



Development of a National Hydrogen Strategy and Action Plan for Accelerating Thailand's Net-zero Target



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Chapter 1. Introduction

The Paris Agreement 2015 has raised global community's intention to contribute to combat climate change crisis by limiting the temperature increase to 1.5 degrees Celsius above pre-industrial levels. Under the Agreement, Thailand's government has established goals to reach carbon neutrality by 2050 and net zero greenhouse gas (GHG) emissions by 2065.

Hydrogen is one of promising energy technology portfolios that can help us transit to a net-zero society while leveraging local resources and ensuring sustainable growth. Following this rationale, this strategy (draft) aims to establish our pathways on development and use of hydrogen with the most efficient, reasonable, and sustainable solution of multiple relevant technologies across diverse sectors to achieve the ultimate net-zero goal. In detail, the strategy builds on over four decades of coordination of three strategies with 9 tasks and three sets of 6 enablers to reach our vision: to reduce GHG emissions and make the transition towards a carbon-neutral Thailand, which include transiting to a clean hydrogen supply system, diversifying of hydrogen utilization, securing efficient storage transportation, and strengthening hydrogen infrastructure.

The strategy is comprised as follows:

In Chapter 2, we will provide a brief overview of the need for a hydrogen economy and consequent national policy trends of both global community and Thailand.

Chapter 3 will focus on the status of wide-ranging portfolio of hydrogen in Thailand. Technical review of major hydrogen production methods, hydrogen storage and transportation capacity, hydrogen utilization sectors, and infrastructure for foundation of hydrogen economy are included, based on the results of surveys and interviews with experts who have comprehensive understanding in Thailand conditions.

Chapter 4 then illustrates the vision, strategies, and tasks to accelerate Thailand's net-zero target, followed by Chapter 5 which describes the major tasks in hydrogen production, hydrogen utilization, hydrogen storage and transportation, and infrastructure in detail.

Lastly, the discussion is closed with some concluding remarks.

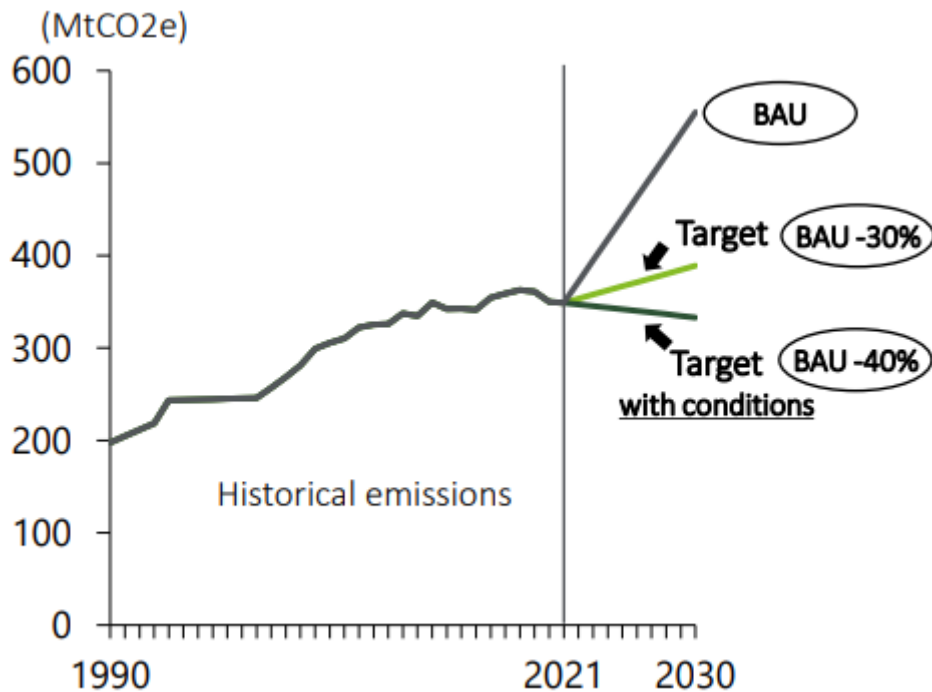
This strategy will provide a guidance to leverage Thailand's strengths in hydrogen R&D and to build up a robust ecosystem for clean hydrogen supported by multiple technologies and stakeholders, which will reduce GHG emissions and bring benefits to the country and the world.

Chapter 2. Background

Section 1. The Need for a Hydrogen Economy

Thailand aims to achieve carbon neutrality by 2050 and net zero GHG emissions by 2065, and set out a target to reduce 30% of GHG emissions from the BAU (business as usual) level by 2030 in its updated Nationally Determined Contribution (NDC) which was submitted in November 2022. The level of reduction could be up to 40% subject to conditions such as development of technologies and infrastructures, and capacity building. Especially, support in policy implementation and investment in carbon reduction technologies, e.g., CCS, CCUS, bio-energy with CCS, DAC, and hydrogen, are required.

[Figure 2-1] Thailand's emission reduction target by 2030



Source: Deloitte (2023), p.124

Hydrogen is a green energy source that produces heat and electricity while emitting no harmful emissions such as GHG and particulate matter (PM), and thus is being recognized as a key contributor to achieving carbon neutrality. The use of hydrogen is expected to reduce a total of 80 gigatons (GT) of cumulative CO₂ emissions by 2050, contributing about 20% of the annual reductions needed in 2050. This will require the use of 660 million metric tons (MT) of clean hydrogen in 2050, which is equivalent to 22% of global energy demand¹ (Hydrogen Council, 2021).

<Table 2-1> Global hydrogen end-use demand until 2050 (MT per annum)

Year	2020	2030	2040	2050
Demand	90	140	385	660

Source: Hydrogen Council (2021)

The construction of a hydrogen economy that employs hydrogen throughout the production, storage, transportation, and utilization cycle is necessary: First, it is possible to generate carbon-neutral power through the utilization of renewable energy in the production of hydrogen, particularly in industries with a significant energy consumption, such as petrochemicals, cement, steel, and aluminum. Second, hydrogen is expected to be utilized in wide range of industries, including power generation and transportation, and can be applied throughout the entire energy production, transportation, and consumption cycle, by which this approach offers the potential for the creation of new industries and the revival of traditional industries. Third, energy storage and flexible power generation using hydrogen can reduce the volatility of renewable energy, contributing to the stabilization of the grid. Finally, energy independence can be expanded by using local technologies to secure new energy sources and replace fossil fuel consumption in the industrial sector.

Thailand should develop its vision, strategy, and plans for building hydrogen economy to achieve the 2065 carbon neutrality goal and to fulfill its role as a member of global hydrogen market.

¹ In 2030, 140 MT of hydrogen (of which 75 MT would be clean hydrogen) will be needed.

Section 2. National and international trends

1. Policies of Major Foreign Countries

A. Hydrogen strategies

As of 2023, a total of 41 governments which account for approximately 80% of global carbon emissions has developed and published their national hydrogen strategies. These countries have set a 2030 clean hydrogen production target of 27~35 MT, which indicates a high level of commitment to hydrogen production and utilization globally (IEA, 2023b). Initially, mostly advanced countries had been establishing and announcing policies to preempt the future hydrogen market based on their respective strengths – as of 2021, 14 countries had announced national hydrogen strategies – for example: the European Union (EU), including Germany, targeted to complement renewable energy sources and reduce carbon emissions in the hydrogen-utilizing industrial sector; South Korea (hereinafter referred to as Korea) and Japan developed strategies to strengthen their energy security and diversify their energy sources focusing on the hydrogen utilization – transportation and power generation sectors; and lastly, countries with abundant renewable energy sources, such as Australia, Chile, and Saudi Arabia, established strategies to secure hydrogen exporter status by mass-producing green hydrogen. However, in recent years, not only the advanced countries but also emerging markets and developing economies (EMDEs) such as Algeria, Brazil, Costa Rica, Ecuador, India, and Namibia have newly established their hydrogen strategies.

Leading countries in global hydrogen landscape include: Germany published *Die Nationale Wasserstoffstrategie* in June 2020, which is an embodiment of the EU-wide hydrogen strategy, *EU Hydrogen Strategy* (European Commission, 2020)². The strategy defines the scope of the hydrogen economy as "Building up and securing the quality assurance infrastructure for hydrogen production, transport, storage, and use, and building trust" and includes goals, visions, a status analysis, and an action plan with concrete measures, covering all hydrogen-

² Production of 1 million tons of green hydrogen (2020-2024), 10 million tons (2025-2030), and use of green hydrogen extensively in hard-to-decarbonize sectors (2040-2050)

related energy, industrial, technological innovation, and international cooperation policies. The main goals are: 1) to increase competitiveness by reducing hydrogen-related costs; 2) to develop domestic market for hydrogen; 3) to strengthen the hydrogen transportation and distribution infrastructure; and 4) to establish an international hydrogen market and international cooperation system.

Korea established the concept of hydrogen economy in 2019³, became the first country in the world to enforce the Hydrogen Act in 2021, and consequently established the *1st Basic Plan for the Implementation of the Hydrogen Economy* in November 2021 which lays a legal basis for the creation of infrastructure for hydrogen industry. The Basic Plan provides short-term (2020), mid-term (2030), and long-term (2050) plans covering hydrogen supply and demand planning, system operation, financing, and infrastructure development, as well as strategies and tasks to achieve the targets of 60% self-sufficiency in clean hydrogen production and 100% utilization of clean hydrogen by 2050. From onwards, there has been a steady policy support in the creation of a hydrogen economy, strategies for utilizing and building infrastructure for fuel cells and hydrogen cell vehicles which are considered to be the country's core strengths, and plans for developing hydrogen production technologies and securing hydrogen supply.

Japan established the *Basic Hydrogen Strategy* in December 2017, the world's first national-level hydrogen industry development strategy. The strategy contains policy goals and strategies covering all areas of hydrogen supply, storage & transportation, and utilization in order to solve environmental problems and strengthen energy security, and it divides the development stage into three stages and sets goals and priorities for each stage respectively for realizing the hydrogen society in 2050. It was subsequently revised once in June 2023 to complement the hydrogen industry strategy to promote overseas expansion of Japan's hydrogen industry, to emphasize safety as an essential means for large-scale hydrogen utilization, and to rationalize and properly apply laws and regulations covering the entire supply chain.

³ The Korean government defined the concept of a hydrogen economy value chain that includes hydrogen production, storage & transportation, and utilization in the *Roadmap to Revitalize the Hydrogen Economy*.

In June 2023, the United States released the *U.S. National Clean Hydrogen Strategy and Roadmap*, a comprehensive strategy that includes goals and action plans for production, processing, transportation, storage, and utilization of hydrogen across the entire value chain. The strategy recognizes the use of affordable, safe, and clean hydrogen as a key enabler of economic and social benefits, with the ultimate goal of achieving carbon neutrality by 2050. The strategy's three pillars are: 1) focusing on the use of clean hydrogen to reduce carbon emissions in hard-to-electrify industries such as chemicals, steel, etc., heavy-duty transportation, and power generation; 2) supporting diverse clean hydrogen production pathways, with a goal of reducing the price of clean hydrogen to \$1/kg by 80% in about 10 years; and 3) building and expanding clean hydrogen hubs comprised of clean hydrogen producers and local resources, feedstocks, infrastructure, and consumers. In addition, the government has laid the institutional groundwork to fully support the clean hydrogen industry by allocating about \$9.5 billion over five years (2022-2026) to build infrastructure for the hydrogen economy through the Infrastructure Investment and Job Act of 2021 (IIJA) and providing a large-scale subsidy support system for clean hydrogen through the Inflation Reduction Act of 2022 (IRA).

Of the ten member states of ASEAN, nine countries, with the exception of the Philippines, have declared carbon neutral or net-zero targets as of June 2022. Among them, Singapore is the only country to have the national hydrogen strategy. In October 2022, the Singapore government announced *Singapore's National Hydrogen Strategy* which aims to reduce the country's GHG emissions to 60 million tons per year by 2030 through hydrogen utilization and to power 50% of its electricity generation with hydrogen by 2050. The strategy identifies power generation, industry, and transportation as the major sectors that account for the reduction of GHG emissions.

B. R&D investments

According to the IEA (2023a; 2023b), the size of government investment in hydrogen technology research, development, and demonstration (RD&D) has been steadily increasing,

and the share of hydrogen in clean energy RD&D budgets has also increased steeply, reaching at 7.5% in 2022. In addition, the global hydrogen market will initially be centered on Europe, Japan, and Korea, which will account for about 20% of hydrogen demand in 2030, then followed by China and North America (Hydrogen Council, 2021).

<Table 2-2> Government RD&D spending for hydrogen (million USD)

Year	2018	2019	2020	2021	2022
Budget	606.8	757.1	872.9	1,380.2	3,125.9

Note: Budget for "hydrogen and fuel cells" technology

Source: IEA (2023a)

As of 2021, a total of 520 large-scale projects of 1 MW or more has been announced worldwide. Of these, 70% are expected to be commissioned before 2030. There are 43 giga-scale projects, demonstrating that hydrogen is gaining momentum, and project capacity is continuing to grow. Projects of 10 GW or more count to nine. Europe is the most active region in the hydrogen space, accounting for 50% of the world's announced hydrogen projects and 35% of the investment (Hydrogen Council, 2021).

C. International cooperation

Cooperation between countries to build a global hydrogen supply chain is also accelerating. In the short to medium term, joint research is being conducted to promote technology development, and in the long term, bilateral cooperation is spreading in preparation for the opening of an international hydrogen trading market. In particular, cooperation between countries targeting different policy orientations, such as technology exporting countries and hydrogen exporting countries, is emphasized to create synergies in hydrogen import and supply chain construction. Since 2022, there have been 31 bilateral discussions on hydrogen-related matters globally. Of these, 15 were trade-related which refers to cooperation agreements to develop international hydrogen supply chains (IEA, 2023b).

2. Trends in Domestic Enterprises

As for the use of hydrogen energy, Thailand is currently only at the beginning. However, Thai government recognizes hydrogen as a key source for emission reduction in power, industry and transportation sectors as mentioned in its environment or energy relevant strategies including *Long-term Low GHG Emission Development Strategy (LT-LEDS)*, *Power Development Plan 2018-2037 (PDP 2018)* and *Alternative Energy Development Plan 2018-2037 (AEDP 2018)*. The Ministry of Energy has already incorporated hydrogen energy into the National Energy Plan⁴ and will continue to push for hydrogen production and use to reduce Thailand's carbon footprint.

In addition, the *National Economic and Social Development Plan 2023-2027 (13th NESDP)* which corresponds to the basic guidelines for economic and social development in Thailand to improve the quality of life has set out targets in hydrogen usage in road transportation sector: to create domestic consumption on various types of fuel cell electric vehicles (FCEV).

It is estimated that there are more than 5,700 medium-to-large enterprises⁵ in Thailand across sectors such as steel, refining, chemicals, power generation, and transportation, by which the market potential is expected to be large (Deloitte, 2023). Currently, various domestic and foreign companies are involved in Thailand's hydrogen sector, with the Energy Generating Authority of Thailand (EGAT) and PTT Public Company Limited (referred to as PTT) leading hydrogen-related projects and collaborating with various foreign companies. Local hydrogen players across the production, storage & transportation, and utilization sectors are listed in Table 2-3.

⁴ The Ministry of Energy develops five plans as follows: (1) Thailand Power Development Plan: PDP; (2) Energy Efficiency Development Plan: EEDP; (3) Alternative Energy Development Plan: AEDP; (4) Natural Gas Supply Plan; and (5) Petroleum Management Plan.

⁵ Companies with 50 employees and above, and with annual revenue of 1.5 million USD and above; Includes companies that have headquarters outside of Thailand

<Table 2-3> Key local players in hydrogen (based on current project participants)

Classification		Companies
Production	Water electrolysis	<ul style="list-style-type: none"> • EGAT, PTT • Linde, Bloom Energy, ACWA Power
	SMR - biogas	<ul style="list-style-type: none"> • C.P. Group • Toyota
	SMR - fossil fuel + CCUS	<ul style="list-style-type: none"> • EGAT • Mitsubishi Heavy Industries
Transport & Storage	Compressed hydrogen	<ul style="list-style-type: none"> • Bangkok Industrial Group (BIG) • Air Liquide, Linde
	Pipeline	<ul style="list-style-type: none"> • BIG • Air Liquide, Linde
	Refueling station	<ul style="list-style-type: none"> • PTT, Bangchak Corporation, BIG, PTT(OR) • Toyota
Utilization	Transportation	<ul style="list-style-type: none"> • PTT, C.P. Group • Toyota
	Refinery	<ul style="list-style-type: none"> • PTT, Thairoil, Bangchak Corporation, IRPC • Esso
	Stationary fuel cell	<ul style="list-style-type: none"> • EGAT
	Thermal power plant	<ul style="list-style-type: none"> • EGAT

Note: Domestic and international companies are shown in separate lines.

Source: Deloitte (2023)

Chapter 3. Status Analysis of Thailand

Section 1. Hydrogen Production

Thailand is currently utilizing hydrogen as an industrial gas, with global companies such as Air Liquide, Linde, and Air Products and Thai companies producing hydrogen. Air Liquide and Linde's hydrogen production plants are located at Map Ta Phut Industrial Estate in Rayong province, while Air Products produces hydrogen at Bang Pa-in Industrial Estate in Phra Nakhon Si Ayutthaya. Thai companies include Bangkok Industrial Gas, which has a hydrogen production plant in Map Ta Phut Industrial Estate, where Air Liquide and Linde's plants are located.

While Thailand is not currently producing clean hydrogen commercially, investments and collaborations are underway to produce clean hydrogen. As described in Chapter 2, large Thai energy companies such as EGAT and PTT, as well as international leaders, are investing in green and blue hydrogen production. Recently, Bangkok Industrial Gas and Ratchaburi Power Plant have conducted a feasibility study on green hydrogen production using floating solar power⁶, and liquefied natural gas (LNG) distribution company IBCLNG has signed an agreement with China's Mingyang Hydrogen Technology to jointly develop a water electrolysis project.⁷

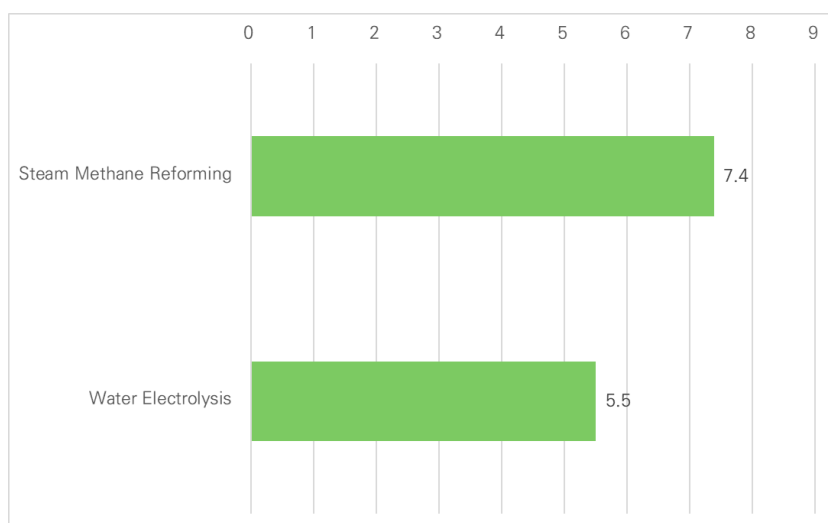
As previously stated, the fact that global leading companies are producing hydrogen in Thailand is positive in terms of investment and industrial capacity building in Thailand. However, it is worth noting that hydrogen production is not balanced between Thai and foreign companies. Currently, hydrogen is consumed within the limited scope of industrial gas, but the transition to a hydrogen economy to achieve carbon neutrality will create a large

⁶ Bangkok Industrial Gas, 2024, Explore Thailand's First Green Hydrogen Production from "Floating Solar Farms," BIG and Ratchaburi Power Plant Join Forces to Embark on Future Energy, February 22, 2024, <https://www.bigth.com/en/big-ratchaburi-power-plant-climate-tech-collaboration/> (accessed on April 19, 2024).

⁷ CGTN, 2024, Thailand to build its 1st commercial green hydrogen project with China, January 28, 2024, <https://news.cgtn.com/news/2024-01-28/Thailand-to-build-its-1st-commercial-green-hydrogen-project-with-China-1qIZQyfhjFu/p.html> (accessed on April 19, 2024).

demand for hydrogen. It is therefore necessary to attract foreign companies to expand Thailand's hydrogen production capacity and stimulate investment in Thailand. However, it is also desirable to have an appropriate balance of Thai and foreign companies in domestic hydrogen production. In order to expand Thailand's hydrogen production capacity in this direction, policies need to be designed in a way that allows Thai firms to internalize superior technology from abroad, while collaborating with foreign firms and technology leaders.

[Figure 3-1] TRL of SMR and Water Electrolysis



Note: TRL - Technology Readiness Level, SMR – Steam Methane Reforming

Source: NIGT

Furthermore, while it is encouraging and positive that the private sector is pursuing clean hydrogen demonstration on a voluntary basis, the current lack of a strategy and roadmap to develop clean hydrogen production technologies more effectively and efficiently at the national level represents a limitation. In the case of steam methane reforming (SMR) technology for blue hydrogen production, Thailand's technology readiness level is only at TRL 7.4, compared to TRL of 9, which is close to the highest level globally (see Figure 3-1). Given that it is essential to improve the maturity of SMR technology for blue hydrogen production, a strategy and roadmap is required to drive further demonstration at the national level. Moreover, a national technology development strategy and roadmap is necessary for water electrolysis technology, which is less mature than SMRs in Thailand. A national clean hydrogen

technology development strategy and roadmap can provide a unified direction for the private sector, universities, and research institutes, enabling them to leverage the country's capabilities. Furthermore, the implementation of tangible and intangible support policies based on the strategy and roadmap can accelerate the development of these technologies.

Section 2. Hydrogen Storage and Transportation

Thailand currently has a prototype hydrogen refueling station in operation in Chonburi province. The station was constructed in 2022 with the participation of PTT, PTT OR, Toyota, and Bangkok Industrial Gas. The hydrogen supplied from the station will be used to power Toyota's fuel cell electric vehicle (FCEV) Mirai, which will be utilized for limousine service between U-Tapao International Airport and Pattaya.⁸ Bangkok Industrial Gas will be responsible for producing the hydrogen supply for the station, which will be transported via tube trailer.

While the voluntary investment of private companies to build hydrogen refueling stations is encouraging, the lack of a large number of stations being built by a variety of companies is a limiting factor for hydrogen storage and transportation. It is only when a large number of hydrogen refueling stations have been built by a variety of actors that the full range of operational issues can be fully understood. It is difficult to fully understand the causes of these issues when the deployment of hydrogen refueling stations is still in its early stages. Furthermore, the lack of hydrogen refueling stations is likely to hinder the rapid deployment of FCEVs at the national level.

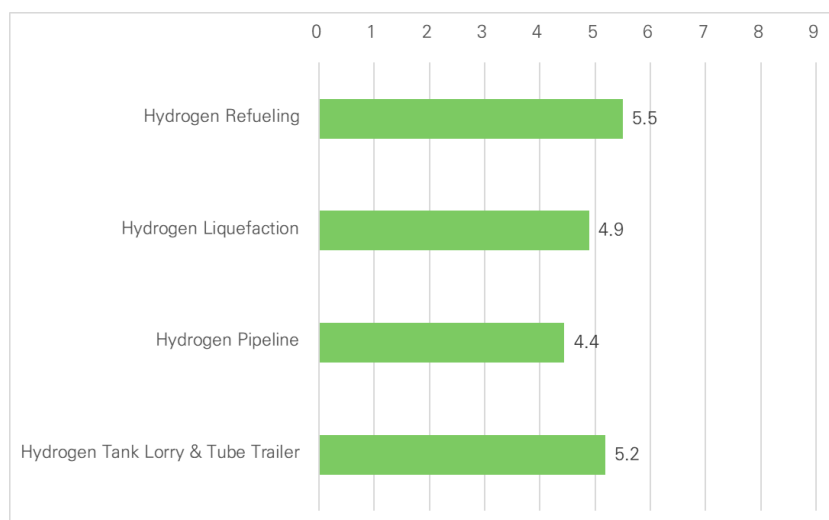
In addition, there is a lack of overall infrastructure such as hydrogen pipelines and large-scale hydrogen transportation vehicles to facilitate the storage and transportation of hydrogen in

⁸ Bangkok Industrial Gas, 2024, Launching Thailand's first hydrogen fueling prototype station, "PTT – OR – TOYOTA – BIG" joins forces to embark on future energy, November 8, 2022, <https://www.bigth.com/en/thailand-first-hydrogen-fueling-prototype-station-opening-ceremony/> (accessed on April 19, 2024).

conjunction with the limited supply of hydrogen refueling stations. Therefore, in the short term, it is necessary to establish a basic supply chain that can connect hydrogen production and demand sites in Thailand. In the long term, it is also necessary to build a supply chain based on liquefied and liquid hydrogen to meet large-scale hydrogen demand. Liquefied and liquid hydrogen has the advantage of being able to transport large amounts of hydrogen relatively cheaply, while hydrogen refueling stations have the advantage of being able to supply commercial vehicles that require hydrogen refueling on a large scale, such as trucks and buses, smoothly.

On the other hand, the maturity of hydrogen storage and transportation technology in Thailand is not yet high, and strategic R&D is needed to increase the maturity of the technology. Thai hydrogen experts assessed the maturity of hydrogen storage and transportation technology to be around TRL 5 (see Figure 3-2). While the maturity of specific technologies may vary, hydrogen refueling and hydrogen tube trailer technologies, which are commercialized globally, are also considered to be less mature in Thailand.

