture, utilisation, and storage; GHG = greenhouse gas; OCGT = open cycle gas turbine.
Source: Economic Research Institute for ASEAN and East Asia (2022).

(2) Sources examined for the first version of TLP

Various data sources were used to guide the assessment of the six elements. The contribution of a technology to energy transition was estimated using reports from the Intergovernmental Panel on Climate Change (IPCC), analysis by The Institute of Energy Economics, Japan (IEEJ), and a literature review of relevant case studies. Affordability assessments were based on IEEJ analysis, reports by the Danish Energy Agency and the International Renewable Energy Agency, and additional case studies (Exhibit 14). Reliability was gauged using the IEA's Technology Readiness Levels (TRL) (Exhibit 15).

Exhibit 14. References Examined for Six Framework Dimensions

	Framework dimensions	Description	Reference
Technology characteristics	**Contribution to energy transition**	GHG emissions intensity and/or reduction impact required to contribute to decarbonisation of a country or company	IPCCs, IEEJ
	Affordability	Estimated cost for technology	IEA, IEEJ, DEA, IRENA etc.
	Reliability/ maturity	Readiness for technology (e.g. commercial at scale, pilot, etc.).	Technology Readiness Level[1] by IEA (deep-dive page to follow)
Additional considerations	**Lock-in prevention considerations**	Eventual emissions reduction plan to reach zero or near-zero emissions.	EU Taxonomy and ASEAN Taxonomy for Sustainable Finance[2]
	DNSH considerations	'Do No Significant Harm' to environmental objectives other than GHG emissions.	
	Social considerations	Mitigate the negative effects of transition activities to the society, e.g. unemployment	

1. International Energy Agency, Energy Technology Perspectives, Clean Energy Technology Guide.
2. All the environmental objectives in the EU taxonomy are covered in the six framework dimensions. All the environmental objectives and essential criteria in the ASEAN Taxonomy for Sustainable Finance are similarly covered in the six framework dimensions.

ASEAN = Association of Southeast Asian Nations, DEA = Danish Energy Agency, EU = The European Union, GHG = greenhouse gas, IEA = International Energy Agency, IEEJ = Institute of Energy Economics, Japan, IPCC = Intergovernmental Panel on Climate Change, IRENA = International Renewable Energy Agency.
Source: Economic Research Institute for ASEAN and East Asia, The First Version of TLP (2022).

Exhibit 15. Technology Readiness Levels (TRL) and Descriptions

	Level	Description
Mature	11	Proof of stability reached – Predictable growth has been achieved.
Market uptake	10	Integration required at scale – The solution is commercial and competitive but requires further integration efforts.
	9	Commercial operation in relevant environment – The solution is commercially available, though it requires evolutionary improvement to stay competitive.
Demonstration	8	First-of-a-kind commercial – The solution is undergoing commercial demonstration, with full-scale deployment in final conditions.
	7	Pre-commercial demonstration – The prototype is working in expected conditions.
Large prototype	6	Full prototype at scale – The prototype has been proven at scale in the conditions where it will be deployed.
	5	Large prototype – Components have been validated in the conditions where they will be deployed.
Small prototype or lab	4	Early prototype – This prototype has been proven in test conditions.
	3	Concept requires validation – The solution needs be prototyped and applied.
	2	Application formulated – The concept and application have been formulated.
	1	Initial idea – The basic principles have been established.

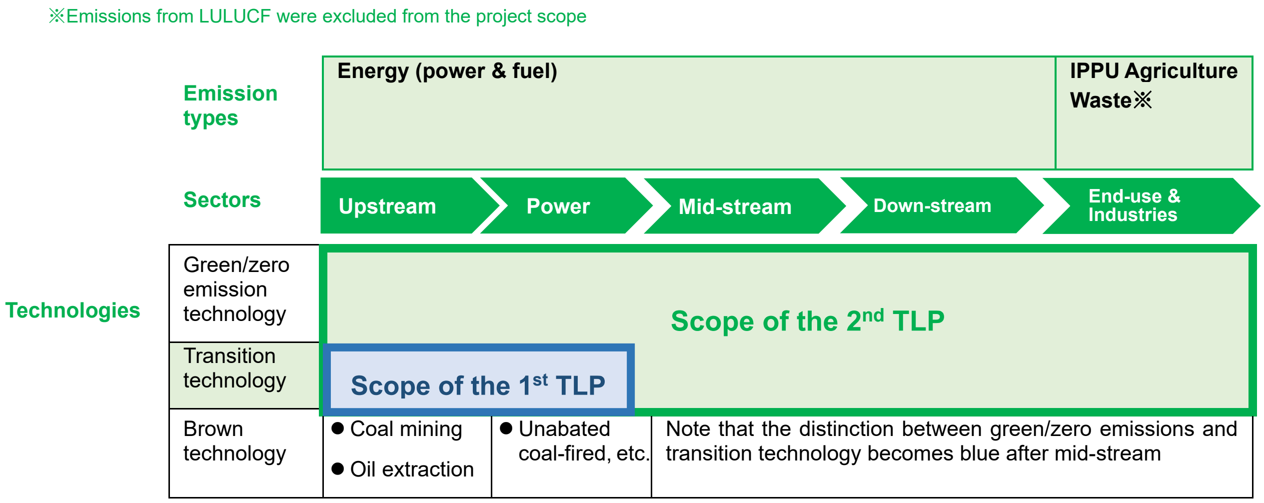
Sources: Economic Research Institute for ASEAN and East Asia (2022), International Energy Agency (2021).

4. The Second Version of TLP

4.1. Expansion of the sectors and technologies covered in TLP

Since the launch of the first version, numerous requests have been made by various entities to expand the coverage of sectors and technologies of TLP. Specifically, there have been requests to identify both green and transition technologies that address energy-related as well as non-energy-related emissions. The second version of TLP therefore aims to cover both green and transition technologies that address emissions across all sectors, including upstream, power, midstream, downstream, and industries, as well as the energy end-use sector (Exhibit 16).

Exhibit 16. Coverage of the Second TLP Version



IPPU = industrial processes and product use, LULUCP = land use, land use change and forestry, TLP = Technology List and Perspectives for Transition Finance in Asia.
Source: Author.

The second version of TLP provides two types of outputs: 1) an inclusive list of potential green and transition technologies and 2) a deep-dive research outcome of selected transition technologies (Exhibit 17). These outputs are intended for different stakeholders, serving various purposes (Exhibit 18). Two deep-dive research outcomes are planned – one for the end-use and industries sectors, and another for the other sectors.

Exhibit 17. Two Outputs in the Second Version of TLP

#	Document	Technology types to be included	Main purpose
1	Inclusive list of potential sustainable/transition technologies (Long list)	Green and transition technologies across all sectors for both energy-related and non-energy-related emissions	To showcase available green and transition technologies for each sector.
2	Deep-dive research outcome of selected transition technologies	Selected transition technologies investigated across six framework dimensions	For financial institutions and other stakeholders to assess the suitability of transition technologies for financing and implementation.

Source: Author.

Exhibit 18. How Different Stakeholders Can Use the Two Outputs

	Inclusive list of potential sustainable/transition (Long list)	Deep-dive research outcome of selected transition technologies
Financial institutions	To understand the landscape of potential green and transition technologies.	To assess the suitability of transition technologies for financing.
Corporations	To identify technologies for decarbonising their businesses.	To plan decarbonisation activities using specific technologies.
Policymakers	To quickly understand the technology landscape and see what can support decarbonisation road maps, strategies, and policies.	To understand how specific technologies can contribute to achieving decarbonisation road maps, strategies, and policies.

Source: Author.

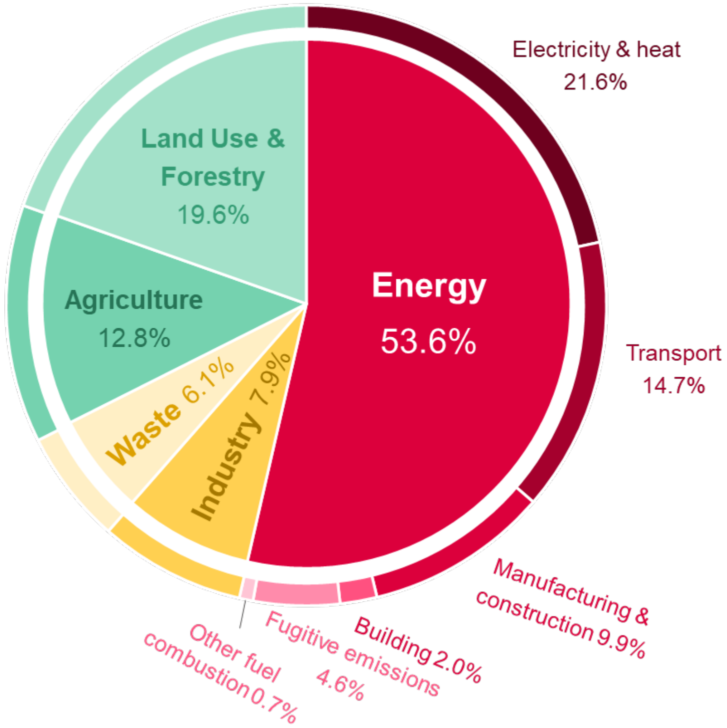
4.2. Methodologies

To create the inclusive list of green and transition technologies, a three-step approach was applied. The first step was to assess the emission profile of ASEAN sectors to identify those with the more urgent decarbonisation needs. The second step was to compile potential green and transition technologies from various sources. The last step was to apply selection criteria to refine the list and group similar technologies under umbrella categories. As a result, 176 technologies were identified as green and transition technologies, classified by their decarbonisation mechanisms (Exhibit 23).

(1) GHG emission profile of ASEAN

As shown in Exhibit 19, the energy sector, including direct fuel combustion and electricity use, is the largest contributor to GHG emissions in ASEAN. Within this sector, the generation of electricity and heat is the largest emitter, followed by direct fuel combustion in transport, manufacturing, construction, and buildings. Fugitive emissions are associated with the fossil fuel production.

Exhibit 19. GHG Emissions by Sector in ASEAN (2021)



Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch, Historical GHG Emissions (2022).

Thus, the second version of TLP focuses on energy-related emissions, including emissions from electricity and heat production and direct fuel combustion. However, in some sub-sectors, such as cement, concrete, glass, iron, and steel, significant emissions arise from chemical processes rather than energy use. For these sub-sectors, technologies addressing process emissions are also considered.

In ASEAN's forestry and other land use (FOLU) sector, major emission sources include peatland management (e.g. peat fires and decomposition), and land-use changes (e.g. conversion to settlements). Peatland management is particularly critical in Indonesia, home to more than half of the world's tropical peatland. Peat fires can be prevented through improved firefighting and surveillance, whilst peat decomposition can be mitigated by restoration initiatives such as soil management planning. Land conversion to settlements, driven by urban expansion, contributes to emissions from reforestation and land use. To reduce these emissions, sustainable soil management must be integrated into urban planning processes. Therefore, addressing emissions from the FOLU sector relies more heavily on regulations, law enforcement, and planning rather than technology alone (IPCC, 2006d; UNEP, 2024).

(2) Data sources referred to for identifying green and transition technologies

To identify potential green and transition technologies across the sectors described above, a wide range of data sources were examined. Examples of these sources include:

- The Clean Energy Technology Guide by the International Energy Agency (IEA) (last updated 14 September 2023)
- Technology Roadmaps for 'Transition Finance' by the Ministry of Economy, Trade and Industry of Japan (METI) (2021)
- Energy Saving/Non-fossil Energy Transition Technology Strategy 2024 by the New Energy and Industrial Technology Development Organization
- Use of the internet search to capture a wide range of green and transition technologies
- Patent and journal databases (used for supplementary purposes)

(3) Selection criteria for the inclusive list of green and transition technologies

Some technologies were not included in the inclusive list of green and transition technologies, mainly because they do not directly contribute to energy transition or emission reduction (Exhibit 19).

Exhibit 20. Criteria for Identifying Green and Transition Technologies

■Technologies that
- Directly contribute to energy transition/ emission reduction
- Require to be newly introduced or repurposed
- Can be deployed stand-alone
- Are TRL 3 or higher as they are at least prototyped and applied
- Come with a geological structure to add some modification to it so that it can store lower-emission fuels or CO2 etc.

■ Technologies that
- Do not directly contribute to energy transition/ emission reduction
- Are new applications of existing technologies and do not require new investment
- Cannot be deployed stand-alone
- Are TRL 2 or lower as they are still at a concept stage without any proof

■ A geological structure which is present in nature and does not require any modification to provide the said function for the energy transition/emission reduction

TRL = technology readiness level.
Source: Author.

Exhibit 21. Examples of Excluded Technologies and Reasons for Exclusion

Excluded Technologies	Reason for Exclusion
• Battery shredding technology for recycling • Optical sorting for battery waste	Those technologies reduce the usage of virgin material, thereby indirectly reducing the carbon footprint of final products. As the emission reduction effect is indirect, they were excluded.
• Aquifer storage to store hydrogen	This is a naturally occurring geological structure and does not require the application of new technology. Hence, it was excluded.
• Multivalent ion battery (TRL2)	TRL 2 indicates the technology is still at the concept stage, without a proven prototype. It would not be useful for TLP users to see technologies at such an early stage, as they are far from commercialisation.
• Hydrogen tanks for hydrogen-fuelled vehicles • On-board fuel storage for airplane	These underlying technologies, which are not standalone solutions, would not be suitable for TLP users as standalone financing proposals. Insulation materials and heat-harvesting materials for buildings were grouped together under the umbrella of 'insulation materials' as they are typically deployed together.

TRL = technology readiness level.
Source: Author.

(4) Result of identifying green and transition technologies

Using the three-step approach described above, 176 technologies were identified as green and transition technologies (Exhibit 22). These technologies were classified into several types based on their decarbonisation mechanisms as shown in Exhibit 22.

Exhibit 22. Number of Technologies Identified by Sector

#	Category		Inclusive List of Green and Transition Technologies (long-list)
I	Upstream		32
II	Power		35
III	Midstream		19
IV	Downstream		4
V	Industries	Buildings	17
VI		Transport	25
VII		Industry (specific)	34
VIII		Industry (cross-cutting)	10
TOTAL			**176**

Source: Author.

Exhibit 23. Types of Identified Technologies

Technology Type	Description	Example Technologies
Renewables	Technologies that generate electricity from renewable sources, mostly identified in the power sector.	Solar, wind, geothermal, hydro, ocean, etc.
Energy efficiency and conservation	Technologies that reduce the use of electricity or fuels, mainly found in the end-use and industries sectors.	Heat pumps, building energy management system, energy-efficient ships, etc.
Fuel switching	Technologies that enable the use of lower-emission fuels such as LNG, biofuels, hydrogen, or ammonia, instead of coal or oil. The was found in most sectors.	Electrolysers for hydrogen production, ammonia storage, biofuel-powered ships, etc.
Electrification	Technologies that replace energy from oil and/or gas combustion with electricity. Although part of fuel switching, it is categorised separately due to its importance.	Electric motorbikes, battery-electric vehicles, battery-electric ships, etc.
CCUS	Technologies that capture, transport, store and/or utilise CO_2.	Direct air capture (DAC), carbon mineralisation, production of chemicals using captured CO_2, etc.
Raw material switching	Technologies that replace GHG-emitting materials with lower-emissions alternatives, mainly in the end-use and industries sector.	DRI with alternative reducing agents, modified fertilisers, etc.
Other	Technologies that do not fit into the categories above but contribute to the transition to a low-carbon economy.	Waste heat utilisation, fugitive emission abatement, nuclear power generation, etc.

CCUS = carbon capture, utilisation, and storage; CO2 = carbon dioxide; LNG = liquefied natural gas; DRI = direct reduced iron; GHG = greenhouse gas.
Source: Author.

5. Sector-specific Needs for ASEAN to Transition to a Low-carbon Economy

ASEAN faces unique challenges in transitioning to a low-carbon economy. These challenges have been thoroughly investigated for each sector to identify green and transition technologies that are appropriate to address the region's specific needs.

5.1. The upstream sector

The upstream sector involves the production of fuels for both direct combustion and power generation. A total of 32 green and transition technologies have been identified to reduce emissions from this sector.

Exhibit 24. Green and Transition Technologies Identified for the Upstream Sector

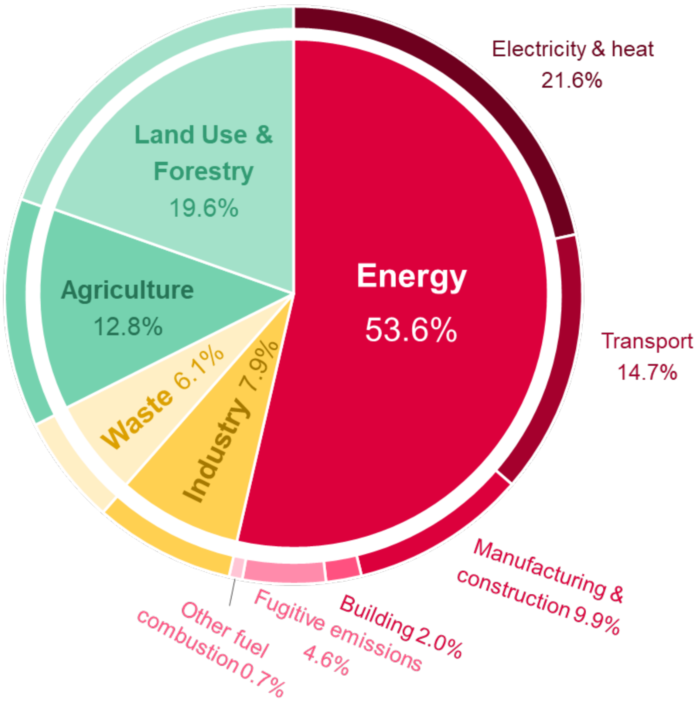
Ref	Technology Name	Ref	Technology Name
I.01	Harber-Bosch process	I.17	Ammonia cracking
I.02	Torrefaction (for high and low-to-medium temperature heating)	I.18	Methane decomposition
I.03	Alcohol-to-jet biodiesel (sustainable aviation fuels)	I.19	Partial oxidation of natural gas
I.04	FAME (SAF)	I.20	Methane reforming (CCU)
I.05	Gasification and Fischer-Tropsch biodiesel (SAF)	I.21	Electrolysers
I.06	HEFA/HVO (SAF)	I.22	Biomass-waste gasification/pyrolosis
I.07	Hydrothermal liquefaction and upgrading (SAF)	I.23	Hydrogen post-production conditioning
I.08	Pyrolysis (biodiesel)	I.24	Natural hydrogen extraction
I.09	Synthetic Iso-Paraffins (biodiesel)	I.25	Water splitting
I.10	Fermentation	I.26	Anaerobic digestion for biomethane and biogas production
I.11	Direct air capture	I.27	Biomass gasification and methanation
I.12	CCUS in fossil fuel production	I.28	Chemical/biological methanation
I.13	Process electrification in gas production	I.29	Synthetic methane from CO and H_2
I.14	Leak detection and repair	I.30	Biomass and waste gasification
I.15	Biological splitting	I.31	CO_2- and electrolytic hydrogen-based methanol production
I.16	Aluminium oxidation	I.32	Methane pyrolysis

CCU = carbon capture and utilisation; CCUS = carbon capture, utilisation and storage; CO = carbon oxide; FAME = fatty acid mehyl ester; H2 = hydrogen; HEFA = hydroprocessed esters and fatty acids; SAF = sustainable aviation fuel.
Source: Author.

(1) The need to reduce emissions in the upstream sector

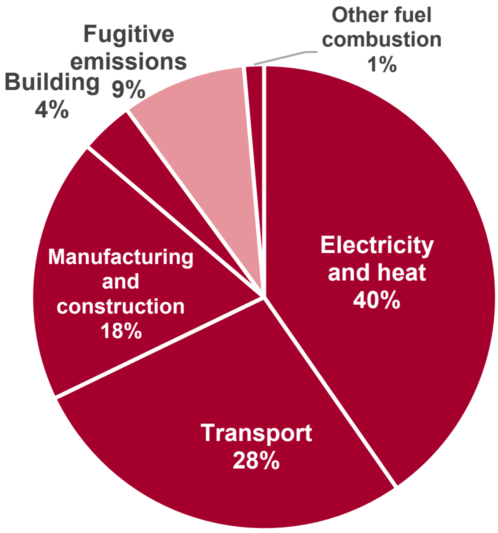
In ASEAN, energy-related emissions account for almost half of the region's total GHG emissions (Exhibit 25). Most of these emissions result from fossil fuel combustion, which is expected to continue rising (International Energy Agency, 2023c). Fossil fuels are used not only in power generation but also directly in the transport, manufacturing, and building sectors (Exhibit 26). Therefore, increasing the production of lower-emission fuels, such as biofuels and green hydrogen, in the upstream sector, will significantly contribute to emissions reductions in both the power and industries sectors.

Exhibit 25. Energy-related GHG Emissions in ASEAN (2021)



Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

Exhibit 26. Energy-related Greenhouse Gas Emissions by Sector in ASEAN (2021)

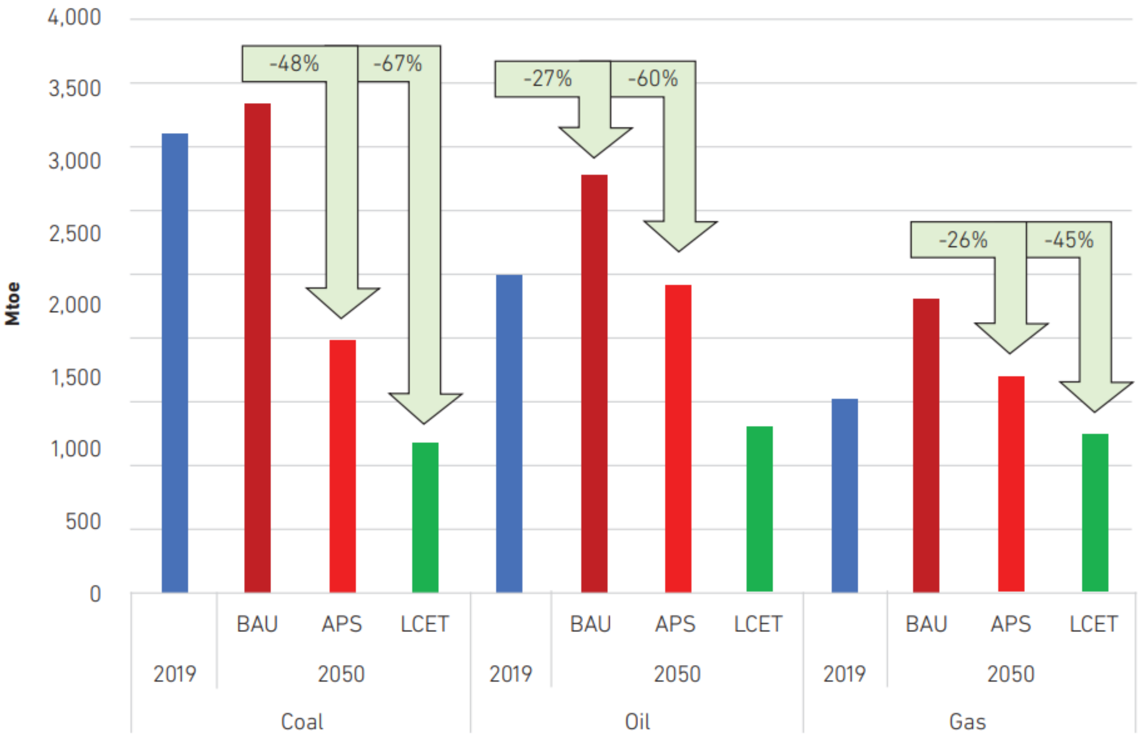


Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

(2) Lower-emission fuels in TLP

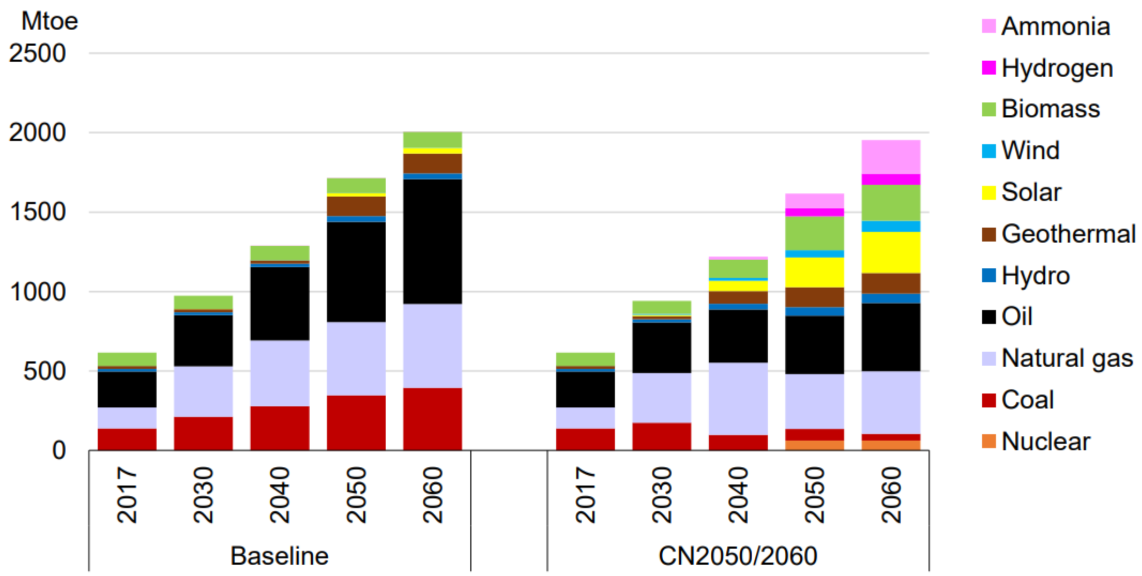
Whilst ASEAN continues its efforts to phase out fossil fuels, particularly coal, these fuels will still play a role in achieving a just and orderly energy transition (Exhibit 27, Exhibit 28). Therefore, in TLP, natural gas and LNG, which emit fewer emissions compared to coal or oil for the same energy output, are considered transition fuels.

