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Study on Accelerating Energy Technology Development in ASEAN: A Case Study of Thailand

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List of Abbreviations and Acronyms

AC	Alternating Current
AEDP	Alternative Energy Development Plan
AHEAD	Advanced Hydrogen Energy Chain Association for Technology Development
ASEAN	Association of Southeast Asian nations
AWE	Alkaline Water Electrolysis
B	Baht
BCG	Bio, Circular, Green
BDF	Bio-Diesel Fuel
BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicle
BIG	Bangkok Industrial Gas Co. Ltd.
BMHT	Beijing Mingyang Hydrogen Technology Co. Ltd
BOI	Board of Investment
BPP	Banpu Power Public Company Limited
CBU	Completely Built-Up Units
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilisation, and Storage
CO_2	Carbon Dioxide
CPO	Crude Palm Oil
CRI	Climate Risk Index
CVLM	Cambodia–Viet Nam–Lao PDR–Myanmar
DAC	Direct Air Capture
DC	Direct Current
DEDE	Department of Alternative Energy and Efficiency
DOE	Department of Energy
DR	Demand Response

DMF	Department of Mineral Fuel
E2G	Second-generation Ethanol
E3G	Third-generation Ethanol
EEP	Energy Efficiency Plan
EGAT	Electricity Generating Authority of Thailand
EOR	Enhanced Oil Recovery
EPPO	Energy Policy and Planning Office, Ministry of Energy
ERI	Energy Research Institute, Chulalongkorn University
ETBE	Ethyl Tertiary Butyl Ether
EU	European Union
FAME	Fatty Acid Methyl Ester
FCV	Fuel Cell Vehicle
FEED	Front End Engineering Design
GC	PTT Global Chemical Public Company Ltd
GDIP	Green Deal Industrial Plan for the Net-Zero Age
GDP	Gross Domestic Product
GENI	Global Energy Network institute
GGC	Global Green Chemical Public Company Limited
GHG	Greenhouse Gas
GPSC	Global Power Synergy Public Company Limited
GX	Green Transformation
H_2	Hydrogen
HRS	Hydrogen Refuelling Station
HySTRA	Hydrogen Energy Supply Chain Technology Research Association
HVO	Hydrotreated Vegetable Oil
HZ	Hitachi Zosen
ICE	Internal Combustion Engine
IEA	International Energy Agency
IPP	Independent Power Producer
IPUU	Industrial Processes and Product Use

IRA	Inflation Reduction Act
IRENA	International Renewable Energy Agency
JERA	Japan's Energy for a New Era
KHM	Kingdom of Cambodia
KHIT	Kawasaki Heavy Industries (Thailand) Co. Ltd
KTIS	Kaset Thai International Sugar Corporation Public Company Limited
LNG	Liquified Natural Gas
LPG	Liquified Petroleum gas
LT-LED	Long-term Low Greenhouse Gas Emission Development Strategy
MC	Mitsubishi Corporation
MCH	Methylcyclohexane
METI	Ministry of Economy, Trade, and Industry
MHI	Mitsubishi Heavy Industry
MLD	million litres per day
MOE	Ministry of Environment
MOECO	Mitsui Oil Exploration Co. Ltd
MOU	Memorandum of Understanding
MT	Million Ton
MTJA	Malaysia-Thailand Joint Authority
MW	Megawatt
NDC	Nationally Determined Contribution
NEP	National Energy Plan
NH_3	Ammonia
NSTDA	National Science and Technology Development Agency
NZ	Net Zero
OFFO	Oil Fuel Fund Office
OR	PTT Oil and Retail Business Public Company Limited
PEM	Polymer Electrolyte Membrane/Proton Exchange Membrane
PDP	Power Development Plan

PTT	PTT Public Company Limited
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
RINA	Registro Italiano Navale
SAF	Sustainable Aviation Fuel
SMR	Steam Methane Reforming
SPP	Small Power Producers
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TDEM	Toyota Daihatsu Engineering and Manufacturing Co., Ltd
TEPCO	Tokyo Electric Power Company
TET	Thaioil Ethanol Company Limited
TMT	Toyota Motor Thailand Company Limited
TPES	Total Primary Energy Supply
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USD	United States Dollar
VAT	Value Added Tax
VPP	Virtual Power Plant
WMO	World Meteorological Organization
WS	Wholesale Price
ZEV	Zero Emissions Vehicle

Executive Summary

The year 2023 is projected to be the warmest on record in terms of global average temperature. ASEAN member countries, already affected by abnormal weather patterns and climate risks, have announced their ambitions to achieve net-zero (NZ) emissions in the future. Meanwhile, Russia's invasion of Ukraine in February 2022 has reinforced the urgency of energy security. The dual need for decarbonisation and energy security has accelerated the development of NZ technologies (NZ techs), prompting countries to invest in research and development (R&D) of new technologies.

In light of this, the present study maps the R&D efforts of ASEAN countries in developing NZ techs across key sectors, specifically power generation and transport. The case study focuses on Thailand, which has set ambitious climate goals: achieving net-zero CO_2 emissions by 2050 and net-zero greenhouse gas (GHG) emissions by 2065.

Thailand, with its tropical climate, lies at the centre of the Cambodia–Viet Nam–Lao People's Democratic Republic–Myanmar (CVLM) corridor and is strategically positioned equidistant from Australia, China, India, and Japan. As an upper middle-income country with a steadily growing economy, Thailand has established a strong industrial base and is recognised as ASEAN's automotive hub. However, the country faces the middle-income trap, declining energy self-sufficiency, and increasing energy demand. While pursuing economic growth, Thailand must address the energy trilemma – balancing energy security, affordability, and sustainability. To tackle these challenges, Thailand is prioritising the development of NZ techs as a key strategy for achieving its climate and energy goals.

An analysis of the R&D maps for the power sector highlights that hydrogen and ammonia co-firing, as well as carbon capture and storage (CCS), remain in the demonstration stage. Similarly, in the transport sector, fuel cell vehicles (FCVs) and hydrogen refuelling stations are also still at the demonstration stage.

In January 2021, the Thai government integrated the Bio-Circular-Green (BCG) Economy Model into its national agenda alongside Thailand 4.0 (NSTDA, 2021), a policy aimed at transforming the country into an innovation-driven economy. The BCG framework seeks to modernise the agricultural sector, establish national health security, and reduce foreign dependency. Within this strategy, biofuels, CCS, and hydrogen are identified as critical areas for advancing net-zero (NZ) technologies, although Thailand still faces challenges in developing these technologies domestically.

Thailand's key strength lies in its abundant agricultural resources, particularly sugarcane and cassava, which are essential for biofuel production. From the perspective of national policy and NZ tech development potential, biofuels, CCS, and hydrogen are Thailand's top three priority areas.

According to this study's analysis, biofuels are widely used in Thailand due to a long history of development and well-established infrastructure. However, challenges remain, such as the slow expansion and modernisation of sugarcane farms, high ethanol prices, and heavy reliance on subsidies for biofuel promotion. Additionally, next-generation biofuel production has yet to commence.

Currently, CCS projects in Thailand primarily focus on domestic CO_2 storage and have not yet advanced to carbon capture, utilisation, and storage (CCUS). The absence of comprehensive laws and regulations further limits progress in this area.

Regarding hydrogen, Thailand has initiated pilot projects in collaboration with various countries, but most remain at the memorandum of understanding (MoU) and demonstration stages. While there are numerous hydrogen production and utilisation projects, relatively few focus on transportation and storage. Given Thailand's abundant renewable energy potential – especially in solar power – there is significant promise for green hydrogen production in the future.

To address these challenges while capitalising on Thailand's strengths, a phased, step-by-step approach would be the most effective strategy for steadily advancing net-zero (NZ) technologies.

- Phase 1 (2030s): Focus on consolidating domestic systems.
- Phase 2 (2040s): Strengthen cooperation with neighbouring countries.
- Phase 3 (2050s): Expand collaboration to multilateral partnerships.

This strategic approach, summarised in Table 1, leverages Thailand's strengths while minimising risks and exploring global expansion opportunities.

In terms of NZ technologies that Thailand should develop domestically, the country should focus on advancing second-generation (E2G) and third-generation (E3G) ethanol technologies to maintain its competitive edge in biofuels. To prepare for future CO_2 utilisation, Thailand should invest in transitioning from CCS to CCUS, with the long-term goal of positioning itself as an Asian CCUS hub, particularly if carbon pricing is introduced. This requires in-house development of CO_2 transportation and storage technologies.

Additionally, Thailand should work on in-house development of e-fuels and methanation technologies, which synthesise CO_2 and hydrogen. Further, it should prioritise the development of:

- Electrolysers for hydrogen production

- Hydrogen transport technologies, including liquefied hydrogen, ammonia, methylcyclohexane (MCH), and toluene
- Utilisation technologies, such as hydrogen co-combustion in thermal power plants

In the transport sector, Thailand must develop fuel cell vehicles (FCVs) and establish a robust hydrogen refuelling station (HRS) network to support widespread hydrogen adoption.

Table 1: Three-step Approach of In-house Technologies (2030s–2050s)

Three Very High Priority Areas	Phase 1 (2030s)	Phase 2 (2040s)	Phase 3 (2050s)
Expansion Axis	Domestic	Neighbouring	Multilateral
Biofuel	Export	Export	Export
CCS	CCS Domestic pilot project	CCUS Cooperation with neighbouring countries	CCUS ASEAN CCUS Hub
Hydrogen	Domestic pilot Project	Export (bilateral)	Trading (multilateral)
Need to be In-house Technology	E2G CO_2 capture and storage technology Green H_2 production and utilisation	E3G CO_2 utilisation technology H_2 transport and storage technology	e-fuel, Methanation CO_2 transport technology H_2 transport and storage technology

ASEAN = Association of Southeast Asian Nations, CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, E2G = second-generation ethanol, E3G = third-generation ethanol.
Source: Authors.

The study has demonstrated that the R&D map provides a comprehensive understanding of a country's technological development, including its strengths, weaknesses, opportunities, and risks. While this report focuses on Thailand as a case study, developing R&D maps for other ASEAN countries would enable a deeper understanding of each member state's unique characteristics. This, in turn, would facilitate a more targeted analysis of potential regional and extraregional cooperation opportunities.

Chapter 1
Background and Objectives

1.1. Background and Purpose of the Study

This chapter summarises the progress of global warming and the status of net-zero (NZ) declarations in the Association of Southeast Asian Nations (ASEAN) member countries, then points out the current situation where decarbonisation and energy security are required to be compatible and discusses industrial policy and NZ technology development. The importance of NZ technology development is increasing not only worldwide but in ASEAN countries as well, and the research and development (R&D) map shows the degree of progress. Thailand is targeted as a case study country.

In December 2023, the World Meteorological Organization (WMO) announced that 2023 was set to be the warmest year on record, in terms of global average temperature. The past 9 years, 2015 to 2023, were the warmest on record. Greenhouse gas (GHG) levels continue to increase. Last year, abnormally high temperatures occurred in many places of the world, along with frequent heat waves, droughts, large-scale floods, and wildfires.

According to the Long-term Climate Risk Index (CRI) from the *Global Climate Risk Index 2021* (Eckstein, Künzel, and Schäfer, 2021), three ASEAN countries were ranked amongst the top 10 countries most affected from 2000 to 2019. Myanmar is in second place, the Philippines in fourth place, and Thailand in ninth place (Table 1.1).

Table 1.1. Long-term Climate Risk Index: Top 10 Countries Most Affected from 2000 to 2019

CRI 2000-2019 (1998–2018)	Country	CRI Score	Fatalities	Fatalities per 100,000 Inhabitants	Losses in million USD PPP	Losses per Unit GDP (%)	Number of Events (2000–2019)
1 (1)	Puerto Rico	7.17	149.85	4.12	4,149.98	3.66	24
2 (2)	Myanmar	10.00	7,056.45	14.35	1,512.11	0.80	57
3 (3)	Haiti	13.67	274.05	2.78	392.54	2.30	80
4 (4)	Philippines	18.17	859.35	0.93	3,179.12	0.54	317
5 (14)	Mozambique	25.83	125.40	0.52	303.03	1.33	57

6 (20)	The Bahamas	27.67	5.35	1.56	426.88	3.81	13
7 (7)	Bangladesh	28.33	572.50	0.38	1,860.04	0.41	185
8 (5)	Pakistan	29.00	502.45	0.30	3,771.91	0.52	173
9 (8)	Thailand	29.83	137.75	0.21	7,719.15	0.82	146
10 (9)	Nepal	31.33	217.15	0.82	233.06	0.39	191

CRI = Climate Risk Index, GDP = gross domestic product, PPP = purchasing power parity, USD = United States dollar.
Source: Eckstein, Künzel, and Schäfer (2021).

Even ASEAN countries affected by abnormal weather and climate risks have announced their ambition to become NZ in the future (Table 1.2). As shown in Table 1.2, eight countries announced the ambition to become NZ in their long-term targets. Four of these countries (Cambodia, Indonesia, Singapore, and Thailand) have developed and submitted long-term mitigation visions, strategies, and targets under the Paris Agreement. All 10 ASEAN member countries have submitted their Nationally Determined Contributions (NDCs) for 2030. ASEAN countries are also moving towards carbon neutrality.

Table 1.2. Net-zero Targets for ASEAN Countries

Country	Target Year
Brunei Darussalam	2050
Kingdom of Cambodia	2050
Republic of Indonesia	2060
Lao People's Democratic Republic	2050
Malaysia	2050
Republic of the Union of Myanmar	NA
Republic of the Philippines	NA
Republic of Singapore	2050
Kingdom of Thailand	NZ CO_2 2050 / NZ GHG 2065
Socialist Republic of Viet Nam	2050

GHG = greenhouse gas, NA = not available, NZ = net zero.
Source: Authors.

Meanwhile, Russia's invasion of Ukraine in February 2022 served as an opportunity to reaffirm energy security. Coal, oil, and gas prices soared sharply, and price volatility has increased. Critical minerals essential to NZ technologies are also unevenly distributed geographically. Not only ASEAN countries, but also many other countries around the world are facing the dilemma of balancing between decarbonisation and energy security.

Tangible and intangible assets such as human resources, money, information, and goods are important for achieving NZ. NZ technologies are particularly crucial. However, currently, the countries rely on import for many NZ technologies. From the industrial policy perspective, it is clearly better for a country to hold the technologies in their own hand, because development of their own technologies can be a strong engine for green growth. For example, NZ technologies are closely linked to industrial policy, such as the Inflation Reduction Act (IRA) of United States (US) (Table 1.3) and the Green Deal Industrial Plan for the Net-Zero Age (GDIP) of the European Union (EU). In March 2023, The European Commission announced the Net-Zero Industry Act. The Act stipulates 'net-zero technologies' and particularly high-priority 'strategic net-zero technologies.' The Act introduces deregulation measures to simplify and shorten the licensing process for setting up manufacturing sites. Table 1.4 lists the net-zero technologies eligible for state financial support in EU member countries.

Table 1.3. Outline of United States' Inflation Reduction Act

Law Name	Date of Establishment	Support Target	Budget Size
Inflation Reduction Act (IRA)	August 2022	➢ Tax credits for clean manufacturing related investments, production ➢ Tax credits for clean fuel production such as hydrogen ➢ Tax credits for purchasers of clean vehicles such as battery electric vehicles	USD369 billion

Source: Authors.

Table 1.4. Technologies Specified by the European Union's Net Zero Industry Act

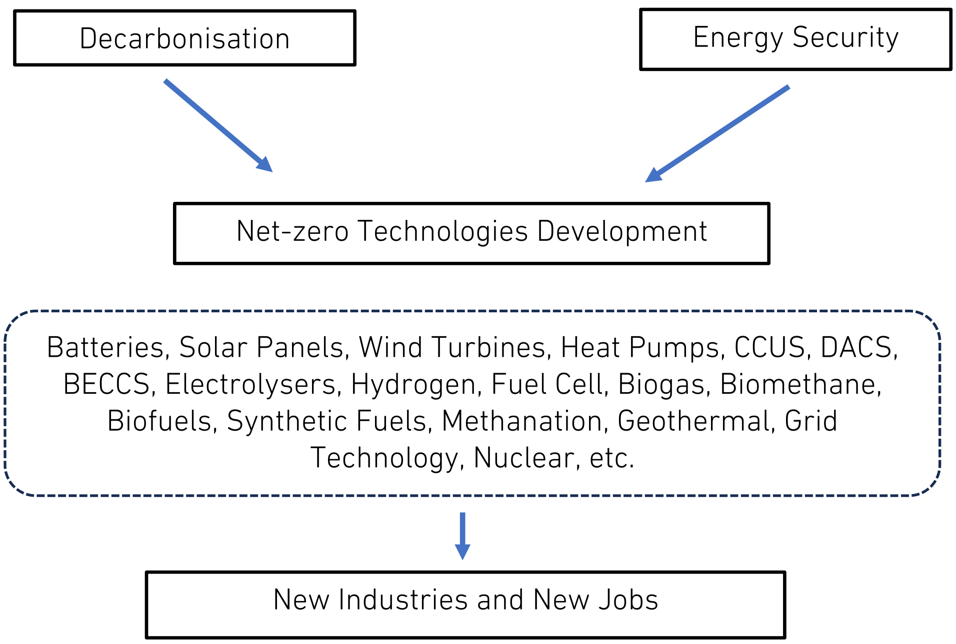
Strategic Net-zero Technologies	Net-zero Technologies Eligible for Financial Support
➢ Solar power/solar thermal technology ➢ Onshore wind and offshore renewable technologies ➢ Battery/storage technology ➢ Heat pump/geothermal technology.	(1) Batteries, solar panels, wind turbines, heat pumps, electrolysers, carbon capture, utilisation, and storage (CCUS) equipment

Strategic Net-zero Technologies	Net-zero Technologies Eligible for Financial Support
➢ Electrolyser/fuel cell ➢ Biogas and biomethane technology ➢ Carbon capture and storage (CCS) technology ➢ Grid technology	(2) Major parts designed and directly input to produce (1) (3) Production and recovery of important raw materials necessary for manufacturing (1) and (2)

Source: Authors.