[Figure 3-2] TRL of Hydrogen Storage and Transportation Technologies



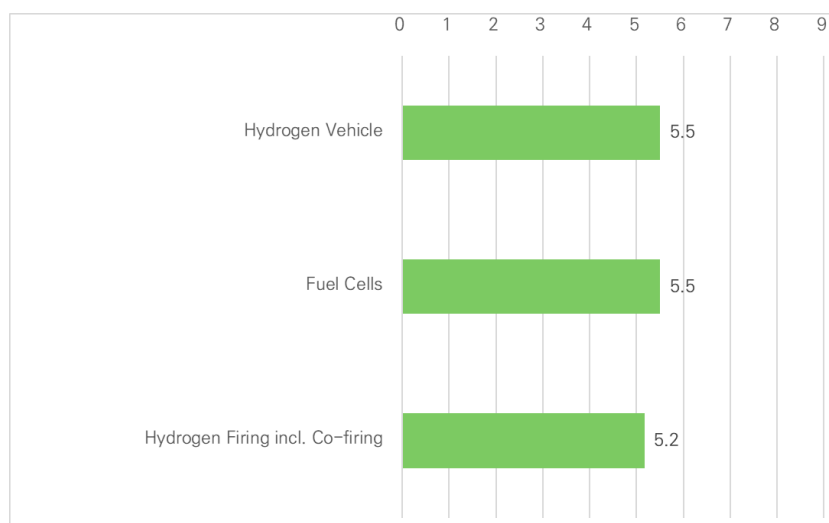
Source: NIGT

Section 3. Hydrogen Utilization

Currently, the utilization of hydrogen in Thailand is quite limited, except for its use as a conventional industrial gas. As a result, there is a lack of demand to drive the vitalization of the hydrogen ecosystem in Thailand. With the exception of hydrogen refueling stations described in Section 2 above, there is currently limited infrastructure in place to refuel vehicles with hydrogen. This makes it challenging to utilize hydrogen in the transportation sector, such as FCEVs, which could drive demand for the hydrogen economy in the short term. The use of hydrogen in the cement, oil refining, and power generation sectors, where it can be utilized outside of the transportation sector, is still in its infancy, even in major countries that have started the transition to a hydrogen economy early. Thailand is no exception.

Meanwhile, research on hydrogen utilization technologies needs to be promoted along with the deployment of infrastructure for hydrogen utilization. Thai hydrogen experts have assessed the maturity level of hydrogen vehicles and fuel cells, two representative hydrogen utilization technologies, to be at TRL 5.5 (see Figure 3-3). While these technologies are already commercialized globally, the maturity of the technology in Thailand is relatively low. This suggests that the country needs to do more than just purchase hydrogen utilization technology and equipment, but also to secure its own technology.

[Figure 3-3] TRL of Hydrogen Vehicle and Fuel Cells Technologies



Source: NIGT

Section 4. Enablers for Foundation Creation

Currently, there are no provisions in Thai law regarding hydrogen technology development, hydrogen manufacturing, installation of facilities, or the development of related industries. This makes it difficult to implement policies with a clear legal basis. With regard to hydrogen-related safety regulations, the Factory Act B.E. 2535 and subordinate laws under the Ministry of Industry regulate hydrogen within the category of industrial gases. However, as the scale of hydrogen production and consumption is expected to expand in the future and hydrogen is expected to be utilized in various fields, it is necessary to revise hydrogen-related safety regulations.

Major universities and research centers in Thailand are engaged in the promotion of education and research on hydrogen. The National Science and Technology Development Agency and the National Energy Technology Center are conducting research on hydrogen and fuel cell technology as one of the energy storage technologies. Chulalongkorn University and King Mongkut University in Bangkok are also conducting research on hydrogen, and researchers at these institutions have published numerous papers on hydrogen and fuel cell technology. The Energy Research and Development Institute of Nakhon Phanom (ERDI) of the University of Chiang Mai is collaborating with German hydrogen company Enapter to establish a comprehensive training center. The center will provide training to policymakers on hydrogen systems and management.

Thailand's leading universities and research institutes are spearheading hydrogen research, indicating that the country is building a robust research foundation for hydrogen technology advancement. However, more R&D resources are necessary to ensure a seamless transition. Hydrogen experts in Thailand have identified funding, facilities, infrastructure, personnel, and institutional constraints (see Figure 3-4). While SMR technology was rated as having more R&D resources than water electrolysis technology, SMR technology was also rated as having a slight shortage of all other resources except for research institutes and universities (Scoring 4.11).

[Figure 3- 4] R&D Resources of SMR and Water Electrolysis



Note: 1 - Highly insufficient, 2 - Insufficient, 3- Slightly insufficient, 4-Average, 5-Slightly enough, 6- Enough, 7-Highly enough

Source: NIGT

On the other hand, Thailand is currently in the early stages of preparing to transition to a hydrogen economy. Currently, there are no nationally promoted hydrogen ecosystem construction projects such as hydrogen pilot cities or hydrogen industry clusters, while the Eastern Economic Corridor (EEC) is being considered as a candidate.⁹ At present, it can be said that the maturity of hydrogen technology is not high and related industries are lacking. However, in the mid- to long-term, it is necessary to promote a hydrogen ecosystem construction project to identify the linkages between technology and industry and the limitations of hydrogen ecosystem operation to minimize trials and errors in building a hydrogen ecosystem at the national level.

Finally, while there is a high level of interest in hydrogen in industry and academia, and some

⁹ Bangkok Biz News, 2023, 'Energy' plans to set up 'Hydrogen Valley' to pilot the EEC area, June 17, 2023, <https://www.bangkokbiznews.com/business/economic/1073744> (accessed on April 19, 2024)

consensus on the need to transition to a hydrogen economy, there is relatively little awareness and interest in hydrogen among the general public. This is due to a lack of events in Thailand that have attracted the attention of the public, such as the announcement of a top-level hydrogen plan or the deployment of large-scale hydrogen facilities. As Thailand transitions to a full-fledged hydrogen economy, it is essential to cultivate public understanding, interest, and consensus on hydrogen, which will support the momentum of government policies. It is therefore vital to continue to promote hydrogen and generate positive consensus.

Section 5. Summary and Strategy Direction

Table 3-1 provides an overview of the status and key issues in each sector in Thailand, as discussed above. A common limitation across the sectors of hydrogen production, storage, transportation, and utilization is the lack of technical capabilities. Additionally, the overall lack of hydrogen-related facilities is identified as a limitation due to the early stage of the hydrogen value chain. Furthermore, the institutional infrastructure, including national technology development strategies, support policies, and supporting laws, was also analyzed as being in its early stages.

The current situation and issues identified suggest the following directions for the development of Thailand's national hydrogen strategy. First, a strategy should be established to secure hydrogen technology through intensive technology development and cooperation. As technological capabilities are fundamental to fostering markets, industries, and economies, the national strategy should include tasks to promote technology development in each sector. In addition to mobilizing the capabilities of innovation actors in Thailand, the strategy should also be approached from the perspective of technical cooperation to close the gap with major foreign countries and effectively secure technologies.

Second, the strategy should be designed to actively promote the deployment of hydrogen-related facilities and foster the industry. Regardless of the level of hydrogen technology, it is

challenging to achieve national GHG reduction through hydrogen technology if there is a lack of deployment and use of hydrogen-related facilities. Consequently, the national hydrogen strategy must include the construction of facilities that the country intends to promote at the national level, as well as the main actors (industries and companies that are the minimum component of industries) that will focus on the construction and operation of such facilities.

Third, it is essential to have in place a robust legal, institutional, and policy framework across the hydrogen ecosystem. When the strategy is aligned with the first two pillars, the legal, institutional, and policy framework can serve as the basis for national actions and provide the impetus for effective implementation of those actions. Therefore, the National Hydrogen Strategy should include actions at the legal, institutional, and policy levels to effectively implement each strategy and task.

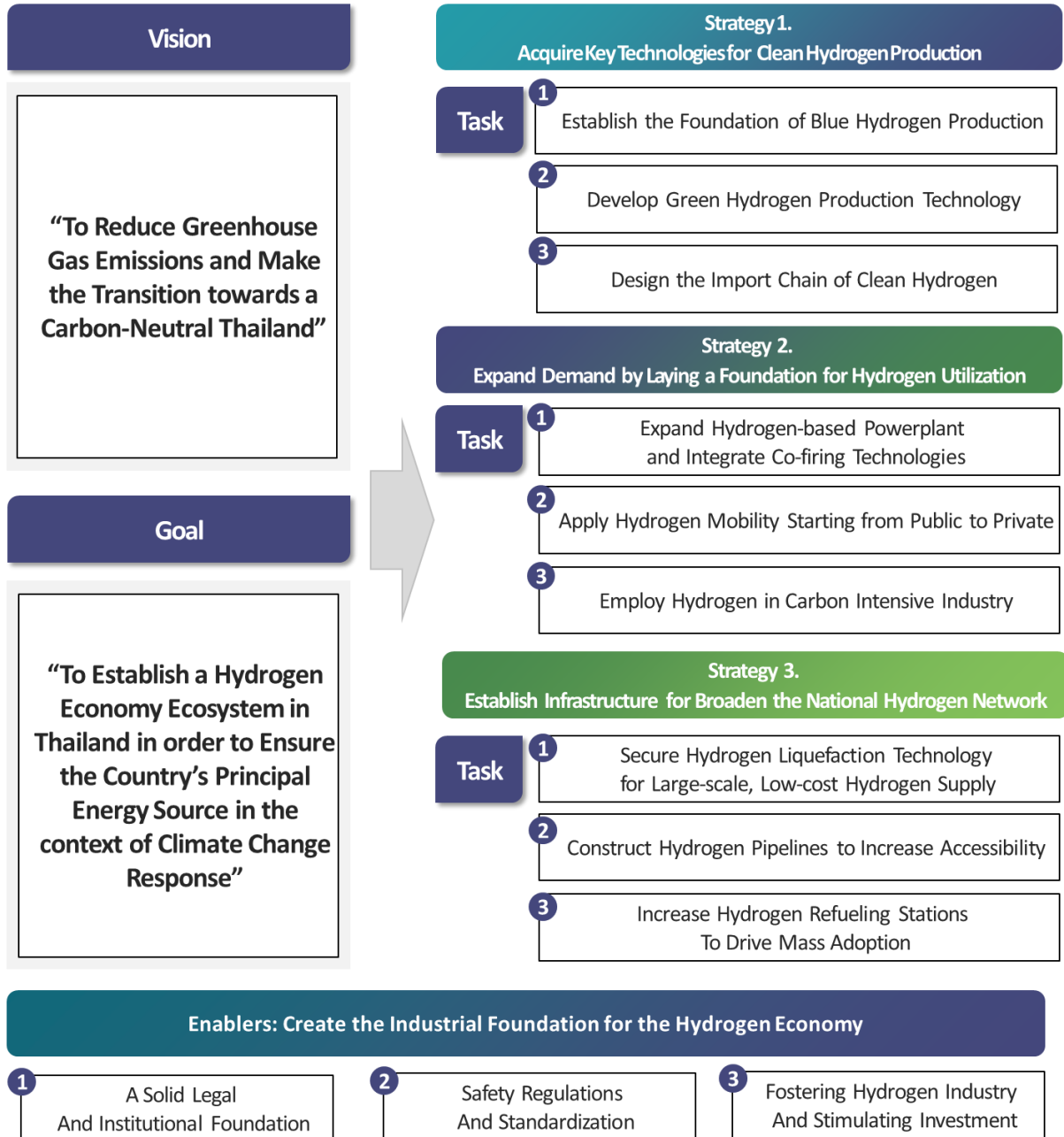
<Table 3-1> 10 Major Issues and Strategy Directions

Top issues by sector			Strategic direction
Hydrogen Production	Gray hydrogen production centered and highly dependent on foreign companies	➔	Securing hydrogen technology through intensive technology development and collaboration
	Lack of relevant infrastructure, including equipment and facilities to produce clean hydrogen		
	Relatively low maturity of hydrogen production technology compared to technology leaders		
	Lack of a national hydrogen production technology acquisition strategy		
Hydrogen Storage and Transportation	Low penetration of hydrogen refueling stations and lack of operational experience		Aggressive deployment of hydrogen production, storage, transportation, and utilization facilities and industry development
	Lack of infrastructure for hydrogen storage and transportation		
	Low technology maturity in		

	hydrogen storage and transportation		
Hydrogen Utilization	Lack of hydrogen utilization		
	Low technology maturity in hydrogen utilization		
Building the Foundation	Lack of relevant legal and institutional framework at the national level		Legal, policy, and institutional frameworks across the hydrogen ecosystem
	Lack of a foundation for building a hydrogen ecosystem		
	Lack of R&D resources for hydrogen		
	Low social interest and resonance		

Source: NIGT

Chapter 4. Vision and Strategy



A vision house for Thailand's national hydrogen strategy was established based on the above review of the need for a hydrogen economy, analysis of domestic and international trends, and analysis of the current status of hydrogen in Thailand. The Vision House consists of the national vision and goals to be achieved through the hydrogen strategy, three strategies to

realize the vision and achieve the goals, and one set of enablers. Each strategy is comprised of three tasks, which collectively drive the strategy forward. The Thailand National Hydrogen Strategy encompasses a total of nine core tasks, in addition to measures designed to create enabling conditions that are fundamental to driving the three strategies.

< Vision and Goal >

The goal of Thailand's National Hydrogen Strategy is to establish a hydrogen economy ecosystem in Thailand in order to ensure the country's principal energy source in the context of climate change response. This will ultimately result in a reduction of the country's greenhouse gas emissions and the transition towards a carbon-neutral Thailand.

< 3 Strategies and 1 Set of Enablers >

To achieve the aforementioned vision, Thailand must secure the core technologies necessary for the production of clean hydrogen (Strategy 1). This will be followed by an expansion of the sources of hydrogen demand (Strategy 2) and the construction of storage and transportation infrastructure to connect hydrogen production and demand (Strategy 3). The core technologies for clean hydrogen production are centered on blue hydrogen and green hydrogen technologies, and an import chain has been designed to secure overseas supply lines. The power generation and mobility sectors are expected to be utilized globally, and thus, they will be developed. Additionally, ways to utilize hydrogen in Thailand's carbon-intensive industries such as cement and oil refining will be explored. In order to supply the clean hydrogen produced to the utilization sites, the hydrogen pipeline network and charging stations will be expanded. Furthermore, hydrogen liquefaction technology will be secured prior to full-scale hydrogen production and consumption.

In order to implement the aforementioned strategies and tasks effectively, it is necessary to create an industrial foundation and prepare enabling conditions in various aspects. These include: 1) legal and institutional aspects, 2) safety management and standards aspects, and 3) industrial development and investment promotion aspects.

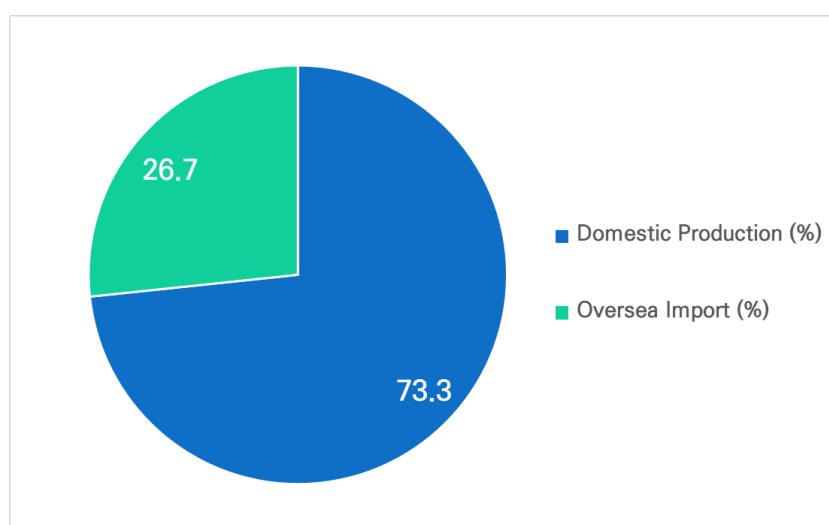
Chapter 5. Strategies and Major Tasks

Strategy 1: Acquire key technologies for clean hydrogen production

The first strategy is to secure clean hydrogen production capacity through the acquisition of key technologies. In order to reduce national greenhouse gas emissions through the transition to a hydrogen economy, hydrogen must be reliably procured from the source of demand. Even if hydrogen utilization technology is secured and related facilities are deployed across the country, it is difficult to operate the facilities effectively if sufficient amounts of hydrogen are not available. Furthermore, it is difficult to expect GHG reduction effects from hydrogen utilization.

At the national level, hydrogen procurement methods can be broadly categorized into indigenous production and foreign importation. Regarding Thailand's hydrogen procurement method, hydrogen experts in Thailand have indicated that Thailand needs to procure about 73.3% of its hydrogen from within the country, given the country's environmental conditions, resources, and technology (see Figure 5-1). Securing Thailand's own production capacity is therefore crucial to making this possible. In the absence of domestic hydrogen production capacity, the country may become overly reliant on external hydrogen procurement.

[Figure 5-1] Appropriate Ratio between Domestic Hydrogen Production and Import



Source: NIGT

In particular, the domestic hydrogen production capacity will allow for the development and import of hydrogen from abroad, providing Thailand with an alternative to simply purchasing hydrogen from abroad. This is partially attributable to Thailand. It is also expected to have secondary economic effects, such as encouraging Thai companies to expand overseas.

If sourcing hydrogen from abroad is a necessity, it is also important to consider where the hydrogen will be introduced. As developed and developing countries transition to a hydrogen economy, many are looking to source some of their hydrogen needs from abroad, which could lead to increased global competition for hydrogen sources. In addition to securing stable sources of hydrogen, there is also a need to diversify the hydrogen import portfolio to ensure the stability of the hydrogen supply chain.

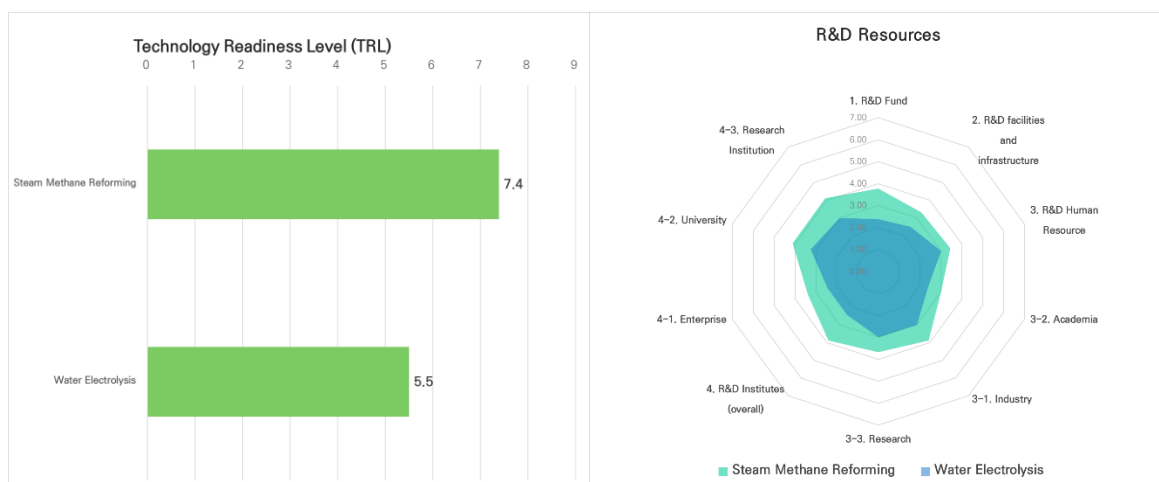
Meanwhile, Thailand's hydrogen production capacity should focus on cleaner hydrogen. As with electricity generation, the intensity of GHG emissions is determined by how hydrogen is produced. The objective of this hydrogen strategy is to achieve net-zero emissions in Thailand. To this end, it is necessary to focus on the production of "clean hydrogen," which will minimize GHG emissions throughout the hydrogen's life cycle.

The scope of clean hydrogen varies depending on the standards set by major countries, but it is generally understood in a narrow sense as so-called "green hydrogen" and in a broad sense as including "blue hydrogen" along with green hydrogen. Green hydrogen is hydrogen produced through water electrolysis utilizing renewable energy sources and does not emit greenhouse gases. On the other hand, blue hydrogen is hydrogen produced by SMR using methane as a raw material, but only when carbon dioxide emitted during the hydrogen production process is captured and stored or utilized, it is referred to as blue hydrogen. The greenhouse gas emissions of blue hydrogen are determined by the carbon dioxide capture rate and the degree of methane leakage.

Securing clean hydrogen production capacity is a strategic need for Thailand, both for green and blue hydrogen. Green hydrogen production capacity is essential to minimize the GHG emissions of the hydrogen value chain in Thailand. However, securing large-scale green hydrogen production capacity is a long-term approach for many countries, and there is a need

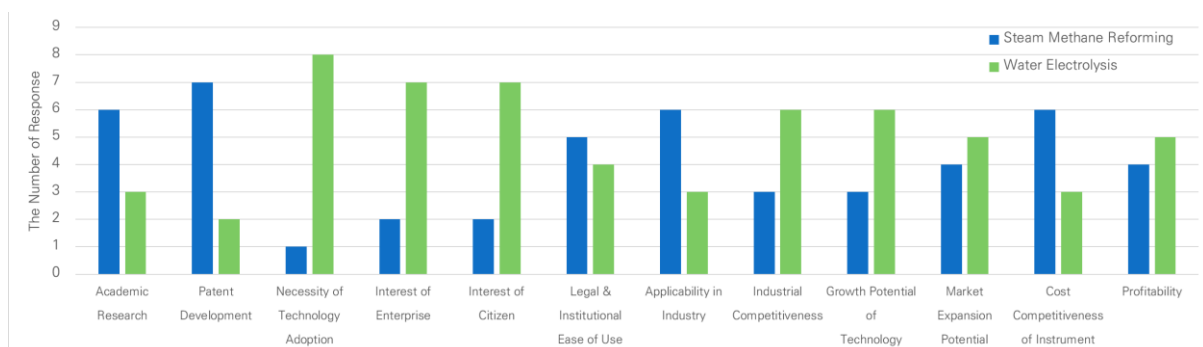
to bridge the gap between the distant future and the present. Blue hydrogen can be considered as a bridge to achieve this goal. Thailand's hydrogen experts have rated the TRL of SMR technology for blue hydrogen production at 7-8, which is more mature than that of water electrolysis technology for green hydrogen production. Furthermore, the funds, facilities and infrastructure, human resources, and institutes to conduct research and development are more abundant than those for water electrolysis (see Figure 5-2). Given these conditions, blue hydrogen represents an opportunity for Thailand to leverage its current strengths. A strategy of producing blue hydrogen in the short to medium term while fostering the hydrogen market and preparing to produce green hydrogen in the long term, such as investing in national R&D for green hydrogen, could be pursued.

[Figure 5-2] TRL and R&D Resources of SMR and Water Electrolysis



Source: NIGT

[Figure 5-3] The R&D Status and Prospects of SMR and Water Electrolysis



Source: NIGT

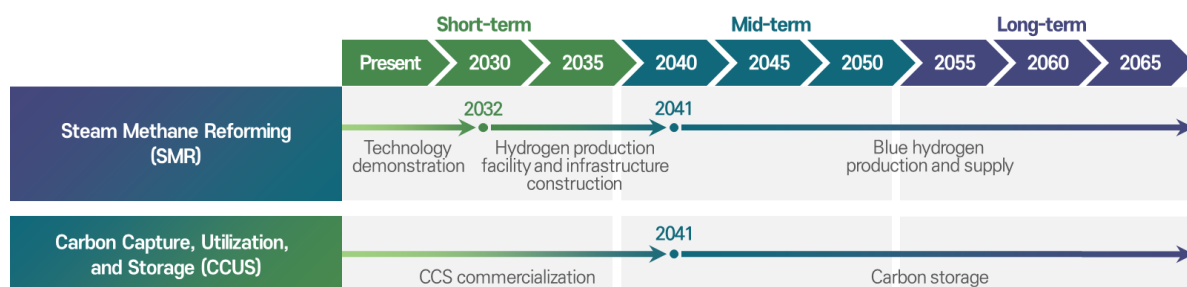
Additionally, Thai hydrogen experts evaluated that the water electrolysis technology for green hydrogen production has a higher level of interest from companies and the public than blue hydrogen production, and that the related industries are competitive and have a higher potential for market expansion (see Figure 5-3). Therefore, green hydrogen production technology is a technology that needs to be secured in the long term under the social and industrial context, with the ultimate goal of reducing greenhouse gas emissions.

In conclusion, Strategy 1, which is entitled "Acquire Key Technologies for Clean Hydrogen Production," comprises two principal objectives: the expansion of blue hydrogen production capacity and the development of green hydrogen production technology. Furthermore, given the potential environmental and resource constraints within Thailand for future clean hydrogen production, it also includes the task of designing and introducing clean hydrogen from abroad. The aforementioned tasks considered various means of acquiring clean hydrogen production capacity, including Thailand's own technology development as well as joint research and demonstration projects with advanced countries. In addition to the technical aspects of clean hydrogen production capacity, the tasks included the deployment of facilities and the development of institutions directly related to it.

Task 1. Establish the Foundation of Blue Hydrogen Production

The first task to acquire clean hydrogen production capacity is to upgrade SMR technology to produce blue hydrogen, develop CCUS technology to remove greenhouse gases from the hydrogen production process, and secure CCS storage (see Figure 5-4).