Exhibit 27. Primary Energy Supply by Fossil Fuel Source, Business-as-Usual Scenario vs Alternative Policy Scenario vs Low-carbon Energy Transition



BAU = business as usual, APS = alternative policy scenario, LCET = low-carbon energy transition, Mtoe = million tonnes of oil equivalent.
Source: Economic Research Institute for ASEAN and East Asia, Energy Outlook and Energy-Saving Potential in East Asia 2023.

Exhibit 28. Primary Energy Supply in ASEAN (CN2050/2060)



Mtoe = million tonnes of oil equivalent, CN = carbon neutrality.
Source: Economic Research Institute for ASEAN and East Asia, Decarbonisation of ASEAN Energy Systems: Optimum Technology Selection Model Analysis up to 2060.

AMS are increasingly adopting biofuel mandates. Indonesia, Malaysia, the Philippines, and Thailand have implemented large-scale biofuel blending programmes, whilst Viet Nam and the Lao People's Democratic Republic are in the process of doing so as of 2020. Thus, natural gas, LNG, and biofuels are recognised as important lower-emission fuels in the development of the second version of TLP.

Exhibit 29. Examples of Biofuel Mandates in ASEAN Countries

Country	Biofuel Mandate
Indonesia	Biofuel mandate has evolved from B2.5 in 2008 to B35 in 2023, with plans for further increases.
Malaysia	Implemented a B10 biodiesel mandate, aiming for B30 by 2025. Regions like Sarawak, Labuan, and Langkawi islands have already reached B20.
Philippines	Plans to increase biofuel mandates were suspended for 3 years due to high bioethanol and biodiesel prices, leaving blending rates at B2 and E10. Despite a refinery capacity of 677.9 million litres per year, actual biofuel production was around 220 million litres in 2023.
Thailand	Plans to reduce biodiesel blending from B10 to B7 and switch bioethanol from E85 to E20, for reasons similar to the Philippines.

ASEAN = Association of Southeast Asian Nations.
Source: ASEAN Centre for Energy (2024).

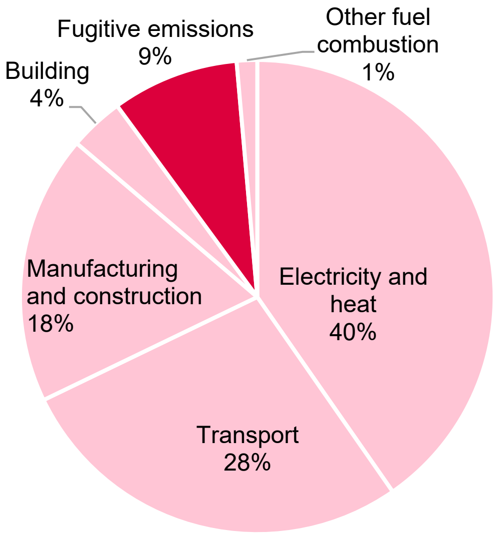
(3) Fugitive emissions

Transitioning away from fossil fuels towards lower-emission alternatives is the key to the energy transition. However, during fossil fuel production, emissions known as 'fugitive emissions' are released, which require close attention in the upstream sector. Whilst there is no universally accepted definition, the upstream sector in TLP follows the 2006 IPCC Guidelines, defining fugitive emissions as including both carbon dioxide and methane (CH_4) emissions. These emissions encompass all intentional and unintentional releases that occur during the extraction, processing, storage, and transport of fuel until its final point of use.

In ASEAN, fugitive emissions account for 9% of the energy-related emissions (Exhibit). Coal is the largest source of fugitive emissions, accounting for more than half of the total fugitive emissions from fuel types, with CH_4 emissions significantly exceeding CO_2 emissions (International Energy Agency, 2023c). In addition, in the energy transition period, natural gas is becoming an important transition fuel, with LNG imports increasing across the region (ERIA, 2024). According to the IEA Global Methane Tracker (2023), it is possible to reduce these emissions by up to 40% at no net cost with incumbent technologies (IEA, 2023). In ASEAN context, this amount represents an additional 0.4 million tonnes of natural gas, or 2%–3% of ASEAN's

LNG annual imports, highlighting the significant impact that methane reduction efforts could have on ASEAN's energy security. Therefore, identifying and prioritising technologies to reduce coal-related fugitive emissions, with a particular focus on methane, is crucial in addressing emissions in the upstream sector.

Exhibit 30. Energy-related Greenhouse Gas Emissions by Sector in ASEAN (2021)



ASEAN = Association of Southeast Asian Nations.
Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

(4) Technology selection hypothesis for deep-dive research

To address emissions from the upstream sector, research should prioritise technologies that support the production of lower-emission fuels, such as biomass, hydrogen, ammonia, and natural gas. In addition, technologies addressing fugitive emissions, particularly methane emissions from coal extraction, production, storage and transport processes, should be emphasised.

5.2. The power sector

The power sector generates electricity by utilising renewable sources and/or combusting fuels. A total of 35 green and transition technologies have been identified to mitigate emissions within this sector.

Exhibit 31. Green and Transition Technologies Identified for the Power Sector

Ref	Technology Name	Ref	Technology Name
II.01	CO_2 storage	II.19	Combined cycle and hybrid plant
II.02	CO_2 transport	II.20	Direct dry steam plant
II.03	Enhanced oil recovery and enhanced gas recovery	II.21	Enhanced geothermal system
II.04	Biomass-fired power plant with CCUS	II.22	Flash steam plant
II.05	CCUS in coal and gas power plant	II.23	Hydropower
II.06	Chemical looping with CCUS	II.24	Ocean thermal
II.07	Combined cycle gas turbine	II.25	Ocean wave
II.08	Supercritical CO_2 cycle	II.26	Salinity gradient
II.09	Low-carbon ammonia co-firing	II.27	Crystalline silicon PV
II.10	Biomass co-firing	II.28	Perovskite
II.11	Integrated gasification combined-cycle biomass power plant	II.29	Thin-film PV
II.12	Fuel cell	II.30	Solar thermal energy
II.13	Low-carbon hydrogen co-firing	II.31	Tidal energy
II.14	Waste to energy	II.32	Airborne wind energy system
II.15	High-temperature reactor and very high-temperature nuclear reactor	II.33	Offshore wind turbine
II.16	Sodium-cooled fast nuclear reactor	II.34	Onshore wind turbine
II.17	Light water nuclear reactor	II.35	Organic Rankine Cycle Power generation
II.18	Binary plant		

CCUS = carbon capture, utilisation, and storage; CO_2 = carbon dioxide; PV = photovoltaic.
Source: Author.

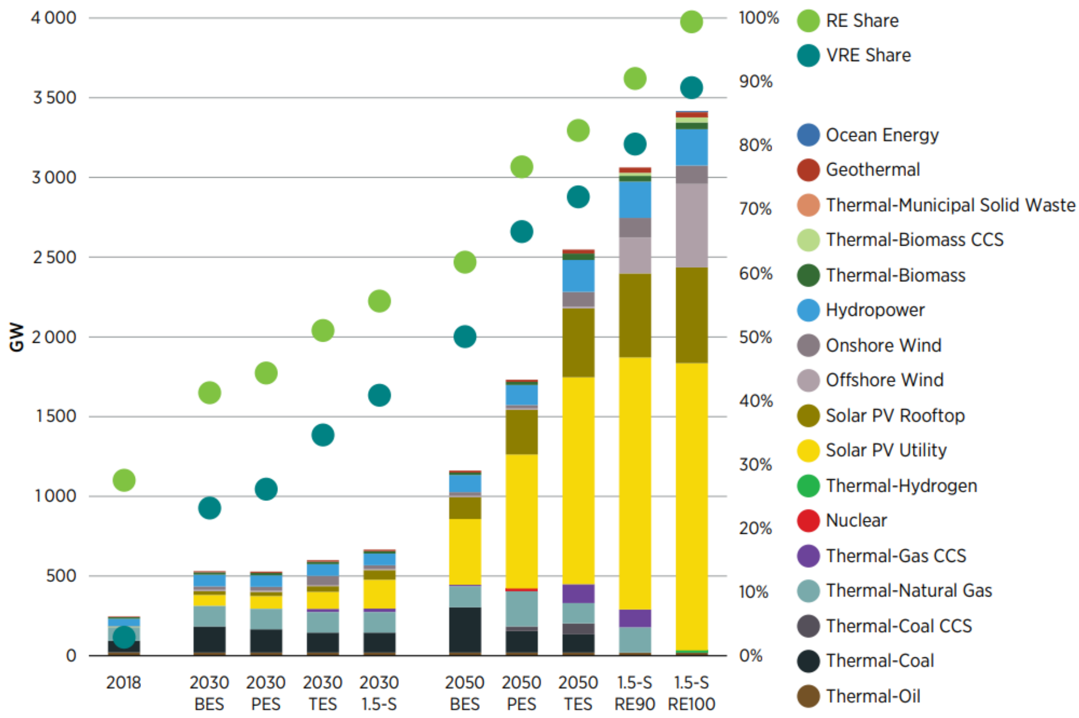
(1) The need for renewable energy and lower emission electricity generation

Electricity in ASEAN is largely generated through the combustion of fossil fuels, with coal being the largest emitter in the power generation sector. Although the need for renewable energy is widely recognised, a tailored approach to decarbonisation is essential, considering the diverse national circumstances across the region (Ministry of Foreign Affairs of Japan, 2023)

The IRENA and ACE report (2022) describes several pathways for energy transition in ASEAN. First, the planned energy scenario considers a future where current and planned policies are applied without drastic changes. Next, the transforming energy scenario (TES) examines the future where readily available and affordable technologies are adopted. Finally, the 1°C scenario (1.5-S) is the most ambitious, aiming for global net-zero emissions by 2050. Exhibit 32 shows te power generation mix of AMS under each of these scenarios.

From the scenario analysis, it is evident that although AMS are implementing policies to increase renewable energy, thermal energy plants will remain important during the transition to a low-carbon economy, given their long operational lifetimes, even under the TES.

Exhibit 32. Power Capacity and Renewables Share by Sources, 2018–2050

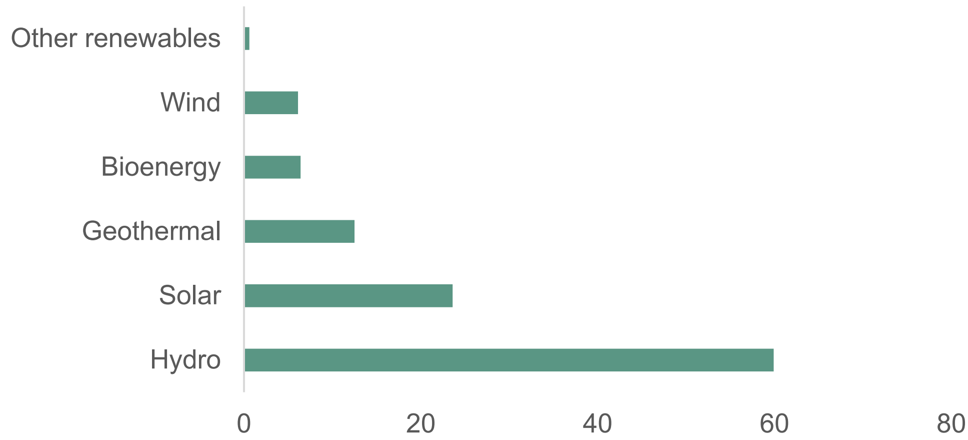


Note: RE = renewable energy; VRE = variable renewable energy.

*Base energy scenario (BES): Assumes current or planned policies are not adhered to or are rolled back. (Similar to business-as-usual scenario)
*Planned energy scenario (PES): Reflects current plans and expected objectives or policies.
*Transforming energy scenario (TES): Largely based on low- and zero-carbon technologies.
*1.5oC scenario (1.5-S): Aiming to reach net-zero emissions by 2050.
CCS = carbon capture and storage, PV = photovoltaic, RE = renewable energy,
Source: International Renewable Energy Agency and ASEAN Centre for Energy (2022).

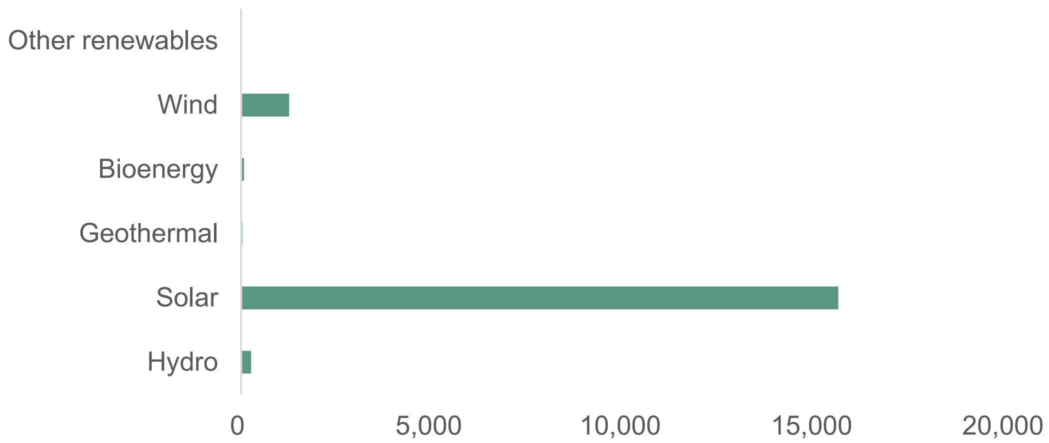
In 2021, ASEAN's installed renewable energy capacity was 108 gigawatts (GW) (Exhibit 26), whilst the potential for renewable power generation across the region was 17,229 GW (Exhibit 27), according to IRENA. The suitability of renewable energy types varies across ASEAN countries due to geographical differences; however solar and wind energies, both onshore and offshore, hold the greatest potential.

Exhibit 26. Installed Renewable Energy Capacity in ASEAN, 2021 (gigawatt)



Source: Mitsubishi Research Institute Inc., based on International Renewable Energy Agency and ASEAN Centre for Energy (2022).

Exhibit 27. Renewable Energy Potential for Power Generation in ASEAN (gigawatt)



Source: Mitsubishi Research Institute Inc., based on International Renewable Energy Agency and ASEAN Centre for Energy (2022).

(2) Challenges in increasing renewable energy capacity

Expanding renewable energy capacity poses challenges in relation to the transmission of renewable energy and grid stability. The power grid operates at a specific frequency (e.g. 50 Hz in Europe and Asia, 60 Hz in North America). If supply exceeds demand, the frequency increases, and if demand exceeds supply, the frequency decreases. Significant deviations from the nominal frequency can damage equipment and lead to power outages. Voltage levels within the grid are also affected by the supply–demand balance. Maintaining correct voltage is essential for the proper functioning of electrical equipment, as imbalances can lead to voltage fluctuations, potentially damaging sensitive equipment. Overloading the grid infrastructure, such as transformers and transmission lines, occurs when supply significantly exceeds demand, causing overheating and physical damage to components. Efficient power generation requires a precise balance between supply and demand, as overproduction leads to waste, whilst underproduction necessitates the rapid activation of additional, more often expensive, generation methods. Thus, ensuring supply–demand alignment is critical for maintaining grid stability.

(3) Technology selection hypothesis for deep-dive research

For the power sector, priority should be given to technologies that address emissions from coal- or gas-fired thermal power plants, such as co-firing and CCS. Additionally, fuel switching, including the use of biomass-derived fuels, natural gas, and LNG as transition fuels, should be considered. Whilst renewable energies, particularly solar and wind, are integral to decarbonising ASEAN's power sector, they are beyond the scope of this deep-dive research, which focuses on transition technologies.

5.3. The midstream sector

The midstream sector encompasses the transmission, storage, and distribution of electricity and fuels. To support the transition to a low-carbon economy, 19 green and transition technologies have been identified to address challenges within this sector.

Exhibit 35. Green and Transition Technologies Identified for the Midstream Sector

Ref	Technology Name	Ref	Technology Name
III.01	DC microgrid	III.11	Power-to-heat
III.02	Demand response systems	III.12	Thermal storage
III.03	Double (dual) smart grid	III.13	Hydrogen pipeline
III.04	Smart grid	III.14	Natural gas supply network
III.05	Flexible AC transmission system	III.15	Ammonia truck
III.06	High-voltage (HVDC) transmission system	III.16	Hydrogen truck
III.07	Ammonia storage tank	III.17	Ammonia tanker
III.08	Battery for grid use	III.18	Hydrogen tanker
III.09	Hydrogen storage	III.19	LNG tanker
III.10	Mechanical energy storage		

AC = alternating current, DC = direct current, HVDC = high-voltage direct current, LNG = liquefied natural gas.
Source: Author.

(1) Challenges in transmitting renewable energies

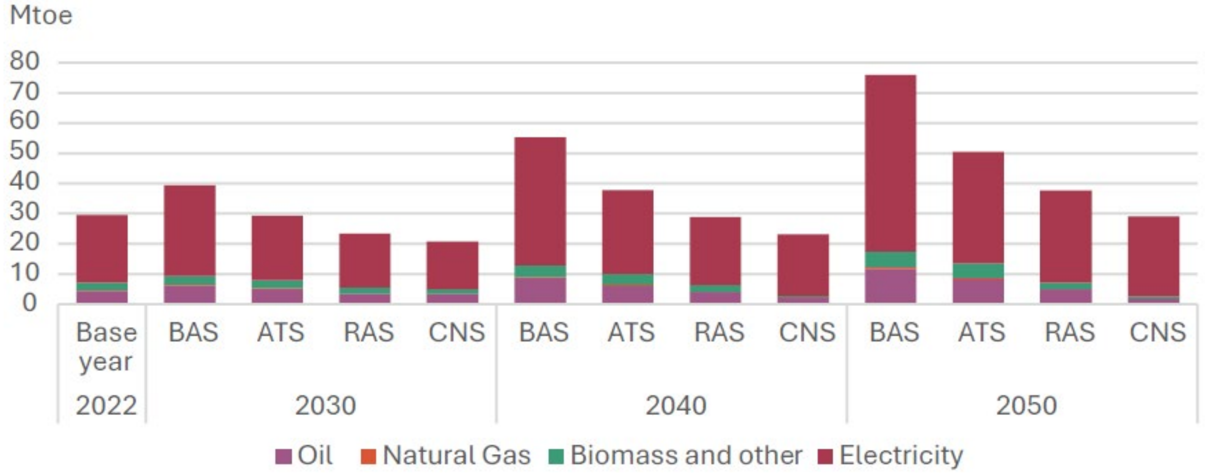
Renewable energy sources, such as solar and wind, have fluctuating production capacities due to variations in sunlight intensity and wind speed, which cannot be controlled. Without appropriate measures, the power generated may not always align with demand when it is needed. Another significant challenge is that these systems are often located in remote areas, far from where the energy is consumed, such as offshore wind farms. The longer the distance electricity must travel from generation to consumption, the greater the line losses, requiring the use of long-distance cables, which can further cause additional losses. Additionally, many renewable energy systems generate direct current (DC), whilst the grid and most appliances require alternating current (AC). For example, solar photovoltaic (PV) systems produce DC, which must be converted to AC using a converter, resulting in some electricity loss during the conversion process.

(2) The need for distributing lower-emission fuels

In non-energy sectors such as transport, industry, and commercial sectors, natural gas and biomass are expected to play important roles in reducing GHG emissions from fuel combustion.

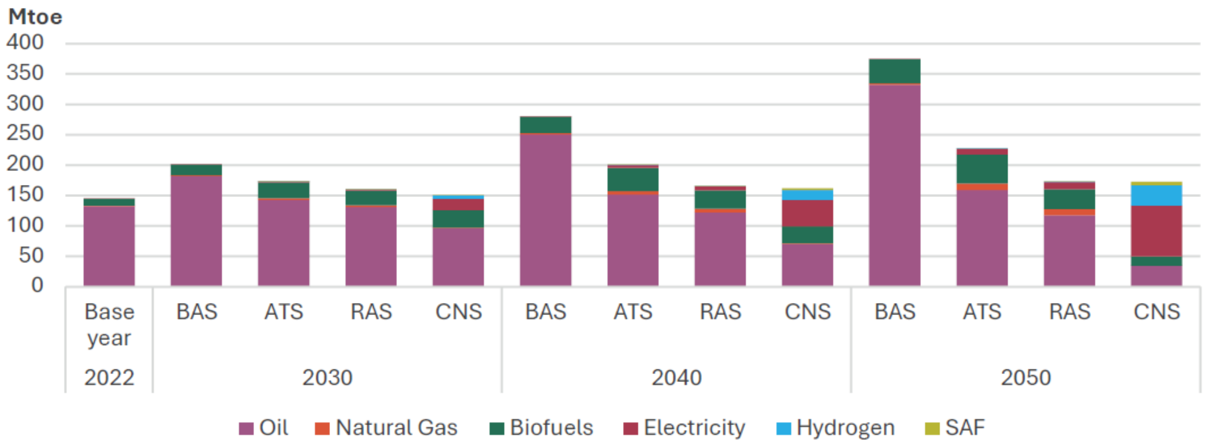
Exhibit 36, Exhibit 37, and Exhibit 38 show fuel consumption forecasts for the transport and industry sectors across three main scenarios described in the 8th ASEAN Energy Outlook Report (ACE, 2024). The baseline scenario (BAU) follows historical fuel consumption trends in AMS. The AMS targets scenario (ATS) reflects a future where national energy policies, especially on energy efficiency and renewable energy, are successfully implemented. The regional aspiration scenario (RAS) assumes least-cost optimisation in the power sector, adhering to the regional targets of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025 – ASEAN's energy cooperation blueprint – whilst incorporating regional standards and accelerated targets of each AMS wherever feasible. Lastly, the carbon neutrality scenario (CNS) is based on net-zero pledges and ambitious decarbonisation efforts by AMS.

Exhibit 36. Commercial Consumption by Fuel Across Scenarios



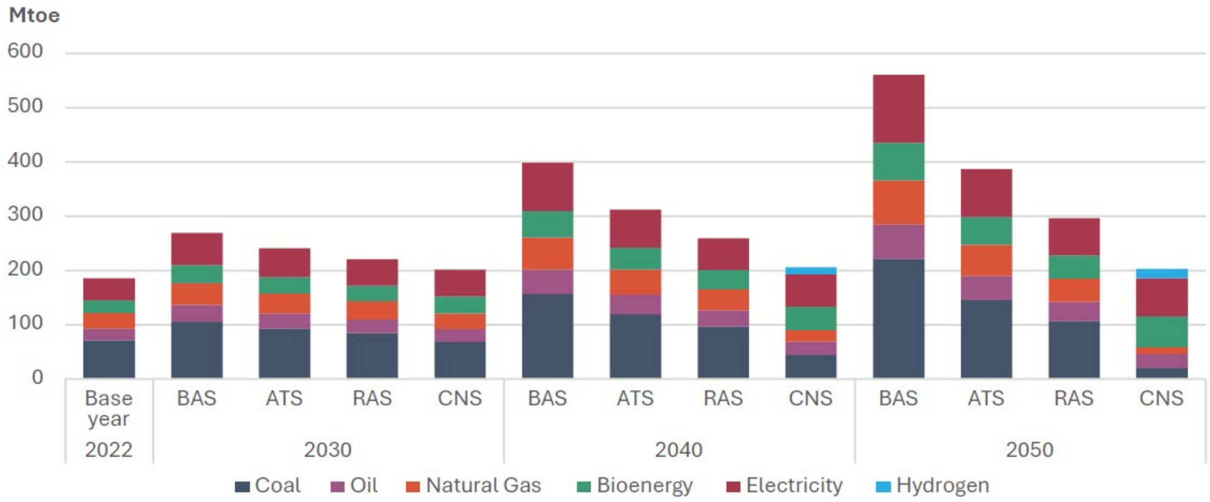
ATS = ASEAN Member States (AMS) targets scenario, BAS = baseline scenario, CNS = carbon neutrality scenario RAS = regional aspiration scenario.
Note 1: In the 8th ASEAN Energy Outlook, the commercial sector energy use includes air-conditioning, lighting, refrigeration, cooking, and others.
Source: ASEAN Centre for Energy, The 8th ASEAN Energy Outlook 2023–2050 (2024).

Exhibit 37. Transport Consumption by Fuel Across Scenarios



ATS = ASEAN Member States (AMS) targets scenario, BAS = baseline scenario, CNS = carbon neutrality scenario, RAS = regional aspiration scenario
Note 1: In the 8th ASEAN Energy Outlook, the transport sector includes road transport, rail transport, domestic aviation, inland waterways transport, and non-specified transport.
Source: ASEAN Centre for Energy, The 8th ASEAN Energy Outlook 2023–2050 (2024).

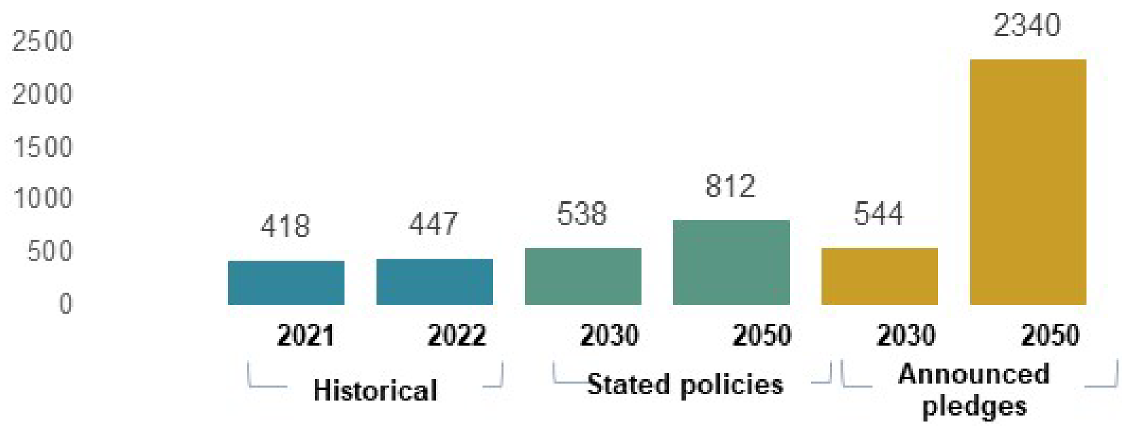
Exhibit 38. Industry Consumption by Fuel Across Scenarios



ATS = ASEAN Member States (AMS) targets scenario, BAS = baseline scenario, CNS = carbon neutrality scenario, RAS = regional aspiration scenario.
Source: ASEAN Centre for Energy, The 8th ASEAN Energy Outlook 2023–2050 (2024).