NZ technology is attracting attention as a solution to both decarbonization and energy security. Net-zero technologies are expected to foster new industries and create new jobs. By focusing on both decarbonization and energy security, NZ technologies will develop strongly. The motivation of achieving energy self-sufficiency improvement and decarbonization will accelerate the innovation competition in NZ technologies.

Figure 1.1. Relationship between Decarbonisation, Energy Security, and Net-zero Technologies



CCUS = carbon capture, utilisation, and storage, DACS = direct air capture with carbon storage, BECCs = bioenergy with carbon capture and storage.
Source: Authors.

For this reason, every country looks at R&D of new technologies. The importance of NZ techs, the degree of development progress of NZ techs, and the degree of in-house production will depend on each country's situation, including factors such as population, GDP, industrial policy, energy mix, the degree of decarbonisation progress, and energy self-sufficiency rate. Therefore, each country has different advantages and disadvantages, or different focus areas of R&D activities.

Based on this recognition, this study will map the status of NZ tech development conducted by ASEAN countries. The study will survey and organize NZ techs by sector (power generation and transport) and will create a template R&D map (Table 1.5).

Table 1.5. Concept of Research and Development Map

Sector	Technology	Priority	Not existing	Fundamental research	Applied research	Prototype	Demonstration	Commercial
Power Generation	A	High			✓			
	B	Mid		✓				
Transport	C	Very High						✓
	D	Mid				✓		
Industry	E	Low	✓					
	F	High					✓	

Source: Authors.

With this R&D map, the study aims to identify area of possible collaborations and areas that could complement each other. This report focuses on technologies, but it also covers not only technologies but also policies involving financial support (subsidies, etc.) and human resources (capacity building, etc.).

The first target country of case study is Thailand. The reasons for targeting Thailand will be explained in Chapter 2.

Chapter 2
Selection of a Target Country

2.1. Reasons for Selecting Thailand

This chapter provides the reason why Thailand is selected the case study country of this study. This chapter analyses Thailand's strengths and weaknesses mainly from the perspectives of geography, climate, economy, and energy, confirming that it is possible to create an R&D map and that it is more suitable as a case study compared to other ASEAN countries.

2.1.1. Geography and climate

Thailand is located the centre of the Indochina peninsula. Thailand has extensive coastline of approximately 3,100 kilometres. Thailand shares borders with four other countries: Cambodia, the Lao People's Democratic Republic, Malaysia, and Myanmar. Thailand is in a tropical area. According to Thailand's Long-term Greenhouse Gas Emission Development Strategy (revised version), the annual mean of maximum temperatures in Thailand indicates a trend of increasing temperatures that is likely to continue.

2.1.2. Economy and Energy

The 10 ASEAN countries have a combined population of more than 600 million. Looking at the seven countries with a population of 10 million or more and at GDP per capita, which is a measure of income level, Thailand and Malaysia are in the lead group (upper middle-income countries) (Table 2.1). However, according to the National Science and Technology Development Agency (NSTDA), Thailand's Bio-Circular-Green Economy (BCG) model homepage, Thailand's economic growth has become stagnant, facing the situation of the "middle-income-trap" syndrome, while the country has also been confronted by disparities and imbalanced development.

Thailand has the following industrial base: agriculture, car manufacturing, oil and gas, petrochemicals, cement, and others. The Thai steel industry does not have blast furnaces, but mainly has electric furnaces. Thailand also produces and exports large amounts of agricultural products, including rice, cassava, and sugarcane. Especially, Thailand is a hub of car manufacturing in ASEAN.

Table 2.1. Population, GDP, and GDP per capita in ASEAN Countries

2022	Population	GDP	GDP per Capita
	million people	USD billion	USD
Brunei Darussalam	0.44	16.6	37,667
Cambodia	15.99	28.5	1,785
Indonesia	274.86	1,318.8	4,798
Lao PDR	7.48	15.3	2,047
Malaysia	32.99	407.9	12,364
Myanmar	53.89	56.8	1,053
Philippines	111.57	404.3	3,623
Singapore	5.64	466.8	82,808
Thailand	70.08	536.2	7,651
Viet Nam	99.46	406.5	4,087
Total	672.4	3657.7	5,440

GDP = gross domestic product.
Source: Authors based on IMF (2023).

As shown Table 2.2, as of 2021, Thailand's total primary energy supply (TPES) is the second largest after Indonesia. Thailand's TEPS per GDP is 6th amongst ASEAN countries. There is room for improvement in energy efficiency. Thailand's CO_2 emissions (fuel combustion) are in 3rd position after Indonesia and Viet Nam. It is in 4th position in terms of CO_2 per TPES. The reason for the low-carbon intensity is thought to be that there are no blast furnaces, there is little coal-fired power, and power is mainly generated by natural gas-fired power. Energy self-sufficiency ratio is 47% and has been consistently declining for the past 15 years. Energy demand is expected to continue to expand in the future, and as Thailand's natural gas production is on the decline, awareness of energy security is increasing.

Table 2.2. Overview of Energy in ASEAN (2021)

2021	TPES	TPES per capita	TPES per GDP (energy efficiency)	CO_2 (fuel combustion)	CO_2 per Capita	CO_2 per TPES (carbon Intensity)	Energy Self-Sufficiency Ratio
Unit	Mtoe	Toe /person	Toe /USD,000	$MtCO_2$	tCO_2 /person		%
Brunei Darussalam	4	9.10	0.31(8)	9.1	20.46	2.28(6)	333
Cambodia	9	0.52	0.36(10)	13.1	0.79	1.46(3)	47
Indonesia	235	0.86	0.22(3)	556.6	2.03	2.37(7)	190
Lao PDR	6	0.75	0.30(6)	17.9	2.41	2.98(9)	143
Malaysia	95	2.83	0.27(4)	225.9	6.73	2.38(8)	98
Myanmar	22	0.40	0.34(9)	27.7	0.52	1.26(1)	127
Philippines	61	0.54	0.16(2)	132.2	1.16	2.18(5)	52
Singapore	35	6.46	0.10(1)	45.5	8.35	1.30(2)	2
Thailand	130	1.81	0.30(6)	234.7	3.28	1.81(4)	47
Viet Nam	95	0.98	0.29(5)	284.8	2.92	3.00(10)	65

GDP = gross domestic product, Mtoe = million tons of oil equivalent, $MTCO_2$ = million tons of carbon dioxide, toe = tons of oil equivalent, TPES = total primary energy supply.
Note: The numbers in parentheses indicate the ranking.
Source: Authors based on International Energy Agency World Energy Balances (2023).

Thailand’s energy infrastructure, including electricity and gas grids, is almost completely integrated and well developed. Power plants and power grids are spread across the country and are well-balanced. According to system installed generating capacity (March 2024) from the power generation corporation, EGAT, the country's installed power generation capacity is 50,801 megawatts (MW,) of which 3,687 MW is thermal (7.26% of the total), 8,400 MW is combined cycle (16.53%), and renewable energy 3,144 MW (6.19%), diesel 30 MW (0.06%), others 1,000 MW (1.97%), purchases from independent power producers (IPP) 18,974 MW (37.35%), purchases from small power producers (SPPs) 9,331 MW (18.37%) and imported 6,235 MW (12.27%). EGAT is primarily responsible for power transmission. The line length is 39,395.728 circuit kilometres.

PTT Public Company Limited (PTT) plays a central role in Thailand's oil industry and is engaged in integrated upstream and downstream oil and natural gas operations. According to PTT home page, PTT at a glance, PTT was established in 1978 as a state-run oil company wholly owned by the government and was demutualised in 2001.

According to PTT 56-1 One Report 2020, upstream and downstream businesses are operated through group companies, with exploration and production activities in country and overseas being handled primarily by PTT Exploration and Production Public Company Limited (PTTEP), and petrochemical and oil refining businesses being handled by PTT Global. Petroleum retail business, including chemical (GC), IRPC, and Thai Oil (TOP), is handled by PTT Oil and Retail Business (OR).

In the domestic gas business field, with few exceptions, PTT is responsible for gas transmission and distribution, and the total length of domestic pipelines has reached about 4,000 km.

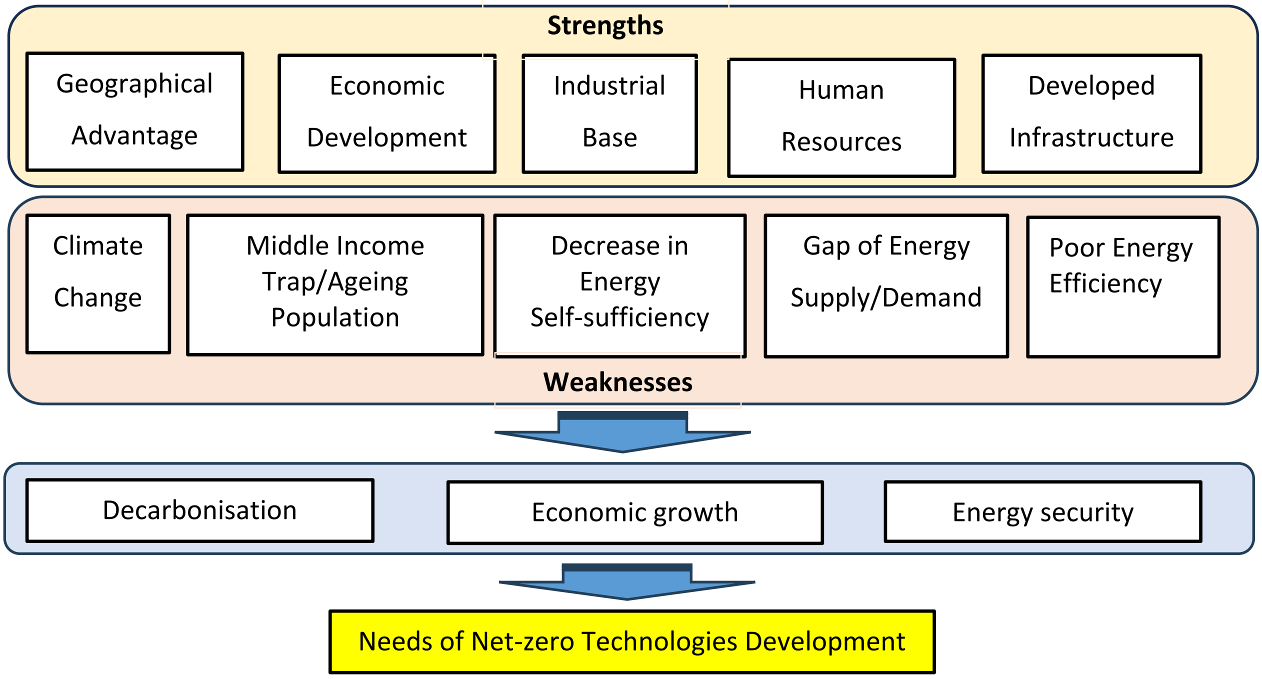
In December 2022, the International Institute for Management Development (IMD) announced the World Talent Ranking 2023, which analyses the competitiveness of human resources in each country and region. Thailand was ranked 45th, behind Singapore (13th) and Malaysia (33rd), ranking highly amongst ASEAN countries. The literacy rate in Thailand is estimated to be around 98%, which is extremely high.

2.1.3. Reasons for Selecting Thailand

In summary, Thailand is geographically centrally located amongst the ASEAN countries and has easy access to other countries. Thailand has a geopolitical advantage, as it is located at the centre of the Cambodia–Viet Nam–Lao PDR–Myanmar (CVLM) fan. It is relatively equidistant from Australia, China, India, Japan, and the Republic of Korea, and its advantages are far superior to those of other ASEAN countries. Thailand also ranks in the top groups in terms of economic development amongst ASEAN countries. Thailand has a solid industrial base and excellent human resources. Infrastructure has been developed in the energy sector, and there are energy links with neighbouring countries, including Cambodia, Lao PDR, Malaysia, and Myanmar. Thailand is relatively technologically advanced amongst ASEAN countries, enabling creation of an R&D map.

On the other hand, Thailand is facing the middle-income trap and an ageing population. Thailand is affected by climate change and countermeasures are urgently needed. Energy efficiency also remains an issue. Although the energy self-sufficiency rate is on the decline, energy demand is expected to increase in the future. Whilst achieving economic growth, Thailand is under pressure to resolve the trilemma of energy independence and decarbonisation. To cope with above mentioned challenges, Thailand is keen to develop net-zero techs to solve the trilemma. These are the reasons for selecting Thailand as a case study country (Figure 2.1).

Figure 2.1. Reasons for Selecting Thailand



Source: Authors.

Chapter 3
The R&D Map: A Case Study of Thailand

This chapter provides an overview of Thailand, including basic information. This chapter then shows research and development (R&D) maps for the power and transport sectors. Amongst many areas, three areas that are particularly important to Thailand (biofuels, carbon capture and storage [CCS], and hydrogen) have been identified. For each of the three areas, an analysis will be conducted on the history and progress, supply and demand, goals and status, and the status of individual projects.

3.1. Overview of Thailand

3.1.1. General Information about Thailand

Table 3.1 shows some basic information about Thailand.

Table 3.1. Basic Information about Thailand

(1) Official country name	Kingdom of Thailand, Capital: Bangkok
(2) National land area	514,000 km^2
(3) Population	66.09 million people (2022)
(4) GDP (nominal)	USD513.5 billion (2023) / GDP per capita $7,331.5 (2023)
(5) Real GDP growth rate	1.9% (2023)
(6) Major industries	Agriculture accounts for approximately 30% of employment, but less than 10% of GDP. The manufacturing industry accounts for about 15% of the workforce, but accounts for about 30% of GDP (the highest percentage).

GDP = gross domestic product, km^2 = square kilometres.
Source: Authors.

Demographic and GDP changes in Thailand

Starting from the 3rd National Economic and Social Development Plan from 1972, the government has placed importance on reducing population growth. Between 1970 and 1990, the total fertility rate fell from about 5.6 to 2.1 children per woman, the fastest decline in Southeast Asia. World Bank data show Thailand's total fertility rate was 1.331 births per woman in 2021 (World Bank World Development Indicators). This low fertility rate, along with increased life expectancy, has led to a rapidly ageing population in Thailand. The working-age population is on a declining trend.

Thailand's GDP has grown rapidly, except during the Asian currency crisis in 1997, the China shock during the 2000s and 2010s, and the coronavirus shock in 2019 (Figure 3.1). Figure 3.2 shows the GDP breakdown since 2000. As of 2022, the service industry accounted for 60%, industry 32%, and agriculture 9%.

Figure 3.1. Demographic and GDP Changes

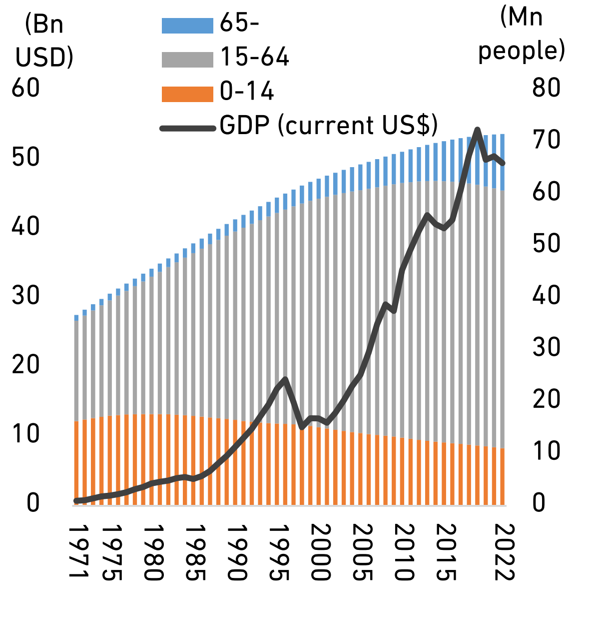
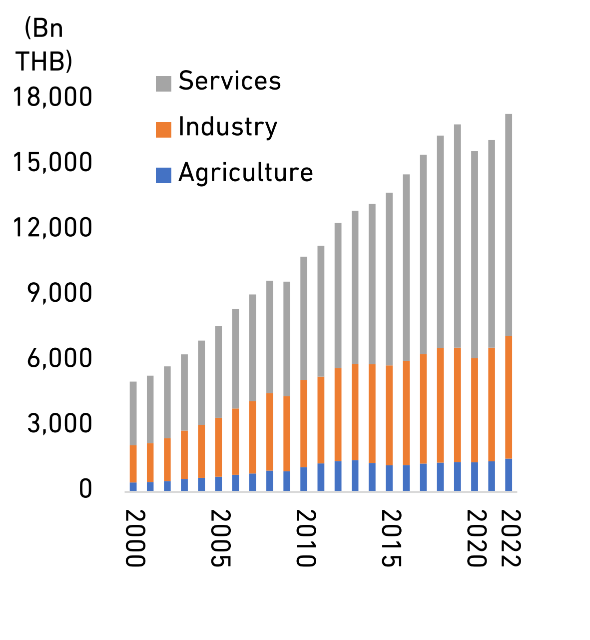


Figure 3.2. GDP Breakdown since 2000



GDP = gross domestic product.

Source: Authors based on World Bank, 'World Integrated Trade Solution'; Asian Development Bank, 'Key Indicators Database'; International Energy Agency, 'World Energy Balances' (accessed 13 May 2024).

Changes in the energy system in Thailand

Here, changes were evaluated in Thailand's energy system using data from the 1970s to 2020s (Figure 3.3) To understand the state of national energy security, we decided to use 5 representative indicators. The following five indicators were created and indexed from the 1970s as 1. The higher the value, the better.