[Figure 5-4] Blue Hydrogen Production Technology Roadmap



Source: NIGT

A. Upgrade Steam Methane Reforming Technology

A - 1. Fully Demonstrate SMR Technology

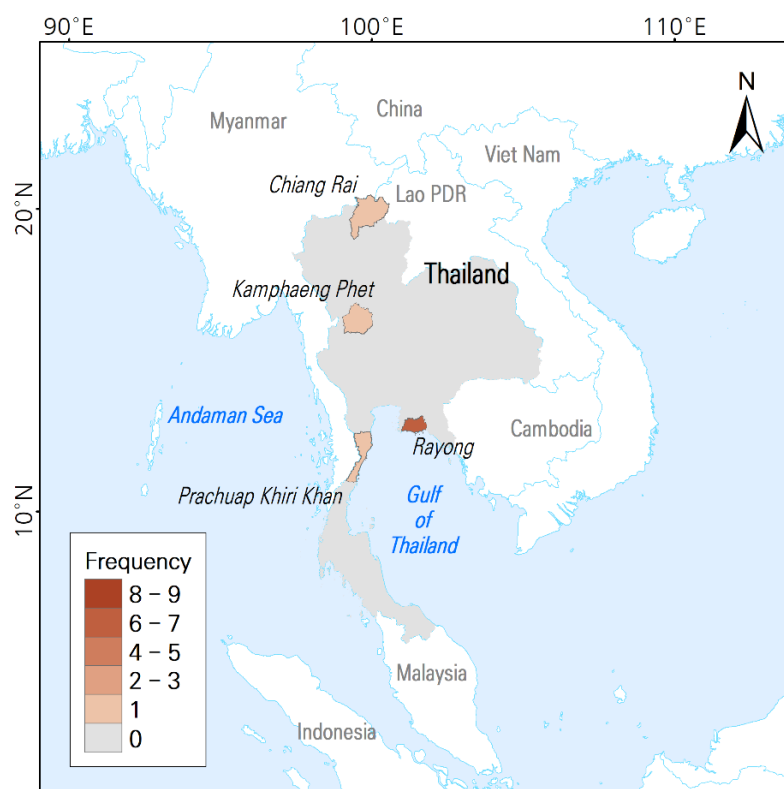
A system prototype is to be designed to produce blue hydrogen utilizing Thailand's current SMR technology, with a large-scale demonstration to be completed by 2032. The objective of this demonstration is to ascertain the technology's capability to produce high-purity hydrogen at a low cost and on a large scale in a working environment.

The feedstock for hydrogen production is either natural gas or biogas, with SMR technology utilizing natural gas and SMR technology utilizing biogas being demonstrated in parallel. In the case of biogas, an upgrading process is required to convert biogas into biomethane, a gas composed of a high concentration of methane, before it can be used in the SMR process. Therefore, the demonstration of blue hydrogen production referred to in this strategy includes tasks such as large-scale scale-up of the biogas upgrading process required by SMR facilities and performance improvement of the upgrading process to produce high-purity biomethane.

In the case of SMR demonstration, the site is selected and the demonstration facility is designed with future actual blue hydrogen production in mind. The construction of a plant requires significant capital and labor investments. When building a system prototype for demonstration, it is expected that a blue hydrogen production facility can be built at a relatively low cost if the next step of utilization is considered. When constructing an SMR demonstration complex, it is essential to consider conditions such as the distance from the feedstock (natural gas or biogas) and fuel (natural gas, electricity) production sites required for blue hydrogen production, the existence of feedstock and fuel supply facilities or the possibility of installing facilities, the distance from the sales site of the hydrogen to be produced, the ease of treating carbon dioxide generated during hydrogen production (CCUS), and the installation of carbon dioxide capture facilities and transportation and storage facilities. In particular, the SMR demonstration using natural gas is designed with the long-term goal of preventing future idle facilities by incorporating biogas-based hydrogen production.

Rayong province is an ideal location for a natural gas-fueled SMR demonstration. The province already has an LNG terminal and is situated adjacent to the Thai Gulf, which has natural gas fields. Many hydrogen experts in Thailand have expressed their opinion that the province is suitable for this project (see Figures 5-5). In particular, PTT Global Chemical, which has a plant in Rayong, has signed a Memorandum of Understanding (MoU) with Japan's Mitsubishi Heavy Industry to conduct joint research on SMR and CCS technology. This is expected to have synergies with the national blue hydrogen production demonstration project. Furthermore, Rayong province is a key region of Thailand's Eastern Economic Corridor, connecting Chonburi and Chachoengsao. The location is considered an ideal one for hydrogen demand from various industries and for supplying hydrogen to the capital city of Bangkok. However, as the SMR demonstration will require a significant investment, an evaluation framework for selecting the demonstration site will be developed and evaluated. This will be done in consultation with technical and policy experts and local governments.

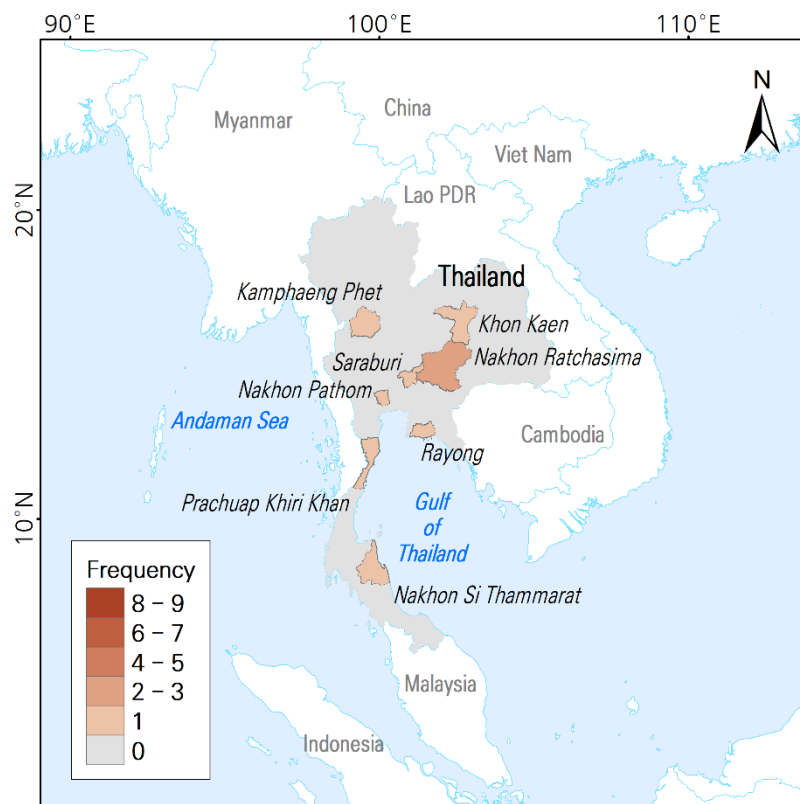
[Figure 5-5] Potential Sites for a SMR-based Blue Hydrogen Demonstration



Source: NIGT

The selection of areas for SMR demonstration utilizing biogas will be based on the various factors described above. Thailand's hydrogen experts have offered a range of opinions on the suitability of various regions for SMR demonstration using biogas, including Nakhon Ratchasima, Nakhon Pathom, Nakhon Si Thammarat, Kamphaeng Phet, Khon Kaen, Prachuap Khiri Khan, and Saraburi provinces (see Figures 5-6). These regions have been identified as key candidates for such demonstration.

[Figure 5-6] Potential Sites for a Biogas-based Blue Hydrogen Demonstration



Source: NIGT

The demonstration will, to the extent possible, make use of the expertise of Thai universities, research institutes, and companies. However, if necessary, collaborations with overseas partners may be considered. These partners could include major countries and companies with experience and technological excellence in hydrogen production through SMRs. These collaborations will involve joint research and joint demonstration projects, rather than just providing the right to conduct projects in Thailand. The objective of such collaborations would

be to assist Thai research groups in internalizing superior SMR technology, and to link overseas investment which enables Thailand to become a key blue hydrogen production base in the Asia-Pacific region.

A - 2. Construct Blue Hydrogen Production Facilities and Produce Clean Hydrogen

The objective is to construct blue hydrogen production facilities and infrastructure by 2041, with the goal of initiating full-scale production and supply of blue hydrogen by 2041. At the time of the demonstration of SMR technology, facilities that are planned for future production will be retrofitted and put into production in a relatively short period of time. Additionally, over a period of approximately ten years, additional blue hydrogen production facilities and infrastructure will be constructed at a site that has been selected based on a number of factors, including the distance from feedstock and fuel production sites, supply facilities, and hydrogen sales outlets.

As will be discussed later, basic hydrogen storage and transportation technology and CCUS technology should be in place by this time, and Thai technology should be available to build these facilities so that they can be linked to the construction of the blue hydrogen production facility. It is also essential to secure appropriate hydrogen utilization sectors that can support the scale of the planned blue hydrogen production facilities, and to advance hydrogen utilization technologies to a certain level by that time.

In the case of blue hydrogen production, Thai companies will have to participate. Those in the oil refining and chemical industry, as well as the industrial gas manufacturing industry, are key candidates. In close cooperation with the central and local governments, they will start producing blue hydrogen, taking into account their willingness and capabilities to invest in blue hydrogen.

Prior to the full-scale production of blue hydrogen by the private sector in 2041, it is necessary to design appropriate hydrogen markets and economic incentives to ensure that the hydrogen produced is easily and actively traded. One of the items that needs to be designed

is the pricing mechanism. In order to expand the production and use of blue hydrogen, it is possible to set a policy price (fixed price) and subsidize the production of blue hydrogen in the early stages of the market. Alternatively, a design that allows blue hydrogen producers to freely determine the price in consideration of various fixed and variable costs could be considered, with subsidies for hydrogen users. However, this necessitates financial expenditure by the government, which should be designed in consideration of the budget at that time and the targeted volume of hydrogen transactions. Additionally, it is important to consider the relative price of green hydrogen in order to incentivize the use of green hydrogen over blue hydrogen nationally, taking into account the future production of the greener alternative. Furthermore, the design of a clean hydrogen certification system is employed, along with the categorization of hydrogen according to its environmental characteristics. This system serves as the institutional basis for the provision of incentives for the production and use of clean hydrogen.

Furthermore, an entity to oversee the hydrogen market will be established. This entity could be an agency of the Ministry of Energy or a new organization could be founded. The hydrogen market management organization will operate a hydrogen trading platform, monitor blue hydrogen production and prices, and produce statistics for the design of future advanced hydrogen policies.

Additionally, safety standards related to hydrogen production are also required, and a safety management organization is established. The safety standards shall be revised or established at the legal level so that safety management of hydrogen production can be promoted at the legal level. In addition, the hydrogen production safety management agency shall designate and establish an independent agency separate from the hydrogen market management agency to make strict judgments on hydrogen production to ensure that hydrogen is produced safely.

Finally, ensure alignment with Thailand's national plans to facilitate blue hydrogen production. It is essential to coordinate with key ministries to ensure that the Gas Plan and Power Development Plan, which include plans for natural gas, as well as the Alternative Energy

Development Plan, which includes plans for biogas, take into account the natural gas and biogas that will be utilized for blue hydrogen production. In particular, as national plans are revised and supplemented every few years, it is crucial to ensure that they are reflected in the national plans before the full-scale construction of blue hydrogen production facilities and infrastructure.

B. Develop CCUS technologies

The development of CCUS technology is crucial to ensure that the hydrogen produced by SMRs is "clean hydrogen." CCUS technology is a crucial component in the production of natural gas-based blue hydrogen. In the case of biogas-based blue hydrogen, CCUS technology is essential to remove greenhouse gases from the natural gas used as fuel. If biogas is used as both fuel and feedstock and the GHG emissions are captured, there is a possibility of negative emissions.

Among the CCUS technologies, it is recommended that priority be given to carbon capture technology, which is essential for the treatment of carbon dioxide, and carbon storage technology, which is technologically mature and can utilize storage sites in Thailand. It is further recommended that the two technologies be acquired and linked in order to commercialize CCS technology by the target date of blue hydrogen production (2041), and that hydrogen be captured and stored from the SMR process in the ground from 2041 onwards.

It is also advised that joint research and demonstration be promoted by combining the capabilities of universities, research institutes, and companies in order to facilitate the commercialization of CCS technology. In particular, due to the significant capital investment required for underground carbon storage, it is important to actively engage companies with experience in drilling, oil production, pipeline operation, and related facilities, and to consider designing incentives such as tax credits for carbon capture and storage.

In addition to collaborative research among research entities in Thailand, international

collaborative research and joint demonstration will be promoted to facilitate the acquisition of carbon storage technology know-how and the tracking of the records of major countries abroad. In particular, we will conduct joint research and demonstration on carbon storage with countries that have oil fields.

CCUs are an attractive option in that they convert the carbon dioxide that needs to be removed into high-value-added products. However, the technology is not yet mature compared to CCS technologies globally, so we are promoting long-term technology development. In the case of CCU technology, the potential exists for carbon dioxide to be emitted back into the atmosphere, depending on the consumption of goods produced through CCU. Alongside the development of CCU technology, the development of technologies that can quantitatively evaluate carbon emissions over the life cycle of products is also being promoted.

C. Secure Storage Sites for CCS

It is necessary to secure a repository of sufficient size to handle the carbon dioxide captured when producing hydrogen from SMRs. By 2041, the target date for the commercial production of blue hydrogen, at least one designated repository must be in place to store the captured carbon dioxide from constructed blue hydrogen production plants. As additional blue hydrogen production plants are scaled up and deployed, storage must be proactively secured to minimize carbon dioxide emissions to the atmosphere from blue hydrogen production.

In order to secure carbon dioxide storage, priority consideration is given to the utilization of oil and gas fields that are currently producing or have ended production in Thailand. Carbon dioxide is utilized as an injection gas in enhanced oil recovery (EOR) in order to increase the recovery rate of oil and gas. Furthermore, many CCS plants internationally store carbon in the ground through EOR. In addition, petroleum reservoirs can be geologically stable reservoirs of fluids even after oil and gas production has ceased, suggesting that decommissioned oil

and gas fields themselves may be promising carbon reservoirs. In particular, the use of producing or shut-in oil and gas fields as carbon dioxide reservoirs has the advantage of requiring relatively low exploration costs. Considering only petroleum reservoirs, Thailand is estimated to have a geological storage potential of about 1,935 million tons.¹⁰

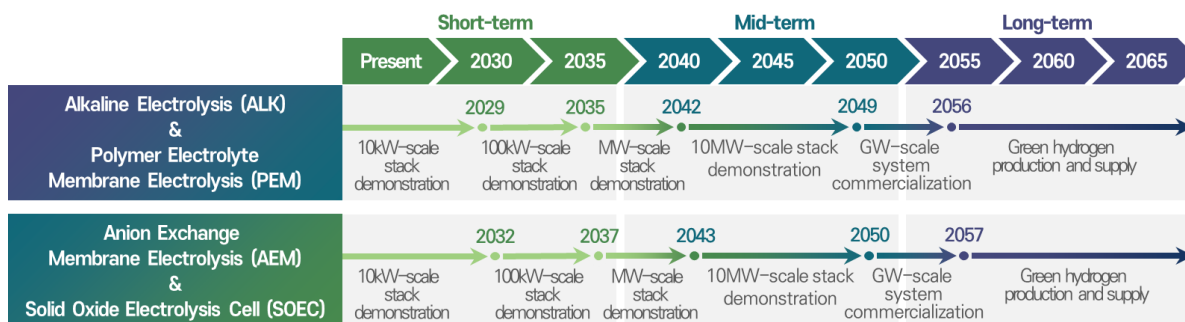
It is recommended that further exploration of Thai territory and territorial waters be conducted in order to develop additional reservoirs, as well as oil and gas fields that are currently in production or have previously been in production. Furthermore, it is proposed that cooperation be promoted with a view to the development of joint domestic and international reservoirs. Exploration for reservoirs will be conducted not only for petroleum reservoirs but also for aquifers. The results of the exploration will be mapped and utilized as a decision-making tool for reservoir development. The development of new reservoirs is a significant and costly undertaking. While it will be primarily undertaken by large Thai companies with substantial financial resources, it will also provide opportunities for various small and medium-sized enterprises to participate. Additionally, it may be advantageous to consider attracting investment from overseas developers to enhance the cost-effectiveness of the development. Furthermore, to overcome the limitations of the geologic storage scale within Thailand's territory, a detailed strategy will be developed in the short term to participate in internationally jointly developed storage projects.

Task 2. Develop Green Hydrogen Production Technology

The second challenge to achieving clean hydrogen production capacity is to develop and secure key water electrolysis technologies to produce green hydrogen (see Figure 5-7).

¹⁰ Wuttipong Kongphetsak, 2020, Carbon Capture and Storage; CCS, in Thailand, Asean Clean Energy Forum 2020, 19 June 2020.

[Figure 5-7] Green Hydrogen Production Technology Roadmap



Source: NIGT

A. Internalize 4 Key Water Electrolysis Technologies

A - 1. Demonstrate Water Electrolysis Technologies Scale by Scale

It is essential that R&D and demonstration be promoted for the commercial production and supply of green hydrogen. The expansion of the water electrolysis system through the expansion of the stack size will be promoted by R&D and demonstration, as will the high efficiency of the water electrolysis system to produce more hydrogen with less power. Furthermore, the capital cost of the system will be reduced through the low cost of various components that make up the electrolysis system, and the durability of the components and the system will be improved to improve its lifespan. Ultimately, the project aims to secure large-scale production capacity for affordable green hydrogen in Thailand.

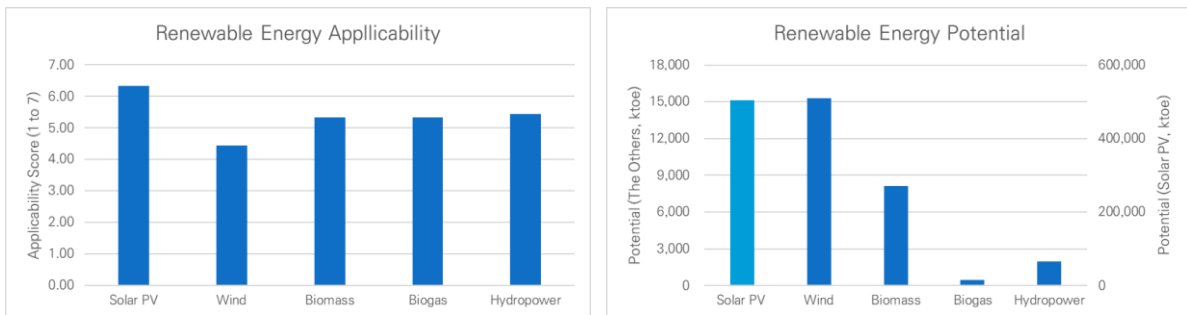
There are four main electrolysis technologies for green hydrogen production, and Thailand is promoting R&D and demonstration of all four technologies. Among the four technologies, alkaline electrolysis (ALK) and polymer electrolyte membrane electrolysis (PEM), which have relatively high technology maturity, aim to complete a 10 kW-scale stack demonstration by 2029, followed by a 10 MW-scale stack demonstration by 2049. For the less mature technologies of anion exchange membrane electrolysis (AEM) and solid oxide electrolysis cell (SOEC), demonstration will be pursued in parallel with ALK and PEM, but with a staggered timeline, with a 10 MW-scale stack demonstration by 2050 (see Figure 5-7).

In the demonstration of water electrolysis technology, as in the demonstration of blue hydrogen, the site is selected and the demonstration facility is designed with the future commercial production of green hydrogen in mind. In order to ensure the viability of the demonstration, it is essential to consider the availability of water, which is the feedstock for water electrolysis hydrogen production, the availability of electric power, and the distance to the outlet of the hydrogen to be produced. In particular, water and power are crucial inputs for the production of green hydrogen. It is therefore advantageous to conduct the demonstration in an area where the relevant water and power grids are well organized, ensuring a smooth supply of both inputs to the hydrogen electrolysis demonstration facility.

Furthermore, when demonstrating water electrolysis technology, the demonstration is conducted in an environment that can be supplied with renewable energy power, such as a renewable energy complex, to the greatest extent possible. As the TRL is gradually increased, the demonstration is essentially carried out in conjunction with renewable energy power. The carbon-free status of water electrolysis hydrogen depends on the electricity generated from any source, and it becomes green hydrogen only when renewable electricity is utilized. Moreover, since renewable energy sources exhibit distinct characteristics in comparison to traditional fossil fuel generation or baseload in terms of volatility, it is imperative to demonstrate water electrolysis technology in conjunction with renewable energy in order to validate the technology in an actual green hydrogen production environment.

Solar power is the preferred source of renewable energy for the hydrogen electrolysis facility. However, other renewable energy sources are also considered to ensure a track record of green hydrogen production utilizing a variety of renewable energy sources. Compared to other renewable energy sources such as wind, biomass, biogas, and hydropower, solar has the most abundant potential in Thailand (see Figure 5-8). Furthermore, it is rated the highest by Thai hydrogen experts in terms of applicability for green hydrogen production. After solar, hydropower, biomass, and biogas have been determined to have good applicability and can be considered for interconnection with solar power if it is difficult to connect to these renewable energy sources, it is also possible to connect to a particular renewable energy source if it is exceptionally abundant or readily available in the region.

[Figure 5-8] Applicability and Potential of Renewable Energy in Thailand



Note: The potential amounts of each renewable energy source were calculated using IRENA(2022)'s potential capacities in GW¹¹ and capacity factors derived from Department of Alternative Energy Development and Efficiency's Thailand Alternative Energy Situation.¹²

Source: NIGT

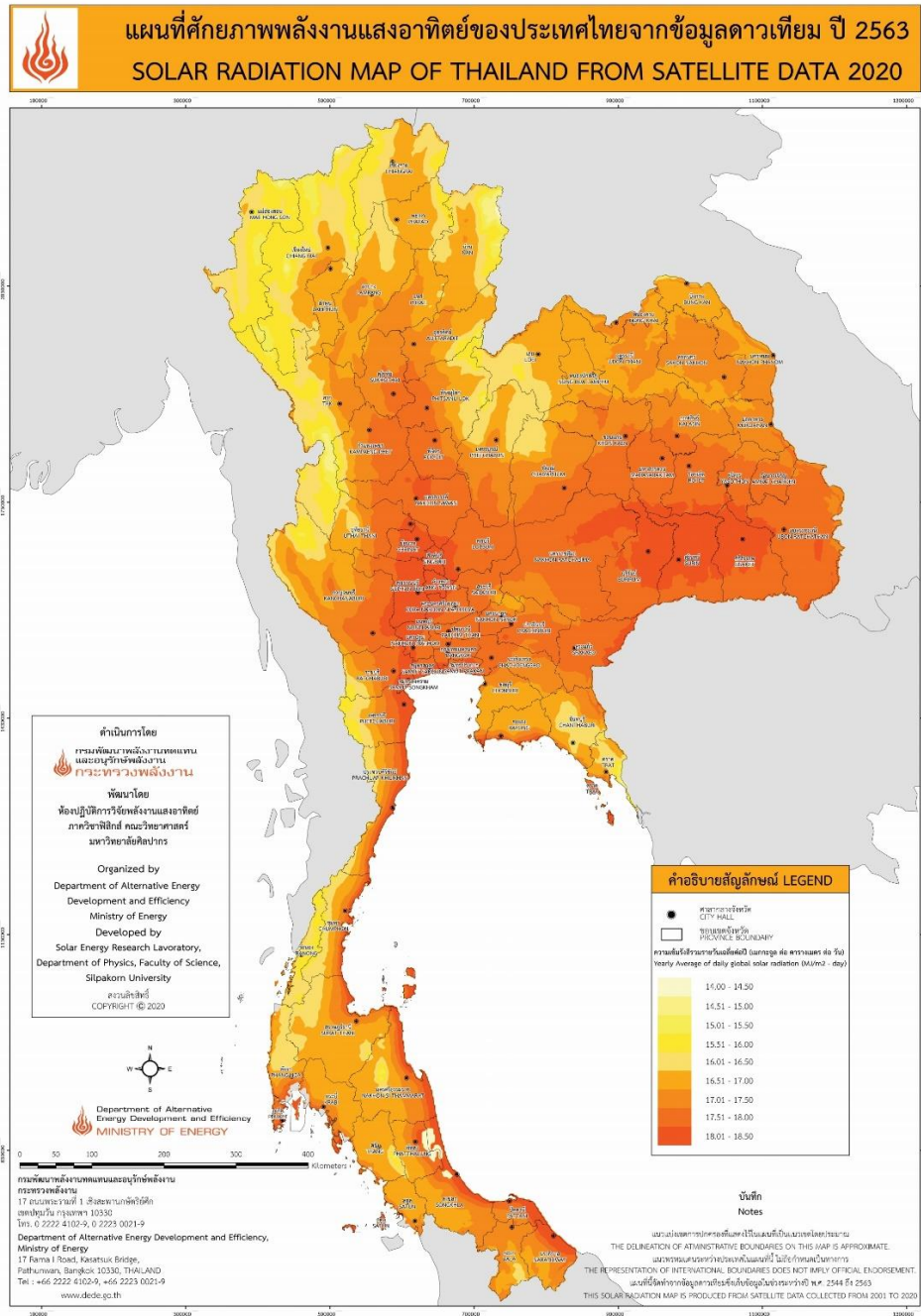
Nakhon Ratchasima province is a potential site for a demonstration of water electrolysis technology in conjunction with solar, biomass, and biogas power generation. Following consultations with hydrogen experts in Thailand, it has been determined that Nakhon Ratchasima province is the most suitable location. According to the Department of Alternative Energy Development and Efficiency, Nakhon Ratchasima province has one of the richest potentials for solar, biomass, and biogas, and is second only to Kanchanaburi in terms of installed renewable energy generation capacity (1,157.79 MW) as of 2021 (See Figure 5-9 and 5-10).¹³ It is recommended that Nakhon Ratchasima province be considered as a potential demonstration site. However, given the significant financial resources required for the demonstration, it is prudent to conduct a comprehensive evaluation of all provinces to identify an appropriate site. This evaluation should involve input from technical and policy experts and ministries. Additionally, it is essential to engage with the local government to ascertain their views on the proposed project and to discuss the potential benefits for the local population.