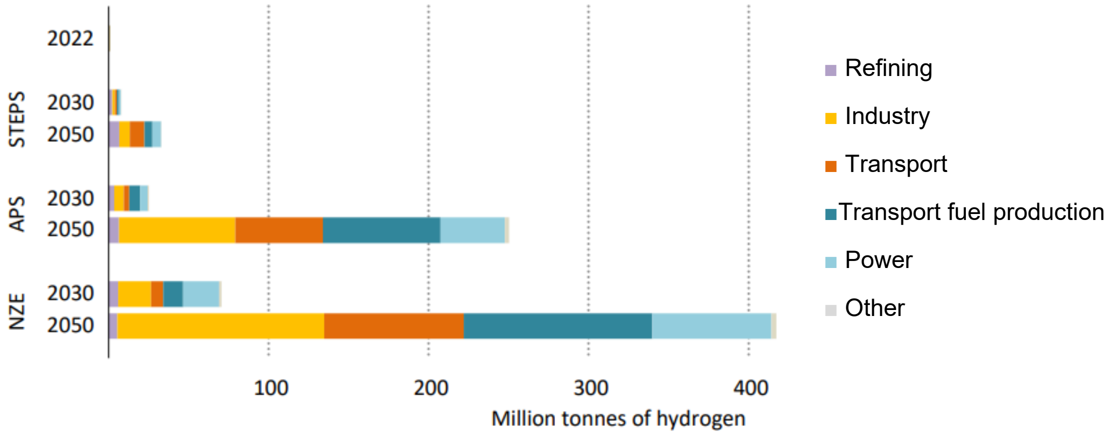
Although hydrogen as a fuel is not yet prominently featured in the energy policies of many AMS (Exhibit), it is expected to play an important role globally in replacing fossil fuels in the industries, transport, and power sectors (Exhibit 28).

Exhibit 39. Hydrogen Demand by History and Scenario in ASEAN (PJ)



PJ = petajoule.
Source: Mitsubishi Research Institute, based on International Energy Agency (2023).

Exhibit 28. Global Hydrogen Demand by Sector and Scenario, 2022–2025



APS = ASEAN Plan of Action for Energy Cooperation Target Scenario, NZE = net-zero emissions scenario.
Source: International Energy Agency (2023).

(3) Technology selection hypothesis for deep-dive research

As mentioned above, renewable energies, particularly solar and wind, have fluctuating production capacities, which can destabilise the grid. To maintain grid stability, technologies that balance renewable energy supply with demand are essential. These include the deployment of electricity storage systems and the implementation of smart grids. Additionally, technologies that reduce transmission losses over long distances and improve AC–DC conversion efficiency are necessary to minimise energy losses during transmission and conversion processes.

For lower-emission fuel distribution, technologies prioritising natural gas and biofuels should be considered. Hydrogen distribution technologies, whilst also important, would take secondary priority, with the focus being on efficient transport and storage solutions for industrial sites.

5.4. The downstream sector

The downstream sector is responsible for delivering electricity and fuels to end-users. To facilitate the transition to a low-carbon economy, four green and transition technologies have been identified to address the sector's challenges.

Exhibit 41. Green and Transition Technologies Identified for the Downstream Sector

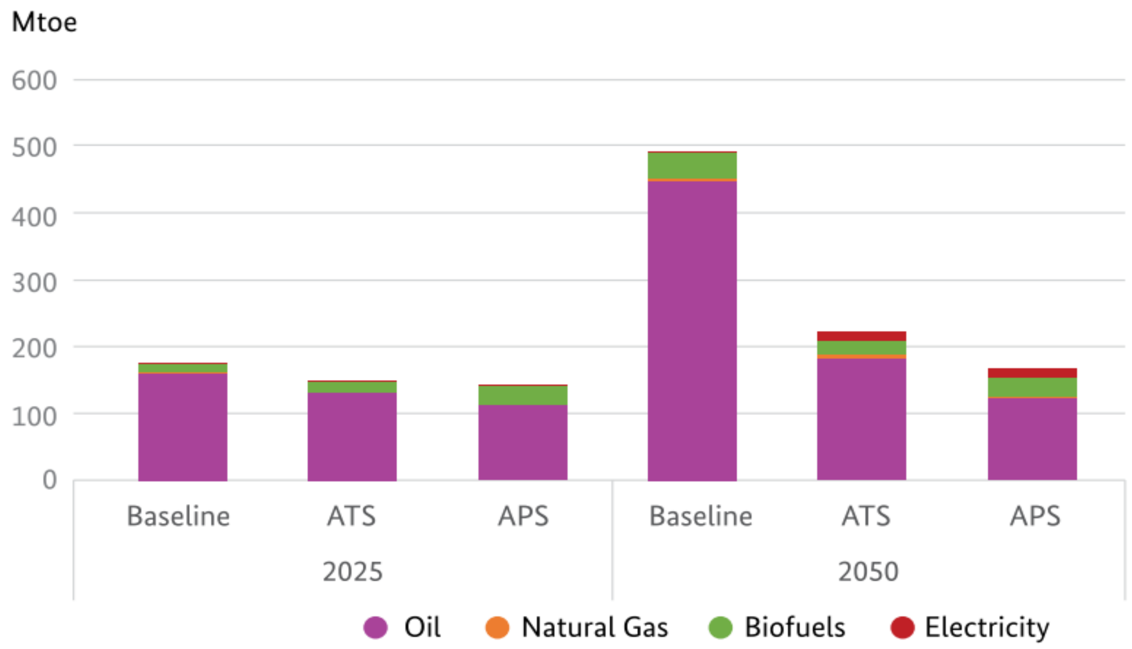
Ref	Technology Name	Ref	Technology Name
IV.01	EV charging	IV.03	Hydrogen station
IV.02	Fast charging for ships	IV.04	Lower-emission fuel bunkering for ships

EV = electric vehicle.
Source: Author.

As the downstream sector provides electricity and fuels to end-users, its technologies must align with the demand for electricity from renewable sources and lower-emission fuels in the end-use and industries sectors. The following analysis is based on two reports that forecast energy demand in these sectors across various scenarios. The first report, the '7th ASEAN Energy Outlook Report' (2022) by the ASEAN Centre for Energy (ACE), includes the BAU, planned energy scenario, and TES scenarios. The second report, 'Renewable Energy Outlook for ASEAN', jointly published by IRENA and ACE, examines the ATS and APS scenarios, as well as the baseline scenario.

In the transport sub-sector, more than 90% of emissions currently come from fossil fuel combustion. Reducing these emissions will require both fuel switching and electrification. According to the 7th ASEAN Energy Outlook Report (ACE, 2022) under the APS in this sector, electric vehicles (EVs) and biofuel mandates are favoured, and strategies to improve fuel efficiency are either established or strengthened to meet regional goals. However, in the current APS, electrification is not prioritised (Exhibit 29 42).

Exhibit 29. Transport Consumption by Fuel Across Scenarios

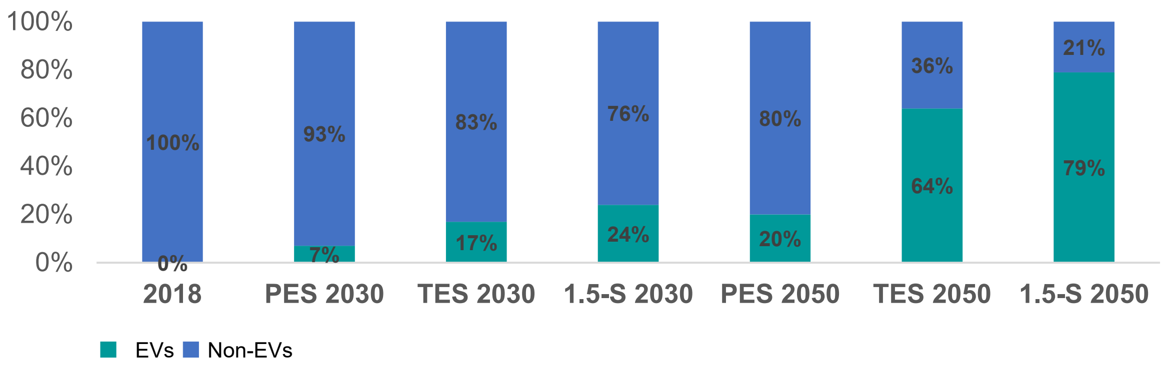


Note: The LCO Scenario and APS have the same value.

APS = ASEAN Plan of Action for Energy Cooperation Target Scenario, ATS = ASEAN Members States Target Scenario, LCO = least cost optimisation.
Source: ASEAN Centre for Energy (2022).

Whilst current policies do not target a high penetration of EVs in road transport, AMS recognised the important role of EVs in driving economic growth and achieving net-zero emissions at the 42nd ASEAN Summit in 2023. Exhibit 43 shows the forecast of EV share amongst road transport vehicles across three scenarios. In 1.5-S, the most ambitious scenario where temperature increase is kept below 1.5^{0}C by 2050, the share of EV is to reach 79%. In preparation for growing EV adoption, AMS agreed to collaborate on improving EV infrastructure, such as charging stations.

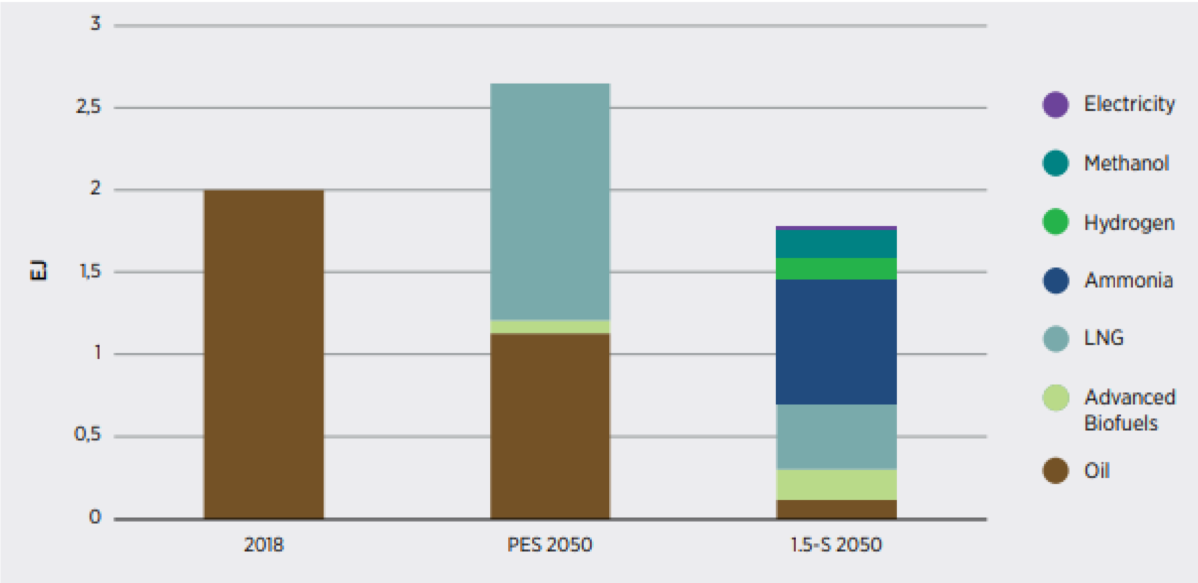
Exhibit 43. Vehicle Share by Technology and Scenario, 2018, 2030, 2050



PES = planned energy scenario, TES = transforming energy scenario.
Source: Mitsubishi Research Institute, based on International Renewable Energy Agency and ASEAN Centre for Energy (2022).

Southeast Asian countries account for approximately 25% of the global bunkering fuel market for international shipping. Although there are currently no clear policies on fuel switching or electrification in domestic navigation, an IRENA analysis shows that LNG and ammonia are expected to play important roles in reducing emissions from international bunkering in ASEAN.

Exhibit 44. International Shipping Bunkering Demand in ASEAN by Scenario 2018–2050



1.5-S = 1.5ºC scenario, LNG = liquefied natural gas, PES = planned energy scenario.
Source: International Renewable Energy Agency and ASEAN Centre for Energy (2022).

Hydrogen is not expected to replace fossil fuels in ASEAN's transport sector under current policies. Instead, its use is expected to focus on oil refining ammonia production, and chemical and steel manufacturing, amongst others (ERIA, 2024). This may be due, in part, to the fact that few AMS have integrated hydrogen strategies into their policies, coupled with the high cost of hydrogen production.

(1) Technology selection hypothesis for deep-dive research

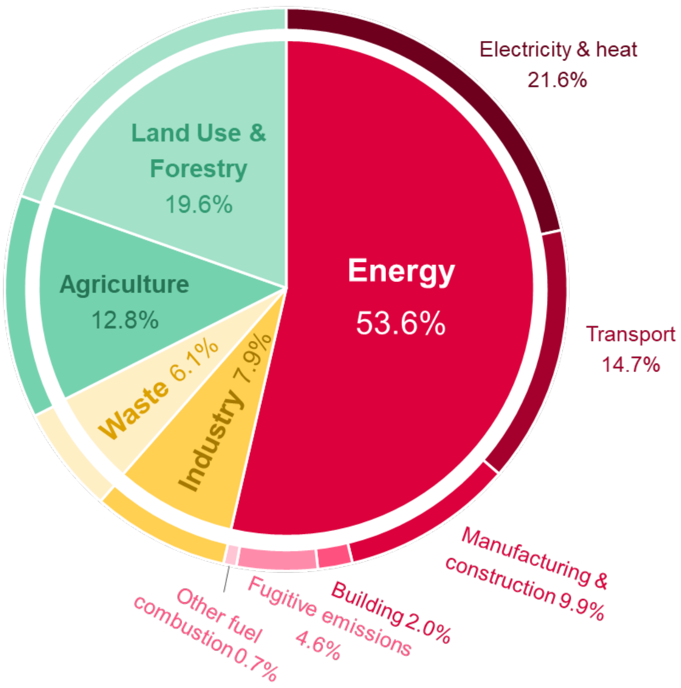
Despite current policies favouring fossil fuels in the transport sector, there are active discussions about increasing EV charging stations. For marine bunkering, LNG and ammonia are expected to become key alternatives. Therefore, the deep-dive research should prioritise EV charging technologies for road transport and LNG and ammonia bunkering technologies for marine navigation.

5.5. The end-use and industries sector

The end-use and industries sector encompasses the use of electricity and fuels to provide services and produce goods.

As shown in the exhibits, in ASEAN, emissions from the energy sector – comprising both direct fuel combustion and electricity use – account for more than 50% of the region's total emissions. Other direct emission sources include industrial processes and product use (IPPU), waste, and agriculture. Within the energy sector, transport is the largest fuel-combusting industry, contributing 14.7% of emissions, followed by manufacturing and construction (9.9%) and buildings (2.0%). In terms of electricity consumption, the building sector accounts for the largest share (53.7%), followed by industries (43.8%), particularly in food and tobacco, machinery, iron and steel, chemical, textile and leather, and cement production.

Exhibit 25. Energy-related GHG Emissions in ASEAN (2021)



ASEAN = Association of Southeast Asian Nations.
Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

Based on GHG emissions data from direct combustion and electricity consumption of electricity by sector, the following sub-sectors have been prioritised for technology identification:

Exhibit 46. High-emission End-use and Industry Sub-sectors in ASEAN Selected for Technology Identification

Transport (use of vehicles)	
Building	Residential
	Non-specific/commercial
Manufacturing industries and construction	
	Iron and steel production
	Cement production
	Chemical production
	Food and tobacco
	Machinery
	Textile and leather
	Non-metallic minerals
Agriculture	
Waste	

Source: Author.

Please note that whilst industries such as food and tobacco manufacturing, and textile and leather manufacturing are identified as high emitters, the decarbonisation technologies applicable to these sectors are cross-sectoral. Therefore, they are summarised under the 'industries cross-cutting' sub-sector.

(1) The transport sub-sector

The transport sub-sector is responsible for moving goods and people from one point to another and encompasses road, rail, navigation, and aviation transport.

To address emissions from this sub-sector, 25 green and transition technologies have been identified. Technologies related to fuel production for transport, including sustainable aviation fuels (SAF), are covered under the upstream sector.

Exhibit 47. Green and Transition Technologies Identified for the Transport Sub-sector

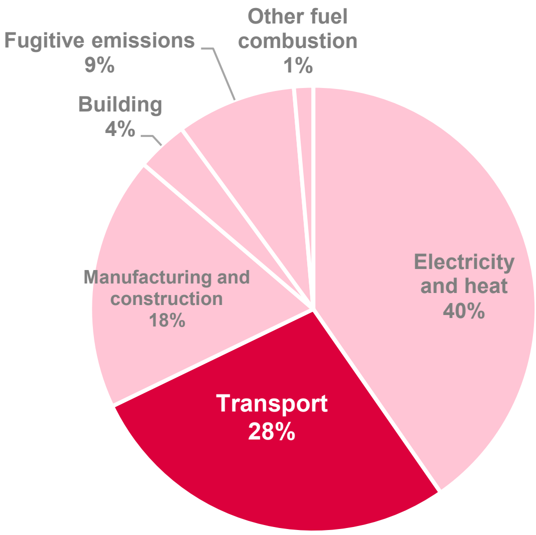
Ref	Technology Name	Ref	Technology Name
V.01	Efficient plane engine	V. 14	Hydrogen fuel cell electric train
V.02	Hydrogen fuel cell plane	V. 15	Gas hybrid train (internal combustion engine and battery)
V.03	Hybrid electric plane	V.16	Battery-electric vehicle
V.04	Battery-electric ship	V.17	Battery-driven freezer and refrigerator truck
V.05	Energy-efficient ship engine	V.18	Electric motorbike
V.06	Ammonia-fuelled ship	V.19	Hybrid electric vehicle
V.07	Biofuel-fuelled ship	V.20	Plug-in hybrid
V.08	Fuel cell electric ship	V.21	Automated and connected vehicles
V.09	Hydrogen-fuelled ship	V.22	Flex fuel vehicle
V.10	LNG-fuelled ship	V.23	Hydrogen fuel cell electric vehicle
V.11	Nuclear-powered ship	V.24	Hydrogen-fuelled vehicle
V.12	Battery-electric train	V.25	Natural gas-fuelled vehicle
V.13	Magnetic levitation		

LNG = liquefied natural gas.
Source: Author.

1) The need to reduce emissions from the transport sub-sector

The transport sector is the second-largest source of emissions from direct fuel combustion in ASEAN, accounting for approximately 33% of such emissions. However, its share of regional electricity use is only 0.37%, suggesting significant potential for accelerating the electrification of transport.

Exhibit 48. Share of the Transport Sub-sector in the Energy-derived Greenhouse Gas Emissions in ASEAN



ASEAN = Association of Southeast Asian Nations.
Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

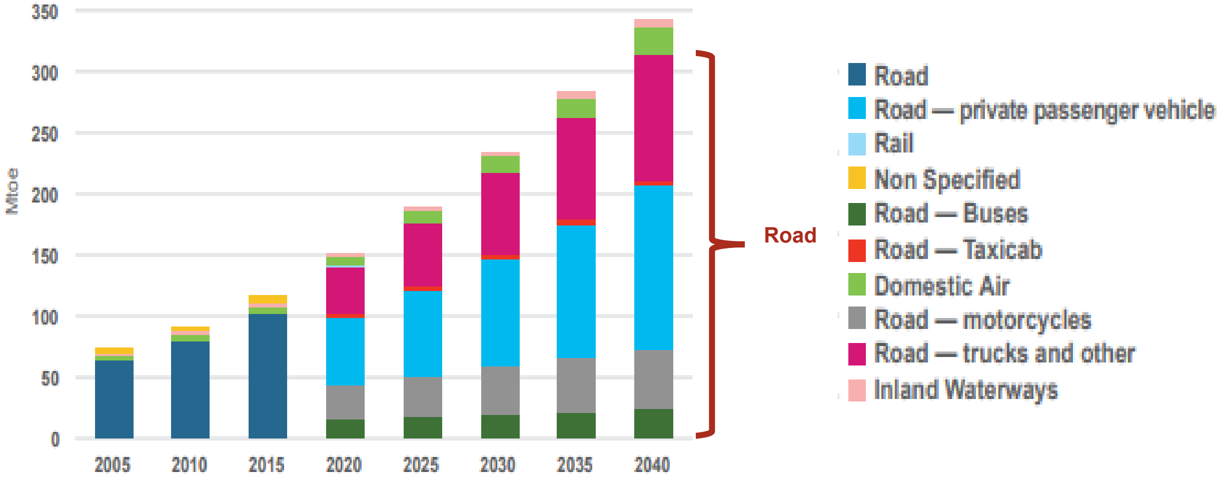
2) Challenges in the transport sub-sector

Currently, road transport accounts for more than 90% of emissions, with domestic aviation and navigation also contributing significantly. As such, these three sectors should be the primary focus of decarbonisation efforts.

The region's transport sector remains heavily reliant on oil products, with gas/diesel oil and motor petrol accounting for more than 90% of CO_2 emissions. Switching to lower-emission fuels, such as natural gas, can play a key role in reducing emissions.

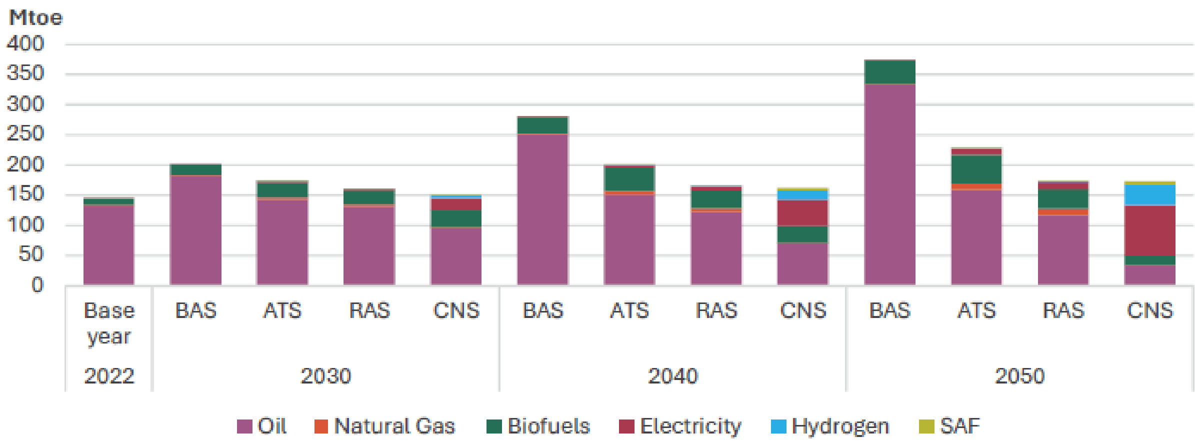
Looking ahead to 2040, energy demand for road transport is expected to significantly outweigh other sub-sectors, with private passenger vehicles taking the largest share, followed by trucks, other vehicles, and motorcycles (Exhibit 51). In the ASEAN target scenario (ATS), a small portion of road transport is expected to be electrified by 2040, with biofuels playing a crucial role in reducing emissions (Exhibit 49).

Exhibit 49. Forecasts for Transport Energy Demand by Mode of Transport (Baseline Scenario)



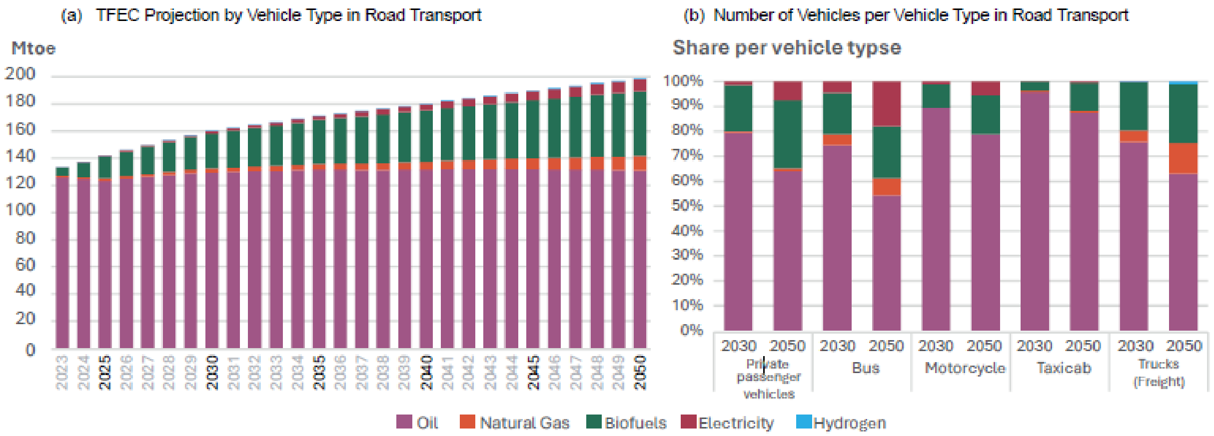
Mtoe = million tonnes of oil equivalent.
Source: ASEAN Centre for Energy (2020).