(a) Self-sufficiency (production/total primary energy supply [TPES])

(b) Energy efficiency (TPES/GDP)

(c) Carbon intensity (CO_2-ton/TPES)

(d) Power generation diversity (share of power generation by power source was evaluated using the Herfindahl index)
(e) TPES diversity (share of TPES by source was evaluated using the Herfindahl index)

In the results based on the 1970s, carbon intensity and self-sufficiency rates have been on the decline due to increased energy consumption (increased fossil fuels) accompanying economic growth. Improvements were seen in TPES diversity, power generation diversity, and energy efficiency.

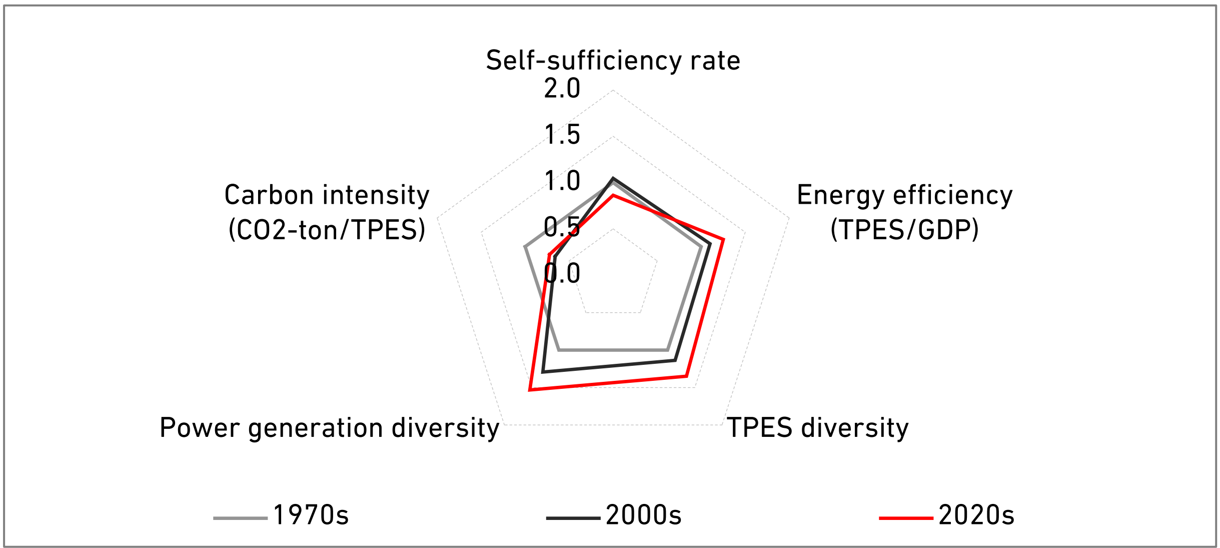
The energy policy trends that have caused these changes, especially the most recent ones, are as follows.

Since the enactment of the Energy Conservation Promotion Act 2535 in 1992, the policy has focused on energy conservation. The National Energy Policy consists of five plans: Energy Efficiency Plan (EEP), Power Development Plan (PDP), Alternative Energy Development Plan (AEDP), Gas Plan, and Oil Plan.

In 2018, the goal of achieving a renewable energy power source composition ratio was brought forwards to 2030 (announcement of a review of long-term goals for power source development). The Power Development Plan (PDP2018) was approved in 2019. The target ratio of fuels for power generation in 2037 is 53% natural gas, 12% coal, 20% renewable energy, and 0% nuclear power.

The national energy policy is expected to be revised around the fall of 2024.

Figure 3.3. Changes in Thailand's Energy System



GDP = gross domestic product, TPES = total primary energy supply.
Note: The index was calculated using the 1970s as 1. The higher the number, the better.
Source: Authors based on IEA World Energy Balances (2023).

Detailed energy-related information in Thailand

Here, we will confirm the details of the structure of energy supply and demand in Thailand. First, Figure 3.4 shows trends in primary energy supply and Figure 3.5 shows power generation.

Crude oil accounts for approximately 50% of total primary energy supply (Figure 3.4). Including natural gas and coal, nearly 90% of our electricity is supplied by fossil fuels. Approximately 60% of the electricity generated is from natural gas and 20% from coal, with a similarly high proportion of fossil fuels being used (Figure 3.5).

Figure 3.4. Total Primary Energy Supply

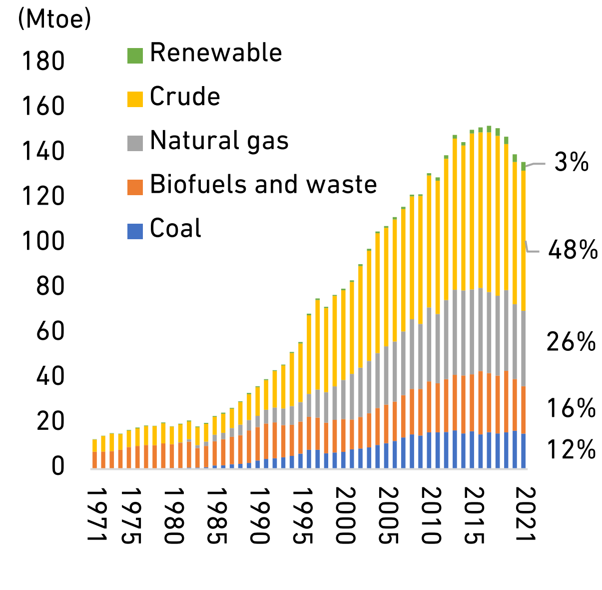
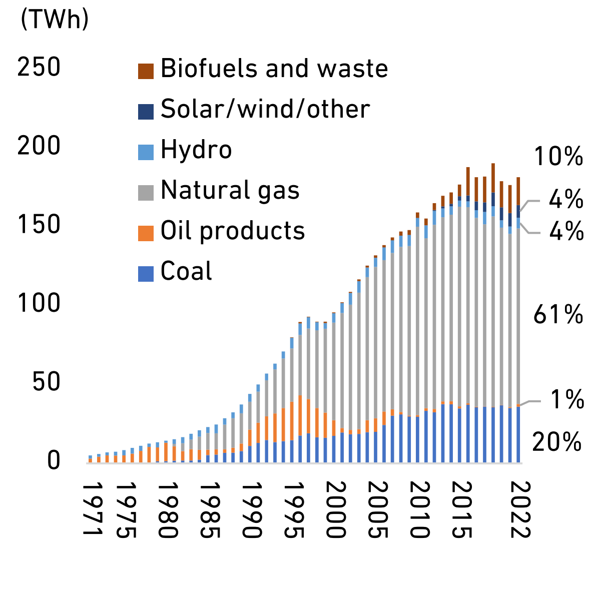


Figure 3.5. Power Generation



Mtoe = million tonnes of oil equivalent, TWh = terawatt-hour.
Source: Authors based on IEA World Energy Balances (2023).

The reason for this energy composition is the existence of abundant domestic natural resources (gas, oil). However, focusing on production volume, and import and export volume, since the 2000s, Thailand has been a fossil fuel importing country (Figures 3.6 to 3.8). As mentioned earlier, this is due to remarkable economic development and population growth. The energy self-sufficiency rate is on the decline (Figure 3.9).

Figure 3.6. Natural Gas Production, Imports, and Exports

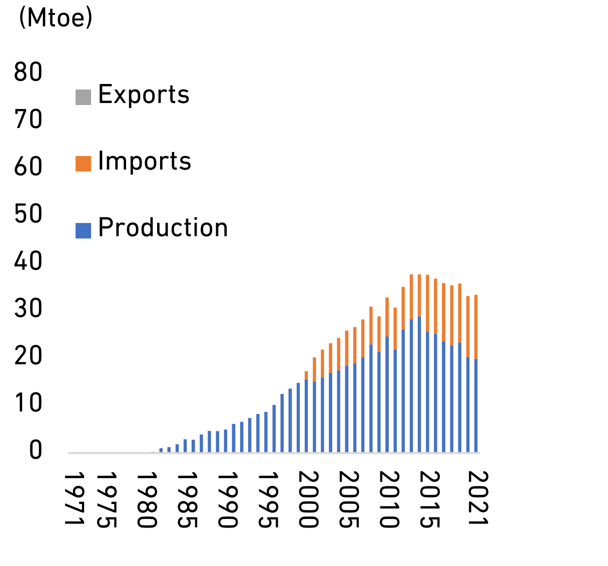


Figure 3.7. Oil Production, Imports, and Exports

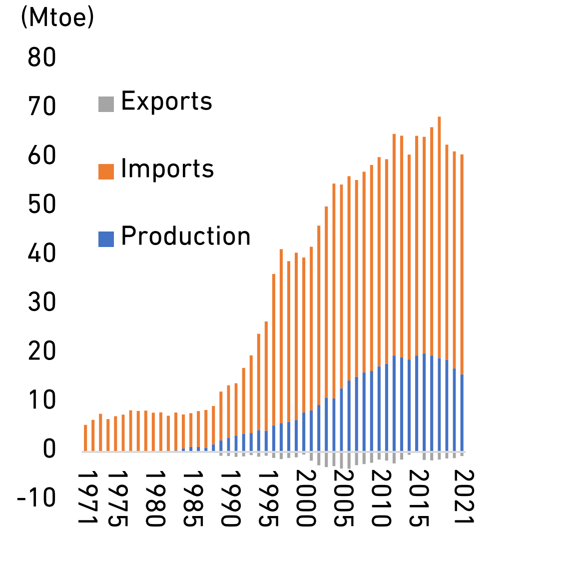


Figure 3.8. Coal Production, Imports, and Exports

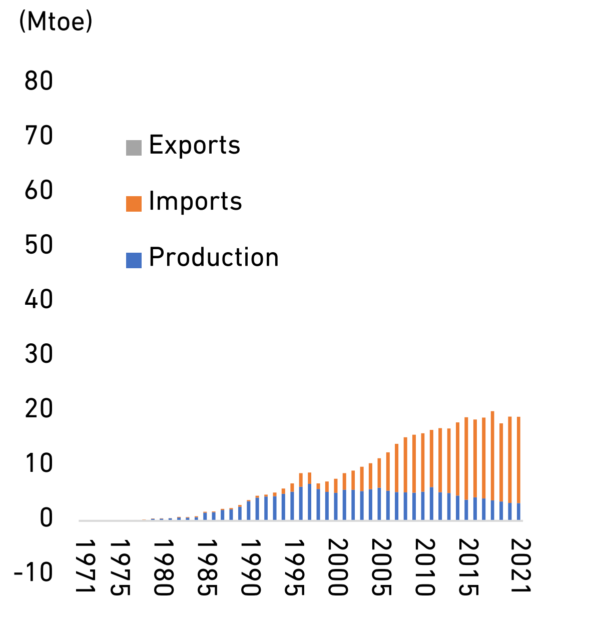
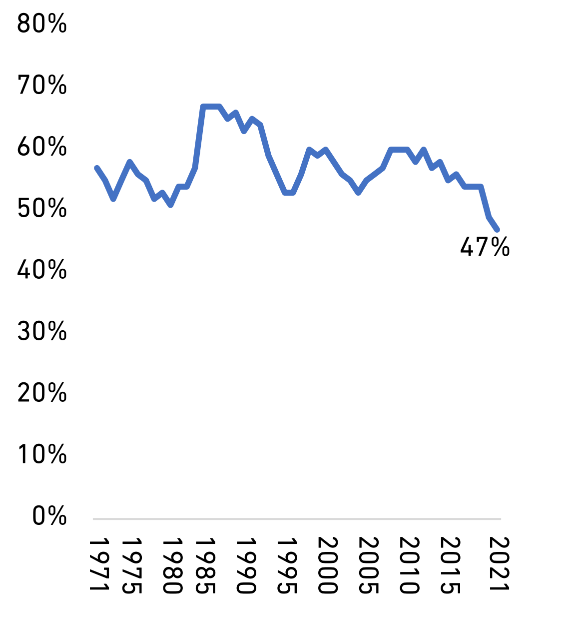


Figure 3.9. Total Energy Self-sufficiency Rate



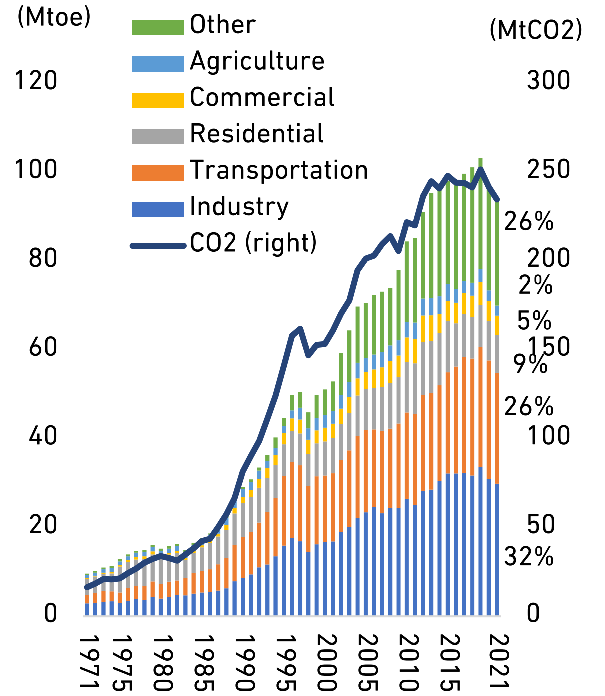
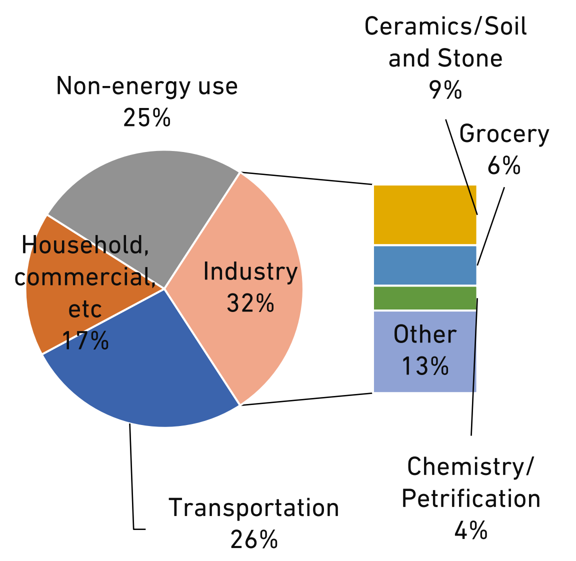
Mtoe = million tonnes of oil equivalent.
Source: Authors based on IEA World Energy Balances (2023).

Figure 3.10 shows the trends in final energy consumption and CO_2 emissions. Focusing on trends in final energy consumption and energy demand by sector and industry as of 2021, much of this demand comes from the industry and transport sectors (Figure 3.10).

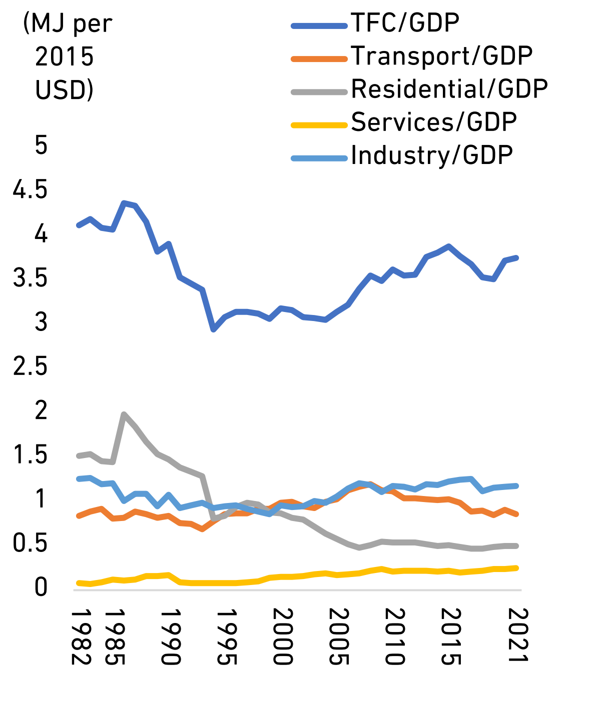
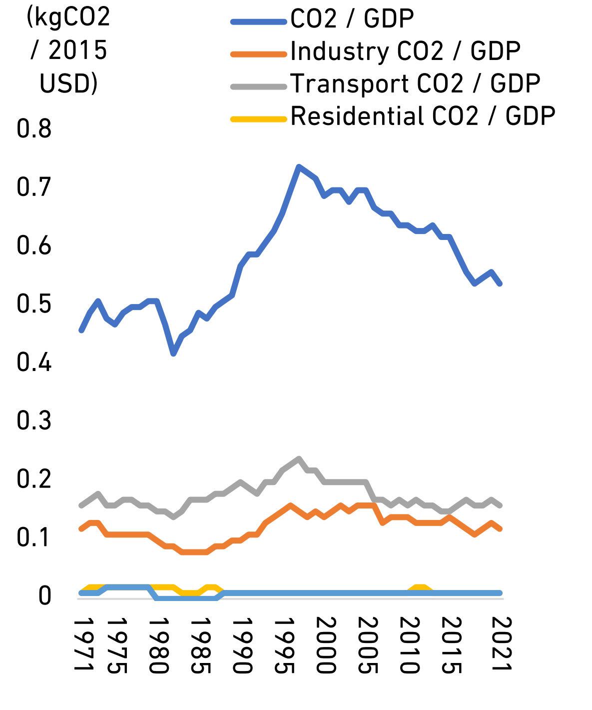
Furthermore, looking at the breakdown of the industry sector, ceramics/soil and stone and chemistry/petrification account for about half (Figure 3.11).

Regarding trends in the degree of energy conservation, improvements have been made in the transportation and housing sectors. On the other hand, the industrial and service sectors are on a deteriorating trend (Figure 3.12).

Also, in terms of carbon intensity, all sectors have shown an improving trend, except recently, but emissions are trending higher in the transport and industrial sectors (Figure 3.13).

Figure 3.10. Final Energy Consumption and CO_2 Emissions from Fuel Combustion	Figure 3.11. Final Energy Consumption in Thailand (2021)
	

Mtoe = million tonnes of oil equivalent.
Source: Authors based on IEA, CO_2 Emissions from Fuel Combustion Statistics: Greenhouse Gas Emissions from Energy and World Energy Balances (2023).