¹¹ IRENA, 2022, Renewable Energy Outlook for ASEAN: Towards a Regional Energy Transition (2nd Edition)

¹² Department of Alternative Energy Development and Efficiency, 2019-2021, Thailand Alternative Energy Situation

¹³ Department of Alternative Energy Development and Efficiency, 2021, Thailand Alternative Energy Situation

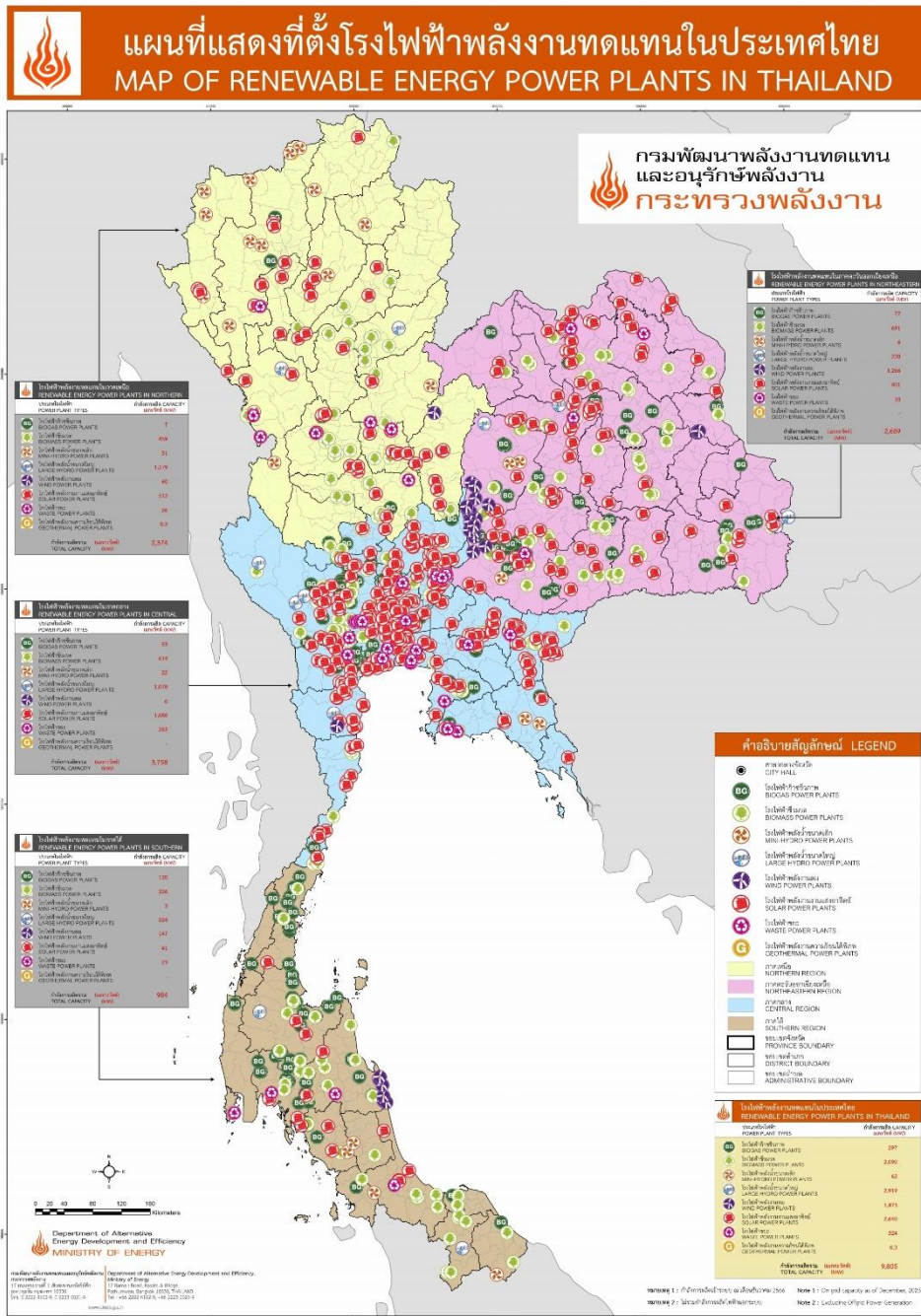
[Figure 5-9] Solar Radiation Map of Thailand



Source: Department of Alternative Energy Development and Efficiency (2023)¹⁴

¹⁴ Department of Alternative Energy Development and Efficiency, 2023, Solar Radiation Map of Thailand From Satellite Data 2020. <https://gis.dede.go.th/gallery-map-view.aspx?p=93> (Accessed on April 18th, 2024.)

[Figure 5-10] Map of Renewable Energy Power Plants in Thailand



Source: Department of Alternative Energy Development and Efficiency (2023)¹⁵

¹⁵ Department of Alternative Energy Development and Efficiency, 2024, Map of Renewable Energy Power Plants in Thailand. <https://gis.dede.go.th/gallery-map-view.aspx?p=223> (Accessed on April 18th, 2024.)

On the other hand, for the demonstration of electrolysis in conjunction with hydropower generation, areas with existing large-scale hydropower facilities, such as Tak province and Kanchanaburi province, should be prioritized.

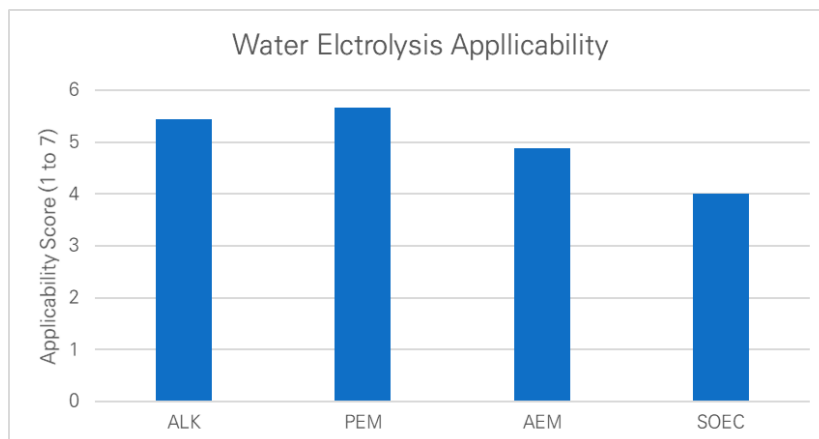
In promoting the demonstration of water electrolysis technology, Thai universities, research institutes, and companies should be the primary entities involved to the greatest extent possible. However, given that water electrolysis technology is already well-developed in major developed countries, and that R&D resources in Thailand are relatively scarce compared to those available for SMR technology (see Figure 5-2), it would be prudent to invest in strengthening R&D resources while also considering collaboration with partners such as major overseas countries and major companies that have developed excellent water electrolysis technology. As with the demonstration of SMR technology, cooperation with overseas partners should be conducted in the form of joint research and joint demonstration. This will facilitate the internalization of the excellent overseas technology into the capabilities of Thai local R&D entities. Furthermore, when promoting water electrolysis technology in cooperation with overseas partners, it should be linked to investment in water electrolysis hydrogen production and renewable energy generation in Thailand. This will lay the foundation for green hydrogen production in the future.

A - 2. Deploy Green Hydrogen Production Facilities and Produce Carbon-Free Hydrogen

ALK and PEM will commercialize the GW-scale water electrolysis system in 2049, commencing full-scale production and supply of green hydrogen in 2056. AEM and SOEC will complete the commercialization of the GW-scale water electrolysis system and begin production and supply of green hydrogen with a one-year staggered timeline. In the promotion of the commercialization of the water electrolysis system, the facilities constructed during the demonstration of the water electrolysis stack will be utilized to the greatest extent possible. In the construction of the water electrolysis system in areas other than the demonstration site, the site will be selected and constructed in consideration of the renewable energy

generation facilities and electricity supply network described in A-1.

[Figure 5-11] Applicability of Water Electrolysis Technologies in Thailand



Source: NIGT

The deployment of water electrolysis systems prioritizes the installation of PEM and ALK systems over AEM and SOEC. According to the opinion of Thai hydrogen experts, the applicability of water electrolysis technology in Thailand is currently rated higher for PEM and ALK than AEM and SOEC due to their higher technology maturity globally (see Figure 5-11). However, this assessment is based on the current international technology development trends and performance. The final prioritization of the water electrolysis system will be determined by conducting the assessment of the advantages and disadvantages of each water electrolysis technology at the demonstration stage before commercialization or at the early stage of commercialization.

The production and supply of green hydrogen will be carried out by Thai companies. In order to utilize their existing capabilities, companies in the industrial gas manufacturing industry and gas supply industry will be encouraged to participate in the production of green hydrogen. Furthermore, the production of green hydrogen will be initiated in close cooperation with the central and local governments, taking into account the willingness and capability of relevant companies to invest in green hydrogen.

The facilities and institutional framework for the supply of green hydrogen in the commercialization phase will be reviewed and improved prior to full-scale electrolysis

hydrogen production and supply. As previously stated in the blue hydrogen section (Strategy 1 - Task 1 - A-2. Construct Blue Hydrogen Production Facilities and Produce Clean Hydrogen), the following areas require review and improvement: hydrogen storage and transportation technologies, hydrogen markets, hydrogen market management entities, safety standards, and related national plans.¹⁶

In addition to the aforementioned facilities and systems, it is also necessary to inspect and expand renewable energy power generation facilities and transmission and distribution networks before the production of green hydrogen. As with SMR-based hydrogen, which is linked to CCUS technology, hydrogen based on water electrolysis is linked to renewable energy power. Consequently, it is essential that renewable energy power generation technology be developed as a standalone strategy until the commercialization of full-scale green hydrogen. At the commercialization stage, it is imperative that the water electrolysis system and renewable energy power generation facilities be adequately integrated. Furthermore, in order to overcome the geographical constraints of renewable energy power generation facilities, it is also necessary to expand sufficient transmission and distribution networks in Thailand. This will ensure that renewable energy power generated from distant locations can be effectively supplied to the water electrolysis system.

B. Support Green Hydrogen Production for Feasibility

It is recommended that design incentive programs be implemented to expand the supply and use of green hydrogen until 2056, when full-scale green hydrogen production is expected. Due to the nature of the new technology, even if it is thoroughly demonstrated, it may be difficult to satisfy the economic feasibility in the early stage of the market due to high fixed and operating costs and low sales revenues. Failure to address this may result in a stagnation of the green hydrogen market. Consequently, it is imperative to implement appropriate economic incentives or impose pertinent obligations on suppliers and consumers of green

¹⁶ Incentives for the supply and use of green hydrogen are discussed in B. Support Green Hydrogen Production for Feasibility.

hydrogen to stimulate the production and utilization of green hydrogen.

As described in the following sections, the basic direction of the system design is to facilitate the expansion of green hydrogen is to facilitate the expansion of green hydrogen production and utilization. This entails a comprehensive examination of the experiences of major countries over an extended period and the adaptation of the design to align with the specific conditions of Thailand. The preliminary system design must be finalized and implemented by 2041, in alignment with the targeted production of blue hydrogen. For green hydrogen, the existing system should be reviewed and supplemented during the commercialization phase of the water electrolysis system (2049-2056). Additionally, additional systems should be designed to promote the use of green hydrogen based on existing experience. This is expected to prevent confusion at the beginning of the system implementation and prevent frequent changes to the system.

In order to expand the supply and demand of green hydrogen, a national certification system for green hydrogen will be designed first. As already mentioned in Strategy 1 - Task 1, a clean hydrogen certification system should be designed in advance of the full-scale production and supply of blue hydrogen (2041). Currently, clean hydrogen certification schemes designed in major countries typically certify hydrogen as clean if the production of 1 kg of hydrogen generates less than 3 to 4 kg of GHGs. Moreover, to encourage the supply and use of hydrogen that generates very little GHG even within the minimum threshold of clean hydrogen, detailed grades are categorized based on GHG emissions. Thailand will review the effectiveness of clean hydrogen certification systems implemented by major countries and design a clean hydrogen certification system that takes into account Thailand's domestic conditions until at least 2041.

It is proposed that a subsidy or tax credit program be designed to expand the supply of green hydrogen in conjunction with a clean hydrogen certification program. One possible avenue for providing subsidies is to offer incentives for the installation of water electrolysis systems. This would have the effect of reducing the initial installation cost of water electrolysis systems. Another potential avenue for providing subsidies is to reduce taxes, such as corporate taxes

that producers (companies) are liable to pay. These tax credits could be linked to the actual amount of green hydrogen produced by the company. It is similarly possible to induce the expansion of the green hydrogen supply by reducing taxes on key inputs (electricity, water) required to produce green hydrogen. Incentives for expanding the supply of green hydrogen should be designed and introduced after a comprehensive review of the incentive systems of major countries and verification of their effectiveness by 2056. The appropriate level of incentives should be determined in consideration of the current and long-term national budget.

To encourage the use of green hydrogen in the national economy, it is recommended that tax credits be considered for the use of green hydrogen. Additionally, mandatory measures such as a clean hydrogen mandate should be considered. Tax credits for the use of green hydrogen can be designed in such a way that producers who use hydrogen as a key input reduce their taxes in relation to the amount of green hydrogen they use. Conversely, a mandatory system for the use of green hydrogen can be designed in a manner analogous to the Renewable Portfolio Standard, which represents the primary system for the generation of renewable energy. This system requires power producers with a certain minimum size to utilize green hydrogen for a minimum proportion of their power generation. Incentives and obligations for the use of green hydrogen should also be approached from a long-term perspective in order to fully examine their effects. Furthermore, the obligation to use green hydrogen should be designed in a way that minimizes the negative effects of regulation while maximizing the national benefits of using green hydrogen. This can be achieved through consultation with relevant ministries and by fully collecting opinions from companies subject to regulation.

Task 3. Design the Import Chain of Clean Hydrogen

A. Jointly Develop Hydrogen Abroad and Diversify Import Portfolio

To effectively introduce overseas clean hydrogen, we select strategic partner countries and jointly develop hydrogen by utilizing their resources. We also organize a portfolio of overseas

hydrogen introduction (purchase) centered on strategic partner countries.

The selection of strategic partners will be made in a short period of time, utilizing the current situation and future prospects in Thailand and abroad. This process will allow for the modification and supplementation of the strategic partners to complete the final demonstration stage of clean hydrogen production technology before the full-scale joint development of overseas hydrogen. In the case of blue hydrogen, strategic partners will be selected based on countries with abundant natural gas or biogas and carbon dioxide storage capacity. In contrast, in the case of green hydrogen, countries with abundant renewable energy resources will be selected. Furthermore, the production cost of each clean hydrogen and the cost of importing it to Thailand must be considered when selecting strategic partners. Prior to finalizing the strategic partner countries, a tool for selecting partner countries will be developed and utilized.

For blue hydrogen, joint overseas development will be promoted from 2032, the target date for the demonstration of SMR technology. Similarly, the promotion of joint overseas development for green hydrogen will commence from 2049 (ALK, PEM) and 2050 (AEM, SOEC), the target dates for the demonstration of electrolysis technology. The objective of overseas joint development is to facilitate the acquisition of a portion of the clean hydrogen produced abroad and its subsequent introduction into the country. This will enable the supply of clean hydrogen in Thailand. Therefore, when pursuing joint development, it is crucial to prioritize the physical security of clean hydrogen, rather than solely focusing on the form of investment or profit sharing.

The portfolio of foreign hydrogen acquisitions (purchases) should be diversified to account for the clean hydrogen production capabilities of strategic partners, while not being overly dependent on any one country or region. This allows for the mitigation of risk in the event of a supply disruption shock in a particular region due to geopolitical events. The composition of the overseas hydrogen import (purchase) portfolio is not fixed at a specific point in time. Rather, when additional overseas hydrogen is required, the purchase is promoted in consideration of the diversification of the portfolio, and the portfolio is reviewed annually

based on the volume and amount of overseas hydrogen imported to establish a mid- to short-term portfolio diversification strategy.

B. Establish Infrastructure for Hydrogen Import

In order to supply Thailand with clean hydrogen, which has been developed or purchased overseas, a hydrogen import infrastructure (terminal) will be established. Even if it is decided to purchase or develop overseas hydrogen, the construction of the infrastructure will take a long period of time. Therefore, the hydrogen import terminal will be planned in consideration of the future hydrogen import volume, with the selection process of strategic partner countries being a key factor in this decision.

The initial consideration for the construction of a hydrogen import terminal is the utilization of existing liquefied natural gas (LNG) terminals, coal terminals, and other similar facilities in Thailand. These existing terminals can be renovated and refurbished to serve as the basis for the new hydrogen import terminal. The construction of a new terminal requires a significant capital investment, and thus, the utilization of existing terminals can reduce the cost of infrastructure construction. Additionally, existing terminals have an advantage in terms of geographical location, as the location of the terminal was selected in consideration of the connections to the industries behind it.

In the construction of a hydrogen import terminal, it is essential to establish a pipeline that connects the import terminal to the destination where the hydrogen will be consumed. Alternatively, hydrogen transportation vehicles, such as tank lorries and tube trailers, can be utilized to facilitate the transfer of the hydrogen. Furthermore, in the long term, the possibility of hydrogen stockpiling should be considered in the event of a sudden influx of hydrogen or disruption to the import process, with the construction of a large-scale storage facility (stockpile) within the hydrogen import terminal or in the vicinity of the terminal.

Strategy 2. Expand Demand by Laying a Foundation for Hydrogen Utilization

This section includes strategies for hydrogen utilization in the power, mobility, and industrial sectors, respectively. The power plant sector represents an important field of application for hydrogen, which is primarily concerned with the balancing of an electricity system. Sectors such as mobility and industry should also be considered, as they are difficult to electrify. Processes that utilize fossil fuels as a chemical feedstock or in the generation of high-temperature heat or long-duration, dispatchable power will require clean fuels such as hydrogen to achieve decarbonization. The following subsections delineate the role of clean hydrogen in each of the aforementioned applications.

Task 1. Expand Hydrogen-based Powerplant and Integrate Co-Firing Technologies

In the power generation sector, our objective is to expand the use of hydrogen in power generation. This will be achieved by (1) expanding the deployment of fuel cell power generation facilities in the short term, (2) demonstrating the viability of ammonia blending with coal power generation in the mid-term, and (3) expanding the proportion of hydrogen blending in the long term. In order to achieve this, we will utilize relevant policy support tools.

First, the deployment of fuel cell power generation facilities is expected to contribute to the establishment of a hydrogen-based ecosystem. This will be achieved by creating a stable demand for hydrogen, revitalizing the hydrogen economy and expanding private investment. Initially, gray hydrogen will be utilized, then the use of blue and green hydrogen will be expanded when conditions for utilization are established through the production and import of clean hydrogen. In order to optimize the distribution of fuel cell power generation facilities, it is essential to reinforce their role as distributed resources. This can be achieved by distributing them to data centers, industrial complexes, large buildings, residential complexes, and gas stations in urban centers. Furthermore, it is necessary to require them to have a certain level of flexibility in order to contribute to the stability of the power system through output increase and decrease functions.

Second, developing fundamental technologies, constructing infrastructure, and demonstrating coal-to-ammonia blending should be carried out. In detail, we will develop fundamental technologies such as combustion and storage technologies for blending 20% ammonia (~2030), construct infrastructure for commercial power plant fuel supply (~2035), and select a few power plants for demonstration (~2037). Securing the source technology for ammonia blending necessitates the development of technologies for removing nitrogen oxides from large amounts of ammonia input, preventing unreacted ammonia leakage and treating unburned ammonia. When selecting generators for demonstration and commercialization, it is essential to consider the remaining design life of at least 10 years, economies of scale due to large-scale coal power complexes, and power generation capacity in accordance with NDC targets. Consequently, the objective is to achieve 20% ammonia blending by 2040, after which the ammonia blending rate will be increased gradually in order to achieve carbon neutrality and promote ammonia elimination by 2065. During the phase of promoting ammonia elimination, it is necessary to develop and demonstrate technology for large-capacity, high-efficiency coal generators with high residual value, considering the recovery of investment costs of elimination facilities and the maximization of carbon reduction.

Third, the development of source technology for hydrogen blending in LNG gas turbines, the construction and demonstration of infrastructure, and the formulation of plans for hydrogen electrification must be pursued. Initially, the objective is to achieve 5% hydrogen blending in LNG gas turbines by 2040, with subsequent gradual expansion of the blending ratio to 10% by 2050 and 20% by 2060. The timing of the strategy is contingent upon the capacity of the gas turbine and the power capacity. Given that small gas turbines are primarily utilized as emergency power sources, our objective is to develop technology for blending with existing fuels, and subsequently, technology for blending natural gas and hydrogen. Once the technology has been demonstrated in areas where hydrogen production is feasible, we will proceed to develop it for use in distributed or emergency applications (hospitals, data centers, etc.). The utilization of medium-sized gas turbines will facilitate the advancement of domestic distributed, cogeneration, industrial, and export-oriented development. Additionally, the integration of hydrogen mixing functions into existing gas turbine designs under development

will be pursued, with a subsequent objective of commercialization upon the completion of the demonstration phase. Subsequently, a demonstration plan for the demonstration of large-scale all-electric turbines will be established, with the timing of commercialization to be determined in accordance with the proportion of renewable energy and hydrogen supply and demand at that time.

It is recommended that a Clean Hydrogen Production Standard (CHPS) be introduced to establish and promote hydrogen-fueled power generation, with a particular focus on clean hydrogen power generation. Given that clean hydrogen power generation is currently uncompetitive in the market due to the high fuel cost, it is challenging to attract significant investment in power generation projects. Therefore, the introduction of a policy tool that compensates for this and promotes investment is necessary. It is recommended that a hydrogen power generation obligation be introduced initially, with a subsequent transition to a clean hydrogen power generation obligation when the requisite conditions for the utilization of clean hydrogen are met. The targets of the obligation should be considered to be power generators and electricity sales companies. The settlement method should be differentiated according to the type of power generation, such as coal-generator-ammonia hybrid power generation and hydrogen turbine hybrid power generation, and the type of power market participation, such as preferential purchase system and power market bidding. In addition, we will also support the revision of related regulations, such as expanding the use of ammonia from fertilizer and industrial use to power generation.

Task 2. Apply Hydrogen Mobility Starting from Public to Private

The mobility sector, which encompasses transportation, is responsible for a significant portion of GHG emissions: In response to this, the global trend is toward accelerating automotive de-energization. While the mobility industry has mainly focused on battery electrification of passenger vehicles, hydrogen and fuel cells offer great opportunities for applications that require long driving ranges, fast refueling, large, and heavy loads. Consequently, the mobility sector is striving to expand the use of hydrogen mobility in three

key areas: (1) expanding the supply of hydrogen vehicles, (2) promoting the introduction of various hydrogen mobility applications other than road transportation, and (3) utilizing relevant policy support as tools.

First, the introduction of hydrogen passenger cars and the expansion of their use will be discussed. This will be done in stages by 2030, 2040, and 2050. Moreover, given that commercial vehicles, such as trucks and buses, emit a greater quantity of GHG and air pollutants than passenger vehicles, we will expand the supply of hydrogen vehicles with a particular focus on commercial vehicles. In addition, we will collaborate with local governments to convert city buses, short-distance intercity buses, and wide-area buses to hydrogen buses, and encourage the replacement of public sector-operated buses. We support the commercialization of not only passenger and commercial vehicles but also special vehicles through R&D support. For instance, we will advocate for the utilization of hydrogen cleaning vehicles in the public sector, and the development, demonstration, and verification of technologies for the modification of public hydrogen special vehicles such as street sweepers, sprinkler trucks, and food waste collection vehicles by modifying existing cargo vehicles to introduce hydrogen special vehicles. Other projects include the introduction of hydrogen for towing cargo carts at airports and the development of common parts technology applicable to various airport special vehicles; the introduction of hydrogen vehicles for loading and unloading equipment, container handling equipment, and hydrogen vehicles in and out of ports; and the application of hydrogen fuel cell power systems to indoor logistics transportation systems such as forklifts and unmanned vehicles in factories.

Hydrogen mobility is still in its infancy of deployment, and the lack of hydrogen refueling stations and the high cost of fuel compared to electric vehicles are currently limiting its mass adoption. To address this issue, a mobility fund will be established to support the shortfall in the budget for local government subsidies to purchase hydrogen vehicles and repay it in installments according to the local government's situation. Also, the construction of commercial charging stations must be expanded to major transportation hubs, allowing for self-charging; operating hours must be adjusted and nighttime charging fees reduced; safety standards for charging stations must be developed; fuel and purchase subsidies for hydrogen

buses must be improved, taking into account the fuel cost level of comparable electric vehicles; and finally, support must be provided for fuel cell replacement costs. Furthermore, it is recommended that targets be introduced and promoted for private consumers, such as rental car companies to purchase eco-friendly vehicles, and increase the mandatory purchase rate of hydrogen and electric vehicles for public institutions.