Exhibit 50. Transport Consumption by Fuel Across Scenarios



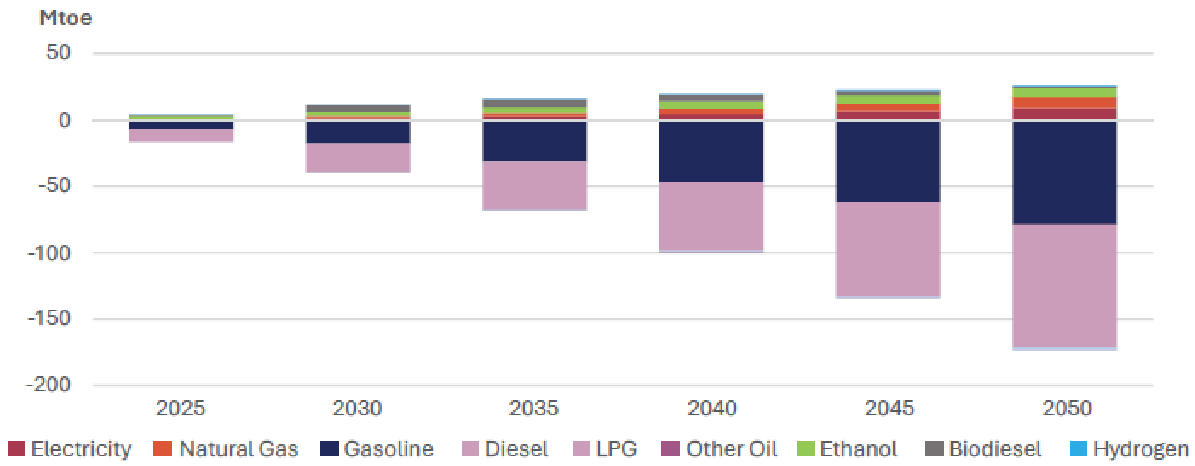
BAS = baseline scenario, ATS = ASEAN Member States (AMS) targets scenario, RAS = regional aspiration scenario, CNS = carbon neutrality scenario.
Source: ASEAN Centre for Energy, The 8th ASEAN Energy Outlook 2023–2050 (2024).

Exhibit 51. Road Transport Fuel Consumption in ATS



ATS = ASEAN Member States (AMS) targets scenario, TFEC = total final energy consumption.
Source: ACE, The 8th ASEAN Energy Outlook 2023–2050 (2024).

Exhibit 52. Fuel Shifting in Road Transport, ATS vs BAS



BAS = baseline scenario, ATS = ASEAN Member States (AMS) targets scenario.
Source: ASEAN Centre for Energy, The 8th ASEAN Energy Outlook 2023–2050 (2024).

3) Technology selection hypothesis for deep-dive research

Given the current situation and future trends, decarbonisation efforts in the transport sector should focus on fuel switching, such as the use of biofuels, and the electrification of road transport, followed by aviation and navigation.

(2) The building sub-sector

The building sub-sector encompases the use of electricity and other forms of energy to power equipment in commercial and residential buildings. To address emissions in this sub-sector, 17 green and transition technologies have been identified.

Exhibit 53. Green and Transition Technologies for the Building Sub-sector

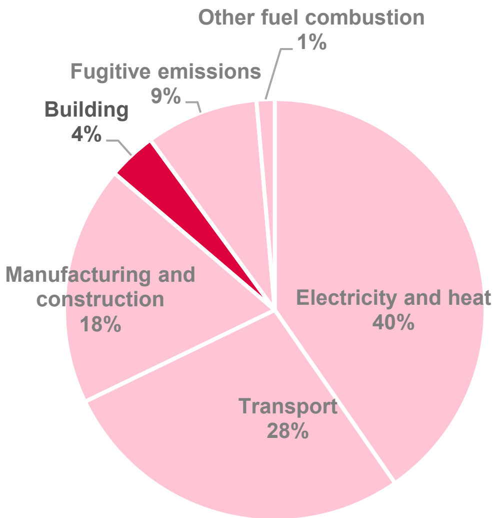
Ref	Technology Name	Ref	Technology Name
VI.01	Building energy management system	VI.10	Quad generation
VI.02	Evaporative cooling	VI.11	Trigeneration systems (heating, cooling, and electricity)
VI.03	Solid-state equipment cooling	VI.12	Heat harvesting using building-integrated materials
VI.04	Energy-efficient household appliances	VI.13	Reflective materials, insulating materials for walls and façades, insulating window
VI.05	Energy-efficient lighting	VI.14	Building integrated photovoltaic systems
VI.06	Energy-efficient ventilation system	VI.15	Building integrated wind turbines
VI.07	Heat pump	VI.16	Appliances using lower-emission fuels
VI.08	Fuel cell co-generation	VI.17	Biomass-fuelled heater
VI.09	Fuel combustion co-generation		

Source: Author.

1) The need to reduce emissions from the building sub-sector

In ASEAN, GHG emissions from direct fuel combustion in buildings are relatively low, accounting for around 4% of total emissions. However, indirect emissions from electricity use are the highest amongst all sectors, accounting for more than half of the region's total emissions.

Exhibit 54. Energy-derived Greenhouse Gas Emissions in ASEAN, 2021

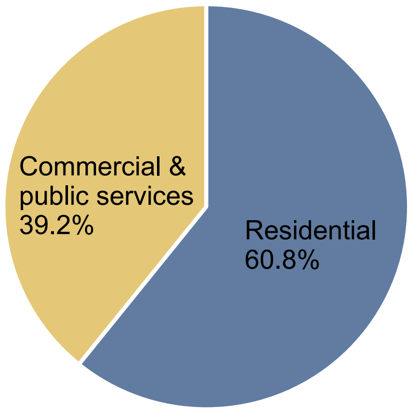


ASEAN = Association of Southeast Asian Nations.
Source: Mitsubishi Research Institute Inc. analysis based on Climate Watch (2022).

2) Challenges in the building sub-sector

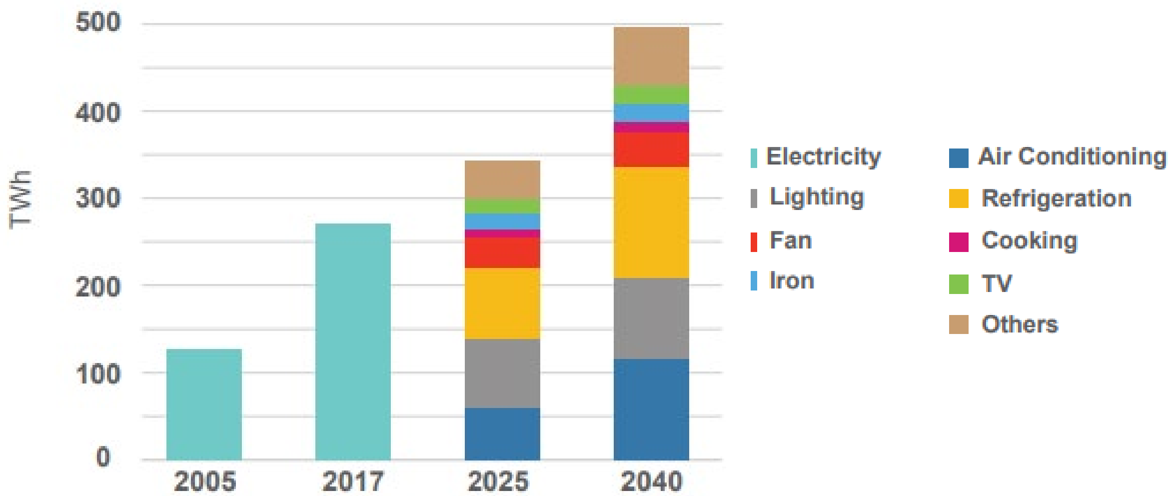
The building sub-sector can be divided into two categories: residential and commercial and public services. The residential category is the larger emitter, with most electricity consumed for space cooling, lighting, and refrigeration (Exhibit). In contrast, very little electricity is used for water heating or space heating. The commercial buildings category includes offices, hospitals, retail establishments, hotels, and other services, with similar pattern of electricity consumption. Most emissions in the building sector are indirect, stemming from electricity use.

Exhibit 55. Electricity Use Breakdown by Sub-sector in ASEAN



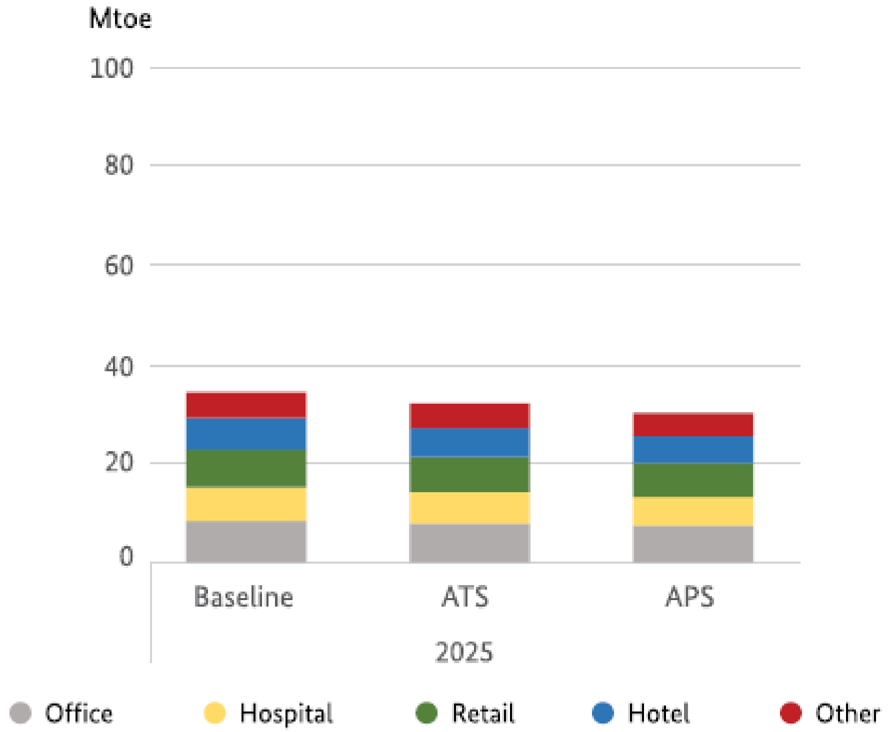
ASEAN = Association of Southeast Asian Nations.
Source: Mitsubishi Research Institute Inc. analysis based on International Energy Agency (2024).

Exhibit 56. Residential Electricity Demand by Home Appliances in ASEAN, Historical and Baseline Scenario



ASEAN = Association of Southeast Asian Nations, TV = television, Twh = terawatt hours.
Source: ASEAN Centre for Energy (2020).

Exhibit 57. Total Final Energy Consumption Projection by Commercial Sub-sector Across Scenarios



APS = ASEAN Plan for Action for Energy Cooperation (Regional) targets scenario, ATS = ASEAN target scenario.
Source: ASEAN Centre for Energy, The 7th ASEAN Energy Outlook 2020–2050.

3) Technology selection hypothesis for deep-dive research

In the building sub-sector, energy-efficient technologies that can reduce electricity consumption are expected to play an important role in emissions reduction efforts.

(3) The cement, concrete, and glass sub-sector

The cement, concrete, and glass sub-sector is responsible for the production of these materials. To address emissions in this sub-sector, 16 green and transition technologies have been identified.

Exhibit 58. Green and Transition Technologies for the Cement, Concrete, and Glass Sub-sector

Ref	Technology Name	Ref	Technology Name
VII.01	Calcium looping (carbon capture and utilisation)	VII.07	Electrolyser for decarbonating calcium carbonate
VII.02	Carbon mineralisation (carbon utilisation)	VII.08	Advanced grinding technologies
VII.03	Direct separation from limestone (carbon capture)	VII.09	All-electric forehearth
VII.04	Oxy-fuelling in cement kilns (carbon capture)	VII.10	NSP kiln
VII.05	Synthetic methane production for power generation (carbon utilisation)	VII.11	Vertical mills
VII.06	Electric kiln	VII.12	Reduction of clinker ratio (using tricalcium aluminate, blast furnace slags, etc.)

NSP = new suspension process.
Source: Author.

1) The need to reduce emissions from the cement, concrete, and glass sub-sector

The cement, concrete, and glass sub-sector contributes 32.8% of the direct combustion emissions in the industry sector in ASEAN. However, it accounts for only 5% of the industry sector's total electricity use.

ASEAN countries, particularly Viet Nam and Indonesia, have significant cement industries. In 2022, both countries ranked amongst the top 10 global cement exporters. With a portion of their exports going to countries with strict emissions regulations, such as the United States, Australia, and France, there is mounting pressure on ASEAN cement exporters to decarbonise their production processes.

Exhibit 59. ASEAN Countries' Share of the Global Cement Export

ASEAN Country	Share of Global Cement Export (ranking)	Export Destinations with Carbon Tariff (share of total export)
Viet Nam	10.20% (2nd)	United States (13.1%), France (1.36%)
Indonesia	2.82% (10th)	Australia (12.8%)
Thailand	2.78%(11th)	Australia (19.4%), United States (6.98%)

Source: The Observatory for Economic Complexity (2024).

The clinker manufacturing process accounts for 80% of the energy use and more than 80% of CO_2 emissions in cement production. Therefore, efforts to decarbonise should focus on improving energy efficiency and switching to alternative fuels or electrification. Additionally, certain aspects of the cement and concrete production, such as concrete curing, offer potential for CCU applications.

Energy consumption and CO_2 emissions in the cement manufacturing process]

Energy consumption

• Quarry	40 MJ/tonne
• Crusher	5 MJ/tonne
• Transport	40 MJ/tonne
• Raw mill	100 MJ/tonne
• **Kiln and preheater/precalcinator**	**3,150 MJ/tonne**
• Cooler	160 MJ/tonne
• Cement mill	285 MJ/tonne
• Logistics	115 MJ/tonne
Total	**3,895 MJ/tonne**

CO_2 emissions other than energy consumption

• Quarry	3 $kgCO_2$/tonne
• Crusher	1 $kgCO_2$/tonne
• Transport	7 $kgCO_2$/tonne
• Raw mill	17 $kgCO_2$/tonne
• **Kiln and preheater/precalcinator**	**479 $kgCO_2$/tonne (Calcination process)**
• **319 $kgCO_2$/tonne (Fossil fuels)**	
• Cooler	28 $kgCO_2$/tonne
• Cement mill	49 $kgCO_2$/tonne
• Logistics	22 $kgCO_2$/tonne
Total	**925 $kgCO_2$/tonne** (MicKinsey & Company, 2020)

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

2) Technology selection hypothesis for deep-dive research

Decarbonisation efforts should prioritise the clinker manufacturing process, as it accounts for 80% of energy consumption in cement production. Key areas of focus should include improving energy efficiency and transitioning to alternative fuels or electrification. Additionally, certain stages of the cement and concrete production process could utilise CO_2, providing opportunities for CCU applications.

(4) The chemicals sub-sector

The chemicals sub-sector is responsible for producing raw chemical materials for further manufacturing. To address emissions in this sub-sector, four green and transition technologies have been identified.

Exhibit 60. Green and Transition Technologies to Address Emissions from the Chemicals Industry

Ref	Technology name	Ref	Technology name
VII.13	Chemical production from CO_2	VII.15	Utilisation of naphtha in fluid catalytic cracking
VII.14	Production of functional chemicals using flow method	VII.16	Production of chemicals from bio-derived materials

Source: Author.

1) The need to reduce emissions from the chemicals industry

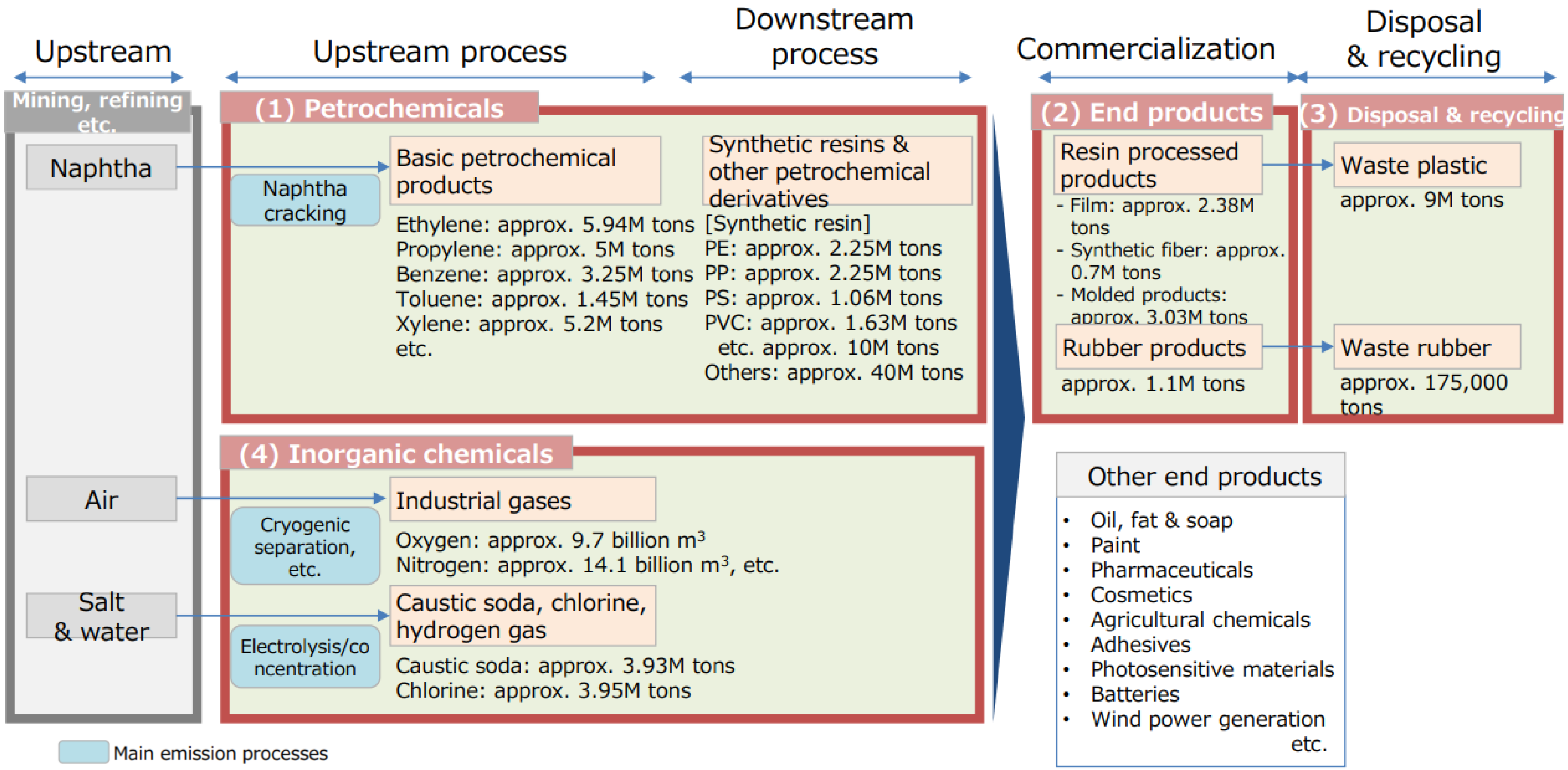
The chemical sub-sector accounts for 8.7% of direct combustion emissions in ASEAN'S industry sector and approximately 6.3% of its electricity consumption.

Although the chemicals industry in ASEAN is relatively small, it is growing rapidly. Singapore leads the region, but countries like Indonesia, Viet Nam, and Malaysia are expanding their capacity for basic petrochemical production. This growth has raised concerns about potential overcapacity in certain products, such as olefins and aromatics (KPMG Global Energy Institute, 2014).

In the chemicals industry, CO_2 can be utilised in the production of various chemicals, including olefins, highlighting potential opportunities for CCU.

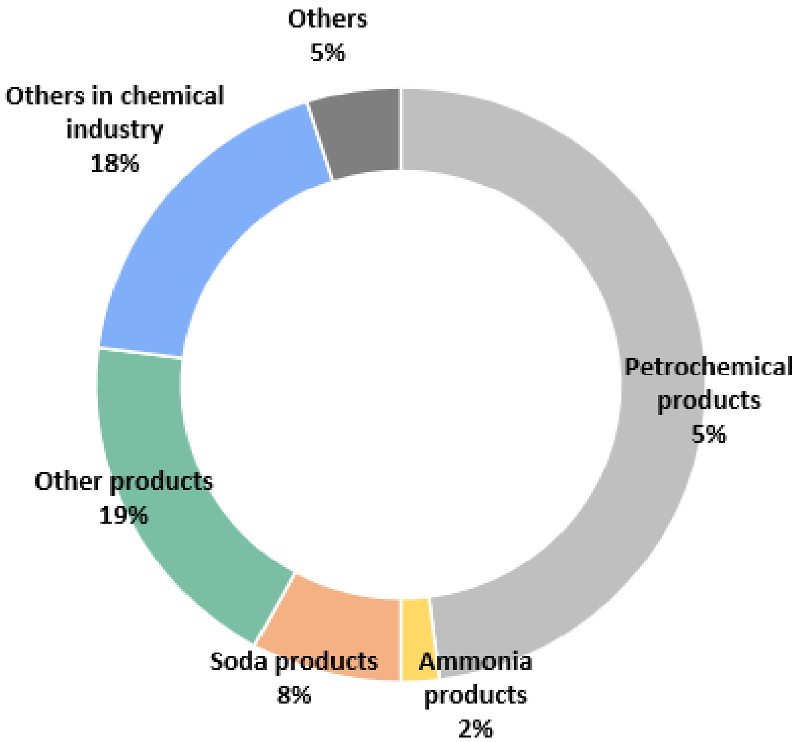
The industry is broadly divided into petrochemicals and inorganic chemicals, with petrochemicals being the main contributor to emissions. Amongst petrochemicals, upstream processes, which involve the production of basic petrochemical products, are the most energy-intensive and responsible for a significant portion of energy-related emissions.

Exhibit 61. Process of Chemical Production



M = million, m^3 = cubic metre, PE = polyethelyne, PP = polypropylene, PS = polysterene, PVC = polyvinyl chloride.
Source: Ministry of Economy, Trade and Industry, Japan (2021a).

Exhibit 62. Breakdown of Emissions from Chemical Industry Energy Sources in Japan as an Example (FY2019)



Source: Mitsubishi Research Institute Inc., based on the Ministry of Economy, Trade and Industry, Japan (2021).

2) Technology selection hypothesis for deep-dive research

In the petrochemicals segment, upstream processes are the most energy-intensive and thus account for much of the energy-related emissions. Therefore, the focus for technology selection in the chemicals sub-sector should be on decarbonising these upstream processes.

(5) The iron and steel sub-sector

The iron and steel sub-sector is responsible for producing iron and steel for further manufacturing use. To address emissions in this sub-sector, 11 green and transition technologies have been identified.

Exhibit 63. Green and Transition Technologies for the Iron and Steel Sub-sector

Ref	Technology Name	Ref	Technology Name
VII.17	Oxygen-rich smelting reduction (carbon capture)	VII.23	Electrolyser-based reduction
VII.18	Recycling of CO_2 from steel production process (carbon utilisation)	VII.24	Reduction via alkali metal looping
VII.19	High productivity electric arc furnace	VII.25	Smelting reduction based on hydrogen plasma
VII.20	Plasma torch	VII.26	Utilisation of ferro-coke
VII.21	Utilisation of submerged arc furnace	VII.27	Utilisation of plastic waste for coke production
VII.22	Direct reduced iron		

Source: Author.

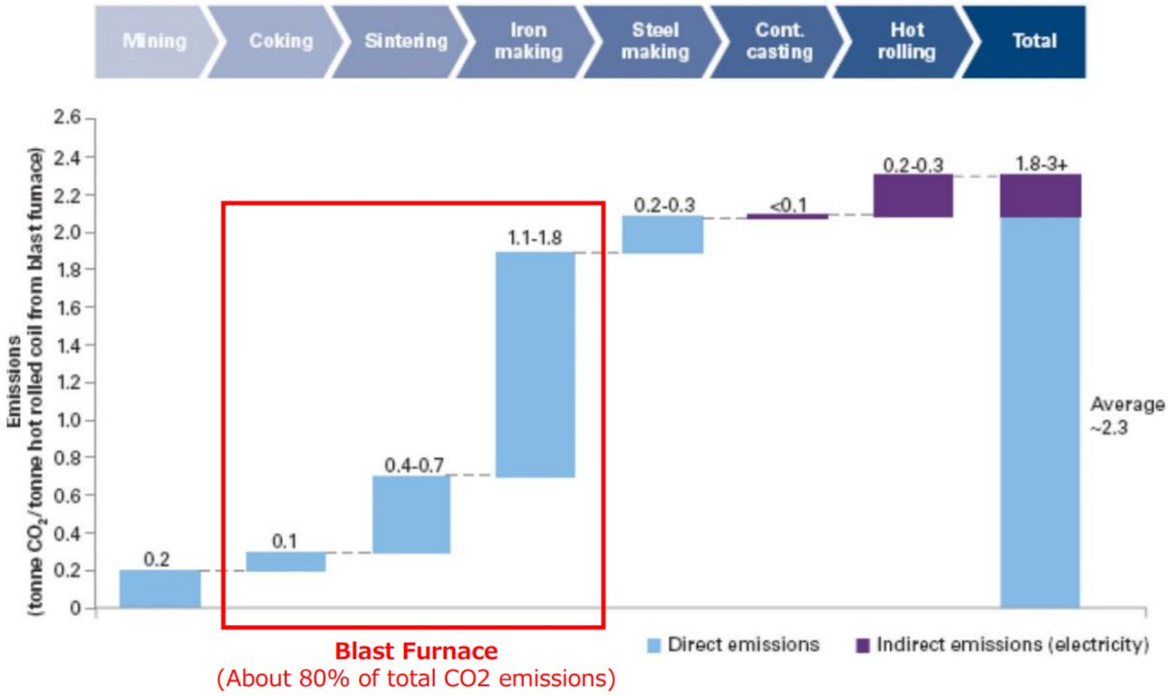
1) The need to reduce emissions from the iron and steel sub-sector

The iron and steel sub-sector contributes 4.8% of the direct combustion emissions from ASEAN's industry sector and accounts for approximately 7.5% of the sector's total electricity use.