Figure 3.12. Trends in Energy Saving Progress	Figure 3.13. Changes in Carbon Intensity (by sector)
	

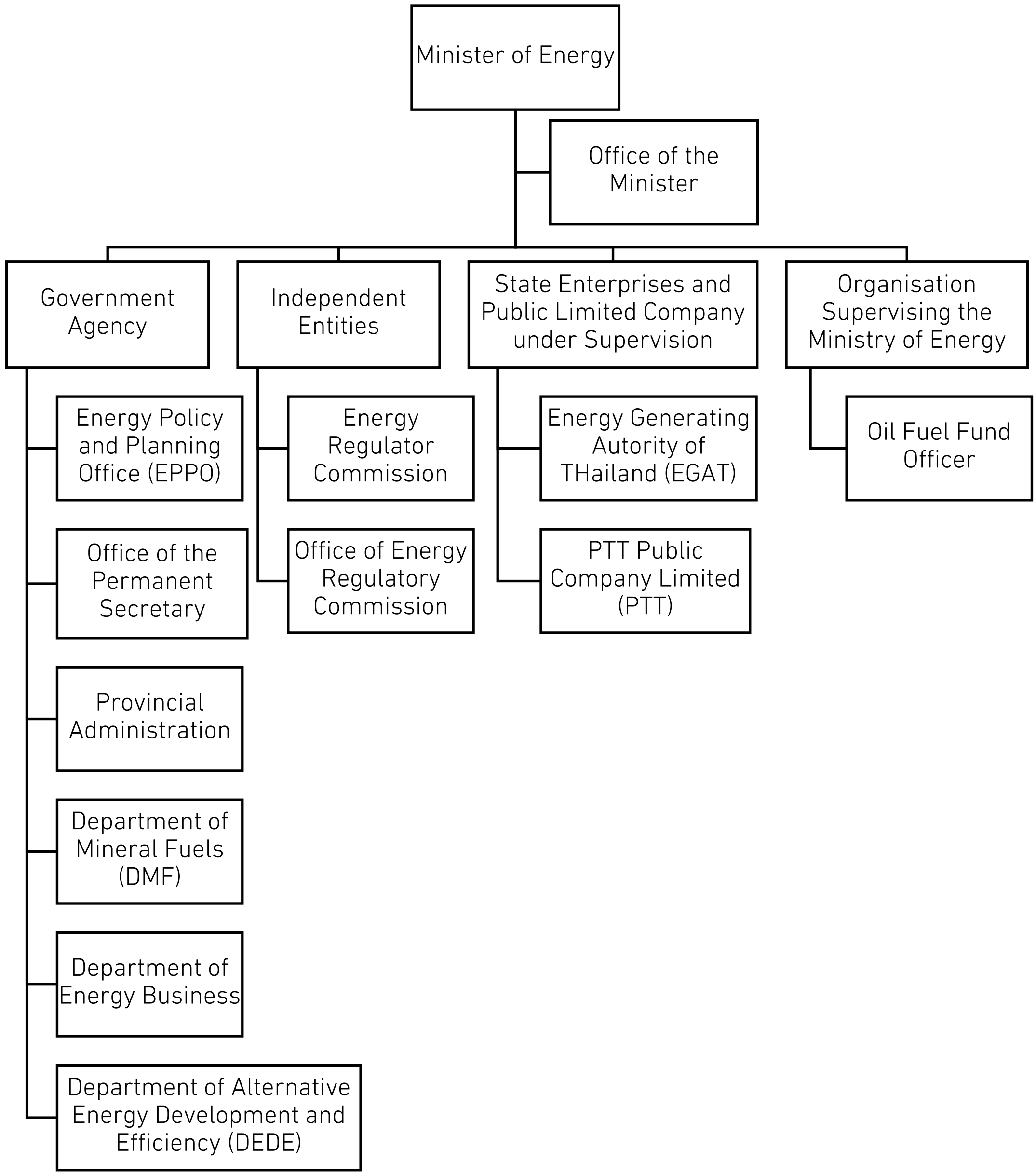
GDP = gross domestic product, MJ = megajoule, TFC = total final consumption, kg = kilogramme.
Source: Authors based on IEA, CO_2 Emissions from Fuel Combustion Statistics: Greenhouse Gas Emissions from Energy and World Energy Balances (2023).

3.1.2. Thailand's Energy Policy

Agencies and departments

The Ministry of Energy oversees energy policy. The departments listed below are under the Department of Energy (Figure 3.14).

Figure 3.14. Department of Energy: Organisation Chart



Source: Authors based on Ministry of Energy.

(a) Energy Policy and Planning Office (EPPO): It monitors energy supply and demand; plans, implements, and evaluates energy policies; and coordinates policies with related organisations. It also operates an Oil Fund with the purpose of preventing domestic energy shortages and stabilising prices.

(b) Department of Mineral Fuels (DMF): It has jurisdiction over the domestic oil and gas upstream sector and is a party to contracts for exploration and development.

(c) Department of Alternative Energy Development and Efficiency (DEDE): It has jurisdiction over regulations related to energy efficiency and energy conservation, as well as research and development of alternative energy.
(d) PTT Public Company Limited (PTT): Its core business is oil and natural gas. It is under the jurisdiction of the Department of Energy.
(e) Electricity Generating Authority of Thailand (EGAT): The core of the electricity business. It is under the jurisdiction of the Department of Energy. It also plays a role as a coal-related administrative agency.

Thailand's Nationally Determined Contribution (NDC)

Here, Thailand's NDC trends will be explained. The timeline is listed in Figure 3.15.

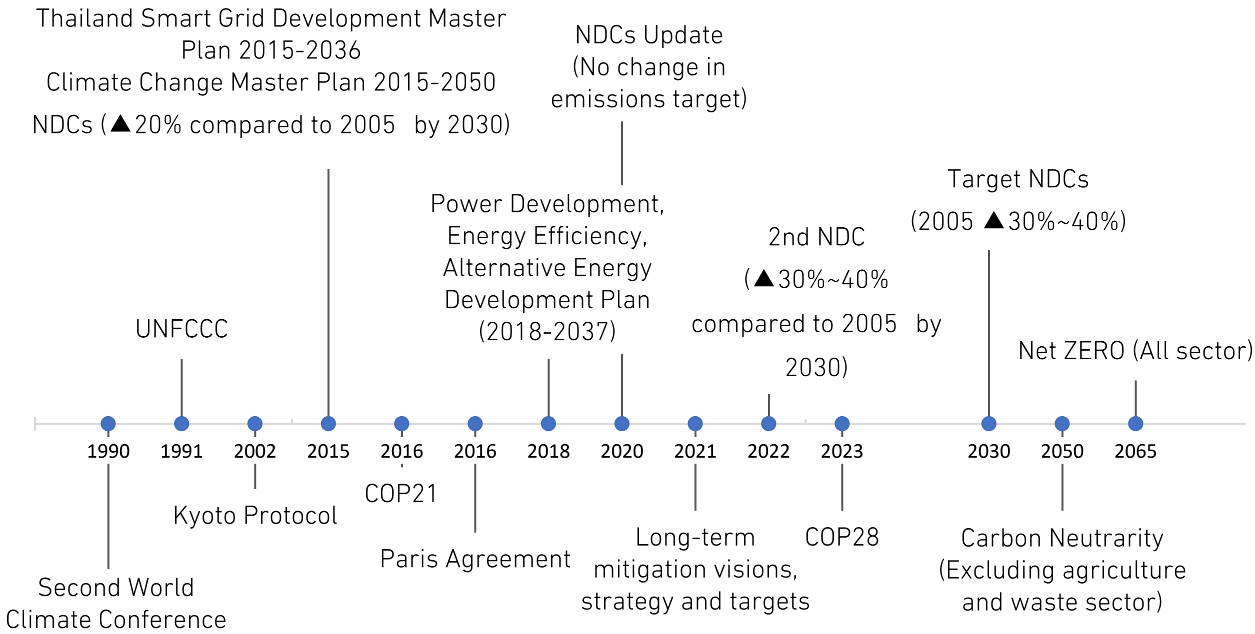
In November 2021, Thai Prime Minister Prayut announced new goals at the United Nations Climate Conference in Glasgow in 2021 (COP26), aiming to achieve net-zero CO_2 emissions by 2050 and net-zero GHG emissions by 2065 (JETRO, 2021). At COP28 in December 2023, the Minister of Natural Resources and Environment Patcharawat reaffirmed the country's commitment to net-zero GHG emissions by 2065.

Under the strategic plan set out below, Thailand has integrated climate change policies, strategies, and plans into its national, sectoral, and municipal plans to address the climate change problem systematically and effectively.

(a) National Strategy (2018–2037)
(b) National Economic and Social Development Plan
(c) Climate Change Master Plan
(d) Nationally Appropriate Mitigation Action (NAMA)
(e) Thailand's Nationally Determined Contribution (NDC)
(f) Long-term Low Greenhouse Gas Emission Development Strategy (LT-LEDS).

To achieve the NDC and LT-LEDS targets, GHG mitigation measures implemented in the energy sector are classified into three main measures: energy efficiency improvement/technology switching, implementation of renewable energy, and carbon capture and storage (CCS).

Figure 3.15. Milestones of Thailand's Nationally Determined Contribution



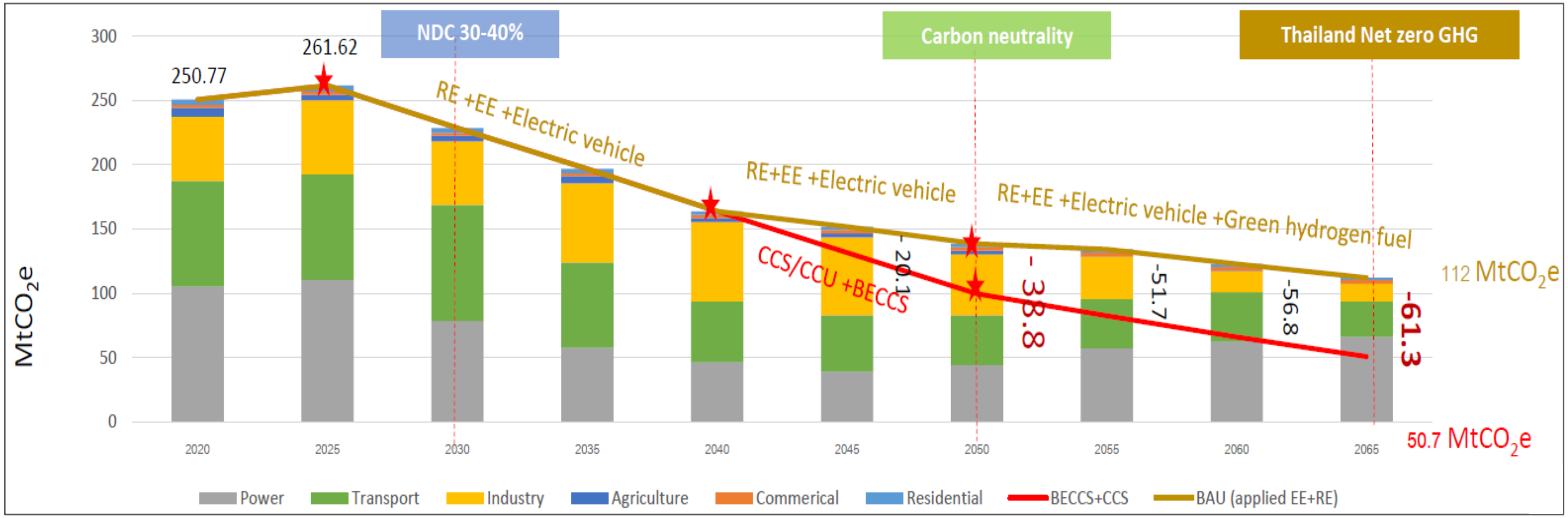
NDC = nationally determined contribution, UNFCCC = United Nations Framework Convention on Climate Change, COP = UN Climate Change Conference.
Source: Authors.

Thailand's carbon neutrality and net-zero greenhouse gas emissions pathway

Thailand's carbon neutrality and GHG net-zero pathway and technology plan of long-term mitigation actions in three key sectors are shown in Figure 3.16 and Table 10.

In this plan, to achieve the 2030 NDC, the development of renewable energy and electricity storage technology, energy conservation, and the spread of biofuels and electric vehicles are positioned as important technologies. Furthermore, since CCU and CCS technologies will be incorporated into the future after 2040, it is necessary that the technologies be established at this point. From 2050 onwards, in addition to the above-mentioned technologies, the spread of green hydrogen fuel is expected to help achieve the NDC goals.

Figure 3.16. Thailand Carbon Neutrality and Greenhouse Gas Net-zero Pathway



NDC = nationally determined contribution, GHG = greenhouse gas, RE = renewable energy, EE = energy efficiency, CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, BECCS = bioenergy with carbon capture and storage, BAU = business as usual.
Source: Department of Mineral Fuels.

Table 3.2. Technology Plan of Long-term Mitigation Actions by Sector

	Transport	Industry	Power
2025	Efficient engine vehicles Renewable (E10, E20, E85, B10, B20) Electric train	Efficient lighting/cooling/motor technologies Renewable (bioenergy) Industrial heat pumps	Energy efficiency Improvement Renewable energy-based technologies Phase out of oil-fired power plants
2030	Phase down of internal combustion engines Most efficient internal combustion engine vehicles Electric vehicle 30@30 Renewable (E10, E20, E85, B10, B20, B100)	Most efficient lighting/cooling/motor technologies Renewable energy (bioenergy)	Solar wind with battery storage
2040			CCS/CCU 68% share of RE electricity Phase down of CFPPs
2045	Most efficient internal combustion engine vehicle with biofuels High share of electric vehicles Fuel cell vehicles	Green hydrogen fuel	
2050		Most efficient electrical devices/boiler Renewable	74% share of renewable energy electricity Combined cycle turbine (natural gas/hydrogen) Phase out of CFPPs Fuel-cell power plants

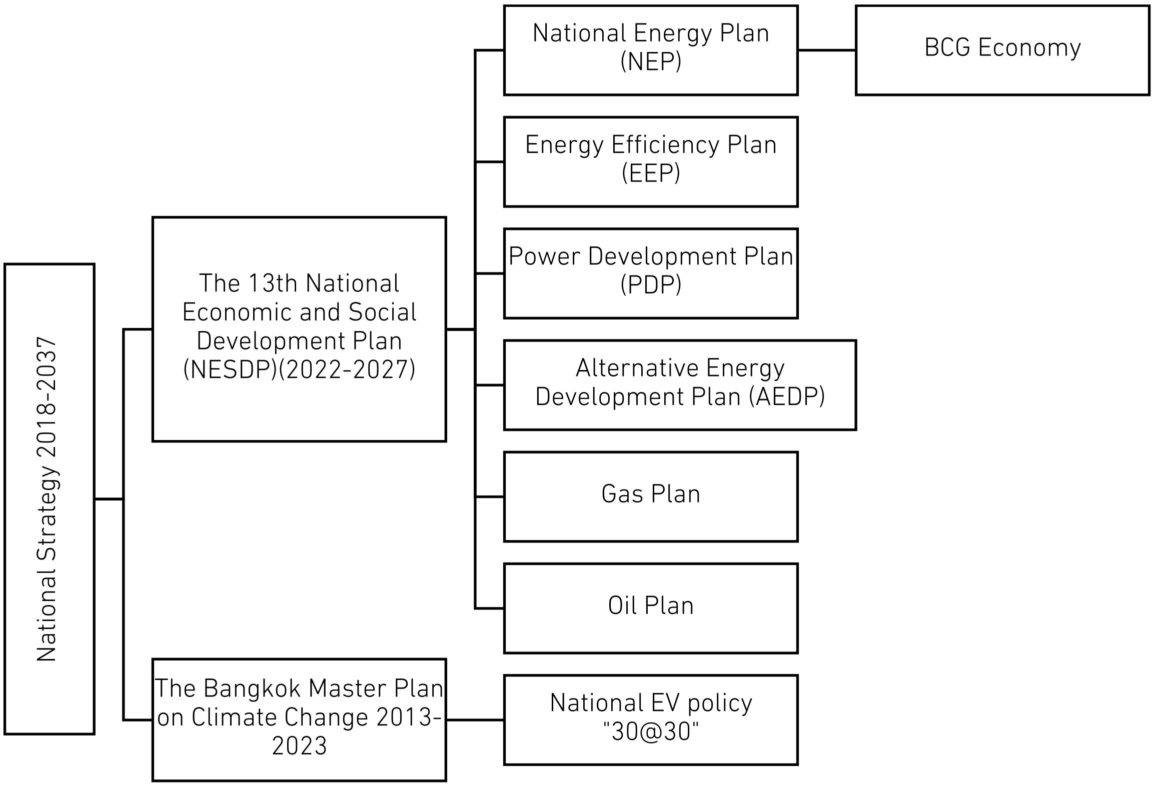
CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, CFPP = coal-fired power plant
Source: Authors.

Medium- and long-term goals in energy policy

Under Thailand's 20-year long-term national development strategy, various national strategic master plans have been created and refined (Figure 3.17).