Second, the scope of hydrogen mobility should be expanded beyond inland transportation to include ships, drones, and aviation. In the case of hydrogen ships, ammonia carriers utilizing LPG carriers are already in operation, and ammonia carriers and propulsion ships, liquefied hydrogen carriers and liquefied hydrogen propulsion ships are being introduced. For ammonia ships, it is necessary to develop and introduce core technologies such as large-scale ammonia engines and supply systems. For liquefied hydrogen propulsion ships, it is necessary to participate in preemptive technology development such as scale-up of fuel cells and to improve infrastructure systems in stages such as establishing test standards for commercialization of new technologies.

There are also options to expand the use of hydrogen to trams, drones, and aviation. There are export opportunities to the European market, where internal combustion engine trains are being replaced by hydrogen trains. This gives us a reason to participate in the development and demonstration of hydrogen tram technology. With regard to hydrogen drones, our focus will be on the public sector market. We will support the demonstration of hydrogen drone utilization centered on local governments, developing goods delivery services, developing hydrogen drones for agriculture and logistics, or long-distance and long-endurance drones. Furthermore, we will develop a plan to target the use of hydrogen fuel cells for UAM (Urban Air Mobility), a new transportation method of the future.

Task 3. Employ Hydrogen in Carbon Intensive Industry

Globally, industry represents the largest end-use sector in terms of energy consumption. In order to expand the utilization of hydrogen in the industrial sector, we will focus on the

refining industry and the cement industry, and utilize relevant policy support tools.

First, hydrogen has long been used in the refining industry, primarily to remove impurities and increase the yield of high-quality refined products. One of the main applications of hydrogen is the process of hydrocracking, which enables the production of higher-value chemicals. This process lowers the amount of energy input and production costs by enabling the conversion of lower-value chemicals into higher-value products. Another application is catalytic reforming, which uses catalysts and hydrogen to convert low-octane naphtha to high-octane gasoline. This process benefits the environment by reducing sulfur content in the fuel. The utilization of clean hydrogen to produce high-value-added products is projected to commence around 2050, with the commercialization of high-value-added product manufacturing following around 2065. Other benefits include the reduction of emissions by using hydrogen fuel cells in the refining industry to power the refining process.

Second, the cement industry will switch from coal to hydrogen as fuel. The fuel for kilns that produce clinker, an intermediate in cement, will be replaced from coal to biomass-linked hydrogen heat sources. At this time, new heat source technologies that utilize hydrogen fuel, such as hydrogen hybrid or all-combustion clinker kilns that utilize bio-friendly heat sources will be developed (2035~). This will be followed by the design and demonstration of hydrogen heat source kiln manufacturing facilities (~2040), and semi-mass-produced hydrogen heat source kiln demonstrations (~2050). These will be applied in stages to old facilities.

Strategy 3. Establish Infrastructure for Broaden the National Hydrogen Network

This session will address strategies for the storage and transportation of hydrogen. The reliable storage and transportation of hydrogen is one of the most essential elements of the hydrogen economy, ensuring the security of energy supply and facilitating a sustainable energy transition, which can ultimately contribute to the revitalization of industries and enhance energy security at the national level. The storage and transportation of hydrogen can be broadly divided into three types, including liquid, solid, and gaseous storage and transportation. Further divisions can be made according to the utilization of pipeline and tube trailers, as well as the compounding and liquefied organic hydrogen carrier (LOHC) utilization. This session will present strategies centered on developing hydrogen liquefaction plant technology to transform hydrogen into efficient form for storage and transportation, building a pipeline network for hydrogen transportation, and expanding hydrogen refueling stations.

Task 1. Secure Hydrogen Liquefaction Technology for Large-scale, Low-cost Hydrogen Supply

Hydrogen liquefaction is a technology that plays a key role in the storage and transportation of hydrogen. There are three different forms of hydrogen that can be used to store and transport hydrogen: liquid, gas, and solid¹⁷. Liquid hydrogen is stored by cooling hydrogen to cryogenic temperatures and converting it to a liquid state. Typically, hydrogen is cooled to a temperature of about -253°C to liquefy it, which greatly reduces its volume and saves space, making it more efficient to transport. Liquefied hydrogen is also relatively safe to store, but it requires high energy consumption and sophisticated systems. LOHC is also one of potential technology options to transport hydrogen safely in a liquid form. This technology refers to a technology that converts hydrogen into a compound form or absorbs hydrogen into a

¹⁷ Soohyeon Kim, 2019, The trend of storage and transportation technology for hydrogen supply vitalization, Auto journal, 41(2)

compound for storage and transportation, and aims to decompose or extract hydrogen from the compound after transportation and supply it. Unlike liquid hydrogen, this method is relatively safer and easier to store and transport in a large scale. Ammonia is widely utilized as a liquid hydrogen carrier. The storage and transportation of hydrogen through compounds is widely used due to its safety and efficiency, with LOHC and ammonia being the most popular. The technology is attracting attention due to its safety and efficiency, but additional costs can be incurred due to hydrogen recovery and regeneration, organic waste treatment, and other factors. Hydrogen can be stored and transported in a solid form. Solid storage technology is defined as the technology which stores hydrogen in a solid material or on the surface of it. Considering the storage capacity and energy efficiency, utilizing hydrogen storage alloy is expected to be the best option for this. Currently, hydrogen is supplied from nearby petrochemical complexes through pipelines or transported in a gaseous state by compressing high-pressure gas into tube trailers for medium and long distances. However, it is essential to develop more efficient hydrogen storage and transportation methods to expand the hydrogen economy in the future.

A hydrogen liquefaction plant is a facility that plays an important role in each industry and energy sector, as it is responsible for the conversion of hydrogen into a liquid state. This process is essential for the revitalization of the hydrogen economy. However, due to the large volume and low pressure of hydrogen in its gaseous state, it is necessary to improve the efficiency of transportation and expand safety through the liquefaction process, especially for long-distance transportation. Furthermore, hydrogen liquefaction plants can not only stably store large amounts of hydrogen by improving the efficiency of space utilization, but also contribute to energy security by efficiently and consistently supplying hydrogen for industrial processes and transportation. In other words, hydrogen liquefaction plants can contribute to the revitalization of the hydrogen economy and the establishment of renewable energy systems by enabling stable hydrogen transportation and supply processes.

For introducing and operating hydrogen liquefaction plant, it is required to ensure the relevant technologies, design a demonstration project, and establish stable operation system. First of all, it is mandatory to lay a foundation of efficient hydrogen storage and transportation

by ensuring hydrogen liquefaction technology through the cooperation with technology leading countries. Currently, Germany and Japan are the technology leaders with relative advantages in hydrogen liquefaction technology. Germany is focusing on developing liquefaction-based hydrogen storage technologies such as liquid hydrogen and liquid organic hydrogen transporters by utilizing its existing natural gas pipeline network and storage facilities. In particular, it is promoting the Power to Gas (P2G) project, which converts electricity generated from renewable energy into hydrogen, stores it, and then utilizes it as electricity when needed. Germany plays a leading role in green hydrogen production among EU member states. As the European Council's presidency, it plays an important role in policies to revitalize the hydrogen economy, such as the introduction of sustainability standards and proof of origin for green hydrogen and the implementation of the European Hydrogen Initiative. Japan is focused on reducing the cost of liquid hydrogen through aggressive government investment in technology development. The HySTRA (Hydrogen Energy Supply Chain Technology Research Association), a Japanese organization comprising companies such as J-Power, Kawasaki Heavy Industries, Iwatani, and Shell Japan, has established a liquid hydrogen supply chain that transports and stores hydrogen extracted and liquefied in Victoria, Australia, to Kobe, Japan. Furthermore, the Advanced Hydrogen Energy Chain Technology Development Association (AHEAD), comprising four major Japanese companies, is demonstrating the establishment of a supply chain to transport hydrogen extracted from gas generated by the Brunei LNG plant in the form of liquid hydrogen. Furthermore, we are engaged in the advancement of liquefied hydrogen carriers for the transportation of hydrogen abroad. We have constructed and operated the inaugural hydrogen carrier, the "Suiso Frontier," as part of the Hydrogen Energy Supply Chain (HESC), a lignite hydrogenation project in collaboration with the Australian government. It is imperative to collaborate with advanced countries such as these to secure hydrogen liquefaction technology and to develop it in a manner that is tailored to the specific conditions and circumstances in Thailand.

Second, there is a need for site selection and demonstration projects to maximize the overall process efficiency of hydrogen from production to supply by 2040. Currently, Thai experts have identified Rayong and Nakhon Ratchasima as candidate regions for efficient clean hydrogen production. These regions have been analyzed as having advantages for hydrogen

production due to their abundant resources and adjacent industrial parks. In order to enhance the efficiency of hydrogen conversion and supply, hydrogen liquefaction plants should be situated in proximity to hydrogen production facilities. Demonstration projects should be encouraged through government investment and private participation in order to obtain empirical data on the hydrogen liquefaction process in Thailand.

Third, it is essential to establish a foundation for efficient operating systems and operations of hydrogen liquefaction plants by 2055. In order to ensure the establishment of hydrogen liquefaction plants in parallel with production targets that are expected to utilize large amounts of clean hydrogen, it is necessary to provide support for the entire hydrogen distribution process, including shipping centers, trailers, and liquefaction stations. In addition, it is necessary to implement improvements to related regulations and systems and to introduce support policies. Furthermore, it is required to secure manpower to operate hydrogen liquefaction plants by establishing a capacity building program for specialized personnel.

Task 2. Construct Hydrogen Pipelines to Increase Accessibility

The construction of hydrogen supply pipelines represents one of the most fundamental facilities for the establishment of a hydrogen supply system. These pipelines play an essential role in the stability and functionality of the system as a whole by serving as the conduit for the interconnection of hydrogen supply and demand. In order to ensure the long-term stability and reliability of the hydrogen pipeline network, it is essential to construct a hydrogen pipeline network centered around the areas where hydrogen is produced or utilized. Once this network is operational, it is then necessary to demonstrate the integration of hydrogen blending into the existing pipeline infrastructure.

In order to enhance the efficiency and effectiveness of the hydrogen pipelines, it is important to identify the optimal distance for hydrogen pipelines linked to hydrogen production areas and to construct the piping network in accordance with the specific demand characteristics

of each hydrogen production area. As previously stated, Rayong and Nakhon Ratchasima are designated as the optimal regions for clean hydrogen production in Thailand based on local expert survey. In the event that a demonstration project for hydrogen production is planned in these two regions, it is imperative to construct the hydrogen pipeline network around them. It is essential to establish a foundation for a pipeline network that connects hydrogen production sites to potential demand sites, including nearby industrial parks, power plants, and charging stations. This network needs to be optimized by separating pipes for power generation and industrial use from pipes for transportation. In this process, it is of the utmost importance to introduce or develop robust and durable materials that are resistant to hydrogen strength and internal pressure. This is to ensure the safety of the hydrogen pipelines. Additionally, it is vital to implement hydrogen leak detection and prevention systems to prevent safety accidents.

Furthermore, it is crucial to gradually expand the hydrogen supply through the demonstration of hydrogen entrainment. Hydrogen blending refers to the process of using hydrogen mixed with other fuels, which can enhance the stability of energy supply by ensuring energy diversity and contribute to achieving carbon neutrality through carbon emission reduction. Prior to the demonstration of hydrogen blending, it is essential to establish safety standards by analyzing the impact of changes in pipe quality, such as pressure and brittleness, depending on the percentage of hydrogen blending, and the gas equipment type of demand site. The fundamental policy tools must be prepared to support this process, which is estimated to occur around 2030. Afterwards, it is necessary to commence with local pipelines in stages, around 2040, and gradually expand to the national pipeline network. Concurrently, it is essential to conduct safety verification and impact analysis. The expansion of the centralized pipeline network and the establishment of a regional pipeline network by 2055 will facilitate the efficient connection of the supply and demand of hydrogen, thereby contributing to the revitalization of the hydrogen economy.

Task 3. Increase Hydrogen Refueling Stations to Drive Mass Adoption

One of the most significant challenges in the revitalization of the hydrogen economy is the expansion of hydrogen demand and the diversification of demand sources. The expansion of hydrogen mobility represents a key strategy for addressing this challenge. To achieve this, it is required to develop a robust hydrogen refueling station infrastructure and to strategically locate hydrogen refueling stations in areas with high demand. The expansion of refueling station infrastructure plays an important role in accelerating the transition of national energy systems. In the long run, it can contribute to securing energy accessibility and uniformity in the country.

Currently, Thailand's hydrogen mobility market is still in its early stages, with various policies in place to actively support the introduction and deployment of hydrogen fuel cell vehicles. When establishing hydrogen refueling stations in the initial stages, it is essential to deploy an equivalent number of stations per region or area in a balanced manner under public initiative by 2040. Subsequently, the number of stations should be expanded in regions and areas with higher demand, such as major cities and transportation and logistics hubs, and policies should be implemented to encourage private participation in the process by 2055.

In the process of supplying and expanding hydrogen refueling stations, not only should new refueling stations be considered, but also the introduction of hydrogen refueling stations at existing gas stations. By utilizing the existing transportation network, initial costs can be reduced, and informing consumers of the locations of new charging stations becomes unnecessary, thus promoting efficient hydrogen utilization. In this process, it is necessary to propose a win-win business model in cooperation with the existing gasoline industry. Furthermore, regulations that may be a barrier to the installation of hydrogen chargers should be identified and improved in advance.

Overall, in order to effectively introduce and expand hydrogen refueling stations, it is necessary to actively seek partnerships with domestic and foreign companies, and promote private investment in hydrogen refueling projects through policy support and incentives. Furthermore, it is essential to establish technical standards and regulations to guarantee the security and efficacy of charging stations. Additionally, it is vital to conduct environmental

impact assessments to ensure sustainable development and to prepare in advance for licensing and complaints.

Enablers: Create the Industrial Foundation for the Hydrogen Economy

This section introduces a series of enablers that are crucial for realizing the strategies needed to establish the industrial foundation for the hydrogen economy. First, a robust legal and institutional foundation is essential. Second, to ensure hydrogen safety, comprehensive lifecycle safety standards will be established, taking into account the variety of hydrogen production methods and specific requirements for storage and transportation. Third, in order to foster the hydrogen industry and stimulate investment, several measures are required. These include cultivating advanced hydrogen-related professionals and a specialized workforce, enhancing international cooperation to acquire hydrogen technology know-how and build a joint hydrogen ecosystem, and boosting financial and tax incentives to support industry growth.

Enabler 1. A Solid Legal and Institutional Foundation

Currently, Thailand lacks an institutional foundation for hydrogen technology development and industry development. In light of this, it may be necessary to implement regulatory changes across a number of areas. In order to enhance the supply and utilization of clean hydrogen, there is a need to examine, on the long term, the cases of significant countries and design a system that takes into account the conditions of Thailand. As previously indicated, the fundamental institutional design should be finalized and implemented by 2041 in order to align with the target date for blue hydrogen production. With regard to green hydrogen, it is recommended that the existing system be reviewed and supplemented during the commercialization phase of the water electrolysis system (2049-2055). In addition, it is proposed that additional systems be designed to promote the use of green hydrogen based on existing experiences.

First, the introduction of a certification system for clean hydrogen can serve as a foundation for defining clean hydrogen and building a hydrogen economy ecosystem centered on clean

hydrogen. In particular, the system should be introduced and implemented by 2032, when the demonstration of blue hydrogen is completed, to enable wider utilization of various forms of hydrogen and provide clear institutional standards. In addition, the use of clean hydrogen should be promoted through the introduction and activation of Clean Hydrogen Portfolio Standards (CHPS). The objective of the CHPS system is to expand hydrogen power generation by imposing obligations on electric utilities to purchase and supply hydrogen power. This ultimately promotes the production and use of hydrogen and is the basis for revitalizing the hydrogen economy. It is expected that revitalization of the hydrogen value chain through the activation of the CHPS system and the linkage between the systems that provide tangible incentives to participating companies through the clean hydrogen certification system will accelerate the preparation of the foundation for the revitalization of the hydrogen economy.

In addition, it is necessary to secure a variety of surplus renewable energy sources and large-scale interconnection operation experience through the operation of regulatory sandboxes and free zones. A regulatory sandbox is a system that reduces the scope of regulatory application so that operators can prioritize the launch of new products or services based on new technologies under certain conditions to test and verify their value and economics, and aims to discover and reflect areas in need of regulatory improvement based on this. Free Regulatory Zones represent a system that eases relevant regulations for specific regions, with the objective of promoting balanced regional development through local investment and job creation. Additionally, they aim to foster strategic and innovative industries.

Finally, as initial public acceptance of new technologies and facilities is considered to be one of the most important factors in the medium to long term, it is essential to build public consensus by preparing various policy measures to resolve conflicts of interests and increase public acceptance of hydrogen-related facilities and facilities. In particular, hydrogen-related facilities have encountered significant opposition from residents in many countries due to concerns about safety. Therefore, it is necessary to actively promote the safety of hydrogen infrastructure based on scientific facts in order to allay the concerns of nearby residents when expanding hydrogen-related infrastructure.

Enabler 2. Safety Regulations and Standardization

A - Establishment and revision of safety standards and regulations for hydrogen-related equipment and facilities

It is crucial to ensure that life cycle safety standards are in place for the safe use of hydrogen. As hydrogen production methods vary, safety standards should be set based on empirical results as technology develops. With regard to hydrogen transportation, it is vital to strengthen safety management in view of the expansion of hydrogen transportation by pipeline and overseas imports. Furthermore, safety standards for liquefied hydrogen ISO tank containers should be established. In the storage sector, it is crucial to institutionalize safety standards for liquefied hydrogen storage tanks and set dedicated safety standards for pressure vessels at hydrogen refueling stations. With regard to hydrogen utilization, it is vital to establish safety standards for fuel cells for hydrogen mobility and hydrogen refueling stations, as well as to evaluate and demonstrate the performance of blending city gas and hydrogen as needed. In addition to developing a comprehensive plan that is tailored to the current situation and incorporates the insights of industry, academia, and research experts throughout the formulation process, it may also be beneficial to consider establishing a regular review committee that can periodically review and revise the plan to address emerging issues and new technologies. This will ensure that the plan remains aligned with the latest developments and promotes the rationality of safety management.

In terms of safety regulation, it is recommended that safety management laws and regulations be prepared and harmonized through legislative-level amendments or the enactment of a hydrogen law. It is also recommended that legal obligations be imposed on hydrogen suppliers and users for safety management. In terms of safety inspection and training, it is recommended that an infrastructure for the inspection of hydrogen supplies and liquefied hydrogen be established, as well as a training and practice infrastructure for the professional training of hydrogen safety managers. Furthermore, it is recommended that safety management organizations be designated and expanded in order to secure expertise

in hydrogen safety management and ensure that safety standards are systematically developed and managed.

B- Progress on hydrogen-related standardization

It is important for the Thai government to stay informed about developments in international standards for the hydrogen industry as it advances technology development. International standards for hydrogen technology have been the responsibility of TC 197, a technical committee of the International Organization for Standardization (ISO), since its establishment in 1990. Led by Canada, the United States, Japan, Germany, and the Netherlands, the objective is to develop international standards for systems and components for the production, storage, transportation, measurement, and use of hydrogen. The group's primary objective is to facilitate market access for hydrogen technologies. It gives high priority to all specifications that call for standardization in hydrogen technology-related areas and liaises with other ISO TCs, as well as IEC TC 105, the National Hydrogen Association, and the European Clean Hydrogen Alliance. The main points covered in the meetings of these working groups to date require follow-up. It is also important to strengthen the linkages with R&D and standardization bodies in Thailand related to hydrogen technology.

There are three main areas that are targeted for national standards development strategy: hydrogen production, hydrogen storage containers, and hydrogen safety. First, in the field of hydrogen production, the areas that require development are the performance evaluation of components according to the hydrogen production method (water electrolysis, SMR, etc.), hydrogen fuel quality, and hydrogen fuel quality evaluation for different hydrogen fuel use. Second, standards for the performance evaluation of hydrogen storage vessels are required for 350 bar and peripheral equipment, 700 bar and peripheral equipment. Finally, standards related to hydrogen safety include certification standards for hydrogen products and safety standards for hydrogen manufacturing and refueling facilities.

Enabler 3. Fostering Hydrogen Industry and Stimulating Investment

A - Cultivating advanced hydrogen-related professionals and specialized workforce

A strategy to develop human resources should consider training both high-level professionals and specialized hands-on workers. Universities such as Chulalongkorn University and King Mongkut University, which are already active in hydrogen research, should be encouraged to develop and operate hydrogen-related curricula, and to train specialized personnel to plan and implement them through large-scale support of hydrogen innovative technology development projects. For field-specific working manpower, a similar approach to that currently being taken by the Energy Research and Development Institute of Nakornping (ERDI) at Chiang Mai University in collaboration with the German hydrogen company Enapter to establish a comprehensive training center will be adopted. This will involve the establishment of a working manpower training base at local universities to train working manpower in line with the workforce needs of specialized industries and local companies. This should be accompanied by the establishment of a policy foundation for strategic hydrogen workforce development. This will enable the implementation of workforce supply and demand surveys, forecasts, job analysis and projections, and information provision systems before 2041, when the blue hydrogen industry is expected to be activated in earnest.

B- Strengthening international cooperation to acquire hydrogen technology know-how and to jointly build a hydrogen ecosystem

Regarding international hydrogen cooperation, Thailand should prioritize cooperation with countries that are directly connected to the establishment of Thailand's hydrogen ecosystem, such as countries that have introduced clean hydrogen. In particular, international joint research and joint demonstration should be conducted to acquire technological know-how and track records of major countries with advanced water electrolysis technology for green hydrogen production. This will allow Thailand to gain access to the latest technological know-how and track records. Furthermore, it is vital to reinforce collaboration with existing

hydrogen cooperation organizations, such as the Hydrogen Council and the European Clean Hydrogen Alliance. Bilateral cooperation must also be strengthened.

In terms of policy cooperation, it is crucial to prioritize areas such as clean hydrogen certification, rules of origin, carbon storage cooperation, hydrogen price disclosure, and project support. Thailand should play an active role in the development of joint assessment criteria for GHG emissions from hydrogen production to delivery, as well as consultations on rules of origin and tariffs among countries involved in the hydrogen production process. It should also contribute to the formation of an appropriate international price through the publication of international hydrogen prices and actively cooperate in hydrogen projects to ensure that they receive maximum support.

Finally, it is also important for Thai companies to collaborate internationally to jointly build hydrogen ecosystems with foreign companies. In addition to international joint research and demonstration of green hydrogen production technologies as mentioned above, it is also necessary to explore opportunities with relevant countries to utilize offshore marine carbon storage to process the carbon dioxide captured during blue hydrogen production. The Thai government should reinforce the private sector-led cooperation system, such as the Hydrogen Thailand Club, from production to storage, transportation, and utilization of clean hydrogen. This will support overseas outreach for technical cooperation and joint project identification, as well as intergovernmental technical cooperation, such as the ASEAN-Korea Industrial Innovation Organization and the Standardization Research Center.

C- Enhancing financial and tax incentives to foster industries

As we have seen, major countries are pursuing policies to mitigate market uncertainty and risk across the hydrogen industry value chain. These policies include offering grants, loans, and tax incentives to de-risk early-stage projects and encourage private investment. After 2049, when the early stage of hydrogen industrialization is expected to move from technology development to commercialization, we will observe a number of industrial achievements,

including start-ups, early investments, and new product launches. To expand application and commercialization R&D, activate venture capital, create large funds, ease regulations such as simplifying start-up procedures, and create markets, policy support will be required.

To stimulate private investment, increased financial and tax support is needed. The Thai government should establish a stable financing system to support the formation of an early hydrogen market and link it to a hydrogen ecosystem centered on private investment. This could be achieved by utilizing the Climate Response Fund, establishing a hydrogen infrastructure fund, and activating a private hydrogen industry fund. These funds could be used to create an early hydrogen market, build hydrogen production and distribution infrastructure, and support the development of promising hydrogen companies. In terms of tax support, it is recommended that tax incentives be continued for R&D and facility investments to create the supply and demand base of the hydrogen economy. It is also proposed that tax support for R&D and facility investment in core technologies related to hydrogen production, storage, and utilization be expanded, and that tax incentives for hydrogen vehicles be reviewed.

Chapter 6. Concluding Remarks

This strategic document's conclusion encapsulates the essence of our comprehensive and forward-thinking approach towards establishing Thailand as a key player in the global hydrogen economy. The strategy, informed by a deep understanding of global trends and Thailand's unique potential, outlines a well-coordinated action plan spanning four decades. It aims to construct an all-encompassing hydrogen ecosystem that addresses every stage of the hydrogen cycle, from production to utilization.

This strategic document concludes with a summary of our comprehensive and forward-thinking approach to establishing Thailand as a key player in the global hydrogen economy. The strategy, which is based on a deep understanding of both global trends and Thailand's unique potential, outlines a well-coordinated action plan spanning four decades. The plan's objective is to construct an all-encompassing hydrogen ecosystem that addresses every stage of the hydrogen cycle, from production to utilization.

In Chapters 2 and 3, we have set forth the compelling case for a shift towards a hydrogen-based economy and provided a comprehensive review of national policies and the current status of hydrogen technologies within Thailand. This background provides a solid foundation for the strategic direction outlined in Chapter 4, which illustrates our actionable roadmap aimed at achieving Thailand's ambitious net-zero targets.

Chapter 5 provides a comprehensive examination of the tactical initiatives across key hydrogen sectors, including production, storage, transportation, and utilization. Each of these sectors has been analyzed to identify opportunities for growth and innovation, ensuring that our approach is both technologically sound and economically viable.