Conventionally, iron is produced by reducing and melting iron ore and coal (coke) in a blast furnace and a basic oxygen furnace (BOF). According to the South East Asia Iron and Steel Institute (SEAISI), steelmaking capacity in ASEAN is expected to grow to 104.4~182.5 million metric tonnes by 2029–2030, with approximately 73.7 million metric tonnes expected to come from the blast furnace/BOF route (S&P Global, 2024)

The blast furnace process alone accounts for about 80% of CO_2 emissions.

Exhibit 64. Emission Breakdown of the Steelmaking Process



CO_2 = carbon dioxide, tonne CO_2 = tonne of carbon dioxide.
Source: The Ministry of Economy, Trade and Industry, Japan (2021b).

2) Technology selection hypothesis for deep-dive research

Decarbonising the iron and steel industry requires a significant reduction in blast furnace use. Emissions are generated both from the process itself and from direct fuel combustion. CCU presents a potential decarbonisation solution for the steel industry, as the captured CO_2 can be recycled as fuel in the steelmaking process.

(6) The industries cross-cutting sub-sector

Whilst certain industries, such as food and tobacco manufacturing, textile and leather production, are identified as high emitters, the decarbonisation technologies applicable to these sectors are often versatile and can be deployed across multiple industries. Consequently, these technologies are grouped under the ‘cross-cutting industries’ sub-sector. In total, 10 green and transition technologies have been identified to address emissions across various sectors. Those technologies are broadly applicable to numerous industries.

Exhibit 65. Green and Transition Technologies for the Iron and Steel Sub-sector

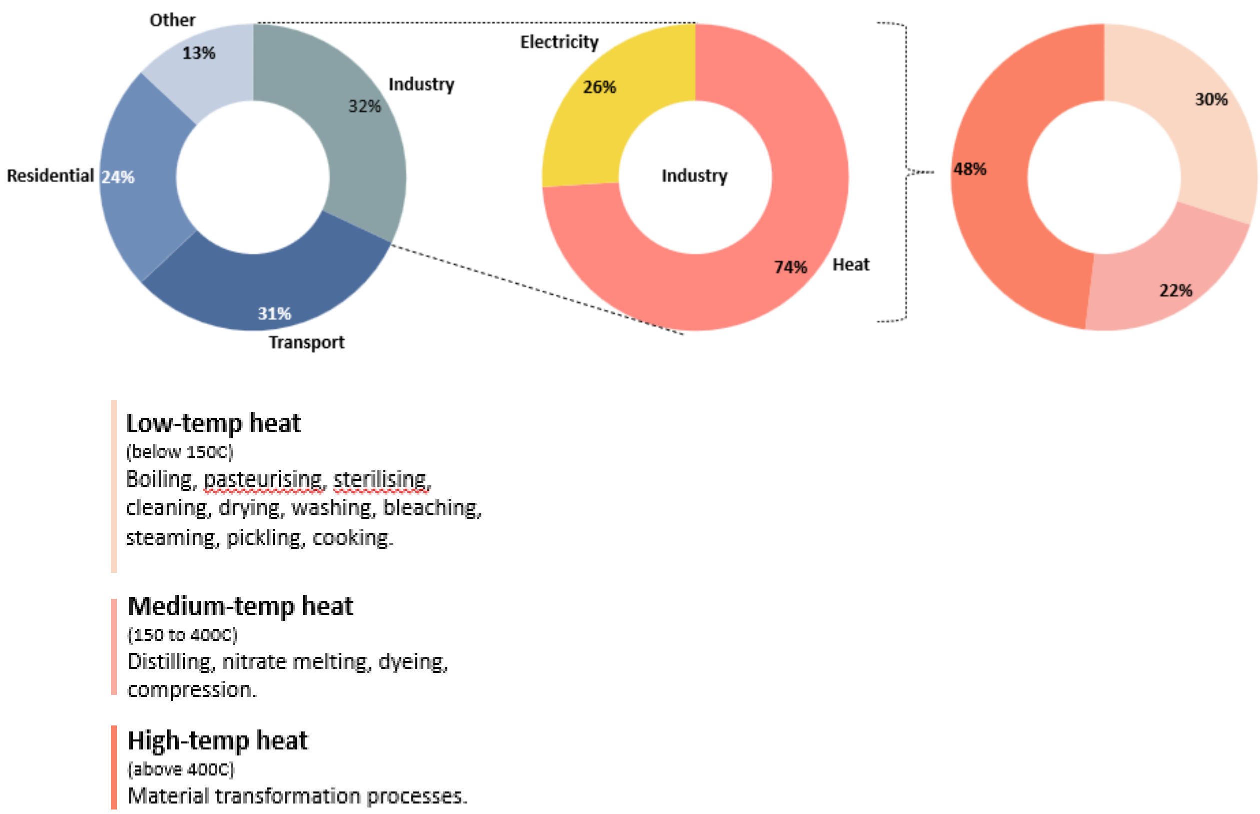
Ref	Technology Name	Ref	Technology Name
VIII.1	Carbon capture	VIII.6	Small-scale once-through boiler
VIII.2	Electric heating	VIII.7	Lower-emission fuel equipment
VIII.3	Large-scale industrial heat pump	VIII.8	Direct heat from renewables
VIII.4	Batteries for industrial use	VIII.9	Use of waste for thermal energy
VIII.5	Advanced EMS (AI, IoT, Automated driving, etc.)	VIII.10	Waste heat recovery

AI = artificial intelligence, EMS = environmental monitoring system, IoT = internet of things.
Source: Author.

1) The need to reduce emissions from different industries

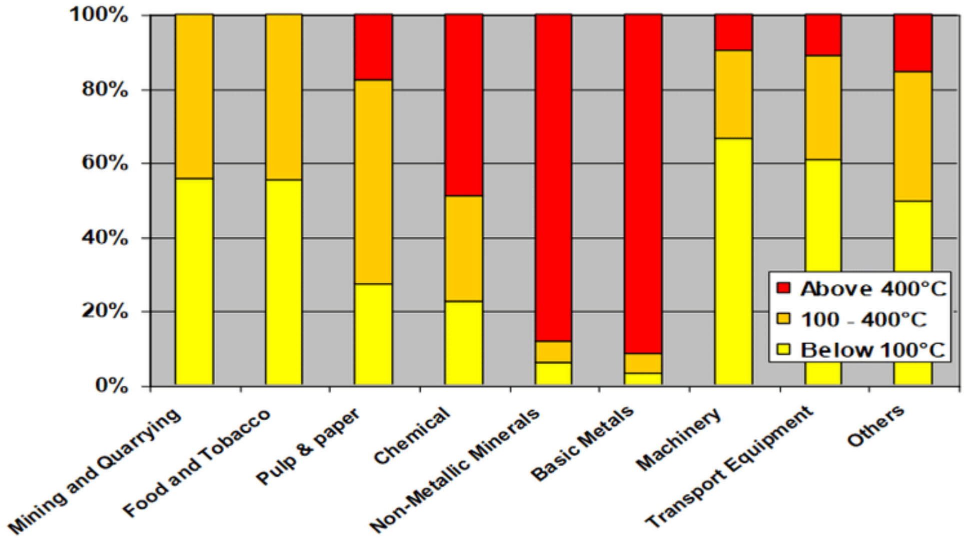
In 2017, more than 70% of global industrial energy was used for heating processes, with 90% of this energy coming from fossil fuels. Light manufacturing sectors, such as food and tobacco, pulp and paper, and machinery, predominantly rely on low-to-medium temperature range (<400ºC).

Exhibit 66. Share and Breakdown of Global Heat Demand in Industry, 2017



Source: International Energy Agency (2017).

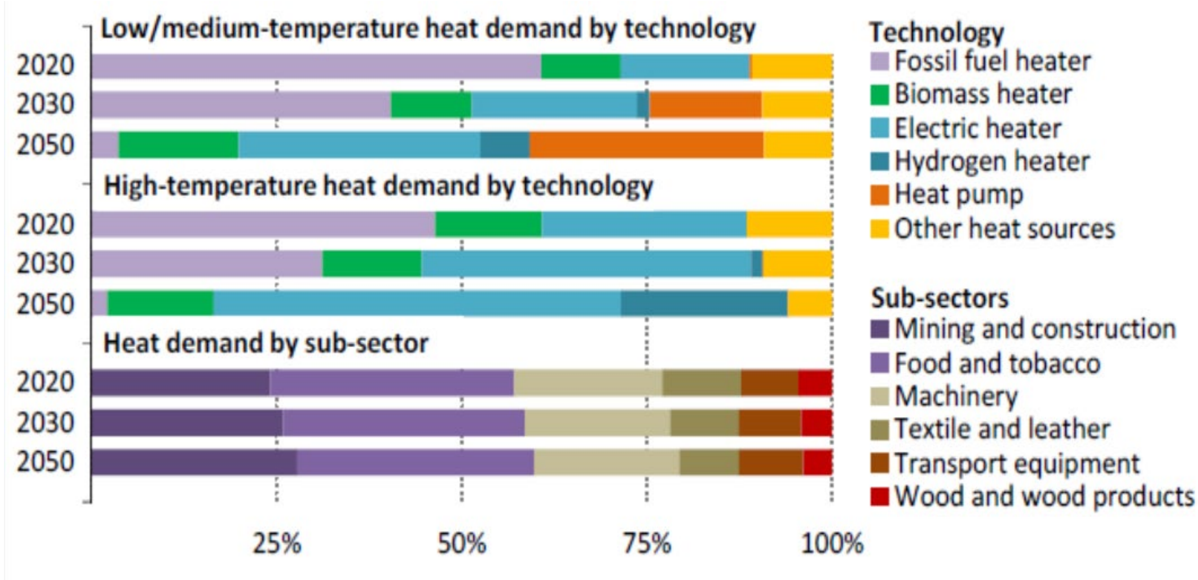
Exhibit 67. Temperature Level of the Industrial Heat Demand by Industry Sector



Source: Sainz-Mañas et al. (2022).

According to IEA's Net Zero Scenario by 2050, the share of electricity in satisfying heat demand for light industries will increase rapidly by 2050, for both low- and medium- temperature heating and high-temperature applications. Specifically, the use of heat pumps in the low-to-medium temperature range is expected to grow significantly. Hydrogen and biomass are also seen as potential transition fuels.

Exhibit 68. Share of Heating Technology by Temperature Level in Light Industries, NZE scenario



NZE = near-zero emissions.
Source: International Energy Agency (2021).

2) Technology selection hypothesis for deep-dive research

In the cross-cutting industry sector, fuel switching and electrification are prioritised to reduce energy-intensive heating processes. However, as the transition away from fossil fuels will take time, carbon capture technologies can also contribute to decarbonisation efforts.

(7) The agriculture sub-sector

The agriculture sub-sector encompasses activities such as raising cattle and cultivating staples and vegetables for human and animal consumption. Four green and transition technologies have been identified for this sub-sector.

Exhibit 69. Green and Transition Technologies for the Agriculture Sub-sector

Ref	Technology Name	Ref	Technology Name
IX.01	Genetic engineering to produce crop with enhanced carbon sequestration	IX.03	Nitrification inhibitors
IX.02	Genetically modified rumen bacteria that produce less methane	IX .04	Addition of electron acceptors to paddy fields

Source: Author.

1) The need to reduce emissions from the agriculture sub-sector

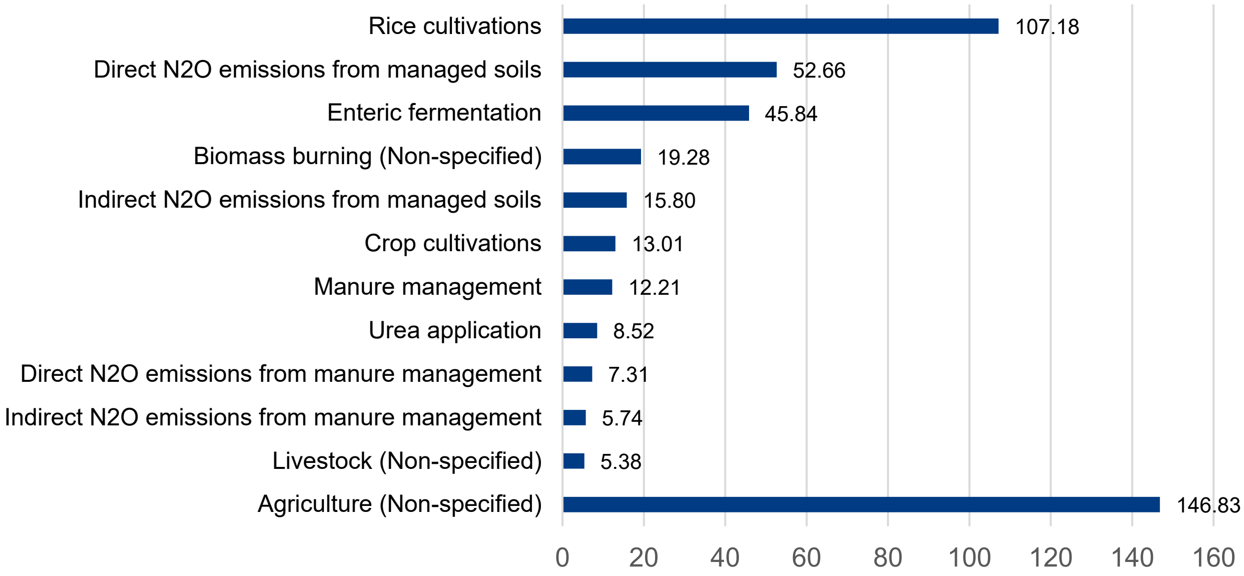
In many ASEAN countries, rice cultivation is a major contributor to agricultural GHG emissions, accounting for approximately 32%. This is due to the widespread use of continuous flooding in rice production, commonly referred to as 'paddy fields.' When fields are flooded, organic matter decomposes with limited access to oxygen, leading to a large amount of methane production through the process of methanogenesis (Walsh, 2023). Technologies that target these conditions could potentially contribute to reducing methane from paddy fields.

Soil management is another major source of GHG emissions in ASEAN. In a natural environment, microbial activities in soils drive the nitrification process, converting ammonia and other compounds into nitrates and nitrites. Anaerobic microbials then reduce these compounds into nitrogen and nitrous oxide, a potent GHG (IPCC, 2000c). The addition of nitrogen, whether through fertilisers, animal manure, crop residues or sewage sludge, is likely to accelerate this emission process. In addition, nitrous oxide emissions can be exacerbated by rainfall (Wilson et al., 2017), which presents challenges for regions in ASEAN that experience extended rainy seasons.

Enteric fermentation, the natural digestive process in ruminants such as cattle, goats, sheep, and buffaloes, is another significant source of emissions. During digestion, microbes in the animal's stomachs ferment feed, releasing methane as a by-product whilst producing energy and nutrients

(IPCC, 2000a). Modern biotechnology offers the potential to reduce methane emissions by minimising energy loss during the fermentation process.

Exhibit 70. Top 10 Emitting Activities in the Agriculture Sector, ASEAN Total ($MtCO_2e$)



ASEAN = Association of Southeast Asian Nations, $MtCO_2e$ = metric tonne of carbon dioxide equivalent, N_2O = nitrous oxide.
Source: Mitsubishi Research Institute Inc. analysis based on country reports (biennial update reports and other sources).

2) Technology selection hypothesis for deep-dive research

Technology selection for the agriculture sub-sector should focus on innovations that address emissions from rice cultivation, soil management, and enteric fermentation.

(8) The waste sub-sector

The waste sub-sector encompasses the management and treatment of waste and wastewater. Three green and transition technologies have been identified to address emissions from this sub-sector.

Ref	Technology Name	Ref	Technology Name
X.01	Anaerobic digestion	X.03	Energy generation from sewage sludge
X.02	Landfill with a methane collection system		

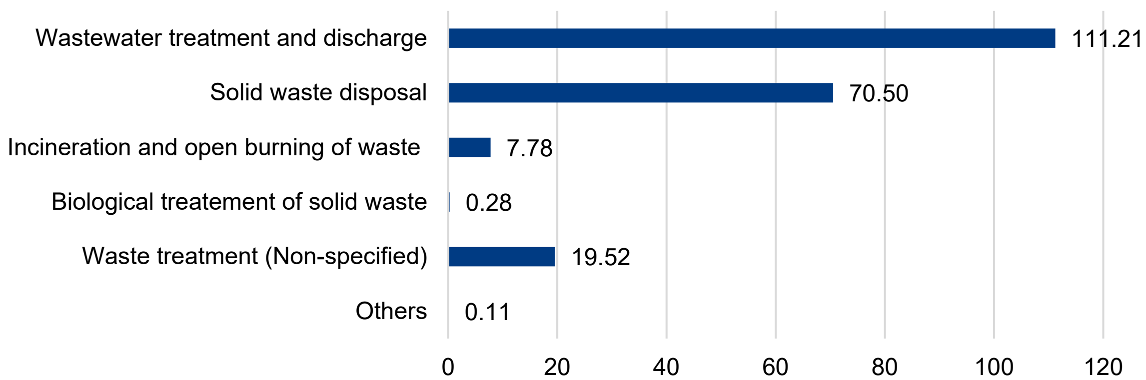
Source: Author.

Wastewater treatment and discharge are the largest sources of emissions in the waste sector across ASEAN, accounting for around 53% of the sector's total GHGs emissions. These processes primarily release methane and nitrous oxide. Methane is produced through the anaerobic decomposition of organic matter in wastewater, whilst nitrous oxide is released during the nitrogen removal process in sewage treatment (IPCC, 2000b). In addition, carbon dioxide emissions and fugitive emissions occur, although to a lesser extent.

Another significant source is the biodegradation of solid waste, particularly at open dumping grounds. Depending on the environmental conditions of these sites, biodegradation can produce either carbon dioxide in aerobic conditions or methane in anaerobic conditions, both of which are major GHGs. In addition, the decomposition of nitrogen-rich organic materials in waste can also result in nitrous oxide emissions (IPCC, 2000b).

According to a United Nations Environment Programme report (2017), open dumping remains a common practice in many ASEAN countries. As municipal solid waste volumes are projected to increase rapidly alongside urbanisation, industrialisation, and economic growth, advanced waste management infrastructure is essential. This includes technologies such as waste-to-energy or methane collection systems to improve resource circularity in the region.

Exhibit 71. Greenhouse Gas Emissions from Waste by Sub-sector, ASEAN Total ($MtCO_2e$)



MtCO2eq = metric tonnes of carbon dioxide equivalent.
Source: Mitsubishi Research Institute Inc. analysis based on country reports (biennial update reports (BURs) and other sources).

5.6. Identification of technologies for the Second Version of TLP

As can be seen above, a wide range of green and transition technologies have been identified across five sectors, totalling 176 technologies (Exhibit 72).

Exhibit 72. Number of Technologies Identified by Sector

#	Category		Inclusive list of both green and transition techs (long-list)
I	Upstream		32
II	Power		35
III	Midstream		19
IV	Downstream		4
V	Industries	Building	17
VI		Transport	25
VII		Industry (specific)	34
VIII		Industry (cross-cutting)	10
TOTAL			**176**

Source: Author.

6. Summary and the Next Phases

6.1. Summary of challenges in transitioning to a low-carbon economy in developing Asia

The transition to a low-carbon economy in developing Asia presents both significant opportunities and challenges. Climate change is an urgent global threat, and the transition to a renewable and sustainable energy-based society is critical. However, developing Asia faces unique obstacles, including infrastructure constraints, energy insecurity, financial challenges, and the economic pressures of industrialisation.

(1) Challenges in transitioning to a low-carbon economy

The challenges for the developing Asia in transitioning to a low-carbon economy include:

- **Infrastructure constraints**. Whilst ASEAN has substantial potential for renewable energy sources like solar and wind, these variable renewable energies require substantial upgrades to power infrastructure to accommodate fluctuations in supply and demand. Many countries lack the necessary infrastructure for renewable energy production and distribution, necessitating significant investment and time.
- **Energy insecurity**. Reliable electricity access remains a challenge in developing Asia. Balancing the need for rapid electrification with carbon emission reductions is complex, slowing the adoption of renewable energy.

- **Financial challenges**. Although global costs for renewable technologies have decreased, capital expenditure for large-scale solar and wind projects remains high in some Asian countries. Limited deployment, underdeveloped supply chains, and stringent content requirements contribute to these costs.
- **Economic development**. Industrialisation and economic growth in the region heavily depend on fossil fuels, which power industries and meet growing energy demands. Transitioning away from these fuels requires considerable investment.

(2) Transition strategies

Given the obstacles in developing Asia, a just and orderly transition is the key, Transitioning must ensure sustainability, affordability, energy security, and reliability to avoid social disruption. A balanced approach is needed, where climate sustainability guides technology choices without compromising energy security.

(3) Identified sector-specific challenges and needs for decarbonising technologies

The TLP document identifies key challenges and decarbonisation needs across key sectors, including upstream, power, midstream, downstream, and end-use and industries sectors. Technologies to address these challenges have been identified for each sector.

1. Upstream sector

Challenges include reducing emissions from fossil fuel combustion and methane emissions during coal extraction and natural gas extraction. A shift to lower-emission fuels such as biomass and hydrogen is essential.

2. Power sector

Coal remains a major source of emissions in the power sector. Integrating renewable sources like solar and wind is challenging due to grid stability and infrastructure limitations. Technologies such as co-firing, CCS, and fuel-switching are necessary to bridge the gap between fossil fuels and renewable energy.

3. Midstream sector

Key challenges include enhancing grid stability, reducing energy losses during transmission, and developing infrastructure for distributing lower-emission fuels like hydrogen, particularly as renewable energy use increases.

4. Downstream sector

To support the transition in the transport sector, infrastructure development is required, such as EV charging stations and bunkering facilities for low-emission fuels.

5. End-use and industries sector

① The transport sub-sector

Road transport is a major emitter, and efforts to promote electrification and fuel switching are critical.

② The building sub-sector

Reducing electricity consumption through energy-efficient technologies is crucial for lowering indirect emissions.

③ The cement, concrete, and glass sub-sector

Decarbonisation challenges include reducing emissions from energy-intensive clinker production, meeting strict export regulations, and improving energy efficiency. Solutions must focus on fuel switching and integrating CCU.

④ The chemicals sub-sector

The petrochemical industry faces emissions challenges from energy-intensive processes. Overcapacity and opportunities for CCU to convert CO_2 into chemicals must also be addressed.

⑤ The iron and steel sub-sector

Decarbonisation requires reducing the reliance on blast furnaces, major emitters of CO_2, and integrating CCU to recycle emissions during the steelmaking process.

⑥ The industry cross-cutting sub-sector

Transitioning from fossil fuels to electrification and low-emission solutions for industrial heating is vital across multiple industries. Although certain industries, such as food and tobacco, are identified as high-emitters, the decarbonisation technologies that address emissions in these sectors are cross-sectoral. Therefore, they are summarised under the ‘industries cross-cutting’ sub-sector.

⑦ The agriculture sub-sector

Technological solutions are needed to reduce methane emissions from rice cultivation and livestock.

⑧ The waste sub-sector

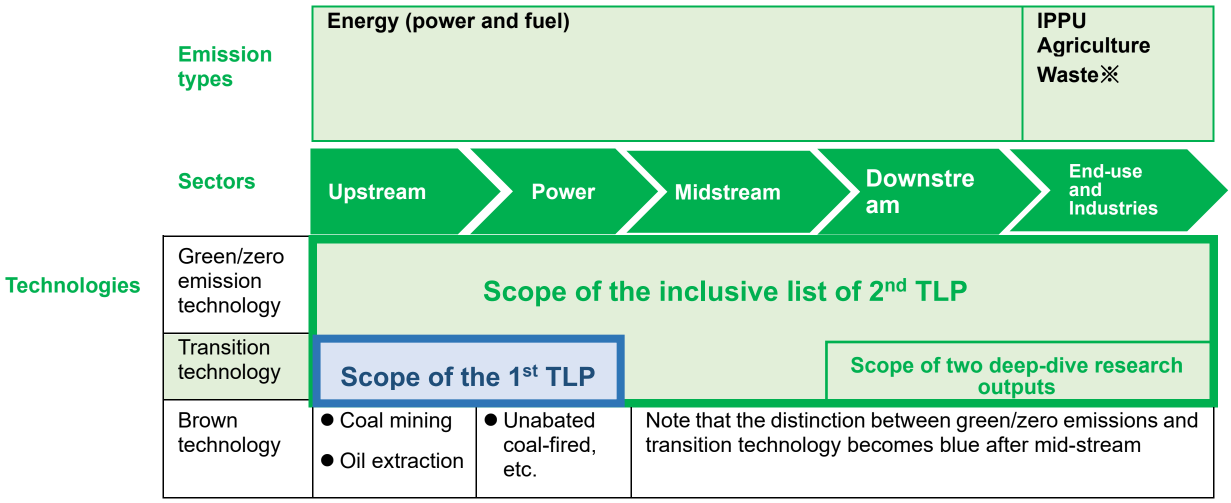
Improving waste management practices and infrastructure is essential to mitigate emissions from waste disposal.

6.2. Future phases

The TLP document is a living resource, with ongoing updates to reflect emerging technologies and changing needs. Future phases will focus on producing two deep-dive research outputs whilst ensuring TLP remains relevant and useful for stakeholders in transitioning to a low-carbon economy. In the next phase, several transition technologies from the end-use and industries sector will be selected for deep-dive research. These technologies will be identified based on emission profiles and the challenges of accelerating the transition to a low-carbon economy. Subsequent phases will examine the midstream and downstream sectors, conducting deep-dive research on selected transition technologies in these areas. The prioritisation of the end-use and industries sector is strategic, as technology selection in this sector will influence choices for the downstream and midstream sectors. After completing the deep-dive research on the end-use and industries sector, technologies for the midstream, and downstream sectors will be identified for deep-dive research.