(a) National Strategy 2018–2037: Long-term national strategy developed under the country's 2017 constitution in Thailand. Various master plans will be formulated under the long-term national strategy.
(b) The 13th National Economic and Social Development Plan (NESDP) (2022–2027): The plan aims to transform Thailand into a high-value-added economy. It has four priorities and 13 milestones (1. High value-added and green economy, 2. High opportunity society, 3. Eco-friendly living, 4. Key enablers for Thailand). Regarding decarbonisation technology, policies and strategies are consistent with priority No. 3 'Eco-Friendly living' and milestone No. 10.
(c) The Bangkok Master Plan on Climate Change 2013–2023: it outlines a comprehensive strategy to address climate change mitigation and adaptation in the city of Bangkok. The plan focuses on various areas, including is environmentally sustainable transport. Under this, Thailand's EV policy '30@30' has been formulated. The policy sets a target for 30% of all passenger cars and pickup trucks produced in Thailand to be electric vehicles by 2030.
(d) The National Energy Policy consists of five plans: Energy Efficiency Plan (EEP), Power Development Plan (PDP), Alternative Energy Development Plan (AEDP), Gas Plan, and Oil plan. Furthermore, various policies and action plans are linked to these five plans.
(e) Energy Efficiency Plan (EEP): This is an updated version of EEDP2015. Under the EEP, seven core measures are laid out to increase the country's energy efficiency, aiming at reducing final energy consumption in 2037 to 30% of the 2010 baseline.
(f) Power Development Plan (PDP): The ratio of power generation fuels in 2037 will be 53% natural gas, 11% coal, 11% hydropower, 19% renewable energy, and 6% energy efficiency improvement. The aim is to expand the total power capacity to 77,211 MW. A total of 25,310 MW of power plants will be shut down by the end of 2037, so an additional 56,431 MW will be needed to reach the target.
(g) Alternative Energy Development Plan (AEDP): By 2037, 30% (38,284 ktoe) of final energy consumption will be supplied from alternative and new energies. Furthermore, by 2037, the cumulative installation targets are 3 GW of wind power, 14.9 GW of solar power (including floating solar power), 5.8 GW of biomass, and 1.6 GW of biogas. The proportion of alternative energy and new energy in the power source mix is expected to be 34.23%.
(h) Gas Plan: Regarding the use of natural gas, the goal is to promote the use of natural gas for environmental measures, accelerate exploration and production of oil and gas fields, expand infrastructure, and strengthen the competitiveness of the natural gas industry.
(i) Oil Plan: It focuses on the management and development of Thailand's oil resources and infrastructure to ensure energy security and meet the country's oil needs. The strategy includes ensuring a stable supply, promoting the use of biofuels, improving the efficiency and competitiveness of the oil supply chain, strengthening infrastructure, and diversifying supply routes.

Figure 3.17. Thailand's Medium- and Long-term Energy Policy Structure



Source: Authors.

The three decarbonisation technologies focused on in this study comply with the policies and national strategies shown below. It should be noted that the National Energy Policy is expected to be revised in late 2024, so changes to the strategy based on the latest situation will be a focus of attention.

(a) Biofuel

The biofuels policy is set out in the AEDP. EPPO presents the basic policy, numerical targets, etc. and DEDE is responsible for specific implementation measures.

(b) Carbon Capture and Storage

CCS is mentioned in Thailand's Long-term Low Greenhouse Gas Emission Development Strategy (LT-LEDS), and the 13th National Economic and Social Development Plan strategic priority No. 3 eco-friendly living and milestone No. 10.

Enhancing the potential use of CCUS technology in power generation is included in the Power Development Plan 2018–2037.

To support CCS, amendment of the Petroleum Act in the Oil Plan is planned. EPPO presents the basic policy, numerical targets, etc., and DMF, EGAT, PTT collaborate for specific implementation measures.

(c) H_2 NH_3

As of April 2024, there is no clear vision or official government policy regarding hydrogen. However, Thailand's Long-term Low Greenhouse Gas Emissions Development Strategy (LT-LEDS) recognises hydrogen as an important mitigation strategy for reducing emissions in the power, industrial, and transport sectors.

3.2. Thailand Research and Development Maps

3.2.1. Power Sector

Thailand will see major changes in the future, including decentralisation of power supply, decentralisation of the market, smaller transmission and distribution networks, two-way power distribution, and active consumer participation in the energy system.

A National Energy Plan is currently being formulated in preparation for the energy transition. It includes the following four points:

(a) Increasing the proportion of renewable energy power generation (50% or more in the power development plan)
(b) Domestic production of EVs (30% by 2030)
(c) Improving energy efficiency by 30% or more
(d) Reconstructing energy through decarbonisation, digitalisation, decentralisation, deregulation, and electrification (4D1E)

In the power and energy sector, decarbonisation is mainly separated into the two components of power generation and storage. Currently, in these sub-sectors, various technological developments are progressing towards and decarbonisation (Table 3.3).

In addition, regarding nuclear power generation, Thailand is positive about introducing it. Most recently, in April 2024, Global Power Synergy Public Company Limited signed a memorandum of understanding (MOU) with Denmark's Seaborg Technologies ApS to investigate the possibility of introducing floating nuclear power plants.

Table 3.3. Research and Development Map of Power Sector

Sub-Sector	Technology	Priority	Not Existing	Fundamental research	Applied research	Prototype	Demonstration	Commercial
Renewable Power	Perovskite Solar	High				✓		
	PV Power /Floating PV	High						✓
	Onshore Wind	Low						✓
	Offshore/Implantable offshore/Floating offshore	Low		✓				
Thermal Power	H_2 co-firing / mono-firing	Very High					✓	
	NH_3 co-firing / mono-firing	Very High		✓				
	CCS	Very High		✓				
Supply and demand balance adjustment	DR/VPP	High					✓	
	Redox Flow battery	High			✓			
	All solid-state battery	High			✓			
	Sodium-ion battery	High				✓		
	Lithium-ion battery	High						✓
	Lithium-ferro-phosphate battery	High						✓

CCS = carbon capture and storage, DR = demand response, PV = photovoltaic, VPP = virtual power plant.
Source: Authors.

3.2.1.1. Sub-sector (Renewable Power)

- **Solar power related**

Thailand is encouraging wind, solar, hydro, biomass, biogas, and waste-to-energy generation.

Solar power has particularly great potential, and the government is placing emphasis on expanding its use of solar power in power generation. Solar power is already being commercialised; in 2007, the Adder scheme was introduced to purchase renewable energy sources at a fixed electricity price plus a premium. In 2013, the Adder scheme was replaced by the feed-in tariff (FIT) scheme. As a result of the widespread use of solar power generation, in 2018 the purchase price was lowered to B2.4 per kWh, the same as for fossil fuel power generation. Also, in June 2021, EGAT announced a policy to raise the power supply target for floating solar power generation included in the Power Development Plan (PDP2018_Rev.1). As mentioned above, solar power generation technology and policies have made considerable progress but there are no next-generation technologies such as bendable solar power generation (perovskite).

- Wind power related

DEDE has been conducting research on the potential of wind power generation since 1975. Wind power generation is expected to play an important role in the future in Thailand as well, and large-scale wind power generation projects are underway with the goal of increasing installed wind power capacity to 3 GW by 2037. However, solar power generation is given priority. Most wind power projects are based on onshore wind power, and offshore wind power is currently being researched.

3.2.1.2. Sub-sector (Thermal Power)

For Thailand, which has a high proportion of gas-fired power generation, technology to decarbonise thermal power generation is extremely important. Therefore, towards decarbonising thermal power, three decarbonisation technologies (hydrogen, ammonia, and CCS) are important.

- H_2 co-firing/mono-firing

Hydrogen power generation can utilise existing infrastructure. Thailand's existing natural gas-fired power plants can be retrofitted to co-fire hydrogen blends without major modifications, enabling the transition to low-carbon power generation while leveraging existing assets and infrastructure. Demonstrations of hydrogen co-firing have already been carried out, and various projects have been launched on EPPO and EGAT.

The government has concluded MOUs with Japan's JERA, Mitsubishi Heavy Industries, Mitsui O.S.K. Lines, Mitsubishi Corporation, Chiyoda Corporation, and others to conduct research and collaborate.

Hydrogen has the potential to replace 20% of the natural gas and liquefied natural gas currently used as leading sources of fuel for power generation in Thailand. In the power plants shown in Figure 3.18, in the future the H_2 mixture in the gas turbine may be planned at 5% to 20% volume.

Figure 3.18. Pilot Case (co-firing fuel in power generation)

Wangnoi, Ayuthaya: 2 x 750 MW

Nam pong power plants,
Korn Kaen: 2 x 325 MW

South Bangkok Power Plant

Bangprakong, Chachoengsao: 2 x 700 MW

MW = megawatt.
Source: Energy Research Institute (ERI), Chulalongkorn University.

- NH_3 co-firing/mono-firing

Regarding ammonia, Thailand has signed an MOU with a Japanese company for co-firing up to 20% ammonia at the BLCP coal-fired power plant (1,434 MW). Elsewhere, Quezon Power and Doosan are exploring ammonia co-firing at EGCO Group's Quezon power plant in the Philippines, and PTT Global Chemical and Mitsubishi Heavy Industries are developing a carbon-neutral petrochemical complex powered by ammonia-fuelled gas turbines. Unlike hydrogen, it is still at the stage of fundamental research.

- Carbon Capture and Storage

CCS in Thailand is in its early stages, and its main purpose is domestic CO_2 storage. CCUS has not been demonstrated for the use of carbon dioxide. PTTEP plans to conduct CCS operations at an offshore natural gas field (Arthit Gas Field CCS) in the Gulf of Thailand. The implementing entities are 80% owned by PTTEP (operator), 16% owned by Chevron, and 4% owned by MOECO. The plan is to inject 700,000 to 1 million tons of CO_2 per year into depleted gas fields by 2026.

Although the introduction of a carbon price is a prerequisite, it will be pointed out that Thailand has the potential to function internationally as a CCS hub due to its geographical location (being halfway between Australia, the Middle East, and East Asia), domestic gas fields, and pipelines..

Sub-sectors (supply and demand balance adjustment)

- Demand Response/Virtual Power Plant

Thailand is actively developing virtual power plant technology and demand response technology projects to improve the efficiency of its power system and support the country's transition to a low-carbon economy.

In 2015, the government released the Smart Grid Development Master Plan 2015–2036. The plan is being developed in stages, divided into short term (2017–2021), medium term (2022–2031), and long term (2032–2036). There are VPPs for which pilot projects and trials are currently underway. For example, EGAT is developing the necessary infrastructure and regulations to support the integration of new energy technologies such as VPP and EV-to-grid (V2G) systems, in line with Thailand's smart grid development plan.

In August 2021, it was reported that EGAT plans to invest B242,567 million over the 10-year period from 2021 to 2030 to improve the power transmission network. The plan will revamp the inefficient power transmission network by investing in high-voltage cables and smart grids.

- Battery related

Thailand also plans to actively incorporate electricity storage technology to adjust supply and demand as renewable energy sources increase. It is certain that electricity storage will be used to adjust electricity supply and demand within Thailand, but its importance as a domestic technology and industry is slightly different from that of hydrogen, ammonia, and CCS.

Various interviews revealed that in Thailand, just like automobiles, assembly is the main activity for batteries. The business model seems to be to import battery parts, assemble them at a factory in Thailand, and then export the batteries.

If Thailand could handle everything from development to export sales domestically, it would be very effective from the perspective of in-house production of decarbonisation technology, but currently the focus is on assembly, and study teams have determined that its importance for industry in Thailand will decrease slightly.

3.2.2. Transport Sector

3.2.2.1. Automobiles

Thailand is one of the automotive industry hubs in Southeast Asia. However, assembly is the main area, and core technologies such as engines for Internal Combustion Engine (ICE) vehicles and batteries for BEVs are provided by the car manufacturer's home country. Therefore, regarding automobile batteries, the country does not have its own technology, and assembles them as parts. To overcome this current situation, Thailand's state-own oil company PTT has launched an EV business company, ARUN PLUS (100% subsidiary of PTT). It also entered a partnership with Taiwan's Foxconn. ARUN PLUS plans to accelerate EV investment in Thailand to expand EV-related equipment such as EV charging facilities and EV batteries. Figure 3.20 shows a prototype of BEV of ARUN PLUS.

Figure 3.20. Prototype of Battery Electric Vehicle

Source: ARUN+ (accessed 23 April 2024).

The government is implementing the 30@30 strategy, which aims to increase the proportion of zero-emissions vehicles such as electric vehicles (EVs) in domestic car production to 30% by 2030. According to an announcement by Thailand's Ministry of Transport, the number of registered EVs rapidly increased to 2.78% (approximately 82,700/2.97 million units) in 2022. The Thailand Board of Investment (BOI) gives the green light for the latest support programme (EV 3.5) such as subsidies to achieve the targets (Table 3.4).

Table 3.4. Main Electric Vehicle Support Programmes in Thailand

Programme	Contents
Sales subsidy (2024–2027)	- Electric passenger cars priced not exceeding B2 million and with battery capacity not less than 50 kWh will be subsidised in the range between B50,000–B100,000 per unit. Those with battery capacity less than 50 kWh will be subsidised at B20,000–B50,000 per unit. - Electric pickup trucks priced not exceeding B2 million and with battery capacity not less than 50 kWh will be subsidised in the range between B50,000–B100,000 per unit. - Electric motorcycles priced not exceeding B150,000 and with battery capacity not less than 3 kWh will be subsidised in the range between B5,000–B10,000 per unit.
Tax reduction	As part of the EV 3.5 package, electric passenger cars priced not exceeding B7 million will be incentivised with the reduction of excise tax from 8% to 2%.
Reduction of imports (2024–2025)	Whilst electrical passenger cars priced not exceeding B2 million , importing EVs as completely built-up units (CBUs) during the first 2 years (2024–2025) will benefit additionally by a reduction in import duties of up to 40%.
Application condition	The conditions for receiving this support measure are as follows. If EV production is to begin in Thailand by 2026, it will be mandatory to produce at least twice the number of completed EV vehicles imported using the relevant subsidy, and if production begins in 2027, it will be obligatory to produce at least three times as many EVs.

B = baht, kWh = kilowatt-hour, EV = electric vehicle.
Note: The relevant agencies will discuss further to stipulate the subsidy rate as appropriate and make proposals for the cabinet's approval.
Source: Authors based on Board of Investment (2023).

In addition to BEVs, the Board of Investment (BOI) has made fuel cell vehicles (FCVs) eligible for preferential treatment from 2023. BOI's EV promotion policy obliges EV manufacturers that receive preferential treatment to produce specified major parts in Thailand within a certain period from the start of production of the vehicle body and provides subsidies. Companies that import and sell BEVs using the system will also be required to produce batteries (cells/modules) domestically from 2026. This is expected to create a domestic supply chain for EV parts in the future.

On the other hand, the production of internal combustion engine (ICE) vehicles is also eligible for machinery import duty exemption. The reason why Thailand continues to offer a wide range of preferential treatment, including for ICE vehicles, is that approximately half of the cars produced domestically are exported. Export destinations include emerging countries, and it is expected that a certain level of demand for ICE vehicles will continue in emerging countries. To meet the wide range of demand from such export destinations, Thailand aims to become an EV manufacturing hub within the ASEAN region, while at the same time also trying to maintain production of ICE vehicles.

As mentioned above, Thailand also places great importance on ICE vehicles, and since many ICE vehicles are currently on the road, Thailand is also keen to decarbonise existing fuels (gasoline, diesel). As shown in Section 3.1, the transport sector ranks first in carbon intensity. Therefore, reducing carbon dioxide emissions from gasoline and diesel vehicles is an urgent issue. Especially, Bioethanol fuel and biodiesel have a long history and are very common in Thailand. As will be discussed in detail in Section 3.4, biofuels are important as decarbonised fuels for the time being and are positioned as the highest priority net-zero techs. Thailand's carbon neutrality and GHG net-zero pathway and technology plan of long-term mitigation actions shows that biofuels and EVs are positioned as important technologies (Table 3.5). Lastly, Thailand aims to pursue the best mix of the most efficient ICE vehicle with biofuels, electric vehicles, and fuel cell vehicles in the future.

Table 1.5. Key Technologies of Long-term Mitigation Actions in the Transport Sector

2025	2030	2045
• Efficient engine vehicles • Renewable energy (E10, E20, E85, B10, B20) • Electric trains	• Phase down of internal combustion engines (ICE) • Most efficient ICE vehicles • Electric vehicles 30@30 • Renewable energy (E10, E20, E85, B10, B20, B100)	• Most efficient ICE vehicles with biofuels • High share of electric vehicles • Fuel cell vehicles

Source: Authors based on Department of Mineral Fuels.

3.2.2.2. Aviation

The aviation sector is one of the hardest sectors for abating greenhouse gases (GHG). It is difficult to electrify aeroplanes, and although there are hopes for aeroplane technology that utilises hydrogen in the future, commercialisation will take time. In addition to being easy to secure raw materials for sustainable aviation fuel (SAF), the SAF project will contribute to the realisation of the bio, circular, green (BCG) economy that the Thai government is promoting. Thus, SAF is vital technology as well. Thai Airways International

(THAI) is promoting the commercialisation of SAF, including partnering with PTT Oil and Retail Business Public Company Limited (OR), to introduce SAF on flights between Phuket and Bangkok. In June 2023 Thailand's Bangchak Group became the first company in Thailand to produce SAF from waste cooking oil (Bangchak, 2023).

As mentioned above, Thailand will continue to develop technologies for biofuels, BEVs, and FCVs in line with progress toward carbon neutrality. Thailand will move forwards with in-house production of battery technology, and at the same time will proceed with the development of next-generation biofuels. FCVs are at the demonstration stage; however, Thailand is accumulating hydrogen technology. Biofuels are expected to continue to be used after 2045 and are a technological field with the highest priority in promoting current decarbonisation.

Table 3.6 shows the R&D map by each sub-sector in the transport sector.