This strategy anticipates the challenges of transitioning to a cleaner energy paradigm and seeks to leverage Thailand's inherent strengths in research and development, fostering collaboration among government, industry, academia, and communities. The strategy is designed to foster a symbiotic relationship between multi-technological advancements and

stakeholder engagement, ultimately creating a robust and adaptable hydrogen ecosystem that can withstand future challenges and opportunities.

By promoting the use of clean hydrogen, Thailand is well-positioned to significantly reduce its greenhouse gas emissions, in line with global climate change mitigation goals. This unified approach will undoubtedly contribute to a more sustainable and resilient economy, positioning Thailand for a greener and more prosperous future. Furthermore, it will serve as a model for other nations, reinforcing the role that hydrogen can play in the global quest for a sustainable and net-zero carbon society. This strategy reaffirms our resolve to make Thailand a global leader in hydrogen innovation and demonstrates the transformative power of clean energy.

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Appendix 1. Survey Design & Analyses

1. Background of the Survey

This study conducted an expert survey to identify and diagnose the current status of local technology levels for the development of Thailand's national hydrogen strategy. The scope of hydrogen production technologies was limited to steam methane reforming (SMR) and water electrolysis. The survey targeted 56 project managers who have experience in promoting hydrogen-related R&D projects at TRRR-PMU over the past 10 years from 2012 to 2023. The questionnaire was composed of items that can evaluate experts' perceptions of technologies for hydrogen production by reviewing various theoretical discussions on technology level evaluation, and reflected various methods such as technology level and technology valuation.

There are a variety of ways to assess skill level and valuation.

① Technological Importance

Technical significance refers to the impact and importance of a given technology to the relevant industry sector or to the national industry as a whole. The evaluation methodology is based on scoring the importance of the technology's scope of application and position in the industry. Thailand's technological importance is evaluated by prioritizing the importance based on expert qualitative assessment.

② Technological Level Assessment

A method of assessing the evolutionary stage and maturity of a technology. The maturity level of the technology is evaluated by categorizing it from stage 1 to stage 9. Experts in the field of hydrogen technology in Thailand are evaluated as ambassadors, and the evaluation scores are averaged or standardized to evaluate the level of technology.

③ Investment Cost-Based Assessment

It evaluates the value based on the cost of technology development. It is a method to evaluate the technology development environment related to hydrogen technology in Thailand by comparing the amount of infrastructure investment with the amount of existing research and development expenditure.

④ Industrial Value-Based Assessment

It is a method to evaluate the impact and value of hydrogen technology development on the industry, taking into account the expected market size in Thailand, competitiveness within the industry, and the potential for supply chain integration.

⑤ Expected Revenue-Based Assessment

A method for assessing the expected future revenues from hydrogen technology, including an assessment of the expected timing of market demand penetration. Based on expert qualitative assessment, it evaluates the possibility of securing a price advantage and considers the possibility of securing a revenue model based on commercialization.

⑥ Paper-Based Maturity Assessment

Academic research on hydrogen technology in Thailand is evaluated in terms of number of publications, citations, and academic impact.

⑦ Patent-Based Maturity Assessment

The number, scope, and citations of hydrogen-related patents in Thailand are reported to assess the maturity and innovation of the technology by aggregating the number, scope, and citations of patents.

⑧ Legal/Regulatory-Based Assessment

Evaluate the value and sustainability of hydrogen technology within the legal and institutional environment in Thailand, including the level of regulation, intellectual property protection, government policies and regulatory environment.

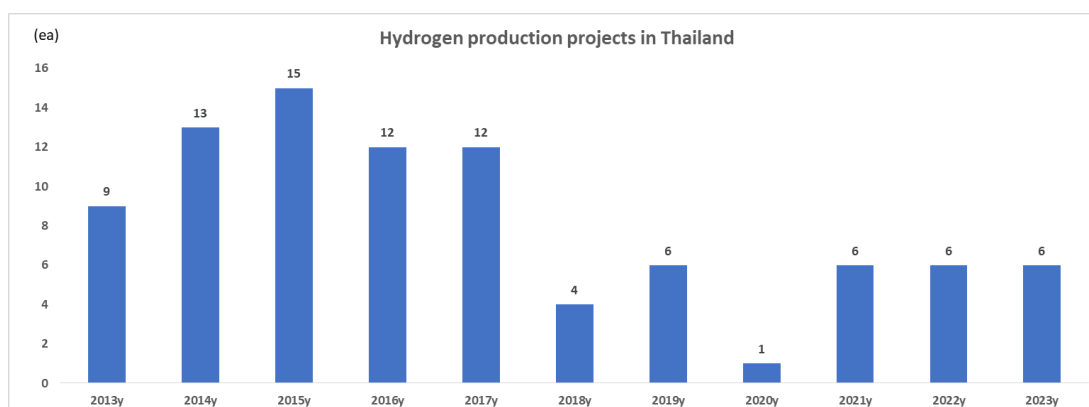
[Application of Theoretical Concepts]

Methodology	Application	Survey question
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		number (Appendix.2)
① Technological Importance	Perception of Power Generation Resource	A3
② Technological Level Assessment	Technology Maturity(TRL)	A1
	Technological Level and Gap	
③ Investment Cost-Based Assessment ④ Industrial Value-Based Assessment ⑤ Expected Revenue-Based Assessment ⑥ Paper-Based Maturity Assessment ⑦ Patent-Based Maturity Assessment ⑧ Legal/Regulatory-Based Assessment	R&D resource level (R&D Fund, R&D facilities and infrastructure, R&D Human Resource, Industry, Academia, Research, R&D Institutes, Enterprise, University, Research Institution	A2
	Acceptance of hydrogen production technology	A6
⑧ Legal/Regulatory-Based Assessment	Target Year of technology demonstration	B1
	Region for technology Demonstration	B2

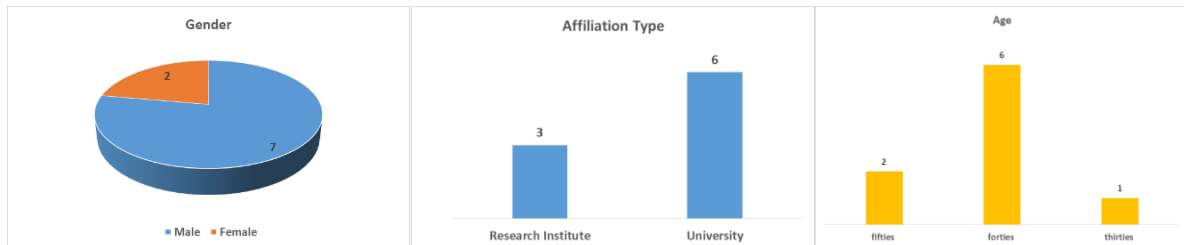
2. Subject and Duration of the survey

The survey was conducted among 37 managers of 90 R&D projects funded by the Ministry of Higher Education, Science, Research and Innovation over the past 10 years, from 2012 to 2023. The survey was conducted from March 4 to 29, 2024.



3. Survey Results

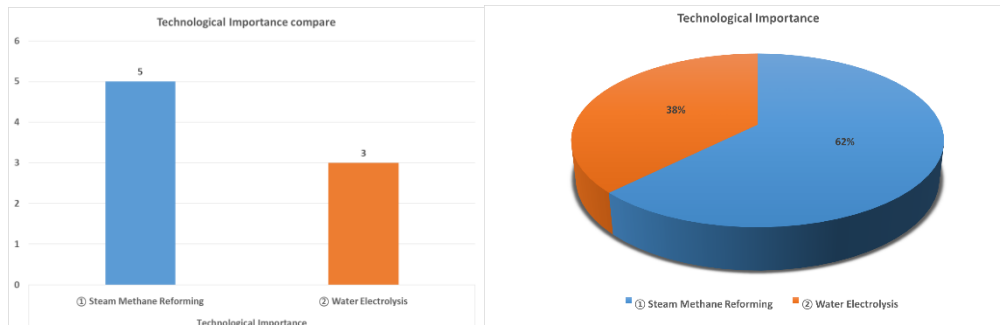
We received responses from 9 project managers out of 37 R&D project managers. The gender of the respondents is split between 7 men and 2 women, with 6 from universities and 3 from research institutes. The age range of the respondents is split between 2 in their 30s, 6 in their 40s, and 1 in their 50s.



4. Analysis Results

(1) Assessment on relative technical importance

First, of the two hydrogen production technologies, SMR and water electrolysis, more experts said it was important for Thailand to utilize SMR technology than water electrolysis.



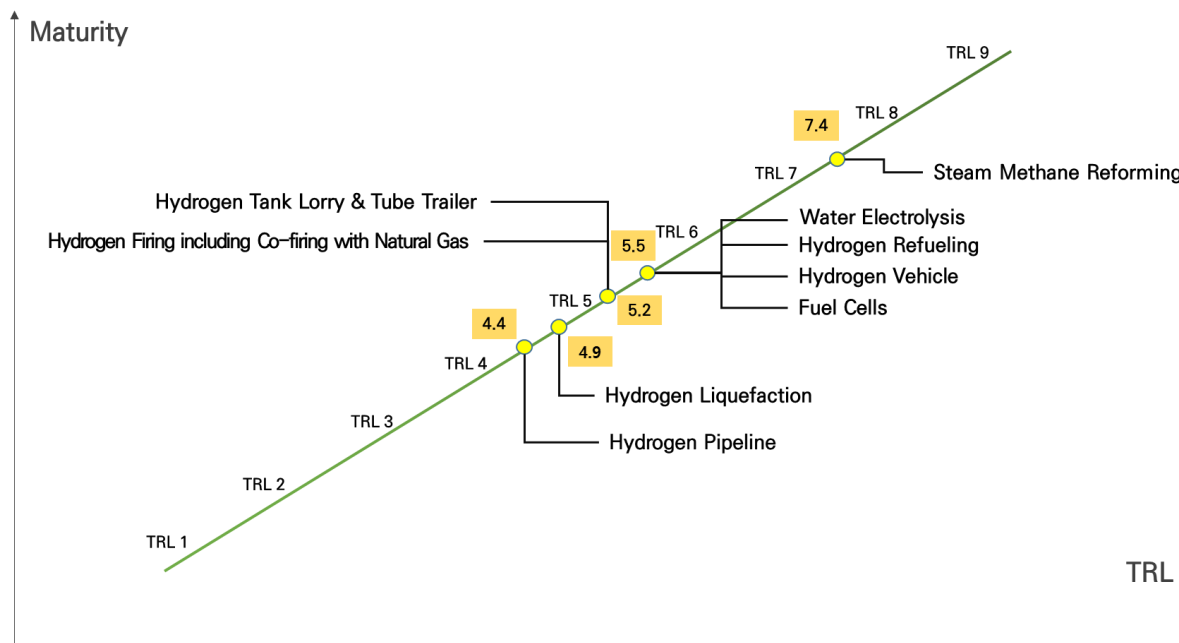
Note: Only 8 out of 9 total respondents completed this survey.

(2) Assessment on technical maturity

In terms of technology maturity for hydrogen-related technologies, SMR technology is the most mature technology in Thailand, with an average TRL of 7.4. Water electrolysis, hydrogen refueling, hydrogen vehicles, and fuel cell technologies are the second most mature technologies in Thailand after SMR, with a TRL of 5.5. The least mature technology is hydrogen

pipeline, which is rated at TRL 4.4.

Technology Maturity in Thailand

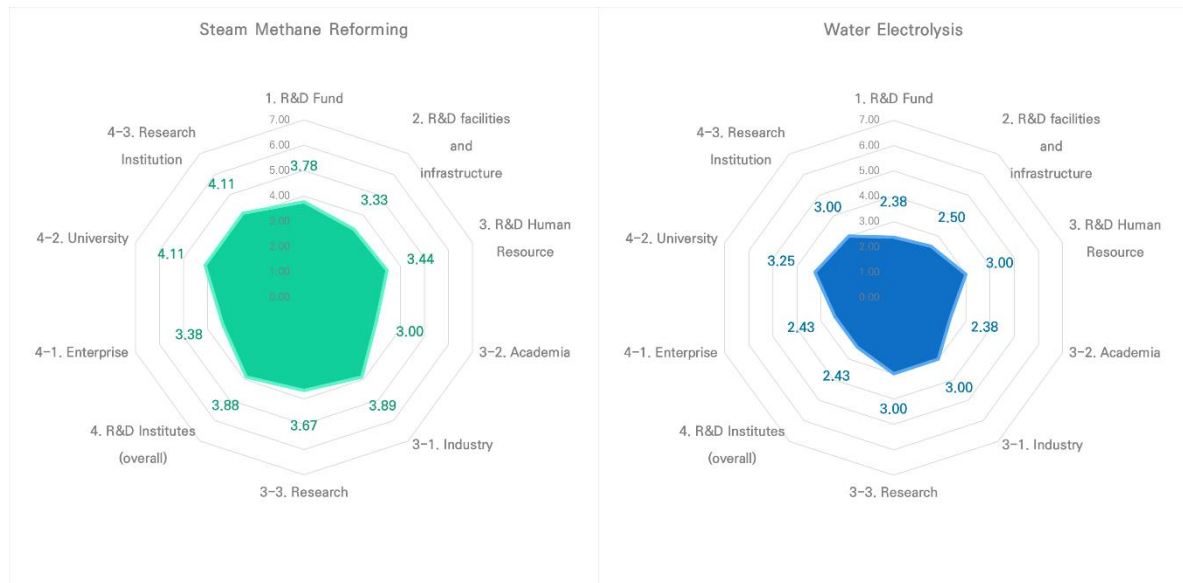


According to Thai experts, the best technology for SMR is the United States, and the technology level of Thailand compared to the United States is 58% and the technology gap is 5.5 years, while the best technology for Water Electrolysis is Germany and Japan. Compared to Germany, Thailand's technology level is 38% and the technology gap is 5.6 years. Compared to Japan, Thailand's technology level is 42%, but the technology gap is larger at 7.3 years.

SMR			Water Electrolysis		
Country with the Highest Technology Level	Thailand Technology level	Technology Gap in Years	Country with the Highest Technology Level	Thailand Technology level	Technology Gap in Years
USA	58	5.5 years	Germany	38	5.6 years
			Japan	42	7.3 years

When comparing the R&D resource competitiveness of SMR and water electrolysis in Thailand, SMR is rated as having abundant R&D resources in all sectors. However, SMR

technology was also found to have insufficient R&D resources on average, except for universities and research centers.

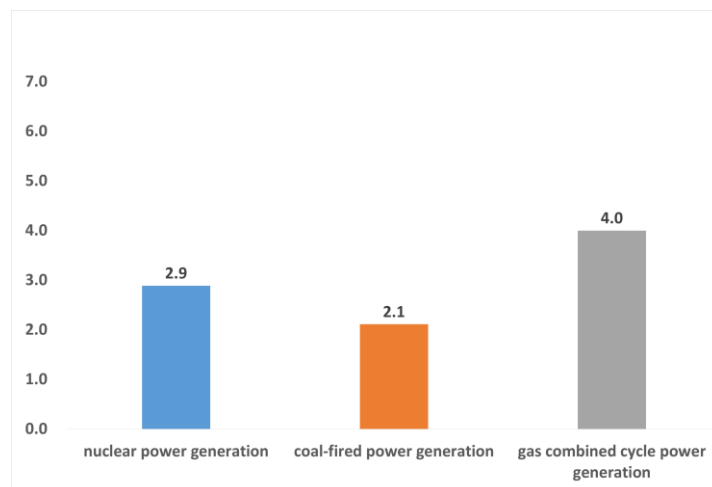


The following is a comparison of the R&D status and prospects of SMR and water electrolysis among hydrogen generation technologies. SMR is more advanced than water electrolysis in terms of scientific and technological capabilities, as evidenced by the number of papers and patents. A higher percentage of respondents indicated that water electrolysis technology is the technology that needs to be transferred and introduced from leading countries, and there is also greater interest among companies and general citizens in water electrolysis technology.

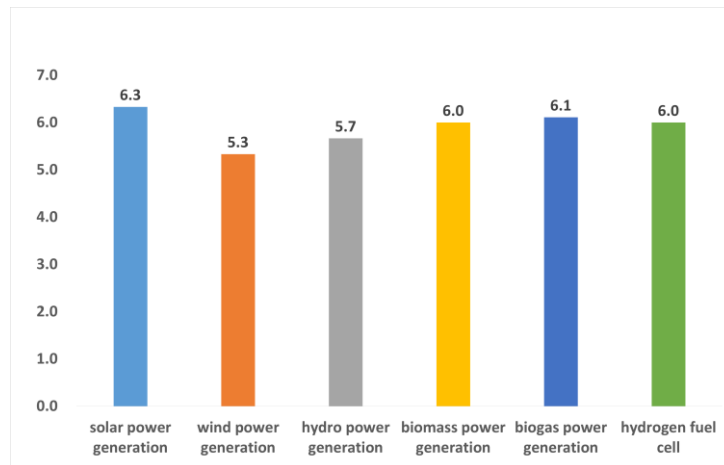
SMR was perceived as the technology with the greatest potential for adoption from a legal, institutional, and industrial perspective. SMR also demonstrated a clear advantage in terms of industrial comparative advantage. In contrast, water electrolysis was identified as the technology with the highest ease of installation and profit potential in the market.



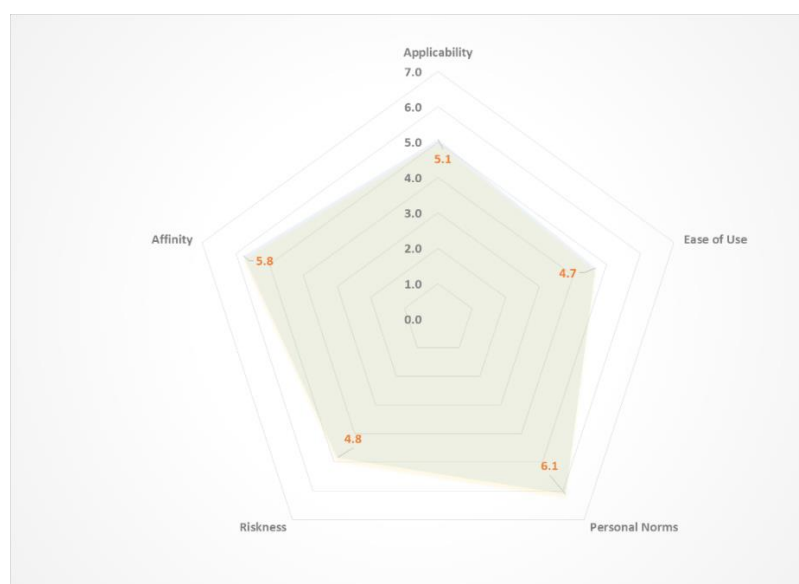
Respondents were most likely to favor gas combined cycle generation as a baseload power source, while coal-fired generation was the least favored.



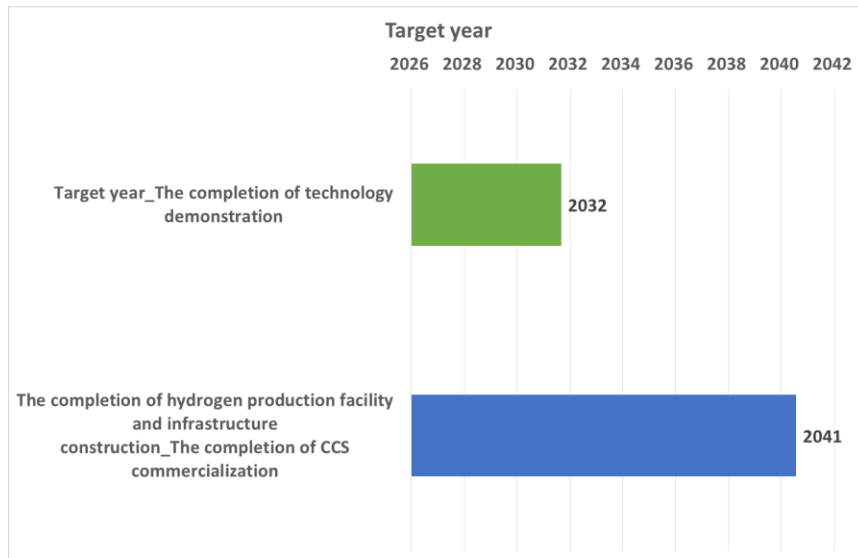
Among renewable energy sources, solar power is the most preferred source of electricity generation, followed by biopower. Wind power was the least preferred source of energy.



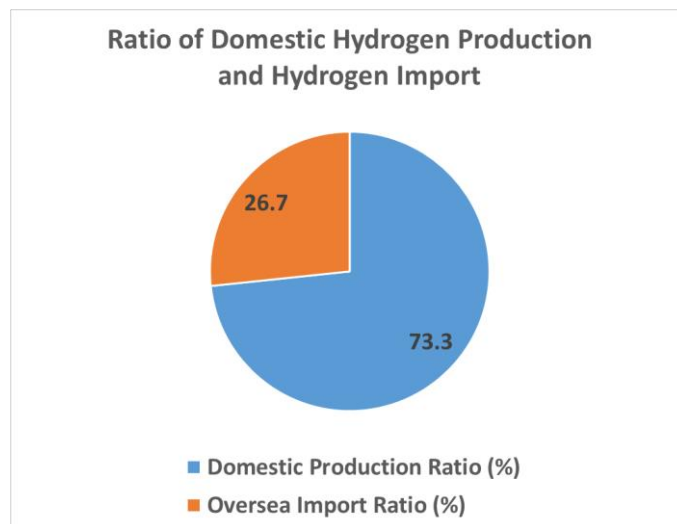
When asked about the technical acceptability of hydrogen technology, respondents were generally positive with an average score of 5.1 for the technical acceptability of hydrogen production technology (national and regional development). When asked about the difficulty of installing and expanding hydrogen production facilities, respondents answered moderately with an average score of 4.7. Regarding the perceived value of the government's plans to promote hydrogen technology, the average score was 6.1, and the average score for perceived risks was 4.8. On average, the respondents had a positive view of hydrogen technology adoption with an average score of 5.8.



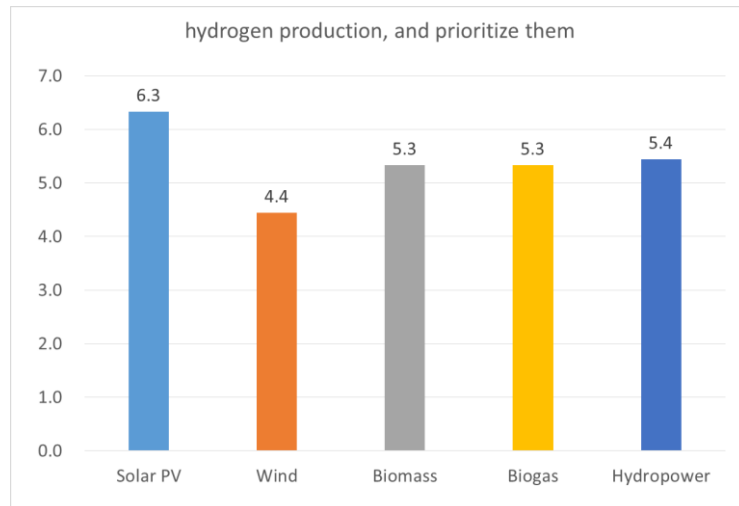
The target date for completing the technology demonstration of SMR technology to achieve carbon neutrality was 2032, and the target date for commercialization of hydrogen production facilities and CCS facilities was 2041.



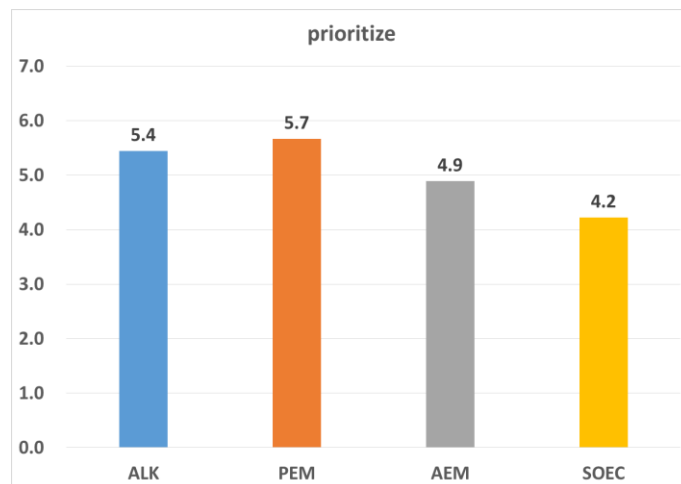
When it comes to the appropriate proportion of domestic production and foreign imports to achieve carbon neutrality, domestic production was the most popular choice at 73.3%.



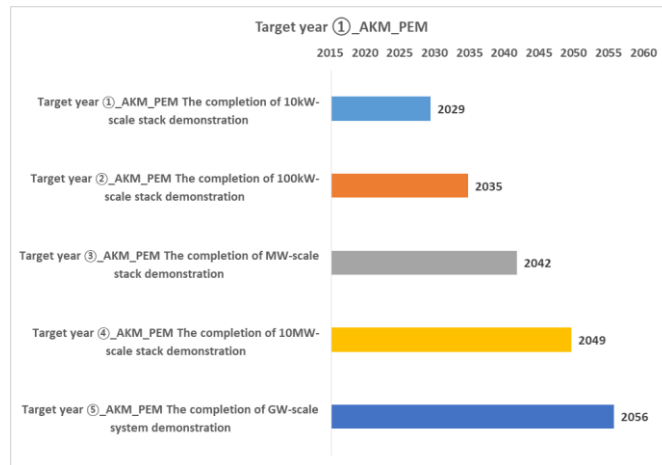
When asked about the suitability of energy sources for hydrogen production technologies, solar power was the most popular choice with an average score of 6.3, followed by hydropower with an average score of 5.4.