Exhibit 73. Different Outputs of Technology List and Perspectives

Note: Emissions from LULUCF were excluded from the project scope



IPPU = industries processes and product use, LULUCF = land use, land use change, and forestry.
Source: Author.

Appendix: List of Acronyms

Acronym	Full Form
ASEAN	Association of Southeast Asian Nations
BAU	business as usual
CCUS	carbon capture, utilisation, and storage
CO2	carbon dioxide
DNSH	do no significant harm
EC	essential criteria
EMS	energy management system
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
GHG	greenhouse gas
HEV	hybrid electric vehicle
HVO	hydrotreated vegetable oil
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LNG	liquefied natural gas
METI	Ministry of Economy, Trade, and Industry (Japan)
PHEV	plug-in hybrid electric vehicle
PV	photovoltaic
SAF	sustainable aviation fuel
TES	transforming energy scenario
TLP	Technology List and Perspectives
TRL	technology readiness level

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Appendix:

Inclusive List of Green and Transition Technologies

Explanation of each technology readiness level defined by the International Energy Agency and matched development stage defined in the Ministry of Economy, Trade and Industry (Japan) transition roadmaps

Category	TRL	IEA	METI Transition Roadmaps
Mature	11	Proof of stability reached – Predictable growth	Deployment or expansion of introduction or practical application or commercialisation
Market uptake	10	Integration required at scale – Solution is commercial and competitive, but requires further integration	
	9	Commercial operation in relevant environment – Solution is commercially available, but requiring evolutionary improvement to stay competitive	
Demonstration	8	First-of-a-kind commercial – Commercial demonstration. Full-scale development in final conditions	Demonstration with large-scale equipment or technology demonstration or proof to be deployed by 2030
	7	Pre-commercial demonstration – Prototype working in expected conditions	
Large prototype	6	Full prototype at scale – Prototype proven at scale in conditions where it will be deployed	Demonstration with large-scale equipment or technology demonstration or proof to be deployed by 2040
	5	Large prototype – Components proven in conditions where it will be deployed	
Small prototype or lab	4	Early prototype – Prototype proven in test conditions	Research and development or development of basic technology on experimental machines
	3	Concept requires validation – Solution must be prototyped and applied	
	2	Application formulated – Concept and application have been formulated	
	1	Initial idea – Basic principles have been derived	

Green and transition technologies (Upstream)

The ASEAN taxonomy offers two assessment approaches: the foundation framework and the plus standard (PS). Under the PS approach, six focus sectors and three enabling sectors have been identified as being particularly important to ASEAN's sustainability journey due to their significant contributions to both greenhouse gas emissions and the economy of Southeast Asia.

#	Focus Sector
1	Agriculture, forestry, and fishing
2	Electricity, gas, steam, and air conditioning supply
3	Manufacturing
4	Transport and storage
5	Waste supply, sewage, and waste management
6	Construction and real estate

#	Enabling Sector	Explanation
1	Information and communication	Digital transformation drives efficiency in emissions-intensive sectors through data-driven solutions, resource efficiency software, meteorological adaptation, and direct mitigation measures, all supported by physical infrastructure such as data centres, which are essential for decarbonisation.
2	Professional, scientific, and technical	This transformation is closely linked to the implementation of efficiency measures across various sectors, alongside technical studies, and research focused on decarbonising the economy. Examples include solar water heater installations, building retrofits, renewable energy installations, and equipment upgrades.
3	Carbon capture, storage, and utilisation	Artificial carbon capture, storage, and transformation technologies are vital for reducing emissions in high-emission sectors like cement and steel manufacturing as well as facilitating the transition of certain sectors, such as natural gas plants, by integrating with carbon capture and storage systems.

Source: ASEAN, 'ASEAN Taxonomy versions 1–3'.

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.01	Upstream	Ammonia production	Chemical reaction	Harber-Bosch process	The Haber-Bosch process for ammonia synthesis operates at high temperature (400°C–650°C) and pressures (100–400 bar), using a catalyst. Most of the energy mainly comes from the exothermic reaction, with some electricity needed for control systems. Alternatives to steam methane reforming include producing syngas from hydrogen via electrolysis or biomass gasification.	8 ~ 11	Enabling sector 3 (Carbon capture, storage, and utilisation)	International Energy Agency (IEA) Clean Energy Technology Guide
I.02	Upstream	Bioenergy production	Biocoal	Torrefaction (for high-temperature heating or low-to medium-temperature heating)	Biomass can be torrefied by heating it without oxygen at 200°C–400°C, transforming it into 'bio-coal' with properties similar to coal, making it suitable for industrial applications. This process helps reduce emissions from industrial heat demands, but its potential is limited by the scarcity of sustainable biomass and competition with other sectors.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.03	Upstream	Bioenergy production	Biofuel	Alcohol-to-jet biodiesel (sustainable aviation fuel [SAF])	The alcohol-to-jet (ATJ) process converts alcohols (such as methanol, ethanol, or butanol) into renewable diesel or jet fuel through steps like dehydration, oligomerisation, hydrogenation, and distillation. ATJ is certified by the American Society for Testing and Materials (ASTM) for SAF, blendable up to 50%. Demand for SAF is high in a net-zero future, as alternatives such as electrification are costly or impractical for long-haul flights.	7	Focus sector 4 (Transportation and storage)	IEA Clean Energy Technology Guide
I.04	Upstream	Bioenergy production	Biofuel	FAME (SAF)	Fatty acid methyl ester (FAME) biodiesel is produced by reacting vegetable or waste oils with methanol using a catalyst, yielding biodiesel and glycerine, which is then purified. Biodiesel can be blended with fossil diesel (5%–7%) for road transport or used in its pure form (100%) in marine engines. However, the limitations of FAME biodiesel include blending capacity, the sustainability of feedstock, and the availability of waste oil.	9 ~ 10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.05	Upstream	Bioenergy production	Biofuel	Gasification and Fischer-Tropsch biodiesel (SAF)	The biomass-based Fischer Tropsch pathway, known as bio-FT or biomass-to-liquid (BTL), converts biomass into liquid fuels. Biomass such as wood or agricultural residues is gasified into syngas, which is then converted into hydrocarbon liquids via the Fischer-Tropsch process. This method avoids competition with food crop and produces ‘drop-in’ fuels that are compatible with existing infrastructure. However, it faces challenges such as tar buildup during production.	7 ~ 8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.06	Upstream	Bioenergy production	Biofuel	HEFA/HVO (SAF)	Hydroprocessed esters and fatty acids (HEFA) or hydrogenated vegetable oil (HVO) are renewable diesel fuels and drop-in biokerosene. Produced via hydrotreatment, this process uses hydrogen to break down oils into hydrocarbons. Compared to FAME biodiesel, HVO/HEFA offers better stability and properties. It is ASTM-certified for aviation fuel, with the capability to be blended up to 50%.	4~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.07	Upstream	Bioenergy production	Biofuel	Hydrothermal liquefaction and upgrading (SAF)	Hydrothermal liquefaction (HTL) and catalytic hydrothermolysis (CHJ) use high-pressure water and heat to convert wet biomass into gases and bio-oil, often with the aid of an alkali catalyst. This bio-oil, which contains less oxygen, can be refined into high-quality fuels such as diesel and sustainable aviation fuel, with HTL certified by ASTM.	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.08	Upstream	Bioenergy production	Biofuel	Pyrolysis (biodiesel)	Pyrolysis involves heating biomass without oxygen, yielding bio-oil and biochar. Fast pyrolysis, which occurs within seconds, primarily produces bio-oil from dry biomass, which can be further refined into fuels like diesel. It can also be co-fed into refineries alongside crude oil. Higher technology readiness level (TRL) biofuels alternatives are available.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.09	Upstream	Bioenergy production	Biofuel	Synthetic Iso-Paraffins (biodiesel)	The ‘sugars to hydrocarbons’ pathway converts biomass sugars directly into diesel and jet fuel-like hydrocarbons, using either biological or catalytic methods. Synthetic iso-paraffins, an ASTM-certified sustainable aviation fuel (SAF), can be blended at up to 10%. In a net-zero world, the demand for SAFs is high, as alternatives are either costly or technically impractical.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.10	Upstream	Bioenergy production	Biofuel	Fermentation	Fermentation refers to technologies that generate bioenergy, particularly bioethanol, through fermentation processes. This includes enzymatic fermentation to produce lignocellulosic bioethanol, sugar and starch bioethanol, as well as syngas fermentation.	8~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	
I.11	Upstream	CCS business	Direct Air Capture	Direct Air Capture	Direct air capture (DAC) extracts CO_2 from the atmosphere using an air contactor, where a fan draws air through surfaces treated with potassium hydroxide to capture CO_2 as a carbonate salt. The CO_2 is then purified, compressed, and prepared for storage or utilisation, with chemical reactions sustaining the process.	4 ~ 9	Enabling sector 3 (Carbon capture, storage, and utilisation)	Internet search

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.12	Upstream	Fossil fuel based	CCUS	CCUS in fossil fuel production	This term encompasses CCUS technologies applied to fossil fuel-based production. These include CCUS in gas production, heating processes, refineries, and fluid catalytic cracking (FCC).	3~7	Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
I.13	Upstream	Fossil fuel based	Electrification	Process electrification in gas production	Electrification methods in gas production include offshore power sources with microgrid systems and grid integration via subsea cables. LNG plants, which currently rely on direct drive compressors and gas turbines, are significant CO_2 emitters. Switching to electrified, renewable-powered electric compressors could cut emissions by up to 80%, contingent on the implementation and local grid's emissions intensity.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.14	Upstream	Fossil fuel based	Fugitive emissions abatement	Leak detection and repair	Methane emissions, the second-largest contributor to global warming, totaled 70 million tonnes (Mt) in 2020, with 25% attributed to fugitive emissions. Leak detection and repair (LDAR) is a cost-effective method to tackle this issue, targeting leaks throughout the oil and gas value chain. LDAR systems can reduce emissions by up to 95%.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)
I.15	Upstream	Hydrogen production	Biological reaction	Biological splitting	Biotechnologies for green H_2 from biomass include: 1) dark fermentation (DF), which uses organic matter to produce H_2 and biobased molecules without light, offering low costs but affected by microbial interactions. 2) Water-splitting photosynthesis by algae and cyanobacteria generates H_2, although oxygen inhibition limits it. 3) Bioelectrochemical systems use microbial electrolysis cells for H_2 production.	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.16	Upstream	Hydrogen production	Chemical reaction	Aluminum oxidation	Hydrogen can also be produced via water/steam aluminum oxidation under pressure (up to 40 bar) and relatively low temperatures (up to 300℃), using catalysts. Alkaline compounds are needed to prevent the formation of an oxide layer. Whilst this method shows potential for low-emission hydrogen, alternatives like CCS and electrolysis are currently	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
					more cost-effective.			
I.17	Upstream	Hydrogen production	Chemical reaction	Ammonia cracking	Ammonia cracking decomposes ammonia into nitrogen and hydrogen at high temperatures (600°C–900°C) using iron, consuming 30% of the energy content of ammonia. Lower temperature cracking (~450°C) uses precious metals like ruthenium, but further innovation is required to improve efficiency and reduce costs. Although hydrogen can be transported as ammonia, energy-intensive cracking is needed to convert if back into pure hydrogen.	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.18	Upstream	Hydrogen production	Chemical reaction	Decomposition from methane	Methane splitting, also known as pyrolysis or cracking, decomposes methane into CO_2-free hydrogen and solid carbon at high temperatures. This process can involve catalytic, thermal, plasma thermal, and plasma non-thermal methods, with the separated solid carbon usable in various industrial applications.	3~8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.19	Upstream	Hydrogen production	Chemical reaction	Partial oxidation of natural gas	In partial oxidation, natural gas reacts with a limited amount of oxygen, yielding hydrogen and carbon monoxide (CO) instead of CO_2 and water due to the insufficient oxygen supply. A subsequent water–gas shift process generates more H_2 and CO_2. This exothermic reaction, when coupled with carbon capture, reduces CO_2 emissions from hydrogen production, making it vital for net-zero strategies.	5 ~ 6	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.20	Upstream	Hydrogen production	Chemical reaction	Reforming from methane (CCU)	Hydrogen is also produced through steam-reforming, where methane reacts with high-temperature steam to produce H_2 and CO (syngas). Variants of this technology include single reformers, gas-heated reformers, electrically powered steam reforming, sorption-enhanced steam reforming, catalytic steam methane reforming, and underground reforming with CCUS.	4~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.21	Upstream	Hydrogen production	Electrolyser	Electrolyser	Electrolysis uses electricity to split water into H_2 and O_2. This broad category encompasses specific technologies such as alkaline electrolysers, anion exchange membrane electrolysers, polymer electrolyte membrane electrolysers, and solid oxide electrolyser cells.	6~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.22	Upstream	Hydrogen production	Gasification	Biomass-waste gasification/pyrolosis	This is an umbrella term for H_2 production technologies from solid feedstock through thermochemical processes. This category includes technologies such as biomass-waste gasification and pyrolysis.	6	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.23	Upstream	Hydrogen production	Hydrogen conditioning	Hydrogen post-production conditioning	This is an umbrella term for technologies used in post-production H_2 treatment, including hydrogen liquefaction, liquid organic hydrogen carriers, and hydrogen compression.	6~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	-
I.24	Upstream	Hydrogen production	Mining	Natural hydrogen extraction	Natural hydrogen, produced through iron oxidation and radiolysis, is being explored in iron-rich and radioactive areas using methods similar to those for hydrocarbon exploration. Targeted are source rocks, migration pathways, and reservoirs like volcanic sills or salt layers. However, incomplete surveys and economic uncertainties limit its role in the net-zero transition.	5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.25	Upstream	Hydrogen production	Water splitting	Water splitting	Water splitting refers to technologies that split water into oxygen and hydrogen using catalysts, thermal energy, or thermochemical reactions. Examples include photocatalytic water splitting and water splitting powered by solar, nuclear, or very high-temperature reactors (VHTR).	4~5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.26	Upstream	Methane production	Biomethane	Anaerobic digestion for biomethane and biogas production	This term encompasses technologies that use anaerobic digestion to produce bioenergy, such as biogas and biomethane via methanation with hydrogen, or CO_2 separation. Anaerobic digestors break down biomass – such as animal manure, municipal solid waste, and agricultural residues – without oxygen, producing biogas (a mixture of methane and CO_2).	3~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.27	Upstream	Methane production	Biomethane	Biomass gasification and methanation	This term encompasses technologies for producing methane via biomass gasification and methanation, which can be small-scale, catalytic, or combined methods. Biomass with high lignocellulosic content is gasified in an oxygen-restricted environment to produce syngas (H_2, CO, and CO_2). The syngas is cleaned, with CO_2 removed, dried, and then converted to biomethane via catalytic or biological methanation.	4~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.28	Upstream	Methane production	Methanation	Chemical/ biological methanation	This term refers to technologies for producing methane from CO_2 via chemical or biological methanation. These methods convert CO or CO_2 to methane via hydrogenation, using a catalyst. Carbon sources include CO from syngas generated by gasification or pyrolysis, or CO_2 from exhaust gases, fermentation, anaerobic digestion, or direct air capture.	7	Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
I.29	Upstream	Methane production	Synthetic methane	Synthetic methane from CO and H_2	Fischer Tropsch synthesis converts CO_2 (via the RWGS reaction) and hydrogen into synthetic liquid hydrocarbons. Key challenges include the thermal stability of CO_2 and reaction efficiency. The process produces light olefins, petrol, kerosene, and value-added chemicals, using iron, cobalt, or ruthenium catalysts. Synthetic fuels are crucial for decarbonising sectors such as long-distance shipping and aviation.	6	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
I.30	Upstream	Methanol production	Biomass gasification	Biomass and waste gasification	Biomass can replace fossil fuels in methanol production by converting it into syngas. Whilst this reduces direct fossil fuel use, the limited availability of sustainable biomass limits its potential. The process is capital- and energy-intensive, making it more costly than alternatives like hydrogen and CCS.	8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.31	Upstream	Methanol production	Chemical reaction	CO_2- and electrolytic hydrogen-based methanol production	Syngas, mainly composed of CO_2 and hydrogen, is produced from methane and used to make methanol. This process relies on hydrogen from water electrolysis and waste CO_2 from industrial sources. It can eliminate direct fossil fuel use if renewable electricity powers hydrogen production and CO_2 is sustainably sourced.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Upstream)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
I.32	Upstream	Methanol production	Chemical reaction	Methane pyrolysis	Methane pyrolysis generates CO_2-free hydrogen and solid carbon, which can be used in various applications. This process produces syngas for methanol production without emitting CO_2 and requires minimal adjustments to subsequent processes. Although it shows potential for reducing emissions in methanol production, CCS technology is currently more advanced. Additionally, projects are exploring the use of hydrogen in the production of methanol and ammonia.	8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.01	Power	Carbon capture, utilisation, and storage (CCUS)	Carbon capture and storage (CCS) business	CO_2 storage	This entry covers various CO_2 storage technologies, with the most common options including depleted oil and gas reservoirs, and aquifers.	11	Enabling sector 3 (CCUS)	IEA Clean Energy Technology Guide
II.02	Power	CCUS	CCS business	CO_2 transport	CO_2 transport methods include pipelines, shipping, and trucks. Pipelines transport CO_2 in various forms, requiring refrigeration and compressors. Shipping is used for long-distance transport and requires infrastructure for liquification, loading, and storage at both departure and receiving ports.	6~10	Enabling sector 3 (CCUS)	-
II.03	Power	CCUS	CCS business	Enhanced oil recovery/ Enhanced gas recovery	CO_2 injections can occur during oil and gas production to enhance oil/gas recovery. After these operations, a large portion of the injected CO_2 may remain permanently trapped in the reservoir. Further monitoring may be necessary to confirm that the CO_2 remains securely stored underground.	11	Enabling sector 3 (CCUS)	IEA Clean Energy Technology Guide
II.04	Power	CCUS	CCUS in power plants	Biomass-fired power plant with CCUS	In biomass-fired power plants employing post-combustion capture with chemical absorption, CO_2 is separated from flue gas using solvents like amines. The CO_2 is then released at high temperatures, allowing the solvent to be regenerated for continued use in capturing emissions.	6~7	Enabling sector 3 (CCUS)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.05	Power	CCUS	CCUS in power plants	CCUS in coal/gas power plant	CCUS in coal or gas power plants captures emitted CO_2, preventing its release into the atmosphere. A common method is chemical absorption, where CO_2 reacts with a solvent, such as amines, to form an intermediate compound. Heat is then used to regenerate the solvent, producing a concentrated stream of CO_2. This process can capture around 90% of CO_2 emissions.	6~9	Enabling sector 3 (CCUS)	1st Technology List and Perspectives (TLP)
II.06	Power	CCUS	CCUS in power plants	Chemical looping with CCUS	Chemical looping combustion (CLC) utilises metal oxides to burn fossil fuels whilst capturing CO_2 emissions. Fluidised bed CLC operates with two reactors: one oxidises an oxygen carrier with steam to generate H_2, whilst the other oxidises fuel to produce CO_2, operating in a continuous loop. Fixed-bed CLC alternates between oxidation and reduction in a single reactor, enabling efficient hydrogen production with high purity and continuous operation.	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.07	Power	Fossil fuel-based	Thermal	Combined cycle gas turbine	Combined cycle gas turbine (CCGT) power plants, which use both gas and steam turbines, achieve higher efficiency (60%) compared to open cycle turbines and coal plants (40%). The generating capacity ranges from 300 megawatts (MW) to over 1,000 MW, with availability exceeding 80%, and a technical lifespan of over 25 years.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.08	Power	Fossil fuel-based	Thermal	Supercritical CO_2 cycle	Supercritical CO_2 (sCO_2) cycles replace conventional steam with CO_2 at temperatures and pressures above its critical point, where it exists in both liquid and gaseous phases. These cycles offer the potential for higher efficiency, lower emissions, and reduced costs, benefitting from high CO_2 capture rates and potentially lower water consumption. However, operational challenges such as combustion dynamics remain a focus area for further study.	5 ~ 6	Enabling sector 3 (CCUS)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.09	Power	Fuel switching	Thermal	Low-carbon ammonia co-firing	Low-carbon ammonia co-firing in coal-fired power plants involves modifying the boiler and investing in additional facilities like ammonia tanks. Ammonia is mixed with pulverised coal before entering the burner zone for combustion. Optimising boiler design is crucial for stable flame and nitrogen oxide (NOx) reduction. Technological advancements may allow higher co-firing ratios, but beyond a certain threshold, replacing the steam turbine with a gas turbine could boost thermal efficiency.	3~5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)
II.10	Power	Fuel switching	Thermal	Biomass co-firing	Biomass co-firing combines renewable biomass with fossil fuels like coal or gas in existing power plants to cut greenhouse gas emissions and fossil fuel dependence. This method works across different plant types, enabling a shift towards sustainable energy production with minimal adjustments.	10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	New Energy and Industrial Technology Development Organization (NEDO) Energy Saving and Non-fossil Energy Conversion Technology Strategy

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.11	Power	Fuel switching	Biomass	Integrated gasification combined-cycle biomass power plant	In integrated gasification combined-cycle biomass plants, biomass is converted to synthesis gas, which contains hydrogen and carbon monoxide. The syngas undergoes a water–gas shift reaction to enhance hydrogen and convert CO to CO_2. CO_2 is then separated using methods like adsorption, whilst the hydrogen powers a combined-cycle turbine for power generation. This approach can potentially achieve negative emissions if the CO_2 is permanently stored.	3	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.12	Power	Fuel switching	Fuel cell	Fuel cell	Fuel cell technologies, including molten carbonate and solid oxide fuel cells, are suitable for hybrid hydrogen fuel cell-gas turbine systems. These cells convert hydrogen into electricity and heat without direct emissions, achieving over 60% electric efficiency (or 80% when including heat output). They also maintain higher efficiency at partial loads, making them ideal for flexible operations.	6~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.13	Power	Fuel switching	Hydrogen	Low-carbon hydrogen co-firing	Low carbon hydrogen can be used alone or mixed with natural gas in power plants, although adjustments to burners are necessary. Most gas turbines can handle up to 5% hydrogen without significant changes. With infrastructure updates, standard turbines may run on up to 60% hydrogen, although challenges such as autoignition and combustion instability arise. Pure hydrogen firing is still in the early pilot stage.	7~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)
II.14	Power	Fuel switching	Waste	Waste to energy	There are four types of waste-to-energy technologies: direct combustion, thermochemical gasification, anaerobic digestion, and landfill capture. Direct combustion burns waste to generate steam for electricity; gasification converts waste carbon to syngas; anaerobic digestion produces biogas from organic waste; and landfill gas capture extracts gas from landfills. The commercial viability of these technologies depends on waste supply, economics, and alternative waste management strategies.	10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	1st Technology List and Perspectives (TLP)
II.15	Power	Nuclear	Nuclear reactor	High-temperature reactor and very high-temperature nuclear reactor	Very high-temperature reactors (VHTR) generate extremely high temperatures (up to 1,000°C) for hydrogen production and industrial heat applications, achieving high efficiency using Brayton cycles. These reactors are designed to produce 250 MW electricity or 600 MW of heat, using helium coolant and graphite-moderated fuel. Key challenges include developing materials that can withstand high temperatures and optimising fuel design. China and Japan currently have prototype reactors in operation.	7~8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.16	Power	Nuclear	Nuclear reactor	Sodium-cooled fast nuclear reactor	Sodium-cooled fast reactors (SFRs) are well-established Generation IV technologies that use a fast neutron spectrum, liquid sodium coolant, and closed fuel cycles with multi-recycling of nuclear materials. Full-scale designs, capable of up to 1,500 MW, typically use mixed uranium–plutonium oxide fuel. SFRs operate at higher temperatures (550℃), which enhances their potential for non-electricity applications. However, key challenges remain, including reducing capital costs and improving passive safety systems.	8～9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.17	Power	Nuclear power	Nuclear reactor	Light water nuclear reactor	This term refers to both large-scale and small modular light water nuclear reactors (LWRs), the most common type of water-cooled reactors. LWRs include pressurised water reactors (PWRs) and boiling water reactors (BWRs). PWRs use separate steam generators, whilst BWRs generate steam directly from the reactor core. Both types require U-235 enriched fuel.	6~11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.18	Power	Renewables	Geothermal	Binary plant	This term encompasses binary-cycle geothermal plant technologies, including closed-loop, hybrid closed-loop systems, the Kalina process, and the organic Rankine cycle. These plants transfer heat from geothermal hot water to another liquid, which turns to steam and drives a turbine to generate	5~11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
					electricity.			
II.19	Power	Renewables	Geothermal	Combined cycle and hybrid plant	Some geothermal plants employ a combined cycle, adding a traditional Rankine cycle to utilise waste heat from the binary cycle, enhancing electrical efficiency. Hybrid geothermal power plants combine geothermal technology with other heat sources, such as concentrating solar power, to increase brine temperature and enhance power output.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IRENA https://www.irena. org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.20	Power	Renewables	Geothermal	Direct dry steam Plant	Dry steam plants, accounting for about a quarter of today’s geothermal capacity, directly utilise dry steam piped from production wells to the plant and then to the turbine.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.21	Power	Renewables	Geothermal	Enhanced geothermal system	Enhanced geothermal systems (EGS) tap into the earth's heat where conventional sources are unavailable. EGS involves engineering extensive heat exchange areas in hot rock by enhancing permeability via fracturing. Heat transfer occurs by pumping water into fractured rock and cycling it through a power plant. Despite potential, future costs remain uncertain.	6	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.22	Power	Renewables	Geothermal	Flash steam plant	Flash steam plants, comprising most of current geothermal capacity, utilise reservoirs with temperatures surpassing 180°C. As pressure drops, water boils into steam, powering turbines to generate electricity. The remaining hot water may undergo multiple flashing to produce more steam. Despite being a mature technology, its deployment hinges on local potential.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.23	Power	Renewables	Hydropower	Hydropower	Hydropower, which generates electricity from falling water, provides 16% of global power. It is categorised into run-of-river, reservoir, and pumped storage plants.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
					As a mature and cost-competitive technology, it plays a crucial role in clean energy production and provides flexibility to the power grid.			
II.24	Power	Renewables	Ocean	Ocean thermal	Ocean thermal energy conversion (OTEC) utilises temperature gradients in ocean depths to generate energy, and it can also enable sea-water air conditioning (SWAC) and desalination. SWAC is economically viable for cooling, particularly in European commercial and data centre applications, expanding its utility beyond power generation.	5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.25	Power	Renewables	Ocean	Ocean wave	Wave energy converters (WECs) harness wave movement to generate energy and can be installed near the shore or over 100 metres offshore. Unlike tidal technology, wave technology is still evolving, with various prototypes being tested globally. There are four main types: point absorber, attenuator, hinged flap, and oscillating water column (OWC). Developers are working towards higher power ratings and commercial viability.	6 ~ 7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.26	Power	Renewables	Ocean	Salinity gradient	Salinity gradient technology utilises osmotic pressure between seawater and freshwater, but it requires further development for widespread adoption. The Netherlands, Mexico, and several other countries are actively testing and advancing this technology.	4	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.27	Power	Renewables	Solar PV	Crystalline silicon PV	Most photovoltaic (PV) modules use wafer-based crystalline silicon (c-Si) technology. The manufacturing process involves growing silicon ingots, slicing them into wafers, making cells, and assembling modules. Currently, single-crystalline modules offer higher efficiency (14%–20%) than multi-crystalline ones. Further efficiency improvements are anticipated, making c-Si more competitive in sunny regions.	9 ~ 10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.28	Power	Renewables	Solar PV	Perovskite	Perovskite-based thin-film PV technology, which does not rely on silicon, shows potential due to its high light absorption. Whilst laboratory efficiency has reached 25%, this has only been achieved in small cells. Challenges remain in scaling production and improving durability, as larger cell manufacturing processes are yet to be developed, and longevity issues persist.	4 ~ 5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.29	Power	Renewables	Solar PV	Thin-film PV	Thin-film solar cells, a second-generation technology, are created by depositing thin layers of photovoltaic material onto substrates. Commercial variants include hydrogenated amorphous silicon, cadmium telluride, and copper indium selenide-copper indium gallium selenide (CIS-CIGS). Organic thin-film PV cells use dye or organic semiconductors. Research and development (R&D) have developed low-cost technologies like copper zinc tin sulphide, Perovskite, and organic solar cells, though stable products are still under development.	5~8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.30	Power	Renewables	Solar thermal	Solar thermal energy	This term encompasses solar thermal energy technologies, including solar towers, parabolic troughs, linear Fresnel reflectors (LFRs), and solar thermal district heating. These systems concentrate sunlight to generate high temperatures for electricity production by using mirrors to focus sunlight onto a receiver, heating a fluid to produce steam, which then drives a turbine generator.	7~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.31	Power	Renewables	Ocean	Tidal energy	Tidal energy technologies include tidal range, which generates electricity through conventional hydropower principles, and tidal stream turbines, which work similarly to wind turbines.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Fuel Type	Tech Group	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
II.32	Power	Renewables	Wind	Airborne wind energy system	Airborne wind energy systems (AWES) convert wind energy into electricity using kites or unmanned aircraft tethered to the ground. These systems include lift-type and drag-type designs. AWES offer advantages such as reduced material use, lower costs, faster deployment, and the ability to harness stronger winds at higher altitudes. Applications range from small off-grid power solutions to large-scale offshore production. Though operational, reliability is still being developed.	4 ~ 5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Power)