Table 3.6. Research and Development Map of the Transport Sector

Sub-Sector	Technology	Priority	Not existing	Fundamental research	Applied research	Proto type	Demonstrati on		Commercial
Automobiles	Hybrid EV	High							✓
	Plug-in Hybrid EV	High							✓
	Battery EV	High							✓
	Fuel cell EV	High					✓		
	Rapid charger	High							✓
	Hydrogen refuelling station	High					✓		
	Biofuel (E10, etc.)	Very High							✓
	Biodiesel (B10, etc.)	Very High							✓
	Advanced biofuel cellulosic ethanol, HVO, HEFA	Mid			✓				

Sub-Sector	Technology	Priority	Not existing	Fundamental research	Applied research	Proto type	Demonstration		Commercial
	Advanced biofuels: BTL fuels	Mid			✓				
	E-fuel	Low	✓						
	Automated driving technology	Mid					✓		
Railway	Fuel cell train	Low	✓						
	Diesel hybrid train	Low	✓						
	Battery Train	Low					✓		
Aviation	Sustainable aviation fuel (SAF)	High					✓		✓
	Electric hybrid aeroplane	Low	✓						
	Hydrogen aeroplane	Low	✓						
Navigation	Ammonia hydrogen fuel vessel	Mid					✓		
	Biofuel ship	Low	✓						
	E-fuel ship	Low	✓						

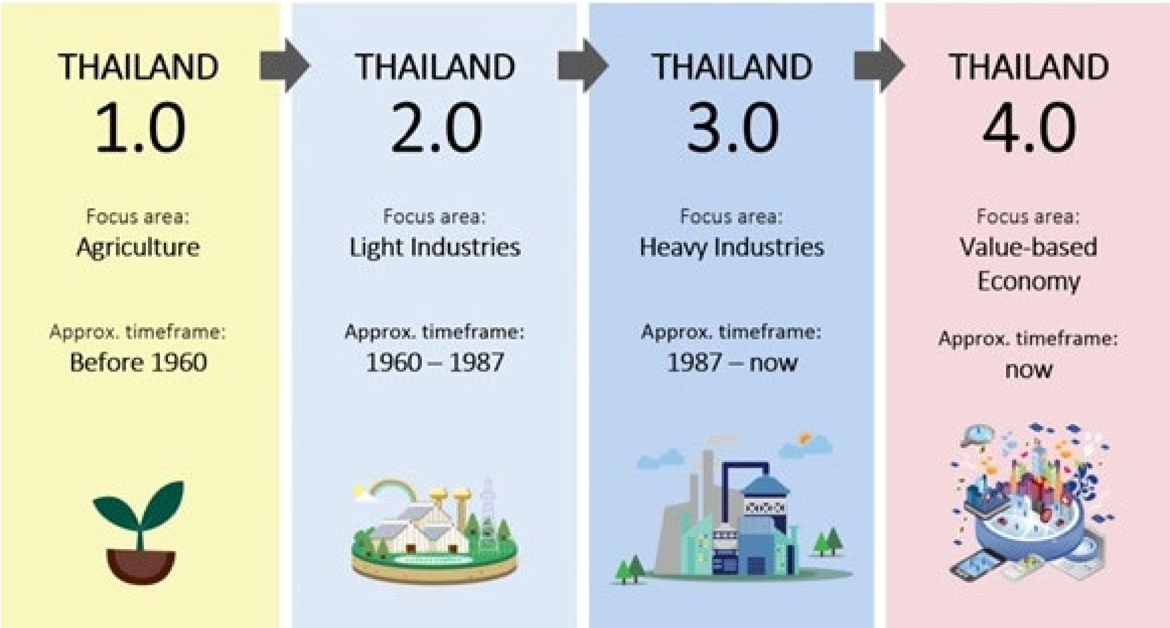
BTL = biomass to liquid, EV = electric vehicle, HVO = hydrotreated vegetable oil, HEFA = hydroprocessed esters and fatty acids.
Source: Authors.

3.3. Three High Priority Areas for Thailand

3.3.1. Related Economic and Energy Policies

Over several decades, Thailand has progressed through three economic development phases. In the first phase, Thailand 1.0, emphasis was placed on the agriculture sector. Then came Thailand 2.0, with the focus on light industries, enabling the nation to upgrade from a low-income to a middle-income economy. In the third phase, Thailand 3.0, the focus was shifted to heavy industries to sustain economic growth. During this period, however, Thailand's economic growth became stagnant, facing the situation of the 'middle-income-trap' syndrome, whilst the country was also confronted with disparities and imbalanced development. To cope with these challenges, Thailand 4.0 policy was introduced. Thailand 4.0 aims to transform the current economy to one that is much more innovation-driven – shifting from traditional farming to smart farming, from labour to knowledge workforce, and from importing technologies to inventing innovative solutions (Figure 3.20).

Figure 3.20. Thailand 4.0

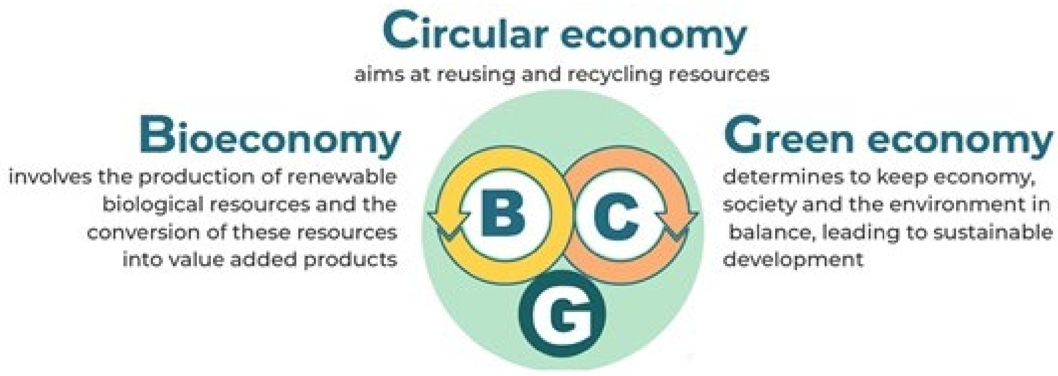


Source: NSTDA, 'BCG Model' (accessed 7 May 2024).

To revive the economy, which has fallen due to the impact of the novel coronavirus, the Thailand government is strengthening agriculture and biotechnology, in which the country has strengths, as well as promoting the BCG economy. In January 2021, the government will include BCG in its national agenda alongside Thailand 4.0. BCG will be a vehicle to modernise Thailand's agriculture sector, establish national health security, and reduce foreign dependency. The BCG Committee approved the 2021–2026 BCG Strategic Plan. The BCG Strategic Plan will focus on four sectors: 1) food and agriculture, 2) medical and wellness, 3) bioenergy, biomaterial, and biochemical, and 4) tourism and creative economy.

BCG has been conceptualised to drive economic and social development. BCG is an integration of bioeconomy, circular economy, and green economy (Figure 3.21).

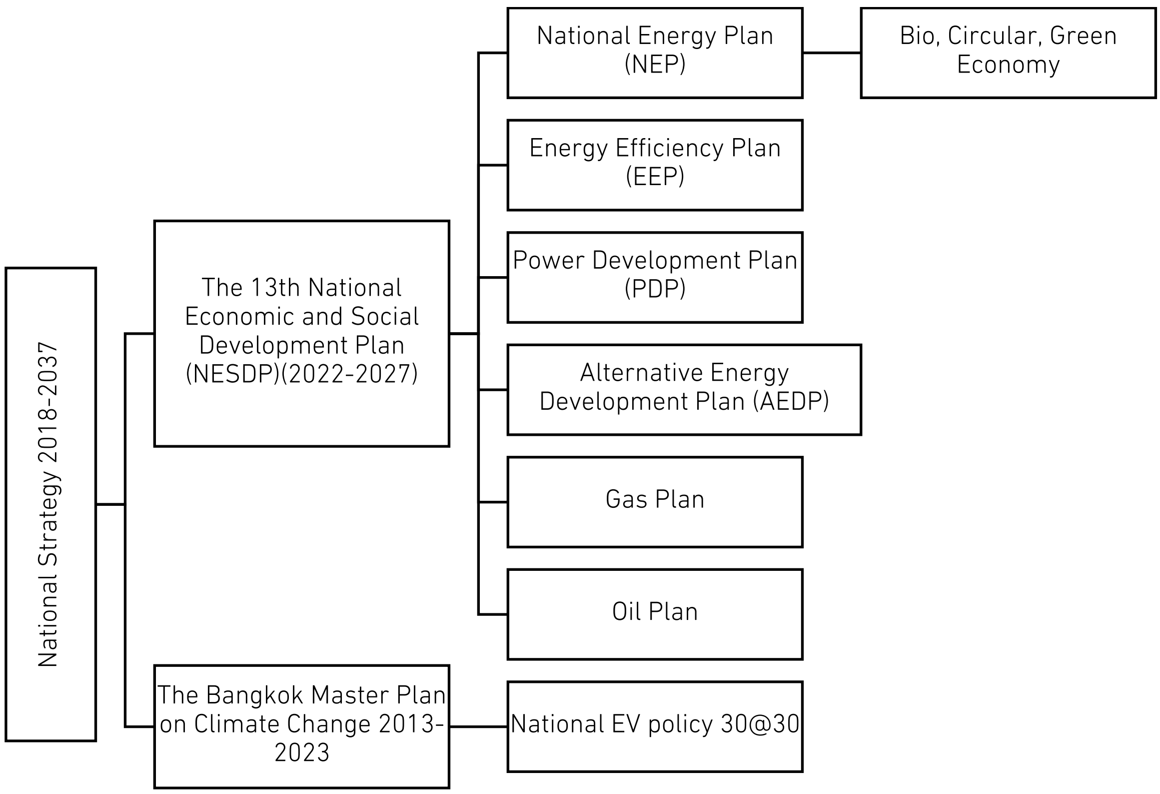
Figure 3.21. Bio, Circular, Green Concept



Source: NSTDA 'BCG Concept' (accessed 7 May 2024).

Also, it should be confirmed here that the BCG economy is a subordinate concept of energy-related policies (Figure 3.22) (Table 15). Technologies that are particularly consistent with this subordinate concept are the decarbonisation technologies promoted by the government, which have a high priority in solving domestic issues and allow for the maximum use of domestic resources.

Figure 3.2. Thailand's Medium and Long-term Energy Policy Structure (repost)



Source: Authors.

Table 3.7 Five Action Plans for Bio, Circular, Green Economy on Energy

Action Plans on Green Energy	1. Adjust power and heat production portfolio to low carbon
	2. Adjust the energy consumption and production in transport sector to low carbon
	3. Increase energy efficiency
	4. Biorefinery
Actions Plans on Carbon Sink	5. Increase CO_2 absorption

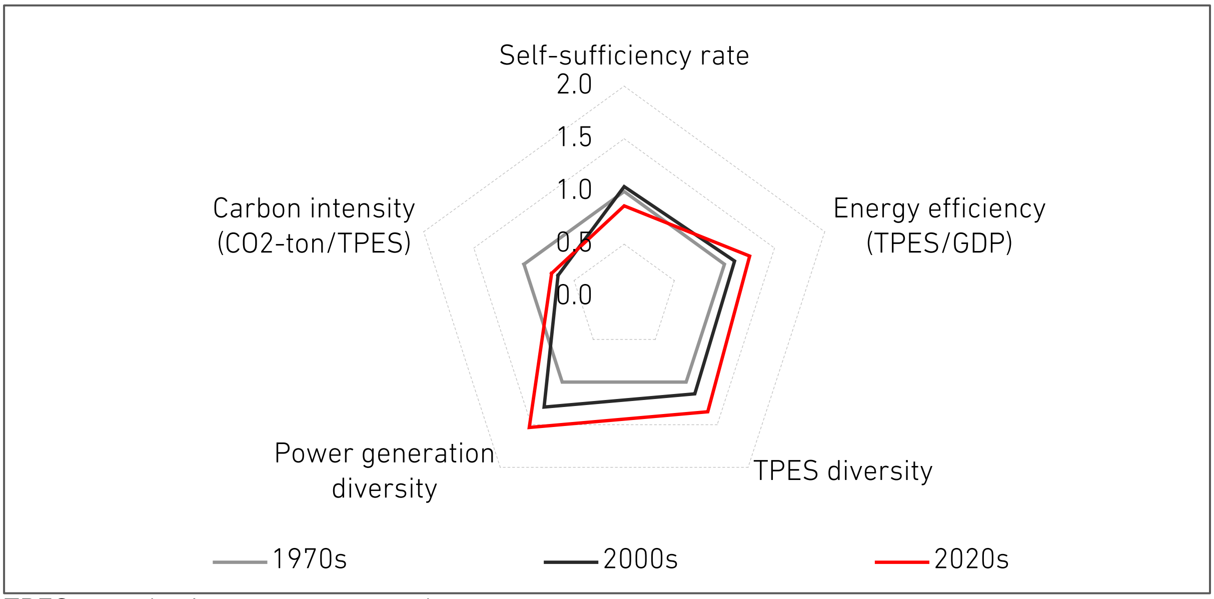
Source: Authors.

3.3.2. External Environment

There is a macro situation that supports the priority of superordinate concepts. Most of this is a reprint of Section 3.1. Figure 3.23 shows an index of energy trends up to the 2020s, with the 1970s as 1, and the self-sufficiency rate is on the decline.

First, there is the decreasing energy self-sufficiency rate and worsening carbon intensity due to increasing energy demand (the higher the number, the better).

Figure 3.23. Changes in Thailand's Energy System



TPES = total primary energy supply.
Note: The index was calculated using the 1970s as 1. The higher the number, the better.
Source: Authors based on IEA World Energy Balances (2023).

Second is the increasing demand for energy. Figure 3.24 and Figure 3.25 shows trends in total primary energy supply and demographic and GDP changes, and the continued use of fossil fuels is important to support Thailand's rapid economic growth.

Figure 3.24. Total Primary Energy Supply

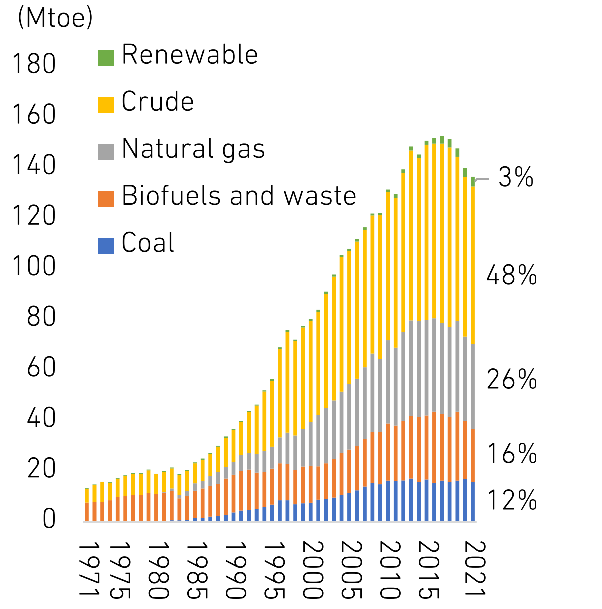
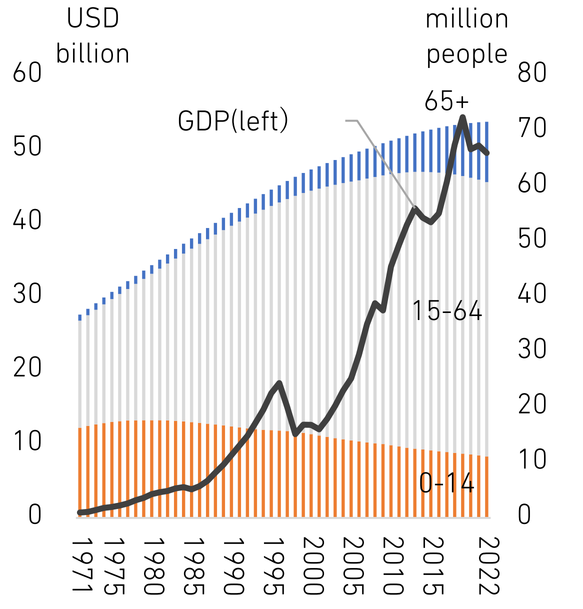


Figure 3.25. Changes in Demographics and GDP



Mtoe = million tonnes of oil equivalent, GDP = gross domestic product.
Source: Authors based on IEA's World Energy Balances (accessed 13 May 2024).

3.3.3. Three Areas of High Priority for Thailand

Based on the current situation of Thailand (economy, energy, strategy, and policy), and alignment with BCG's five-point energy action plan (1. Adjust power and heat production portfolio to low carbon, 2. Adjust the energy consumption and production in transport sector to low carbon, 3. Increase energy efficiency, 4. Biorefinery, 5. Increase CO_2 absorption), for Thailand, where the use of fossil fuels continues to be important, from the perspective of using technology that can decarbonise fossil fuels and utilising the country's own resources, the top three high priority items are biofuel, CCS, and H_2 (Figure 3.26).

Figure 3.26. Top Three Very High Priority Items

Biofuel	CCS	Hydrogen

CCS = carbon capture and storage.
Source: Authors.

For Thailand, promoting and developing H_2/NH_3 and CCS projects with regional cooperation will help improve carbon intensity and achieve carbon neutrality by 2060. In addition, Thailand has an abundance of agricultural products and abundant renewable energy (solar resources), so the development of biomass and renewable energy will help improve the country's energy self-sufficiency rate.

3.4. Three Important Technologies

3.4.1. Biofuel

Thailand's advantages in bioeconomy

BCG economy aims to modernise Thailand's agricultural sector and reduce foreign dependency. As Thailand is blessed with robust agricultural activities, rich natural resources, and diversity in term of both biological resources and physical geography, the country is in an excellent position to take on bioeconomy. Thailand is amongst the top producers and exporters of several agricultural commodities, including rice, cassava, sugarcane, and palm oil (Figure 3.27). Some of these crops are significant to both food and energy security. Currently, Thailand is blessed with an abundance of biofuel raw materials such as sugar and cassava, and there is no conflict with food sources.