In terms of preference for hydrogen production technology, PEM technology is the most preferred, followed by ALK water electrolysis technology.



Regarding the target date for the introduction of demonstration facilities for hydrogen production technologies, AKM and PEM technology sectors responded that the average target date for demonstration of 10KW facilities is 2029, 100KW is 2035, MW-scale equipment is 2042, 10MW is 2049, and GW-scale equipment is 2056.



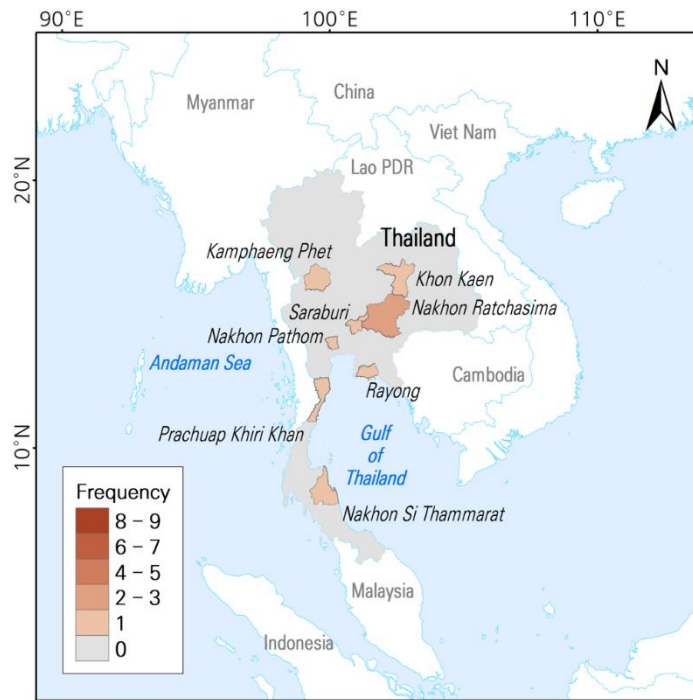
On average, the AEM and SOEC technology sectors responded that the demonstration target for 10KW equipment is 2032, 100KW is 2037, MW equipment is 2043, 10MW equipment is 2050, and GW equipment is 2057.



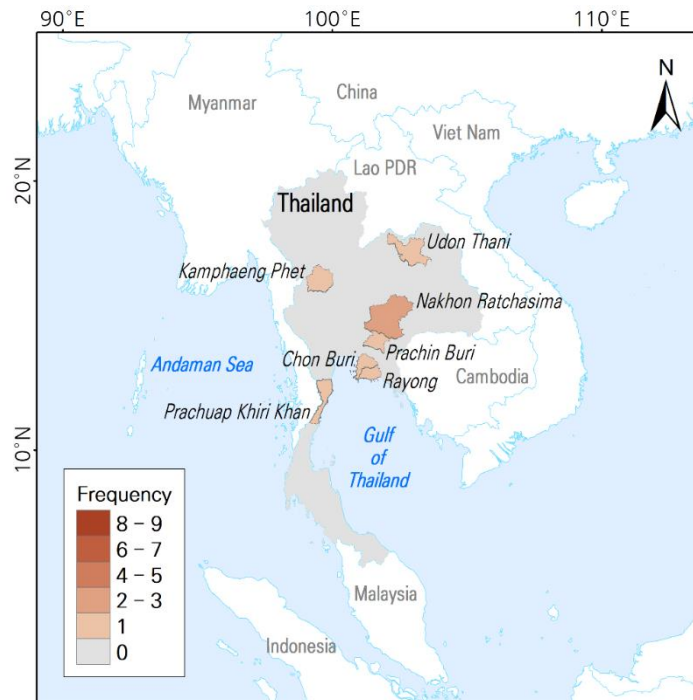
(2) Preferred Region for Technological application

Question	Result
<p>B-1. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from solar PV</p>	<p>The map displays the preferred regions for demonstrating water electrolysis technology. The regions are color-coded according to a frequency scale: 8-9 (darkest brown), 6-7 (dark brown), 4-5 (medium brown), 2-3 (light brown), 1 (tan), and 0 (grey). The highest frequency regions (8-9) are located in the northern part of Thailand, specifically in Chiang Rai and Kamphaeng Phet. Other regions with frequencies of 4-5 and 6-7 are located in the southern part of Thailand, including Prachuap Khiri Khan and Rayong. The map also shows neighboring countries and bodies of water like the Andaman Sea and Gulf of Thailand.</p>
<p>B-2. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from solar PV</p>	<p>The map displays the preferred regions for producing hydrogen with water electrolysis technology. The regions are color-coded according to a frequency scale: 8-9 (darkest brown), 6-7 (dark brown), 4-5 (medium brown), 2-3 (light brown), 1 (tan), and 0 (grey). The highest frequency regions (8-9) are located in the eastern part of Thailand, specifically in Chon Buri, Chanthaburi, and Rayong. The map also shows neighboring countries and bodies of water like the Andaman Sea and Gulf of Thailand.</p>

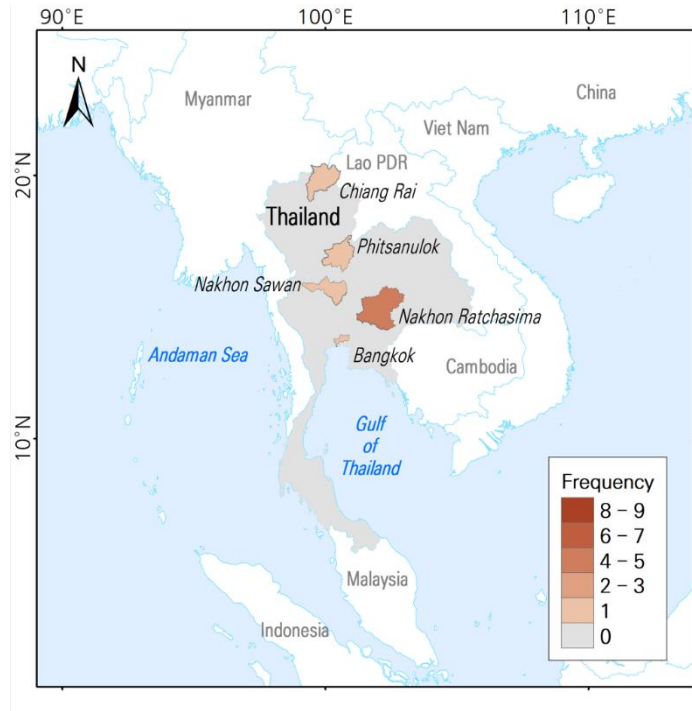
B-3. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from wind power



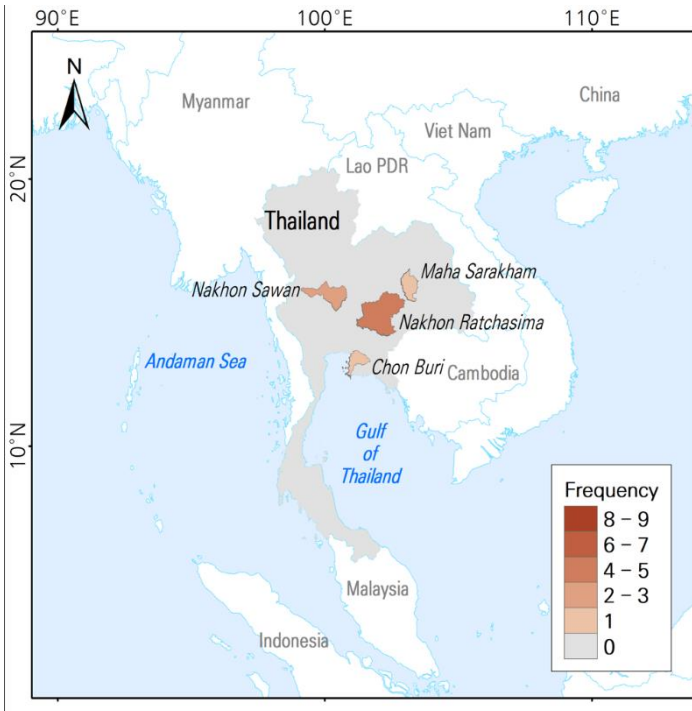
B-1. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from wind power



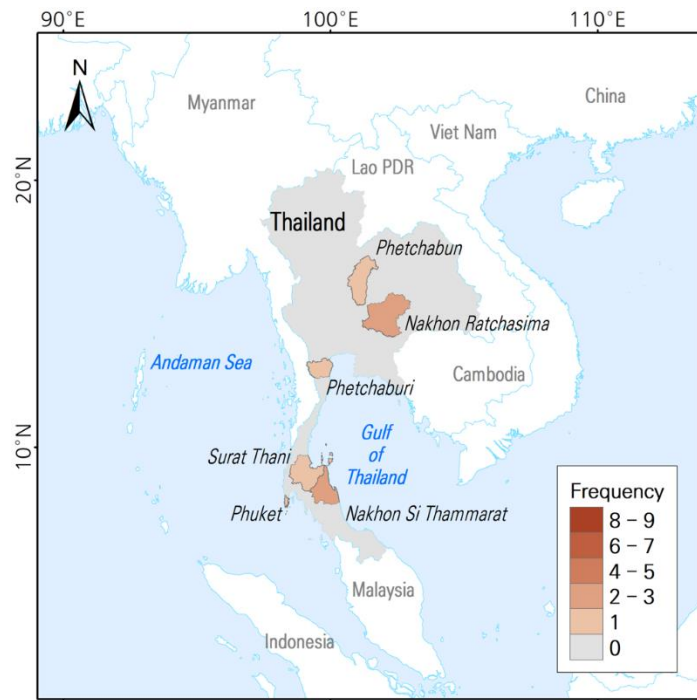
C5-1. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from biomass



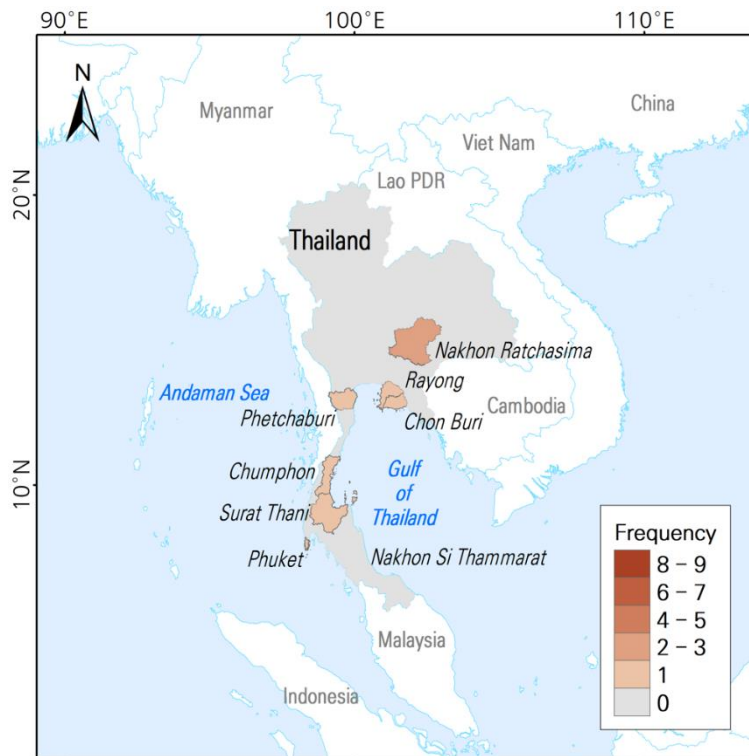
C5-2. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from biomass



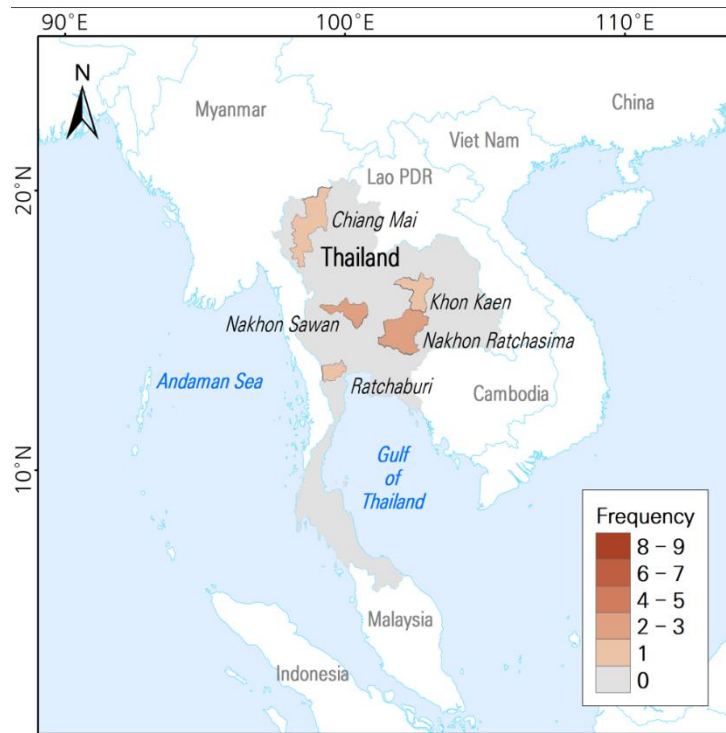
C5-3. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from biogas



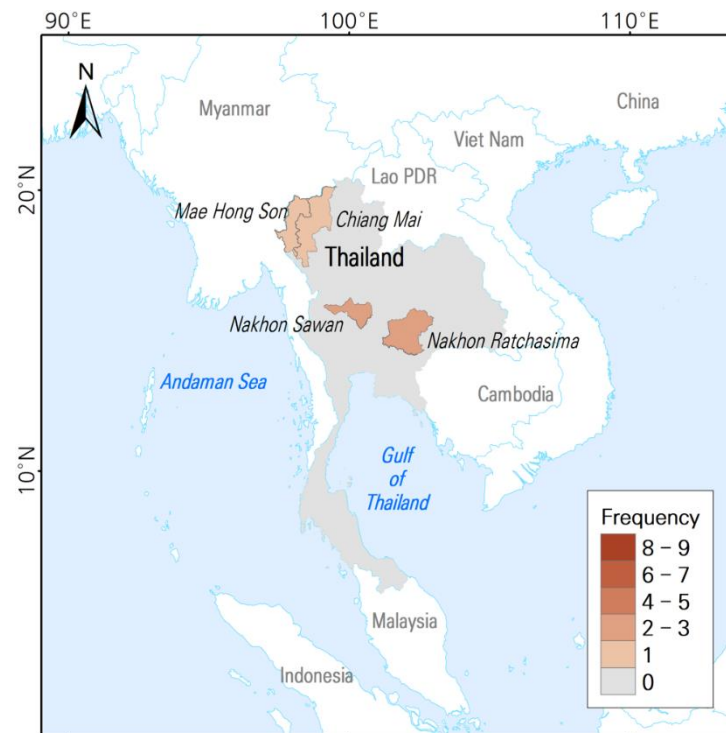
C5-4. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from biogas



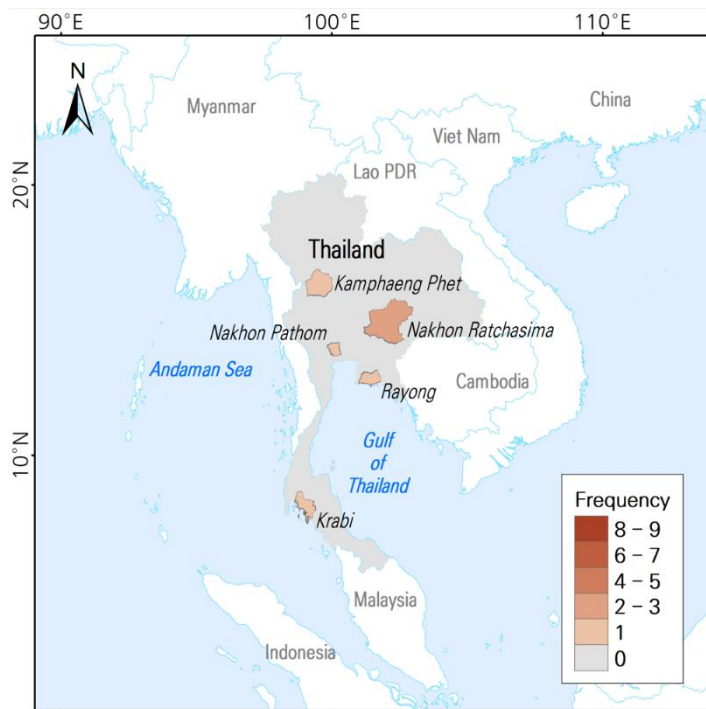
C5-5. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from hydropower



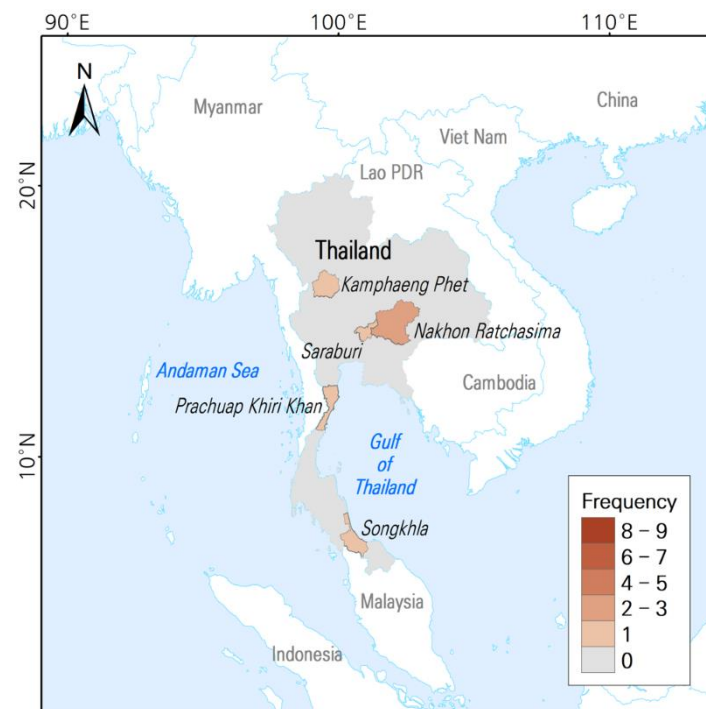
C5-6. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from hydropower



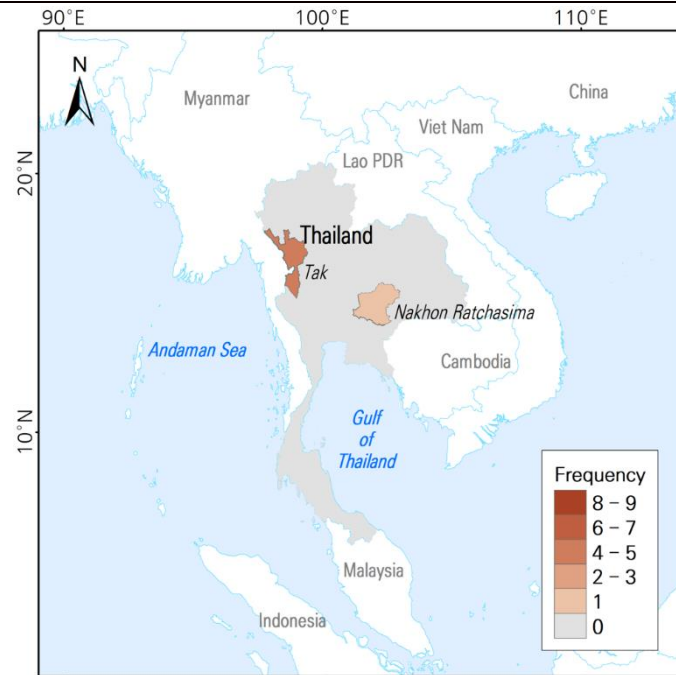
C5-7. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from biogas



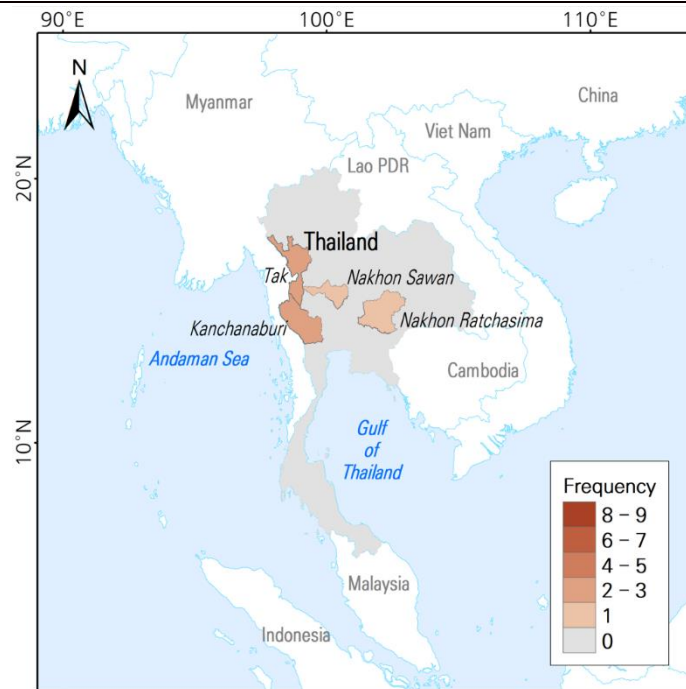
C5-8. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from biogas



C5-9. Preferred Region for demonstrating water electrolysis technology utilizing electricity generated from hydropower



C5-10. Preferred Region for producing hydrogen with water electrolysis technology utilizing electricity generated from hydropower



Appendix 2. Survey Questionnaire

According to Section 15 of the Statistics Act, B.E. 2007, information pertaining to individuals' privacy in this survey is strictly protected.

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Survey for Establishing National Hydrogen Strategy of Thailand

We wish you and your organization continued success and prosperity.

We are the research team of National Institute of Green Technology in Korea for designing the national hydrogen strategy of Thailand. We are supporting the Office of National Higher Education Science Research and Innovation Policy Council (NXPO) in Thailand to establish their national hydrogen strategy through Technical Assistance (TA) program of UN Climate Technology Centre & Network (CTCN).

- ◆ National Institute of Green Technology is the affiliated institute of the Ministry of Science & ICT established to lead the expansion of green technology achievement in Korea by creating global cooperation network and plan and support comprehensive policy enhancing the competitiveness of green technology by jointly cooperating with global outstanding green technology research institute.

This survey aims to understand the basic status of hydrogen production in Thailand including technology development level and R&D capacity, and establish national hydrogen strategy considering the opinions of local experts. It is being proceeded targeting project managers who managed hydrogen R&D projects in Thailand from 2012 to 2023.

The responds for this survey will be utilized only for research purpose, and all the personal information and the information related to your affiliation will be confidential under any circumstances based on <The Statistics Act, B.E. 2007, Section 15>.

We would highly appreciate it if you could support us from your busy schedule to establish the national hydrogen strategy of Thailand.

March, 2024

Implementer	National Institute of Green Technology (Rep. of Korea)	National Designated Entity	The Office of Higher Education Science Research and Innovation Policy Council (Thailand)
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[Personal Information]

Basic Information	Name		Affiliation	Type	① Firm, ② University, ③ Research Institute, ④ Government
	Sex	① Male, ② Female, ③ Others		Name	
	Age			Department	
	Major			Position	
	E-mail		Contact	Tel.	
				Mobile	

The Outline of Hydrogen Production Technology

Hydrogen production technologies are widely classified into four categories, including thermochemical, electrochemical, biological, and photoelectrochemical approach. According to the research of NIGT, steam methane reforming(SMR, thermochemical approach) and water electrolysis(electrochemical approach) are the major technologies which are globally emerging or commercialized.

SMR is the technology which turns methane(CH_4) into hydrogen(H_2) and carbon oxide(CO) by reacting with steam($\text{H}_2\text{O}(\text{g})$). This technology mainly utilizes natural gas as a fuel and feedstock to produce hydrogen(biogas also can be applied as feedstock). Combining SMR and Carbon Capture, Utilization, and Storage(CCUS) technology, the amount of carbon emission from SMR procedure can be reduced. The hydrogen produced by the aforementioned procedure is called “blue hydrogen”.

Water electrolysis is the technology which produces hydrogen(H_2) and oxygen(O_2) by decomposing water(H_2O). For hydrogen production, it uses electricity as a fuel and water as a feedstock. In this sense, for producing green hydrogen which does not emits greenhouse gas, it is mainly considered to utilize the electricity from renewable energy resources.

Technology	Fuel	Feedstock
Steam Methane Reforming	Natural Gas	Natural Gas Biogas
Water Electrolysis	Solar Wind Biomass Biogas Hydropower	Water

The questions below are about the aforementioned technologies, SMR and water electrolysis.