Ref	Sector	Tech type	Tech group	Tech name	Description	TRL	Relevant activity in ASEAN taxonomy*	Source
II.33	Power	Renewables	Wind	Offshore wind turbine	Seabed-fixed offshore wind turbines currently dominate offshore wind capacity. Whilst their energy capture and power generation processes are similar to onshore turbines, they are optimised for marine environments. Foundation types include monopiles, multi-piles, gravity foundations, and suction caissons, supported by structures like tubular towers, jackets, tripods, lattice towers, and hybrids.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.34	Power	Renewables	Wind	Onshore wind turbine	Wind turbines convert the kinetic energy of wind into electricity via a rotor and generator. Onshore turbines are versatile, capable of being installed in a wide range of locations and climates, from coastal regions to deserts. As an evolving technology, onshore wind turbines continue to grow, performance, and service capabilities, making onshore wind a key renewable resource.	9 ~ 10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
II.35	Power	Waste heat utilisation	Energy efficiency	Organic Rankine cycle power generation	An organic Rankine cycle (ORC) system uses low to medium-high temperature heat sources (80℃–400℃) for power production, efficiently exploiting low-grade heat. Traditionally, ORC cycles use axial or radial inflow turbines, but Exergy's radial outflow turbine innovation offers greater efficiency, particularly for customised ORC power plants.	7 ~ 9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	NEDO Energy Saving/Non-fossil Energy Conversion Technology Strategy

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.01	Midstream	Electricity distribution	DC microgrid	Direct current (DC) microgrids use DC power generated from photovoltaic (PV) sources and battery storage to directly power DC loads, such as electric vehicle (EV) charging and lighting, without the need for DC/AC conversion, thereby enhancing efficiency. With AC/DC converters, they can also connect to the grid and support AC loads. Fully DC systems improve efficiency by eliminating conversion losses, particularly in cases where electricity is produced and consumed locally.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.02	Midstream	Electricity distribution	Demand response systems	A hybrid network combines energy-consuming equipment and batteries to provide demand response services to the electricity grid. Using smart grid principles, it rotates energy use based on flexibility and fills gaps with battery power, ensuring reliability without relying on on-site batteries. This system delivers robust flexibility services, aiding the integration of renewable energy sources into the grid.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.03	Midstream	Electricity distribution	Double (dual) smart grid	A double smart grid combines smart electricity and district energy networks, optimising the synergies amongst electricity, heating, and cooling loads. It also facilitates the use of renewable energy sources such as PV, solar thermal, and power-to-heat, as well as waste energy resources. This enhances system efficiency and scalability, making it particularly suited for dense, mixed-use urban districts.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.04	Midstream	Electricity distribution	Smart grid	A smart grid uses digital technologies to manage the distribution of electricity, coordinating generators, operators, and users to meet demand efficiently. It minimises costs and environmental impacts whilst maximising reliability, resilience, flexibility, and stability. Key technologies include smart inverters, dynamic line rating, and	7~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
				virtual inertia fast frequency response (FFR), most of which are well-developed.			
III.05	Midstream	Electricity distribution	Flexible AC transmission system	Flexible alternating current transmission systems (FACTS) comprise technologies that provide reactive power support, enhance controllability, improve stability, and increase power transfer capabilities within AC systems. They are essential for supporting variable renewable energy sources, distributed generation, and new electric demands. Key components include series compensation, synchronous condensers, static synchronous compensators, static VAr compensators, and mechanically switched capacitor damping networks.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.06	Midstream	Electricity distribution	High voltage (HVDC) transmission sytem	High-voltage direct current (HVDC) systems use DC for power transmission, enabling efficient long-distance electricity transfer and offshore wind farm integration. Recent advancements have made HVDC systems economical, offering flexible power control and robust network support. Operating at voltages between 320kV and 1100 kV, with capacities up to 12GW, HVDC is ideal for transmitting power from remote renewable resources and over long distances, surpassing HVAC systems.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.07	Midstream	Energy/fuel storage	Ammonia storage tank	Ammonia is stored as a liquid, with modern atmospheric tanks capable of holding up to 50,000 tonnes. Low-pressure storage is preferred due to its lower capital costs. Future ammonia storage units could serve as fuel bunkers if ammonia is adopted as a fuel for shipping.	11	Not found	IEA Clean Energy Technology Guide
III.08	Midstream	Energy/fuel storage	Battery for grid use	This term refers to various grid-connected batteries for storing excess electricity, including lithium-ion, sodium-ion, redox, solid-state, and metal-air batteries. A battery energy storage system (BESS) charges from the grid or power plants, storing energy for later discharge to provide electricity or other grid services when needed.	7~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.09	Midstream	Energy/fuel storage	Hydrogen storage	This term covers hydrogen and ammonia storage methods, including salt and lined hard rock caverns, liquid hydrogen tanks, and metal hydrides. Hydrogen can be stored as a gas in high-pressure tanks, as liquid at cryogenic temperatures, or within solids through adsorption or absorption.	4~11	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.10	Midstream	Energy/fuel storage	Mechanical energy storage	This term includes mechanical energy storage technologies, including liquid air, compressed air, gravity-based storage, and flywheels. These systems convert electrical energy into kinetic or potential energy, which is then reconverted to electricity when needed. They help balance grid demand during peak periods and provide services like frequency regulation, primary response, and voltage control.	6~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.11	Midstream	Energy/fuel storage	Power-to-heat	This entry covers power-to-heat technologies, where energy is stored as heat, and electricity can be generated when needed. These technologies include sorption process storage, molten salt storage, and solids heat storage, amongst others.	5~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.12	Midstream	Energy/fuel storage	Thermal storage	This term covers thermal storage technologies such as geothermal networks, phase-changing materials, solid-solid thermal storage, and thermochemical storage. Thermal energy storage involves heating or cooling a medium, such as water in a tank, to store energy for later use when energy supply is limited.	8~9	Not found	IEA Clean Energy Technology Guide
III.13	Midstream	Fuel distribution	Hydrogen pipeline	Hydrogen pipelines can either repurpose existing natural gas pipelines or be newly constructed.	8~9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.14	Midstream	Fuel distribution	Natural gas supply network	Natural gas is transported from wells to customers via pipelines, using a mainline system that includes transmission pipes and compressor stations. Investment in these systems depends on factors as pipe diameter, thickness, pressure, length, and compression ratio.	9~11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	METI Transition Road maps
III.15	Midstream	Fuel distribution	Ammonia truck	Truck transport is the most expensive way for transferring ammonia, mainly used for distances under 150 km or where other transport means are unavailable. It typically supplies retail distribution centres or small fertiliser manufacturers. Truck capacities range from 15 to 30 tonnes of ammonia in pressurised tanks (10–28 bar), depending on regional regulations.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	From internet search

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.16	Midstream	Fuel distribution	Hydrogen truck	For small hydrogen demands, multi-element gas container trailers equipped with steel or composite pressure vessels are used. Steel tubes carry 380 kg at 180–250 bar, whilst composite vessels can transport 560–900 kg at 350–500 bar. Cryogenic trailers transport 1500–3000 kg of liquid hydrogen. Trucks are cost-effective for small-scale, short-distance hydrogen transport.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
III.17	Midstream	Fuel distribution	Ammonia tanker	Ammonia is transported in fully refrigerated, non-pressurised vessels, often originally designed for liquefied petroleum gas (LPG) transport. With a boiling point of -33℃, ammonia can be carried by LPG carriers, provided they contain no copper or zinc components. Annual ammonia shipments total around 20 million tonnes. Research is ongoing into using ammonia as fuel and enabling vessels to transport both LPG and ammonia. Hydrogen may also be traded in the form of ammonia, which would require tankers at ports.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.18	Midstream	Fuel distribution	Hydrogen tanker	Ships designed for hydrogen transport include liquified hydrogen tankers and liquid organic hydrogen carrier tankers.	7~11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
III.19	Midstream	Fuel distribution	LNG tanker	Synthetic methane can be utilised within existing infrastructure, such as liquefaction stations, liquefied natural gas (LNG) carriers, receiving stations, and pipelines.	7～8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	METI Transition Roadmaps

Green and transition technologies (Midstream)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
IV.01	Downstream	Electricity charging	EV charging	This term covers EV charging technologies, including smart, fast, ultra-fast, conductive, inductive charging, and battery swapping. The growing EV market is driving advancements in public charging infrastructure, particularly fast and ultra-fast chargers along highways, which support longer journeys and reduce range anxiety – a key barrier to wider EV adoption.	6~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
IV.02	Downstream	Electricity charging	Fast charging for ships	Fast-charging equipment, whether using plugs or wireless devices, is essential for recharging electric ships' batteries. Battery-electric ferries recharge at each docking. High-power charging systems (up to several MW) require active cooling solutions for cables and connectors, with solutions, such as water, air, fluid cooling, or superconductive cables. Due to their lower energy density, electric ships are suited for short-distance routes.	7	Focus sector 2 (Electricity, gas, steam, and air conditioning supply)	IEA Clean Energy Technology Guide
IV.03	Downstream	Hydrogen refuelling	Hydrogen station	Hydrogen refuelling stations (HRSs) are crucial infrastructure for the deployment of fuel-cell electric vehicles. These stations feature strong tanks, either above or below ground, and can refuel up to 60 passenger cars. HRSs operate at high pressures and use compressors to reduce the volume of hydrogen gas.	9~11	Focus sector 4 (Transport and storage)	METI Transition Roadmaps
IV.04	Downstream	Lower-emission fuel supply	Lower-emission fuel bunkering for ships	This term also refers to lower-emission fuel bunkering technologies for ships, using fuels like ammonia, hydrogen, and methanol. Bunkering supplies fuel to ships either onshore via barge, truck, or pipeline, or offshore by barge, which is necessary for long journeys where ships cannot carry sufficient fuel. Fuel is transferred through a bunker hose.	4~9	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.01	Transport	Aviation	Efficient engine plane	Efficient plane engine	Geared turbofans with ultra-high bypass ratios aim to reduce energy use by up to 25%, with bypass ratios exceeding 15 in pre-commercial stages. Open rotor jet engines promise efficiency gains of up to 28%, but face challenges such as noise and practical limitations, particularly for larger aircraft and long-distance flights. As a result, they are less compatible with current aircraft designs compared to geared turbofans.	4~7	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.02	Transport	Aviation	Fuel cell plane	Hydrogen fuel cell plane	Hydrogen fuel cell-powered aircraft leverage advancements in hybrid and battery-electric propulsion in aviation, offering a sustainable alternative as energy carriers shift. With the potential for longer ranges than electric aircraft, they aim to enable zero-emission medium- and long-haul flights, positioning hydrogen as a key player in the future of sustainable aviation.	6~7	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.03	Transport	Aviation	Hybrid plane	Hybrid electric plane	Hybrid electric aircraft, whilst still using liquid jet fuels, achieve substantial reductions in energy consumption due to their more efficient powertrain designs.	6~7	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.04	Transport	Navigation	Electrification	Battery-electric ship	Battery-electric ships rely on shore-based electricity grids to charge their batteries whilst docked, limiting their use to short-distance routes due to current energy density constraints. Despite low projections for their overall adoption in the shipping sector by 2050, they could still account for 5% of energy use in domestic shipping under net-zero emissions (NZE) scenarios, especially in future zero-emissions zones on water.	8~9	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.05	Transport	Navigation	Energy efficiency	Energy-efficient ship engine	Rotor sails, like Flettner rotor sails, utilise the Magnus effect to generate lift perpendicular to wind flow, reducing the power demand on ship engines by harnessing wind energy. Particularly effective on slow-steaming vessels, they promise fuel savings of 5%–8%, potentially rising to 12%–20%, with minimal maintenance requirements. Additionally, kites towed by ships can provide additional propulsion under optimal wind conditions, reducing fuel consumption by 10%–20%, though they require sufficient deck space and favourable weather conditions.	8~9	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.06	Transport	Navigation	Fuel switching	Ammonia-fuelled ship	Ammonia-powered combustion engines offer a potentially carbon-free solution for long-distance ship propulsion. Ammonia's high energy density and existing infrastructure for storage and transport make it a viable option for large-scale adoption. However. challenges include its toxicity, ignition properties, and the need for infrastructure scaling. Modified internal combustion engines are being explored as one approach to harness this promising synthetic fuel.	6~7	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.07	Transport	Navigation	Fuel switching	Biofuel-fuelled ship	Ethanol and methanol engines are similar in design to petrol engines, requiring only moderate modifications, making these biofuels compatible with existing production lines. Ethanol is currently the most cost-effective biofuel, whilst ethanol can be produced either as a biofuel or as a synthetic fuel via electrolysis from low-carbon electricity with a carbon source. However, the availability of sustainably sourced biomass for methanol production is limited.	8~9	Focus sector 4 (Transport and storage)	

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.08	Transport	Navigation	Fuel switching	Fuel cell electric ship	Hydrogen or methanol, when utilised in fuel cells, can generate electricity through chemical reactions, producing only water as a byproduct if sourced from renewable energy. Whilst maritime applications are currently limited to outputs of up to 100 kW, initiatives like the Norwegian hydrogen ferry and H2Ports are advancing fuel cell technology in ports, enhancing efficiency and safety whilst reducing carbon emissions.	6	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.09	Transport	Navigation	Fuel switching	Hydrogen-fuelled ship	This vessel type uses an internal combustion engine fuelled by hydrogen. Current engines employ a diesel-hydrogen blend, with pure hydrogen engines in development. Hydrogen engines offer higher power density than fuel cells, making them potentially suitable for long-distance, carbon-neutral propulsion in ocean-going vessels, despite challenges with bunkering infrastructure and hydrogen's low energy density.	4 ~ 5	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.10	Transport	Navigation	Fuel switching	LNG-fuelled ship	LNG bunkering infrastructure is expanding and is now available in major shipping hubs. Switching to LNG offers regulatory compliance, competitiveness, and environmental benefits, including reducing the energy efficiency design index (EEDI) rating and carbon intensity indicator by 20%, ensuring longer compliance than conventional vessels, cutting nitric oxide (NOx) emissions by 80%, virtually eliminating sulfur oxides (Sox) and particulate matter (PM), and potentially lowering GHG emissions by 23% with modern engines.	10~11	Focus sector 4 (Transport and storage)	From internet search

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.11	Transport	Navigation	Fuel switching	Nuclear-powered ship	Nuclear-powered ships use pressurised water reactors with highly enriched uranium, providing high power output and long operational lifespans. Future marine applications may employ small modular reactors (SMRs) like very high-temperature reactors (VHTRs) or molten salt reactors (MSRs), potentially eliminating the need for refuelling. However, high costs and safety concerns continue to limit broader adoption.	4~5	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.12	Transport	Rail	Electric train	Battery electric train	Battery-electric trains operating on non-electrified tracks provide zero emissions, low CO_2 solutions, depending on the carbon intensity of the electricity used. Designed for suburban and short intercity routes due to their limited range, they cater to non-electrified lines lacking low-CO_2 fuel infrastructure, emphasising shorter-distance applications.	8	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.13	Transport	Rail	Electric train	Magnetic levitation	Maglev trains levitate above rails using electromagnetic forces between onboard superconducting magnets and ground coils. This eliminates wheel–rail friction, enabling higher speeds and reducing operating costs due to fewer moving parts and lower rolling friction.	9	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.14	Transport	Rail	Fuel cell train	Hydrogen fuel cell electric train	Hydrogen fuel cell systems power electric motors for trains running on non-electrified tracks, offering an alternative to diesel. This solution depends on future availability of cost-effective, abundant low-carbon hydrogen. It targets regions with significant non-electrified rail lines, such as interregional lines in the Americas, most conventional lines in Africa, and substantial portions of railways in India and Europe.	8	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.15	Transport	Rail	Hybrid train	Gas hybrid train (internal combustion engine and battery)	In the absence of catenary lines, trains can draw energy from high-capacity batteries or gas engines, with braking energy also recovered and stored. The future viability of this solution hinges on the large-scale production of cost-effective synthetic methane from low-carbon electricity. It is intended for partially or non-electrified rail lines, which are common on interregional and conventional routes across continents like North and South America, Africa, India, and Europe.	8	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.16	Transport	Road	Electrification	Battery-electric vehicle	A battery electric vehicle (BEV) uses batteries, almost exclusively lithium-ion (Li-ion) today, arranged in a battery pack. This pack is combined with inverters and an electric motor to convert the electrical energy stored in the batteries into mechanical energy. Heavy-duty vehicles, such as urban buses and trucks, may require larger battery capacity than light-duty vehicles like passenger cars.	9~10	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.17	Transport	Road	Electrification	Battery-driven freezer/ refrigerator truck	The electrification of road transport, coupled with the increasing penetration of renewable and zero-carbon electricity generation, is the most promising pathway for decarbonising light-duty transport in the mid- to long-term.	9~10	Focus sector 4 (Transport and storage)	From internet search
V.18	Transport	Road	Electrification	Electric motorbike	Electric motorcycles are evolving with each new generation, enhancing range, performance, and reducing charging times and weight. Their global adoption is accelerating due to their crucial role in last-mile mobility-as-a-service (MaaS), allowing efficient planning, booking, and delivery of diverse services	9~10	Focus sector 4 (Transport and storage)	From internet search

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.19	Transport	Road	Electrification	Hybrid electric vehicle (HEV)	Hybrid electric vehicles (HEVs) combine an internal combustion engine with electric motors powered by batteries, which are recharged through regenerative braking and the engine itself. HEVs enhance fuel efficiency by utilising electric power for auxiliary functions and reducing engine idling, potentially allowing for smaller engines without compromising performance.	10~11	Focus sector 4 (Transport and storage)	METI Transition Roadmaps

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.20	Transport	Road	Electrification	Plug-in hybrid (PHEV)	Plug-in hybrid electric vehicles (PHEVs) utilise batteries to power an electric motor alongside an internal combustion engine (ICE) powered by petrol. They can be charged via an electrical outlet, the ICE, or through regenerative braking. PHEVs operate on electric power until the battery is depleted, at which point, they seamlessly switch to the ICE. By 2030, PHEVs aim to reduce fossil fuel consumption per kilometre by 30% compared to traditional ICE vehicles.	10~11	Focus sector 4 (Transport and storage)	METI Transition Roadmaps
V.21	Transport	Road	Energy management system	Automated and connected vehicles	Automated, connected, and electrified vehicles promise greater energy efficiency through features like eco-driving and platooning, with shared use further enhancing efficiency. Key advancements in artificial intelligence (AI), sensors, and computing are essential for widespread adoption. However, if limited to private vehicles, these technologies could reduce mobility costs, increase vehicle use, and potentially harm public transit systems.	6~7	Focus sector 4 (Transport and storage) Enabling sector 3 (Information and communication)	IEA Clean Energy Technology Guide
V.22	Transport	Road	Fuel switching	Flex fuel vehicle	Flexible fuel vehicles (FFVs) are equipped with internal combustion engines capable of running on petrol or blends containing up to 83% ethanol, like E85. As of 2022, there are over 20.9 million FFVs in the US, though many owners may not realise their vehicle’s fuel flexibility. FFVs offer an adaptable fuel choice, with slightly different performance	10~11	Focus sector 4 (Transport and storage)	From internet search

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
					characteristics compared to petrol-only vehicles.			
V.23	Transport	Road	Fuel switching	Hydrogen fuel cell electric vehicle (FCEV)	Hydrogen fuel cell systems in fuel cell electric vehicles (FCEVs) generate electricity from hydrogen, allowing for smaller batteries than those in BEVs. Challenges include safety, storage efficiency, and high fuel cell costs, although economies of scale may reduce these barriers. Competitive deployment relies on affordable, low-carbon hydrogen production and distribution technologies.	9	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide

Green and transition technologies (Transport)

Ref	Sector	Subsector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
V.24	Transport	Road	Fuel switching	Hydrogen-fuelled vehicle	Hydrogen engines, an alternative to fuel cells, combust hydrogen directly with 40%–50% efficiency, slightly lower than fuel cells' 50%–60%. However, they avoid the need for rare materials like platinum and offer better transient behaviour and cold-weather performance. Challenges remain in terms of safety, power density, and NOx emissions, with ongoing R&D focused on improving these aspects.	7	Focus sector 4 (Transport and storage)	IEA Clean Energy Technology Guide
V.25	Transport	Road	Fuel switching	Natural gas-fuelled vehicle	Vehicles powered by compressed natural gas (CNG) or liquefied natural gas (LNG) use spark-ignited internal combustion engines, similar to those in petrol vehicles but with lower GHG emissions. CNG and LNG are primarily used in heavy-duty vehicles like buses and trucks, emitting significantly lower levels of CO_2, NOx, and SOx compared to petrol and diesel engines.	10~11	Focus sector 4 (Transport and storage)	DoE, USA