Figure 3.27. Thailand's Competitive Advantages in Bioeconomy

Products	World Ranking	2017 Export Value (Billion USD)	Share of World's Exports
Cassava	1 st	2.75	50%
Sugar	2 nd	2.6	9.4%
Rice	2 nd	5.2	24.9%
Palm Oil	9 th	0.216	0.6%

www.boi.go.th


Cassava


Sugar cane


Palm oil

	Components	Biochemicals		Bio-based Products
Cassava	Starch	Ethanol	Butanol	
	Root	Methane	Citric Acid	
	Pulp	Lactic Acid	Succinic Acid	
Sugar cane	Bagasse	Bioisoprene	Ethanol	
	Root	Succinic Acid	Butanol	
	Internode	Designer Oils	Butanol	
Palm oil	Palm Fibers	Triterpene Alcohol		
	Sludge Oil	4-Methyl Sterols		
		Triacylglycerol		
		Fatty Acid	Sterols	

Bio-based Products:

Animal Feed

Bio fuels
- Biodiesel
- Olefins
- Vegetable Oil
- Bioethers

Foods
- Sweetener
- Cooking Oil
- Food Additives

Bio plastics
- Polylactic (PLA)
- Poly-3-hydroxyburyrate (PHB)
- Polyamide 11 (PA 11)
- Polyethylene (PE)

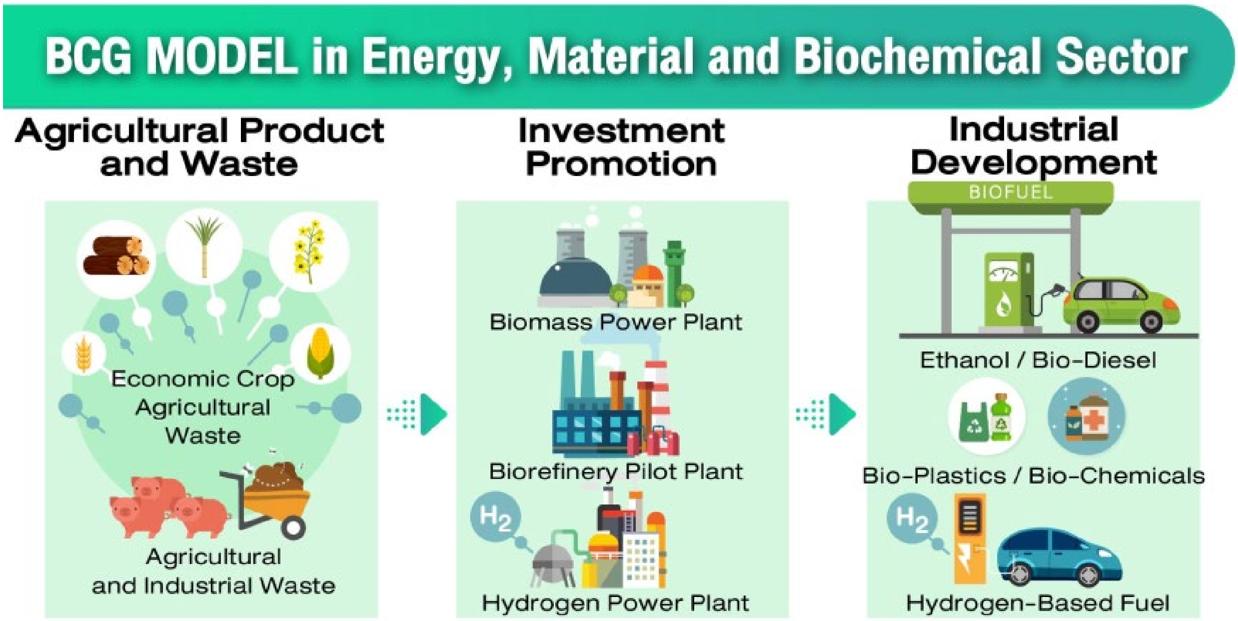
Other Bio-based Products
- Pharmaceuticals
- Cosmetics
- Paper

***www.boi.go.th

Source: NSTDA website 'Thailand's Competitive Advantages in Bioeconomy' (accessed 7 May 2024).

On the other hand, 60% of energy consumed in Thailand is imported and only 15.5% of domestic energy production come from RE. The challenges for the energy sector are energy security and reduction in energy the imports. To modernise Thailand's agricultural sector and reduce foreign dependency, Thailand aims to utilise the agricultural product and waste, biofuel (ethanol, biodiesel) in the agricultural, energy, and transport sectors. BCG model in energy, material and biochemical sector is as follows (Figure 3.28):

Figure 3.28. Bio, Circular, Green Model in Energy, Material, and Biochemical Sector

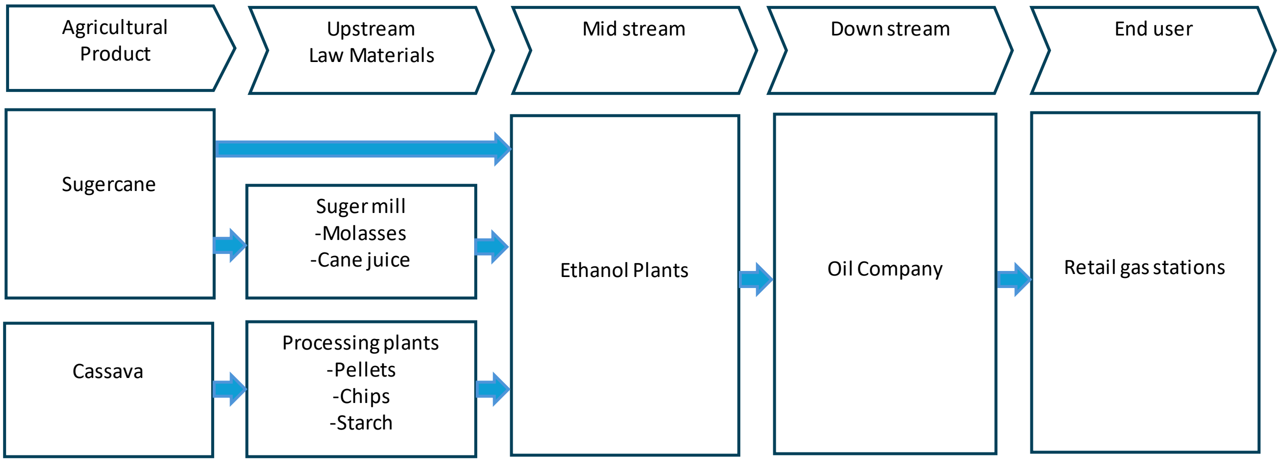


Source: NSTDA, 'BCG Drivers' (accessed 7 May 2024).

Ethanol supply chain

In the supply chain for ethanol production from sugarcane, sugarcane is transported to mills for processing into sugar. Molasses, a by-product, is sent to ethanol plants to be converted into ethanol, which is blended with benzene to produce gasohol 91 and gasohol 95 for distribution to retail gasoline outlets nationwide. Sugarcane can also be processed directly into ethanol. The supply chain for cassava is like that of sugarcane, except that cassava can be made into chips, pellets, and starch for food and non-food industries and for animal feed. It can be delivered directly to ethanol plants for processing and later blended with gasoline into gasohol by oil companies (Figure 3.29).

Figure 3.29. Supply Chain of Ethanol Production from Sugarcane and Cassava

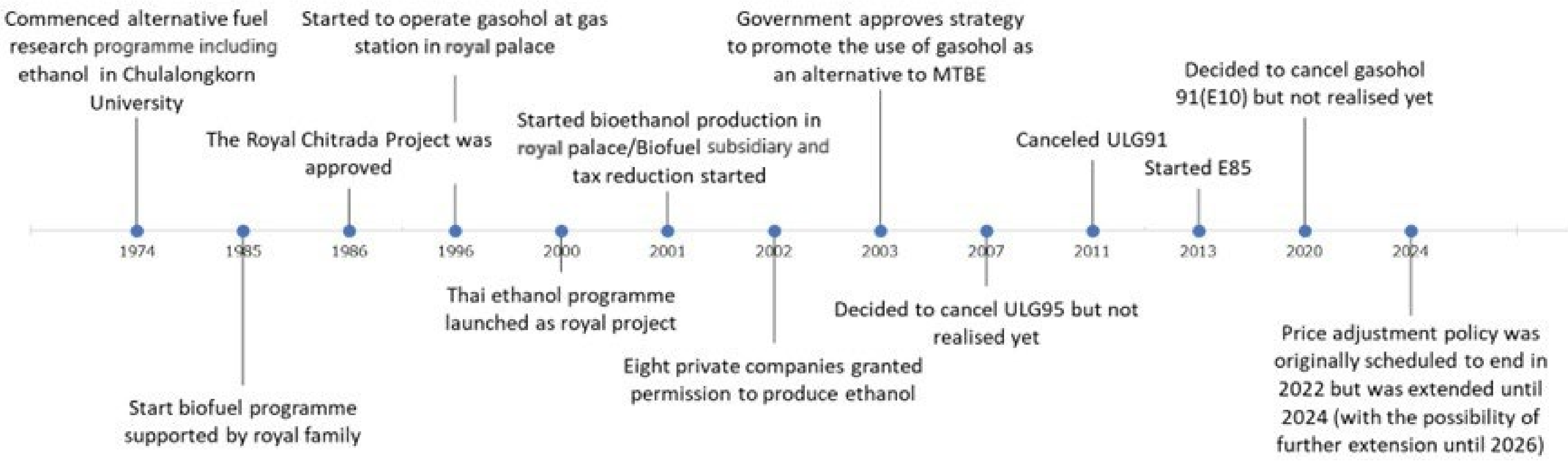


Source: Authors.

History of bioethanol

Thailand's bioethanol development was initiated under the leadership of the Thai royal family. In 2001, promotion measures such as fuel ethanol subsidies and value added tax (VAT) deductions were put in place. From 2005 to 2006, the number of ethanol plants increased, the development of E10-compatible gas stations progressed, and gasohol production and sales became on track (Figure 3.30).

Figure 3.30. History of Bioethanol Development in Thailand



E85 = 85% ethanol, MTBE = Methyl tert-butyl ether, ULG = unleaded gas.
Source: Authors.

Ethanol consumption

Regarding ethanol consumption, bioethanol is mixed with gasoline and used as 'gasohol'. There are currently three types of gasohol in circulation: E10 (10% ethanol blend), E20 (20% ethanol), and E85 (85% ethanol). The mainstream is E10, with small amounts of E20 and E85. There are two types of E10: 95 octane (so-called high octane) and 91 octane (so-called regular), but E20 and E85 only have 95 octane.

According to the biofuel status tracking dashboard of the Ministry of Energy, the combined use volume of high-octane and regular gasoline in 2023 was 31.4 million litres/day (MLD). The breakdown is 0.2 MLD for E85, 5.9 MLD for E20, 18.0 MLD for E10 (95), 6.9 MLD for E10 (91), and 0.5 MLD for unleaded gas (ULG). The proportion of E10 is about 79% (Figure 3.31). With the discontinuation of ULG91 in 2012, the use of E10 increased. Because the price difference between gasohol 95 (E10) and gasohol 91 (E10) is small, the amount of gasohol 91 (E10) used has decreased, and gasohol 95 (E10) has become mainstream. The price difference between E10 and E20 was also small, and E20 also did not grow. The price difference between E10 and E20 does not incentivise the use of E20, and with the postponement of the discontinuation of gasohol 91 (E10) (originally September 2020), ethanol use is below target. The actual use of ethanol was 3.5 MLD (11%) in 2023.The average use of ethanol Alternative Energy Development Plan (AEDP) target in 2023 was 5.5 MLD (19%), whilst the target in 2037 is 5.5 MLD (19%). (Figure 3.32).

Figure 3.31. Trends and Ratio in Gasoline and Ethanol Use

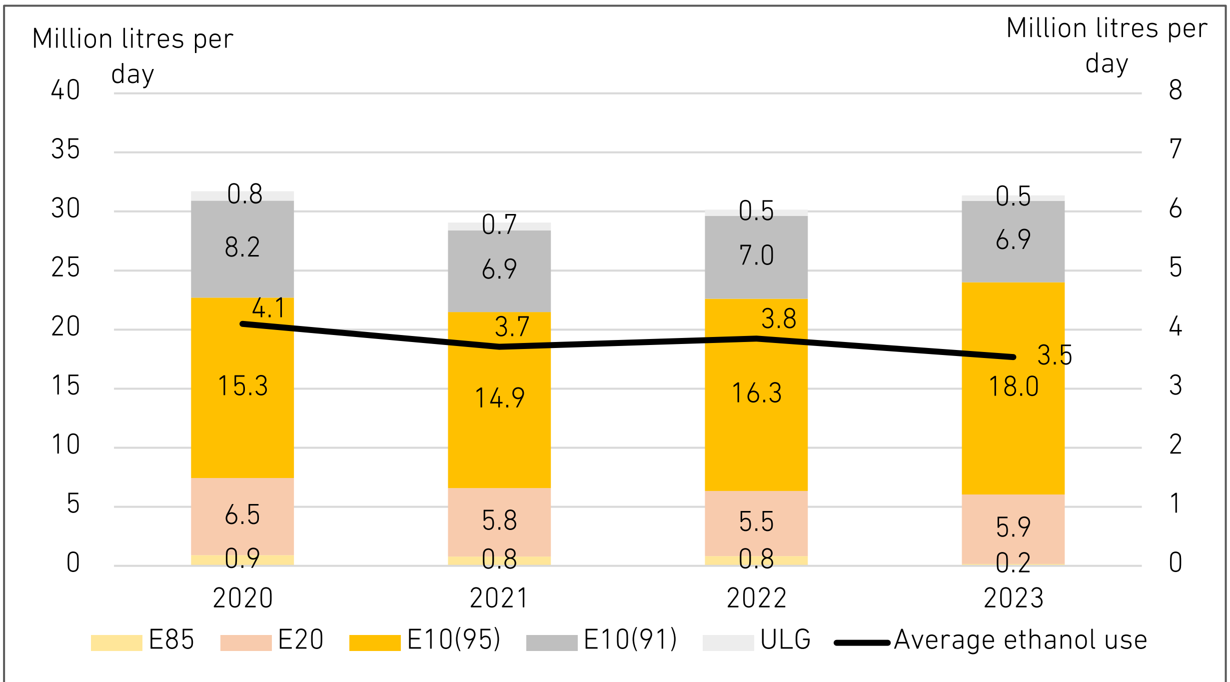
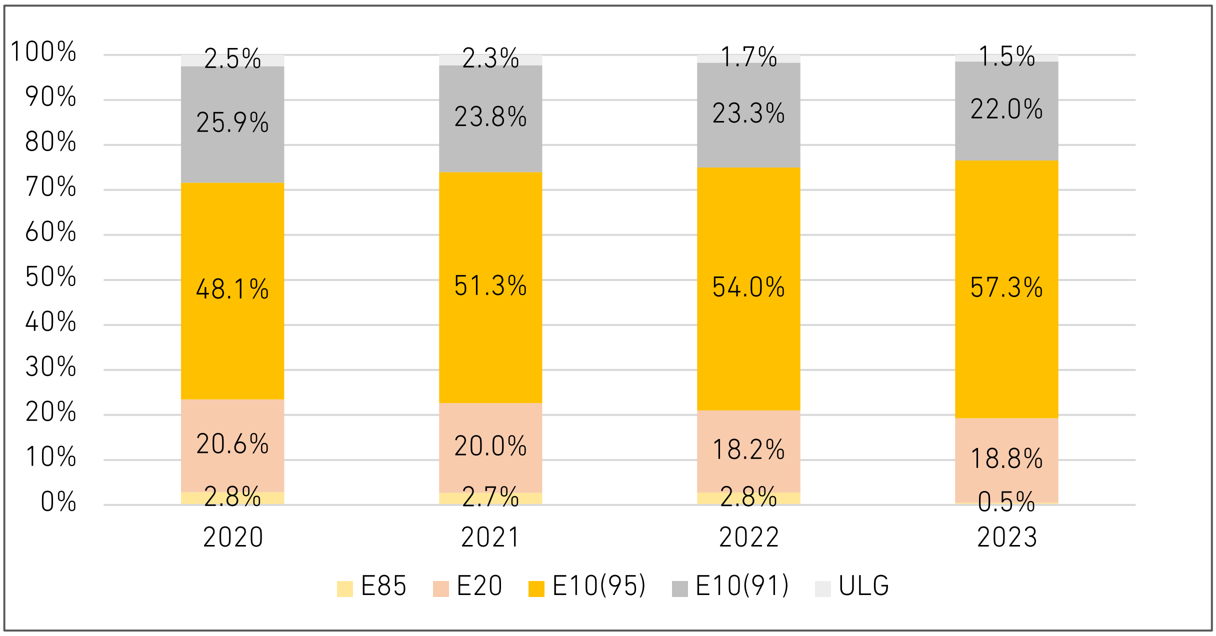
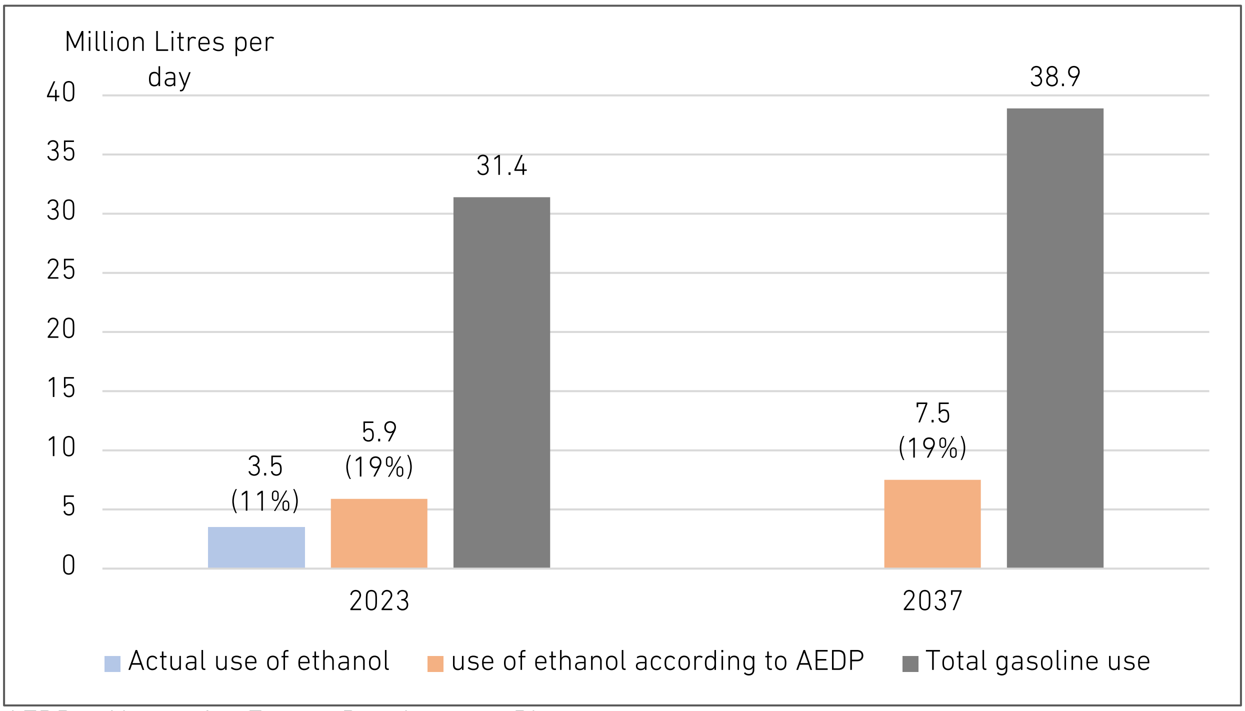


Figure 3.31. *Continued*



E = ethanol, ULG = unleaded gasoline.
Source: Authors based on biofuel status tracking dashboard, Ministry of Energy.