Part A. Hydrogen-related Technology (General)

No	Survey Question																																																																																																				
A1-1	<p>(Technological Importance) From the perspective of expert, please specify the technology highly prioritized to develop in Thailand.</p> <p>① Steam Methane Reforming ② Water Electrolysis</p>																																																																																																				
A1-2	<p>(Technology Maturity) From the perspective of expert, please assess the Technology Readiness Level (TRL) of following core technologies for developing hydrogen economy</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #d3d3d3;"> <th style="width: 20%;">Technology</th> <th colspan="9">TRL</th> </tr> </thead> <tbody> <tr> <td>Steam Methane Reforming</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Water Electrolysis</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Refueling</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Liquefaction</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Pipeline</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Tank Lorry & Tube Trailer</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Vehicle</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Fuel Cells</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> <tr> <td>Hydrogen Firing including Co-firing with Natural Gas</td> <td>①TRL1</td><td>②TRL2</td><td>③TRL3</td><td>④TRL4</td><td>⑤TRL5</td><td>⑥TRL6</td><td>⑦TRL7</td><td>⑧TRL8</td><td>⑨TRL9</td> </tr> </tbody> </table> <p><The Concept of TRL></p> <p>TRL 1: Basic principles observed</p> <p>TRL 2: Technology concept formulated</p> <p>TRL 3: Experimental proof of concept</p> <p>TRL 4: technology validated in lab</p> <p>TRL 5: Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)</p> <p>TRL 6: Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)</p> <p>TRL 7: System prototype demonstration in operational environment</p> <p>TRL 8: System complete and qualified</p> <p>TRL 9: Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)</p> <p>* Source: European Commission Decision C(2014)4995 of 22 July 2014</p>	Technology	TRL									Steam Methane Reforming	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Water Electrolysis	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Refueling	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Liquefaction	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Pipeline	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Tank Lorry & Tube Trailer	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Vehicle	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Fuel Cells	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9	Hydrogen Firing including Co-firing with Natural Gas	①TRL1	②TRL2	③TRL3	④TRL4	⑤TRL5	⑥TRL6	⑦TRL7	⑧TRL8	⑨TRL9
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A1-3	(Technological Level and Gap) From the perspective of expert, please specify the technologically leading country for each hydrogen production technology, and estimate the level of each technology in Thailand and the technological gap between Thailand and the leading country.							
	Technology	Technologically Leading Country	The Comparative Technological Level of Thailand	The Relative Technological Gap Period in Thailand				
	Steam Methane Reforming		%	years				
	Water Electrolysis		%	years				
* Assess the technological level of Thailand in terms of percentage(%) assuming the technological level of leading country is 100%								
A2-1	(R&D Resource) From the perspective of expert, please assess the R&D resource level of Thailand for steam methane reforming technology							
	Steam Methane Reforming	<- Negative(Weak) - Average – Positive(Strong) ->						
		Highly insufficient	insufficient	Slightly insufficient	Average	Slightly enough	enough	Highly enough
	1. R&D Fund	①	②	③	④	⑤	⑥	⑦
	2. R&D facilities and infrastructure	①	②	③	④	⑤	⑥	⑦
	3. R&D Human Resource (overall)	①	②	③	④	⑤	⑥	⑦
	3-1. Industry	①	②	③	④	⑤	⑥	⑦
	3-2. Academia	①	②	③	④	⑤	⑥	⑦
	3-3. Research	①	②	③	④	⑤	⑥	⑦
	4. R&D Institutes (overall)	①	②	③	④	⑤	⑥	⑦
	4-1. Enterprise	①	②	③	④	⑤	⑥	⑦
	4-2. University	①	②	③	④	⑤	⑥	⑦
4-3. Research Institution	①	②	③	④	⑤	⑥	⑦	

Water Electrolysis	<- Negative(Weak) - Average – Positive(Strong) ->						
	Highly insufficient	insufficient	Slightly insufficient	Average	Slightly enough	enough	Highly enough
1. R&D Fund	①	②	③	④	⑤	⑥	⑦
2. R&D facilities & infrastructure	①	②	③	④	⑤	⑥	⑦
3. R&D Human Resource (overall)	①	②	③	④	⑤	⑥	⑦
3-1. Industry	①	②	③	④	⑤	⑥	⑦
3-2. Academia	①	②	③	④	⑤	⑥	⑦
3-3. Research	①	②	③	④	⑤	⑥	⑦
4. R&D Institutes (overall)	①	②	③	④	⑤	⑥	⑦
4-1. Enterprise	①	②	③	④	⑤	⑥	⑦
4-2. University	①	②	③	④	⑤	⑥	⑦
4-3. Research Institution	①	②	③	④	⑤	⑥	⑦

A2-2

(The status and prospects of R&D) Please respond the following questions by comparing two technology from the perspective of Thailand			
Standard	Question	Response (Choose one)	
		Steam Methane Reforming	Water Electrolysis
Academic Research	Which technology is more actively investigated in academic perspective?	①	②
Patent Development	Which technology has more cases of relevant patent application and registration?	①	②
Necessity of Technology Adoption	Which technology needs active technology transfer and adoption from leading countries?	①	②
Interest of Enterprise	Which technology has more interests from enterprises?	①	②
Interest of Citizen	Which technology has more interests from citizen?	②	②
Legal & Institutional Ease of Use	Which technology is relatively easy to apply due to well-organized legal and systematical infrastructure?	②	②
Applicability in Industry	Which technology has higher potential to be applied in industry sector?	①	②
Industrial Competitiveness	Which technology has a higher competitiveness of relevant industry?	②	②
Growth Potential of Technology	Which technology is expected to grow faster?	①	②
Market Expansion Potential	Which technology has higher potential for market expansion?	①	②
Cost Competitiveness of Instrument	Which technology can install relevant facilities with lower cost?	①	②
Profitability	Which technology can make a profit relatively easily?	①	②

A3

(Perception of Power Generation Resource) Please specify your preference on national energy resource from the perspective of Thailand.

A4

Preference on Power Resource for Base Load (*Power resource for 24-hour electricity supply)	Negative <----- Average -----> Positive						
I prefer nuclear power generation.	①	②	③	④	⑤	⑥	⑦
I prefer coal-fired power generation.	①	②	③	④	⑤	⑥	⑦
I prefer gas combined cycle power generation (LPG, LNG).	①	②	③	④	⑤	⑥	⑦
Preference on Alternative Power Resource for fossil fuel power generation	Negative <----- Average -----> Positive						
I prefer solar power generation	①	②	③	④	⑤	⑥	⑦
I prefer wind power generation	①	②	③	④	⑤	⑥	⑦
I prefer hydro power generation	①	②	③	④	⑤	⑥	⑦
I prefer biomass power generation	①	②	③	④	⑤	⑥	⑦
I prefer biogas power generation.	①	②	③	④	⑤	⑥	⑦
I prefer power generation based on hydrogen fuel cell.	①	②	③	④	⑤	⑥	⑦

(Acceptability of hydrogen production technology) Please respond the following questions about acceptability of hydrogen production technology.

Indicator		Negative <----- Average -----> Positive						
Applicability	The expansion of hydrogen production technology can support the stable supply of electricity and heat in a national perspective.	①	②	③	④	⑤	⑥	⑦
	The expansion of hydrogen production technology can support the development of local community.	①	②	③	④	⑤	⑥	⑦
	The expansion of hydrogen production technology can offer me economic benefit.	①	②	③	④	⑤	⑥	⑦
Ease of Use	It is hard for government to expand the hydrogen production technology compared with other energy resource (nuclear power generation, coal-fired power generation).	①	②	③	④	⑤	⑥	⑦
Personal Norms	I have a positive outlook on the national plan for expanding the supply of hydrogen production technology.	①	②	③	④	⑤	⑥	⑦
	I think it is important and valuable to invest on green hydrogen development for future industry.	①	②	③	④	⑤	⑥	⑦
	I think that the expansion of green hydrogen production facilities is socially and environmentally valuable.	①	②	③	④	⑤	⑥	⑦
Riskiness	I think that the expansion of green hydrogen production facilities inflicts a significant harm on the natural environment.	①	②	③	④	⑤	⑥	⑦
	I think that green hydrogen production facilities pose a threat to me and my family.	①	②	③	④	⑤	⑥	⑦
Affinity	I think it is good to expand green hydrogen production for climate change response and greenhouse gas reduction.	①	②	③	④	⑤	⑥	⑦
	I have a positive outlook on the government policy direction which installs or expands green hydrogen production facilities.	①	②	③	④	⑤	⑥	⑦

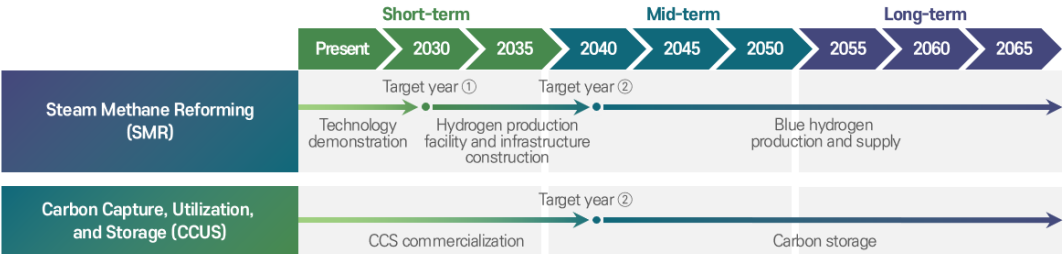
A5

(Ratio of Domestic Hydrogen Production and Hydrogen Import) Some countries have a national plan to import blue or green hydrogen to meet their demand for hydrogen. Considering Thailand's environmental conditions, resources, technological capabilities, and the target year for achieving carbon neutrality (2065), please respond the most appropriate ratio between domestic hydrogen production and overseas import.

A6

Number	Domestic Production Ratio (%)	Overseas Import Ratio (%)
①	100	0
②	90	10
③	80	20
④	70	30
⑤	60	40
⑥	50	50
⑦	40	60
⑧	30	70
⑨	20	80
⑩	10	90
⑪	0	100

Part B. Steam Methane Reforming

No	Survey Question
B1	<p>(Target Year) The following flowchart is the expected timeline of SMR and CCUS technology development designed by NIGT. Please specify the target year of</p>  <p>The flowchart shows a timeline from Present to 2065, divided into Short-term (Present to 2035), Mid-term (2040 to 2055), and Long-term (2060 to 2065). For Steam Methane Reforming (SMR), Target year ① is marked at 2030 (Technology demonstration) and Target year ② is marked at 2040 (Hydrogen production facility and infrastructure construction). For Carbon Capture, Utilization, and Storage (CCUS), Target year ② is marked at 2040 (CCS commercialization). The SMR process includes Technology demonstration (Present-2030), Hydrogen production facility and infrastructure construction (2035-2040), and Blue hydrogen production and supply (2045-2065). The CCUS process includes CCS commercialization (Present-2040) and Carbon storage (2045-2065).</p> <p>Thailand for acquiring steam methane reforming technology to achieve carbon neutrality in 2050 and Net-zero target in 2065.</p> <p>(Target year ①) The completion of technology demonstration</p> <p>① 2025 ② 2030 ③ 2035 ④ 2040 ⑤ 2045 ⑥ 2050 ⑦ 2055 ⑧ 2060 ⑨ 2065</p> <p>(Target year ②) The completion of hydrogen production facility and infrastructure construction / The completion of CCS commercialization</p> <p>① 2025 ② 2030 ③ 2035 ④ 2040 ⑤ 2045 ⑥ 2050 ⑦ 2055 ⑧ 2060 ⑨ 2065</p>

The following table describes 77 provinces of Thailand.



B2

* Source: <https://ontheworldmap.com/thailand/thailand-provinces-map.html> (Accessed 07.03.24)

No	Province	No	Province	No	Province
1	Bangkok	27	Nakhon Pathom	53	Rayong
2	Amnat Charoen	28	Nakhon Phanom	54	Roi Et
3	Ang Thong	29	Nakhon Ratchasima	55	Sa Kaeo(Sa Kaew)
4	Bueng Kan	30	Nakhon Sawan	56	Sakon Nakhon
5	Buriram	31	Nakhon Si Thammarat	57	Samut Prakan
6	Chachoengsao	32	Nan	58	Samut Sakhon
7	Chainat	33	Narathiwat	59	Samut Songkhram
8	Chaiyaphum	34	Nong Bua Lamphu	60	Saraburi
9	Chanthaburi	35	Nong Khai	61	Satun
10	Chiang Mai	36	Nonthaburi	62	Singburi
11	Chiang Rai	37	Pathum Thani	63	Sisaket
12	Chonburi	38	Pattani	64	Songkhla
13	Chumphon	39	Phang Nga	65	Sukhothai
14	Kalasin	40	Phatthalung	66	Suphanburi
15	Kamphaeng Phet	41	Phayao	67	Surat Thani
16	Kanchanaburi	42	Phetchabun	68	Surin
17	Khon Kaen	43	Phetchaburi	69	Tak
18	Krabi	44	Phichit	70	Trang
19	Lampang	45	Phitsanulok	71	Trat
20	Lamphun	46	Phra Nakhon Si Ayutthaya (Ayutthaya)	72	Ubon Ratchathani
21	Loei	47	Phrae	73	Udon Thani
22	Lopburi	48	Phuket	74	Uthaithani
23	Mae Hong Son	49	Prachin Buri	75	Uttaradit
24	Maha Sarakham	50	Prachuap Khiri Khan	76	Yala
25	Mukdahan	51	Ranong	77	Yasothon
26	Nakhon Nayok	52	Ratchaburi		

B2-1	<p>(Region for Natural Gas SMR Demonstration) For demonstrating steam methane reforming technology which utilizes natural gas as fuel and feedstock, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider natural gas supply and linkage with CCUS</p>
B2-2	<p>(Region for Natural Gas SMR production) For producing hydrogen with steam methane reforming technology which utilizes natural gas as fuel and feedstock, please specify the most suitable region and the reason why it is suitable</p> <p>Province: () Reason: ()</p> <p>※ Consider natural gas supply, client for produced hydrogen, and linkage with CCUS</p>
B2-3	<p>(Region for Biogas SMR Demonstration) For demonstrating steam methane reforming technology which utilizes natural gas as fuel and biogas as feedstock, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider natural gas supply and linkage with CCUS</p>
B2-4	<p>(Region for Biogas SMR production) For producing hydrogen with steam methane reforming technology which utilizes natural gas as fuel and biogas as feedstock, please specify the most suitable region and the reason why it is suitable</p> <p>Province: () Reason: ()</p> <p>※ Consider natural gas supply, client for produced hydrogen, and linkage with CCUS</p>

Part C. Water Electrolysis

C1	<p>For electricity generation for water electrolysis, many different renewable energy resources can be utilized. From the perspective of expert, please assess the applicability of each renewable energy resource in Thailand for hydrogen production, and prioritize them.</p>									
	Renewable Energy	Potential of fuels (ktoe)	Applicability (1~7 point scale)							Priority (1-5)
	Solar PV	503,150.02	①	②	③	④	⑤	⑥	⑦	()
	Wind (<i>on-shore</i> <i>/off-shore</i> <i>/total</i>)	6,318.21 8,948.32 15,266.53	①	②	③	④	⑤	⑥	⑦	()
	Biomass	8,152.21	①	②	③	④	⑤	⑥	⑦	()
	Biogas	447.91	①	②	③	④	⑤	⑥	⑦	()
	Hydropower	1,950.04	①	②	③	④	⑤	⑥	⑦	()

The major types of water electrolysis technology are alkaline electrolysis (ALK), polymer electrolyte membrane electrolysis (PEM), anion exchange membrane electrolysis (AEM), and solid oxide electrolysis cell (SOEC).

Among these, ALK and PEM technologies are considered as fully or nearly commercialized, and AEM and SOEC technologies are considered as emerging water electrolysis technologies.

	Alkaline	PEM	AEM	Solid Oxide
Operating temperature	70-90 °C	50-80 °C	40-60 °C	700-850 °C
Operating pressure	1-30 bar	< 70 bar	< 35 bar	1 bar
Electrolyte	Potassium hydroxide (KOH) 5-7 mol/L	PESA membranes	DVB polymer support with KOH or NaHCO ₃ (mol/L)	Ytria-stabilized Zirconia (YSZ)
Separator	ZrO ₂ stabilized with PPS mesh	Solid electrolyte (above)	Solid electrolyte (above)	Solid electrolyte (above)
Electrode / catalyst (oxygen side)	Nickel coated perforated stainless steel	Iridium oxide	High surface area Nickel or NiFeCo alloys	Perovskite-type (e.g. LSCF, LSM)
Electrode / catalyst (hydrogen side)	Nickel coated perforated stainless steel	Platinum coated nanoparticles on carbon black	High surface area nickel	Ni/YSZ
Porosity transport layer anode	Nickel mesh (not always present)	Platinum coated sintered porous titanium	Nickel foam	Coarse Nickel-mesh or foam
Porosity transport layer cathode	Nickel mesh	Sintered porous titanium or carbon cloth	Nickel foam or carbon cloth	None
Bipolar plate anode	Nickel-coated stainless steel	Platinum-coated titanium	Nickel-coated stainless steel	None
Bipolar plate cathode	Nickel-coated stainless steel	Gold-coated titanium	Nickel-coated stainless steel	Catalytic-coated stainless steel
Frames and sealing	PSU, PTFE, EPDM	PTFE, PSU, ETFE	PTFE, Silicon	Ceramic glass

Note: Coloured cells represent conditions or components with significant variation among different companies.
 PESA = Perfluoroalkylsulfonic; PTFE = Polytetrafluoroethylene; ETFE = Ethylene Tetrafluoroethylene; PSF = poly (bisphenol-A sulfone); PSU = Polysulfone; YSZ = yttria-stabilized zirconia; DVB = divinylbenzene; PPS = Polyphenylene sulphide; LSCF = La_{0.2}Sr_{0.8}Co_{0.4}Fe_{0.6}O_{3-δ}; LSM = (La_{0.2}Sr_{0.8})MnO_{3-δ}; Cofer22APU with co-containing protective coating.

	2020				2050			
	Alkaline	PEM	AEM	SOEC	Alkaline	PEM	AEM	SOEC
Cell pressure [bara]	< 30	< 70	< 35	< 10	> 70	> 70	> 70	> 20
Efficiency (system) [kWh/kgH ₂]	50-78	50-83	57-69	45-55	< 45	< 45	< 45	< 40
Lifetime [thousand hours]	60	50-80	> 5	< 20	100	100-120	100	80
Capital costs estimate for large stacks (stack-only, > 1 MW) [USD/kW _e]	270	400	-	> 2 000	< 100	< 100	< 100	< 200
Capital cost range estimate for the entire system, >10 MW [USD/kW _e]	500-1000	700-1400	-	-	< 200	< 200	< 200	< 300

Note: PEM = Polymer Electrolyte Membrane (commercial technology); AEM = Anion Exchange Membrane (lab-scale today); SOEC = Solid Oxide Electrolysis (lab-scale today).

C2

<Characteristics of WE technologies>

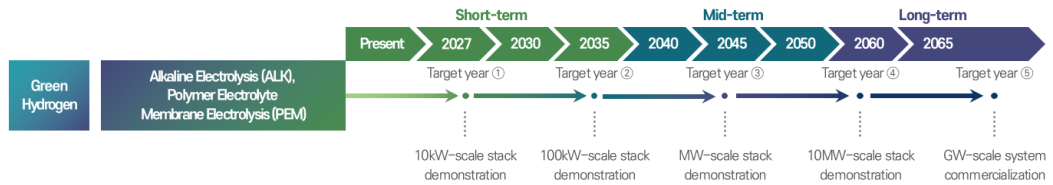
<Performance of WE technologies>

* Source: IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolyzers to Meet the 1.5°C Climate Goal, International Renewable Energy Agency, Abu Dhabi

From the perspective of expert, please assess the applicability of each water electrolysis technology in Thailand, and prioritize based on their suitability.

Water Electrolysis	Applicability (1~7 point scale)							Priority (1-4)
	①	②	③	④	⑤	⑥	⑦	
ALK	①	②	③	④	⑤	⑥	⑦	()
PEM	①	②	③	④	⑤	⑥	⑦	()
AEM	①	②	③	④	⑤	⑥	⑦	()
SOEC	①	②	③	④	⑤	⑥	⑦	()

(Target Year) The following flowchart is the expected timeline of ALK and PEM technology development designed by NIGT. Please specify the target year of Thailand for acquiring alkaline electrolysis (ALK) and polymer electrolyte membrane electrolysis (PEM) to achieve carbon neutrality in 2050 and Net-zero target in 2065.



C3

(Target year ①) The completion of 10kW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ②) The completion of 100kW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ③) The completion of MW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

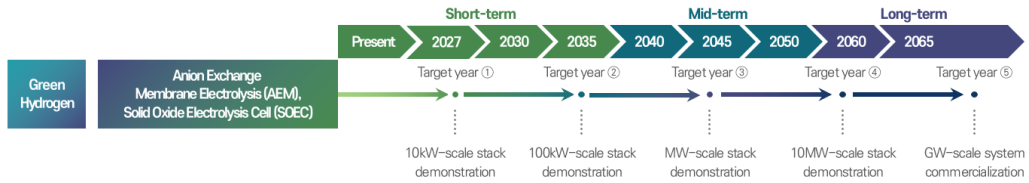
(Target year ④) The completion of 10MW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ⑤) The completion of GW-scale system demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target Year) The following flowchart is the expected timeline of AEM and SOEC technology development designed by NIGT. Please specify the target year of Thailand for acquiring anion exchange membrane electrolysis (AEM) and solid oxide electrolysis cell (SOEC) to achieve carbon neutrality in 2050 and Net-zero target in 2065.



C4

(Target year ①) The completion of 10kW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ②) The completion of 100kW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ③) The completion of MW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ④) The completion of 10MW-scale stack demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

(Target year ⑤) The completion of GW-scale system demonstration

- ① 2025 ② 2027 ③ 2030 ④ 2035 ⑤ 2040 ⑥ 2045 ⑦ 2050 ⑧ 2055 ⑨ 2060 ⑩ 2065

The following table describes 77 provinces of Thailand



C5

* Source: <https://ontheworldmap.com/thailand/thailand-provinces-map.html> (Accessed 07.03.24)

No	Province	No	Province	No	Province
1	Bangkok	27	Nakhon Pathom	53	Rayong
2	Amnat Charoen	28	Nakhon Phanom	54	Roi Et
3	Ang Thong	29	Nakhon Ratchasima	55	Sa Kaeo(Sa Kaew)
4	Bueng Kan	30	Nakhon Sawan	56	Sakon Nakhon
5	Buriram	31	Nakhon Si Thammarat	57	Samut Prakan
6	Chachoengsao	32	Nan	58	Samut Sakhon
7	Chainat	33	Narathiwat	59	Samut Songkhram
8	Chaiyaphum	34	Nong Bua Lamphu	60	Saraburi
9	Chanthaburi	35	Nong Khai	61	Satun
10	Chiang Mai	36	Nonthaburi	62	Singburi
11	Chiang Rai	37	Pathum Thani	63	Sisaket
12	Chonburi	38	Pattani	64	Songkhla
13	Chumphon	39	Phang Nga	65	Sukhothai
14	Kalasin	40	Phatthalung	66	Suphanburi
15	Kamphaeng Phet	41	Phayao	67	Surat Thani
16	Kanchanaburi	42	Phetchabun	68	Surin
17	Khon Kaen	43	Phetchaburi	69	Tak
18	Krabi	44	Phichit	70	Trang
19	Lampang	45	Phitsanulok	71	Trat
20	Lamphun	46	Phra Nakhon Si Ayutthaya (Ayutthaya)	72	Ubon Ratchathani
21	Loei	47	Phrae	73	Udon Thani
22	Lopburi	48	Phuket	74	Uthaithani
23	Mae Hong Son	49	Prachin Buri	75	Uttaradit
24	Maha Sarakham	50	Prachuap Khiri Kha n	76	Yala
25	Mukdahan	51	Ranong	77	Yasothon
26	Nakhon Nayok	52	Ratchaburi		

C5-1	<p>(Solar PV – Water Electrolysis) For demonstrating water electrolysis technology utilizing electricity generated from solar PV, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider the site of solar PV power plant</p>
C5-2	<p>(Solar PV – Water Electrolysis) For producing hydrogen with water electrolysis technology utilizing electricity generated from solar PV, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider the site of solar PV power plant, clients of produced hydrogen</p>
C5-3	<p>(Wind – Water Electrolysis) For demonstrating water electrolysis technology utilizing electricity generated from wind power, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider the site of wind power plant</p>
C5-4	<p>(Wind – Water Electrolysis) For producing hydrogen with water electrolysis technology utilizing electricity generated from wind power, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: () Reason: ()</p> <p>※ Consider the site of wind power plant, clients of produced hydrogen</p>

C5-5	<p>(Biomass – Water Electrolysis) For demonstrating water electrolysis technology utilizing electricity generated from biomass, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the supply of biomass, the site of biomass power plant</p>
C5-6	<p>(Biomass – Water Electrolysis) For producing hydrogen with water electrolysis technology utilizing electricity generated from biomass, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the supply of biomass, the site of biomass power plant, clients of produced hydrogen</p>
C5-7	<p>(Biogas – Water Electrolysis) For demonstrating water electrolysis technology utilizing electricity generated from biogas, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the supply of biogas, the site of biogas power plant</p>
C5-8	<p>(Biogas – Water Electrolysis) For producing hydrogen with water electrolysis technology utilizing electricity generated from biogas, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the supply of biogas, the site of biogas power plant, clients of produced hydrogen</p>

C5-9	<p>(Hydropower – Water Electrolysis) For demonstrating water electrolysis technology utilizing electricity generated from hydropower, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the site of hydroelectric power plant</p>
C5-10	<p>(Hydropower – Water Electrolysis) For producing hydrogen with water electrolysis technology utilizing electricity generated from hydropower, please specify the most suitable region and the reason why it is suitable.</p> <p>Province: ()</p> <p>Reason: ()</p> <p>※ Consider the site of hydroelectric power plant, clients of produced hydrogen</p>