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.01	Building	Energy management system	Building energy management system (EMS)	EMS consists of a smart metres, monitoring devices, control systems, communication networks, and other smart appliances. Smart metres record electricity consumption hourly or more frequently, and report data daily to utilities. They support two-way communication, facilitating time-based pricing and demand response. Automated demand response broadcasts signals to consumers, prompting timely adjustments to energy consumption. Control systems manage heat pumps and energy storage, functioning as virtual power plants, whilst smart thermostats use advanced algorithms for efficient control. Although batteries can store and discharge energy, their applicability in the building sector remains limited.	7~10	Enabling sector 1 (Information and communication) Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.02	Building	Energy-efficient equipment	Evaporative cooling	Evaporative cooling technology reduces temperature by converting sensible heat into vapour enthalpy, mediated by air or water, offering energy and cost-saving without the need for refrigerants. It is most effective in areas with low heating and hot water needs. Further advancements include permeable membrane and desiccant systems. Evaporative coolers, or swamp coolers, are efficient in low-humidity areas, capable of lowering air temperature by 15°–40°F. They are cheaper to install and more energy-efficient than central air conditioning but require more maintenance and are only suitable for areas with low humidity.	4~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.03	Building	Energy-efficient equipment	Solid-state equipment cooling	Solid-state equipment cooling technologies include barocaloric, elastocaloric, electrocaloric, and magnetocaloric cooling. These methods involve applying external forces – such as pressure, mechanical force, electric or magnetic fields – under adiabatic conditions causing a temperature change in the caloric material. All these technologies are still in the development phase, at technology readiness level (TRL) 4~5.	4~5	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.04	Building	Energy-efficient equipment	Energy-efficient household appliances	Electric stoves use vitroceramic or hot plates with integrated electric resistance for cooking. Induction cooking, on the other hand, relies on magnetic induction, offering high efficiency with no negative impact on indoor air quality. Hot water tanks store household hot water, providing a cheap and reliable solution, though their energy density is low. Vacuum-insulated high-temperature water tanks use electric resistance and vacuum insulation, with a potential lifespan of 20 years. However, they are heavy and less efficient than heat pumps. Chilled water storage systems use air, water, or ground conditioning units to store cold water, reducing peak electricity load and associated costs.	8~11	Focus sector 5 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.05	Building	Energy-efficient equipment	Energy-efficient lighting	This entry covers energy-efficient lighting systems, particularly light-emitting diode (LED) technologies, (including OLED, PLED, DC LED, etc.) and smart lighting systems. These systems include LEDs that adjust power output based on natural daylight and automatically turn off when not in use.	9~11	Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.06	Building	Energy-efficient equipment	Energy-efficient ventilation system	Dual-flow ventilation systems involve heat exchange between incoming and exhaust air streams, saving energy through heat and moisture recovery. They offer more controllable heat loss compared to the randomness of natural ventilation. Heat exchanger: Advanced heat exchangers for building-level substations feature new plate designs that reduce pressure loss by 35% and improve heat transfer efficiency by 10%.	10~11	Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.07	Building	Energy-efficient equipment	Heat pump	This entry covers various heat pumps, including air-source, water-source, ground-source, thermally driven, and solar heat pumps. These pumps extract and transfer heat from sources such as air, ground, or water, making them significantly more efficient than traditional heating methods, as they produce several times more heat energy than the electricity used to power them.	8~10	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.08	Building	Energy-efficient equipment	Fuel cell co-generation	Electrochemical devices operate at temperatures up to 80°C, requiring backup systems to meet peak heat demand. They offer high electrical efficiency (48%–66%) and total efficiency, whilst emitting no pollutants. High-temperature models (600°C–850°C) achieve efficiencies between 30%–59%. Cogeneration systems further reduce carbon emissions and energy costs, with combined heat and power (CHP) systems achieving up to 90% efficiency, aiding decarbonisation across multiple sectors.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.09	Building	Energy-efficient equipment	Fuel combustion co-generation	Co-generation systems use lower-emission fuels, such as natural gas and biomass, for combustion, efficiently generating electrical power and hot water. These systems reclaim heat from engines to produce heated water, significantly increasing primary energy efficiency, reducing energy costs, and lowering CO_2 emissions. With an efficiency level of up to 90%, cogeneration can aid in decarbonising power grids, district heating, and industrial facilities.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	From internet search
VI.10	Building	Energy-efficient equipment	Quad generation	Quadgeneration systems produce heating, cooling, and electricity whilst also recovering CO_2 from the exhaust gases, offering a wide range of applications with potentially low or zero carbon emissions.	3	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.11	Building	Energy-efficient equipment	Trigeneration systems (heating, cooling, and electricity)	Trigeneration systems simultaneously generate heating, cooling, and electricity, making them ideal for facilities that require all three continuously, such as data centres, hospitals, and universities. These systems are particularly effective in the ASEAN region, where constant heat demands make sustainable refrigeration solutions essential. District cooling systems, which combine distributed power generation with waste heat utilisation, can meet the air conditioning needs of commercial buildings, hotels, and shopping malls.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.12	Building	Insulation materials	Heat harvesting using building-integrated materials	Building-integrated heat and moisture exchange panels precondition ventilation air in heat recovery ventilators, delivering both energy savings and increased insulation. Phase-change materials store latent heat and improve thermal performance by reducing heat loss and can be integrated into various building components. Solar thermal collectors convert solar radiation into heat for heating and cooling applications, needing packaged solutions to optimise cost and efficiency. Transpired solar heat collectors draw sun-heated air through perforated surfaces, reducing heating demand by converting up to 80% of solar radiation into warm air.	6~9	Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.13	Building	Insulation materials	Reflective materials, insulating materials for wall and façade, insulating window	Reflective paints, sky-facing surfaces, and advanced insulation methods – such as double skin facades, structural insulated panels (SIPs), and vacuum insulated panels (VIPs) – help reduce cooling demand and improve energy efficiency. Trombe walls store solar heat, whilst double skin facades provide enhanced insulation and ventilation. Advanced glazing technologies, such as electrochromic and dynamic glazing, offer significant energy savings and improved comfort.	4~10	Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.14	Building	On-site renewables	Building integrated photovoltaic systems	Photovoltaic systems, integrated into building skins, include thick crystal products (crystalline silicon) and thin-film products (active material on glass or metal). These systems offer high electricity generation potential and are becoming cost-competitive. By 2030, under the Net Zero Emissions by 2050 Scenario, solar PV and wind are projected to meet approximately 40% of building electricity demand.	9	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.15	Building	On-site renewables	Building integrated wind turbines	Wind energy technologies include macro wind turbines for large-scale energy generation and micro wind turbines for local use, known as 'building-integrated wind turbines.' Small turbines, often vertical axis wind turbines (VAWTs), are quieter and aesthetically more appealing than horizontal axis wind turbines (HAWTs). Wind turbines can be connected to the grid or used off-grid. Recent developments focus on improving efficiency, reliability, and reducing costs.	8	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	The Climate Technology Centre and Network (CTCN)

Green and transition technologies (Building)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VI.16	Building	Utilisation of lower-emission fuels	Appliances using lower-emission fuels	Bag digesters and composite material digesters generate biogas through anaerobic digestion for cooking, reducing carbon emissions, and improving indoor air quality compared to solid fuels. Alternatives such as improved biomass stoves, LPG stoves, and solar cooking stoves offer greater fuel efficiency and health benefits. Hydrogen-driven ovens and hobs also provide a clean heat source by using hydrogen to produce heat.	9~11	Focus sector 6 (Construction and real estate)	IEA Clean Energy Technology Guide
VI.17	Building	Utilisation of lower-emission fuels	Biomass-fuelled heater	Biomass, particularly wood, remains a widely used source of heating. Biomass boilers efficiently burn wood to produce heat, with 40% of Europe's sustainably produced wood used for heating, making it a carbon-neutral option. Central heating biomass boilers help reduce GHG emissions and benefit local economies. Modern systems run on pellets, wood chips, or logs, and can integrate with solar thermal systems for higher efficiency.	11	Focus sector 2 (Electricity, gas, steam, and air conditioning supply), Focus sector 6 (Construction and real estate)	From internet search

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.01	Industry (specific)	Cement, concrete, and glass	Carbon capture and utilisation (CCU)	Calcium looping (CCU)	Calcium looping captures CO_2 from high-temperature gas streams using lime (CaO) as a sorbent, forming calcium carbonate ($CaCO_3$) in one reactor, and regenerating lime and pure CO_2 in another. It utilises oxyfuel combustion for heat, potentially lowering energy consumption compared to other capture methods. Well-suited for cement kiln flue gases, it addresses the challenging process emissions in cement production.	7	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
VII.02	Industry (specific)	Cement, concrete, and glass	CCU	Carbon mineralisation (carbon utilisation)	CO_2 from industrial processes can be transformed into building materials through CO_2 curing in concrete and by reacting with waste materials like slag and fly ash to create aggregates, storing CO_2 permanently. CO_2-cured concrete offers cost advantages, whilst using waste materials avoids disposal costs, making them competitive. However, their production remains energy-intensive and requires extensive testing to ensure suitability for structural applications.	9	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
VII.03	Industry (specific)	Cement, concrete, and glass	CCU	Direct separation from limestone (carbon capture)	Direct separation captures CO_2 from limestone during clinker production by heating it in a specialised steel vessel. This method isolates CO_2 emissions from the fuel combustion process, allowing the capture of pure CO_2. It is a promising technology for reducing cement production emissions if further developed and made cost-effective, potentially complementing other CCS methods.	6~7	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.04	Industry (specific)	Cement, concrete, and glass	CCU	Oxyfuelling in cement kilns (carbon capture)	Oxyfuel CO_2 capture involves burning fuel with pure oxygen to produce a CO_2-rich flue gas, which is then dehydrated to obtain high-purity CO_2. Whilst this method, using oxygen from air separation units, is less developed for cement production, it shows potential in conjunction with oxyfuel gas turbines and pressurised systems. Its aim is to cut process emissions, complementing other advanced capture technologies like chemical absorption and calcium looping.	6	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
VII.05	Industry (specific)	Cement, concrete, and glass	CCU	Synthetic methane production for power generation (carbon utilisation)	Producing synthetic methane for power in cement manufacturing can reduce CO_2 emissions by capturing CO_2 from exhaust gases and converting it into synthetic methane for reuse.	5~6	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	Ministry of Economy, Trade, and Industry (Japan) (METI) Transition Roadmaps
VII.06	Industry (specific)	Cement, concrete, and glass	Electrification	Electric kiln	Efforts to electrify cement kilns, crucial for clinker production, are progressing through technologies like plasma arc or resistance-based heating. Although still in the early stages of development, this approach requires renewable electricity to achieve substantial emission cuts. Further progress is needed to reach commercial viability, as this method primarily targets energy-related emissions rather than the process emissions inherent to cement production.	5	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.07	Industry (specific)	Cement, concrete, and glass	Electrification	Electrolyser for decarbonating calcium carbonate	A novel process aims to electrochemically convert calcium carbonate ($CaCO_3$) into calcium hydroxide ($Ca(OH)_2$) using an electrolyser. This generates a concentrated CO_2/O_2 stream suitable for capture, alongside hydrogen for use in subsequent production stages. Currently in early development, this technology requires renewable energy to achieve significant emissions reductions and commercial viability, potentially simplifying CO_2 capture in cement production.	3	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VII.08	Industry (specific)	Cement, concrete, and glass	Energy-efficient equipment	Advanced grinding technologies	Various advanced technologies for grinding raw materials and fuel in cement production are under research, including contact-free systems, ultrasonic-comminution, high-voltage power pulse fragmentation, and low-temperature comminution. These innovations aim to significantly reduce electricity consumption, potentially reducing power use by 10%–20% with roll press systems, whilst also contributing to grid-related CO_2 reductions as electricity grids transition to lower emissions under the NZE scenario.	6~7	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.09	Industry (specific)	Cement, concrete, and glass	Energy-efficient equipment	All-electric forehearth	In glass production, molten glass from the furnace flows into the forehearth, where it is cut into gobs for forming. Precise and uniform heating in the forehearth is crucial for maintaining consistent glass viscosity. Even slight temperature variations can affect viscosity, impacting production rates and increasing scrap rates due to glass breakage. Efficient temperature control also improves fuel efficiency, enhancing overall production performance.	10	Focus sector 3 (Manufacturing)	From internet search

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.10	Industry (specific)	Cement, concrete, and glass	Energy-efficient equipment	NSP kiln	The new suspension preheater (NSP) kiln, an advanced cement firing technology, enhances thermal efficiency through a preheater system featuring cyclones and a calciner furnace. Compared to older methods, NSP and SP kilns reduce the energy required for clinker production by approximately 40%, whilst significantly increasing kiln capacity, making them pivotal for modern cement manufacturing and efficiency improvements.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VII.11	Industry (specific)	Cement, concrete, and glass	Energy-efficient equipment	Vertical mills	Vertical coal mills and blast furnace slag mills, known as verticalisation, have been introduced to enhance energy efficiency in cement production. Reports indicate that vertical roller mills used for raw material grinding can achieve energy efficiency levels of 60%–80% higher than ball mills, whilst vertical mills for cement grinding reduce electricity consumption by 30% compared to tube mills.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VII.12	Industry (specific)	Cement, concrete, and glass	Raw material switching	Reduction of clinker ratio (using tricalcium aluminate, blast furnace slags, etc.)	To reduce cement-related emissions, clinker usage can be reduced by increasing tricalcium aluminate and adding more blast furnace slag in Portland blast furnace slag cement type B. Calcined clay also offers a viable alternative to clinker in blended types of cement.	9	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.13	Industry (specific)	Chemicals	CCU	Chemical production from CO_2	Chemical production from CO_2 includes producing methanol using hydrogen and CO_2; synthesising hydrocarbons through electrolysis and CO_2; and manufacturing polycarbonate, polyurethane raw materials, and dimethyl carbonate (DMC) from CO_2.	7~8	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	METI Transition Roadmaps

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.14	Industry (specific)	Chemicals	Production process improvement	Production of functional chemicals using the flow method	Continuous flow methods, as opposed to conventional batch methods, are increasingly being used to produce functional chemicals. This approach is expected to reduce emissions by 4.91 million tonnes per year by 2030 and 11.7 million tonnes per year by 2050.	9	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VII.15	Industry (specific)	Chemicals	Production process improvement	Utilisation of naptha in fluid catalytic cracking (FCC)	Fluid catalytic cracking (FCC) is the second-largest source of propylene, a by-product of refinery petrol production in refineries. Using naphtha as a feedstock improves the yield and control of olefins. Whilst FCC enhances chemical production efficiency, it does not achieve near-zero emissions.	9	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VII.16	Industry (specific)	Chemicals	Raw material switching	Production of chemicals from bio-derived materials	Olefins, such as ethylene and propylene, can be produced from methanol or ethanol instead of petroleum, bypassing the energy-intensive steam cracking process. Methanol operates at lower temperatures (300℃–450℃). Benzene, toluene, and xylene (BTX) aromatics can be derived from lignin through various methods, though the availability of sustainable biomass may limit the scalability of these processes.	6	Focus sector 3 (Manufacturing)	METI Transition Roadmaps

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.17	Industry (specific)	Iron and steel	CCU	Oxygen-rich smelting reduction (carbon capture)	A new oxygen-rich smelting reduction technology is being developed for steel production, using a reactor where iron ore and powdered coal react to produce liquid iron for high-quality steel. This process emits concentrated CO_2 in a single stack, making it suitable for integrating CCUS. It promises to reduce emissions by 80% compared to conventional methods and is cost-effective compared to other alternatives.	7	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.18	Industry (specific)	Iron and steel	CCU	Recycling of CO_2 from steel production process (carbon utilisation)	Technologies for recycling CO_2 from steel plants, such as thermochemical coupling and converting off-gas into chemicals or synthetic fuels, aim to close the carbon loop and reduce emissions. These processes can lower the lifecycle CO_2 footprint of products, though the total savings depend on the specific inputs displaced.	3~8	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	IEA Clean Energy Technology Guide
VII.19	Industry (specific)	Iron and steel	Energy-efficient equipment	High-productivity electric arc furnace (EAF)	EAFs are recognised for their superior performance across multiple metrics such as yield, energy efficiency, environmental impact, cost, and safety. According to the American Steel Manufacturers' Association, EAFs can double steel production whilst reducing GHG emissions by 75% compared to traditional blast furnaces, highlighting their significant environmental and operational advantages.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VII.20	Industry (specific)	Iron and steel	Energy-efficient equipment	Plasma torch	Plasma torches offer high-temperature heat for various industrial applications, including iron ore pelletisation furnaces. Nippon Steel's tundish plasma heater, which uses a plasma arc with argon to heat molten steel to over 10,000°C, optimises temperature control and more effectively prevents oxidation, nitriding, and carburising than gas combustion methods.	5~10	Focus sector 3 (Manufacturing)	Website of Nippon Steel

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.21	Industry (specific)	Iron and steel	Energy-efficient equipment	Utilisation of submerged arc furnace (SAF)	The direct reduced iron (DRI) process uses low-emission hydrogen for steelmaking and relies on high-quality iron ore (67% iron). To address the challenge of declining ore quality, solutions include using a submerged arc furnace (SAF) to produce DRI with lower-grade ore and adopting hydrogen-based fluidised bed reduction, which eliminates the need for pelletisation.	5~6	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.22	Industry (specific)	Iron and steel	Raw material switching	Direct reduced iron (DRI)	DRI plants traditionally use natural gas or coal to reduce iron ore. Emissions can be significantly decreased by substituting part of these fuels with hydrogen produced through water electrolysis powered by fossil-free electricity. Current technology allows for up to 30% hydrogen replacement, potentially reducing CO_2 emissions by 10%–82% compared to blast furnaces. Additionally, novel biogenic reducing agents are also being explored.	6~9	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VII.23	Industry (specific)	Iron and steel	Raw material switching	Electrolyser-based reduction	Molten oxide electrolysis (MOE) produces liquid metal from oxide feedstocks using electrons, yielding pure metal and oxygen as by-products. When powered by renewable electricity, this electrolytic steelmaking process can achieve CO_2-free production and reduce energy consumption by 30%. MOE can also integrate with variable renewable energy sources for power generation but remains in the early stages of development.	4~5	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VII.24	Industry (specific)	Iron and steel	Raw material switching	Reduction via alkali metal looping	A novel process uses alkali metals to reduce iron ore, separating oxygen and iron. The alkali metals are recycled in a closed loop that requires thermal energy between 300℃–900℃, depending on the stage of the loop. This method efficiently reuses	4	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
					materials and maintains continuous operation.			
VII.25	Industry (specific)	Iron and steel	Raw material switching	Smelting reduction based on hydrogen plasma	Hydrogen plasma smelting reduction (HPSR) uses hydrogen in a plasma state to reduce iron oxides, creating a CO_2-free steel production route when powered by renewable electricity. The process involves a hydrogen plasma arc between a graphite electrode and liquid iron oxide. Although promising, HPSR is in the early stages of development compared to other low-emission steel technologies.	4	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Specific industries)

Ref	Sector	Industry	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VII.26	Industry (specific)	Iron and steel	Raw material switching	Utilisation of ferro-coke	Ferro-coke, made from low-grade iron ore and coal, accelerates the blast furnace reduction reaction due to its ultra-fine metallic iron content. This catalytic effect significantly reduces the amount of coke required in ironmaking, improving efficiency and utilising otherwise unusable materials.	7~8	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VII.27	Industry (specific)	Iron and steel	Raw material switching	Utilisation of plastic waste for coke production	Waste plastics, agglomerated into 20–30 mm, are blended with coal (1% mass) and decomposed in coke ovens into 20% coke, 40% hydrocarbon oil, and 40% coke oven gas. These by-products are used in blast furnaces, the chemical industry, and power plants. Chlorine is converted into ammonium chloride, making the process both efficient and environmentally friendly.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps

Green and transition technologies (Industry cross-cutting)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VIII.01	Industry (cross-cutting)	Carbon capture and utilisation (CCU)	Carbon capture	This umbrella term covers various technologies designed to capture and separate CO_2 from exhaust gas or syngas during industrial processes. These technologies include chemical and physical absorption, adsorption, membrane separation, and cryogenic separation.	7~8	Focus sector 3 (Manufacturing) Enabling sector 3 (Carbon capture, storage, and utilisation)	International Energy Agency (IEA) Clean Energy Technology Guide
VIII.02	Industry (cross-cutting)	Electrification	Electric heating	This category includes a range of technologies for electrifying industrial heating processes, such as radiation heating (using ultraviolet light, infrared, etc.), dielectric heating (using microwave, radio waves, etc.), and rotary compression heaters, amongst others.	6~9	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VIII.03	Industry (cross-cutting)	Electrification	Large-scale industrial heat pump	Large industrial heat pumps, which utilise renewable or waste energy, are used to provide heating and cooling for industrial processes. They are considered large if their output exceeds 100 kW. Critical for the electrification of industry and the decarbonisation of heating and cooling networks, a project in Thailand demonstrated energy cost reductions of 74% and CO_2 emissions reductions of 70% at a food processing factory.	9	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide
VIII.04	Industry (cross-cutting)	Energy management system (EMS)	Batteries for industrial use	Lithium batteries are ideal for industrial applications due to their high energy density, longer lifespan, faster charging, high efficiency, and scalability. They store more energy in a compact form, endure more charge cycles, recharge quickly, have low self-discharge rates, and allow easy system expansion as power needs grow.	9~10	Focus sector 3 (Manufacturing)	From internet search

Green and transition technologies (Industry cross-cutting)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VIII.05	Industry (cross-cutting)	Energy management system (EMS)	Introduction of advanced EMS (AI, IoT, Automated driving, etc.)	Advances in IT for energy management can optimise energy use in production processes. In cement production, combining best-practice technologies combined with energy-efficient equipment can reduce energy intensity by approximately 5.7%.	9~11	Focus sector 3 (Manufacturing) Enabling sector 1 (Information and communication)	Ministry of Economy, Trade, and Industry (Japan) (METI) Transition Roadmaps

Green and transition technologies (Industry cross-cutting)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VIII.06	Industry (cross-cutting)	Energy-efficient heating system	Small-scale once through boiler	Small-scale boilers are more efficient than conventional industrial boilers and can switch to lower-emission fuels, such as once-through boilers.	10	Focus sector 3 (Manufacturing)	Once-Through Water Design | Miura Boilers
VIII.07	Industry (cross-cutting)	Fuel switching	Lower-emission fuel equipment	This term refers to industrial equipment, primarily heating systems like boilers, that can utilise lower-emission fuels, including natural gas, hydrogen, and ammonia, amongst others. These systems help reduce energy-derived CO_2 by reducing the amount of fossil fuel used during combustion.	6~11	Focus sector 3 (Manufacturing)	
VIII.08	Industry (cross-cutting)	Waste/renewable heat utilisation	Direct heat from renewables	Concentrated solar power plants use mirrors to focus solar radiation into high-temperature heat, making them suitable for industrial processes like treating non-metallic particles and producing clinker. Although Concentrated Solar Power (CSP) shows promise for replacing fossil fuels, it is still in the early stages of development, needing cost reductions and facing limitations in areas with less-than-ideal solar conditions. Fully replacing process heat with solar thermal energy remains challenging.	6	Focus sector 3 (Manufacturing)	IEA Clean Energy Technology Guide

Green and transition technologies (Industry cross-cutting)

Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
VIII.09	Industry (cross-cutting)	Waste/renewable heat utilisation	Use of wastes for thermal energy	The use of waste plastics, sludge, and wood waste for thermal energy involves either direct combustion or converting waste into syngas for steam production. Upgrading syngas to methane for gas grid injection offers higher efficiency. Burning waste in cement kilns is the most efficient method, with an efficiency of 90%. However, the main challenge lies in securing long-term customers to support the necessary infrastructure.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps
VIII.10	Industry (cross-cutting)	Waste/renewable heat utilisation	Waste heat recovery	Waste heat from industrial systems can be recycled for power or heat generation, potentially reducing energy costs. Despite this, many industries are hesitant to adopt waste heat recovery technologies due to concerns about possible negative impacts on production.	9~11	Focus sector 3 (Manufacturing)	METI Transition Roadmaps

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Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
IX.01	Agriculture	Genetic engineering	Genetic engineering to produce crops with enhanced carbon sequestration	This biological approach combines traditional breeding and biotechnological methods to develop crop varieties with higher carbon sequestration capabilities, aiding climate change mitigation efforts. Genetically modified crops enhance productivity, improve disease resistance, and reduce GHG emissions by increasing yield, enabling no-till farming, and lowering fossil fuel consumption. However, the implementation requires extensive research, years of development, and adaptation to changing conditions.	5	Focus sector 1 (Agriculture, forestry, and fishing)	From internet search
IX.02	Agriculture	Genetic engineering	Genetically modified rumen bacteria that produce less methane	Modern molecular biotechnology aims to reduce methane synthesis in ruminants by genetically modifying microorganisms. These modified microbes are introduced into the rumen to establish stable microbiota that compete with methanogens, which convert CO_2 and hydrogen into methane. This approach leverages symbiotic microbial relationships but remains in the basic research stage, far from practical application.	4	Focus sector 1 (Agriculture, forestry, and fishing)	From internet search

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Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
IX.03	Agriculture	Modification to fertiliser	Nitrification inhibitors	Nitrification inhibitors reduce nitrous oxide emissions by suppressing soil microbes that convert nitrogen into nitrate, thereby decreasing nitrogen loss and increasing plant uptake. They help lower GHG emissions, reduce water pollution, and increase crop yields. Compounds like SBT butanoate and SBT fluoroate cut N_2O emissions by 4%–5% and reduce global warming potential by 8.9%–19.5%.	10	Focus sector 1 (Agriculture, forestry, and fishing)	World Research Institute
IX.04	Agriculture	Treatment of microorganisms	Addition of electron acceptors to paddy fields	Methane emissions from paddy fields can be reduced by adding electron acceptors (e.g. Fe(III), sulfate), promoting microbial competition with methanogens. Ferrihydrite and gypsum effectively suppress methanogenesis by utilising more favourable electron acceptors. Whilst promising, this method remains experimental, showing incomplete inhibition and requiring further research for practical application.	4	Focus sector 1 (Agriculture, forestry, and fishing)	From internet search

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Ref	Sector	Tech Group (1)	Tech Name	Description	TRL	Relevant Activity in ASEAN Taxonomy*	Source
X.01	Waste	Methane collection	Anaerobic digestion	Anaerobic digestion occurs in closed digesters, which can range from simple to automated designs, and are classified by solids content, feeding mode, temperature, and stages. This process produces biogas (comprising 55%–60% methane, 35%–40% carbon dioxide, and impurities) along with nutrient-rich digestate. Biogas, with energy value of 21–24 megajoules per cubic metre (MJ/m^3), can be used as fuel, for lighting, or electricity generation, whilst the digestate is used as fertiliser.	10	Focus sector 5 (Water supply, sewage, and waste management)	From internet search
X.02	Waste	Methane collection	Landfill with a methane collection system	Installing a landfill methane collection system captures methane for generating electricity or biogas, reducing odours and hazards, and preventing atmospheric emissions. This system also offers economic benefits by generating revenue from the sale of electricity or biogas, delivering both environmental and financial advantages.	9	Focus sector 5 (Water supply, sewage, and waste management)	The Climate Technology Centre and Network (CTCN)
X.03	Waste	Wastewater energy generation	Energy generation from sewage sludge	A wastewater sludge gasification power generation system converts sludge into useful gas (hydrogen and carbon monoxide) for high-efficiency power generation, drastically reducing GHG emissions such as nitrous oxide and carbon dioxide. Partial combustion modifies organic components into clean fuel gas, with high-temperature reactions preventing nitrous oxide emissions and decreasing fossil fuel consumption.	9	Focus sector 5 (Water supply, sewage, and waste management)	From internet search