Figure 3.32. Status and Goals of Ethanol Use



AEDP = Alternative Energy Development Plan.
Source: Authors based on PTIT meeting materials.

Ethanol production

Regarding ethanol production, in 2022 the total installed capacity of bioethanol was 6.57 MLD. Total production capacity in 2022 was 4.09 MLD. The utilisation ratio was 62% (Table 3.8).

Table 3.8. Production, Production Capacity, and Utilisation Rate of Ethanol

	Unit	2018	2019	2020	2021	2022
Bioethanol						
Total Installed Capacity	million litres per day (MLD)	6.57	6.57	6.57	6.57	6.57
Total Production Capacity	MLD	4.07	4.46	4.04	3.64	4.09
Utilisation Rate	%	62	68	61	55	62
Consumption Volume	MLD	4.20	4.45	4.10	3.70	3.85

Source: Authors based on Energy Research Institute (ERI), Chulalongkorn University meeting materials.

In 2023, there were 28 ethanol factories – 13 factories for molasses, 10 for cassava, and 5 for hybrid. The factory size is small (0.15–0.60 MLD) compared to factories in leading ethanol production countries such as the United States (US) and Brazil (Table 3.9).

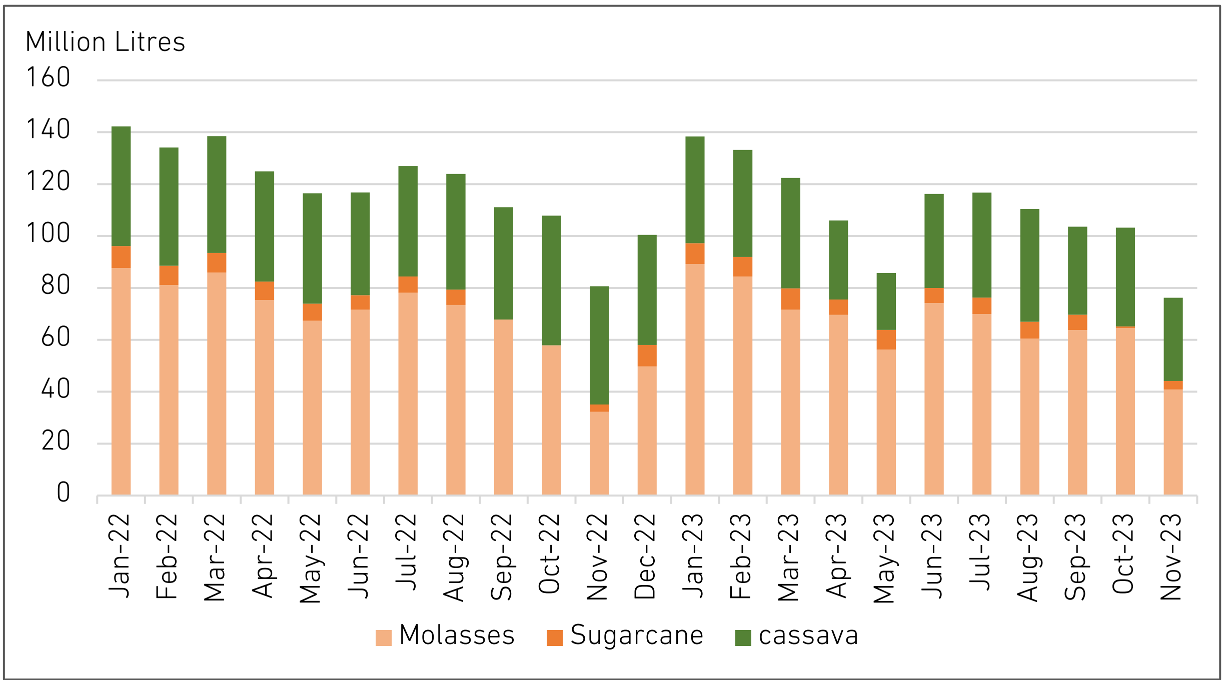
Table 3.9. Production Capacity of Ethanol Factories Classified by Raw Materials, 2023

Raw Materials	Number of Factories	Factory Size	Total Production Capacity
Unit		MLD	MLD
Molasses	13	0.15–0.60	3.6
Cassava	10	0.03–0.40	2.1
Hybrid	5	0.15–0.35	1.1
Total	28		6.8

MLD = million litres per day.
Source: Authors based on PTIT meeting materials.

In Thailand, raw materials of ethanol are molasses, sugarcane, and cassava. Molasses is the main feedstock of ethanol (65%), with cassava in second position (35%), and sugarcane in third position (5%) from January 2022 to November 2023 (Figure 3.33) and this trend remains the same from before.

Figure 3.33. Ethanol Production by Raw Material (January 2022 to November 2023)



Source: Authors based on ethanol information from the Thai Ethanol Producers Trade Association.

More than 99% of bioethanol produced in the world today is called first-generation bioethanol (E1G), which is produced using molasses and starch extracted from edible parts such as sugarcane and corn. E1G has already established production methods and is expected to be in stable supply. On the other hand, E1G competes with the demand for food, and the price of E1G rises the price of grain. In contrast to E1G, second-generation bioethanol (E2G) is produced from inedible raw materials such as stalks and leaves, bagasse, algae, and woody materials including pulp. E2G is expected to be widely used as a means of increasing bioethanol production in the future, since it is made from inedible parts and does not compete with food demand. Thailand is also working on the development of E2G. Figure 3.34 shows an example of a bioethanol plant in Thailand.

Figure 3.34. Bioethanol Factory in Thailand

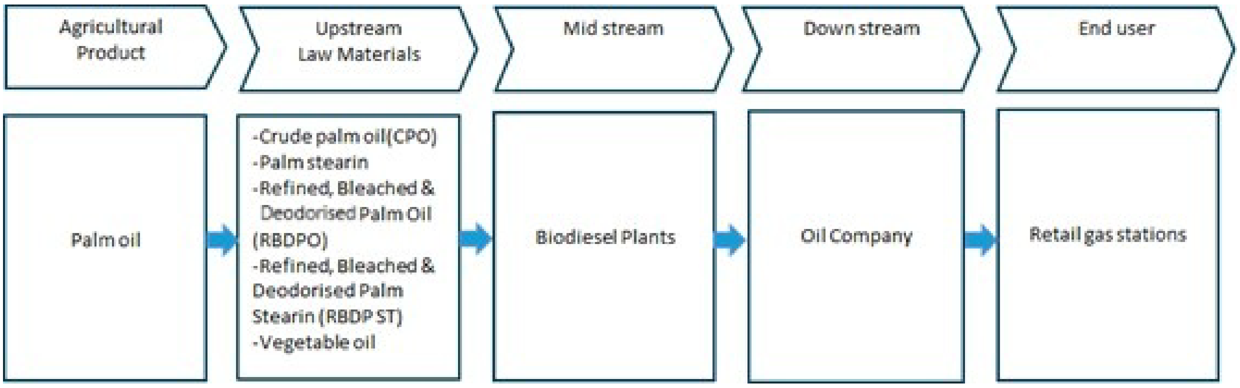
Source: Sumitomo Corporation (2024).

The government is promoting Thailand to be a bio hub of Asia by 2027. In February 2018, the Global Green Chemical Public Company Limited (GGC), a subsidiary of Thailand's chemical manufacturer PTT Global Chemical Public Company Limited (PTTGC), and Kaset Thai International Sugar Corporation Public Company Limited (KTIS) signed a memorandum of understanding to invest in a bioindustries complex in Nakhon Sawan Province (Biorefineries Blog, ,2018). In August 2021, the GGC and KTIS continued the second phase construction of Nakhonsawan BioComplex project after Nature Works LLC decided to invest in a bioplastic manufacturing factory (GGC, 2021). GGC's projects encourage the BCG economy in Thailand.

Biodiesel production

The supply chain for biodiesel from palm oil is shown in Figure 3.35. Palm seeds are crushed at extraction plants to obtain crude palm oil (CPO). This is then sent to biodiesel plants or refineries to be blended with diesel for distribution to gas stations.

Figure 3.35. Supply Chain of Biodiesel Production from Palm Oil

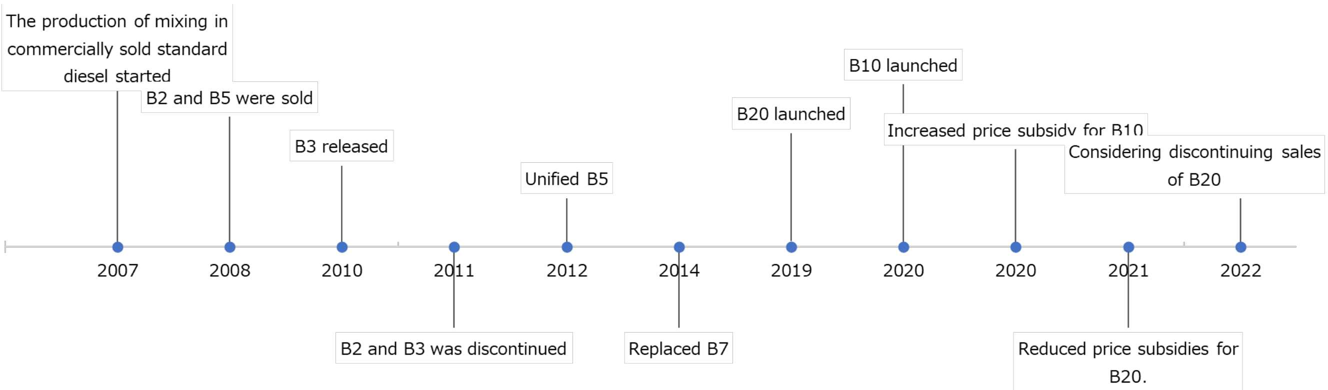


Source: Authors.

History of biodiesel blending

The production of mixing in commercially sold standard diesel started in 2007. Initially, sales began with B2 and B5, and sales of B3 began in 2010, bringing the total to three types of biodiesel. Then, B2 and B3 were discontinued in 2011, and unified into B5 in 2012, and replaced by B7 in 2014. After that B20 launched in 2019, and B10 in 2020. Price subsidy of B10 increased in 2020 and that of B20 decreased in 2021. At present, discontinuation of B20 sales is being considered (Figure 3.36).

Figure 3.36. Biodiesel Blending History in Thailand



Source: Authors.

Biodiesel consumption

In Thailand, diesel fuel is the main fuel used by public transport such as buses, trucks, and container vehicles, and its sales volume significantly exceeds that of gasoline-derived fuels. There are currently three types of biodiesel in circulation: B7 (7% biodiesel blend), B10 (10% biodiesel blend), and B20 (20% biodiesel blend).

According to the biofuel status tracking dashboard (Ministry of Energy), the combined use volume of diesel in 2023 was 65.5 MLD. The breakdown is 64.6 MLD for B7, 0.8 MLD for B10, and 0.2 MLD for B20. The proportion of B7 is about 99% (Figure 3.37).

Sales of the B10 and B20 started in 2019, but the price difference with B7 did not provide enough motivation, and there were many older cars that could only use B7, so B7 is still the mainstream. Subsequently, the price of B20 was adjusted, and the use of B20 decreased. The actual use of biodiesel is 4.4 MLD (7%) in 2023, the average use of the AEDP target in 2023 is 7.0 MLD (11%). The average use of the AEDP target in 2037 is 8.0 MLD (9%) (Figure 3.38).

Figure 3.37. Trends and Ratio in Diesel and Biodiesel Use

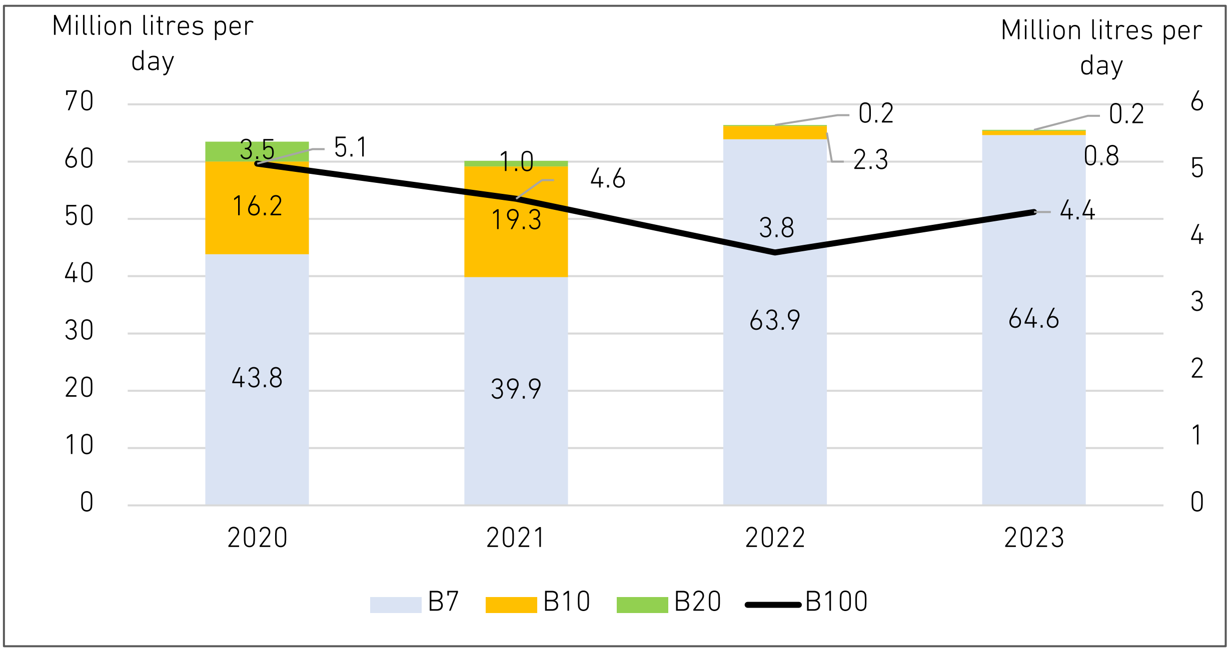
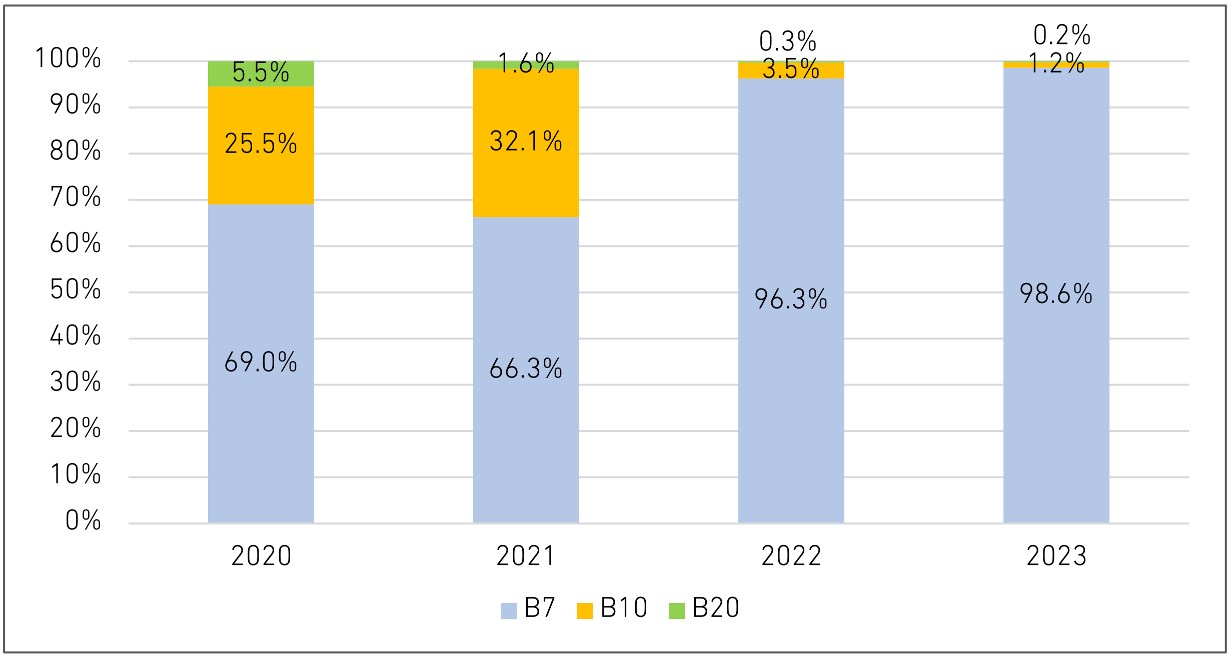
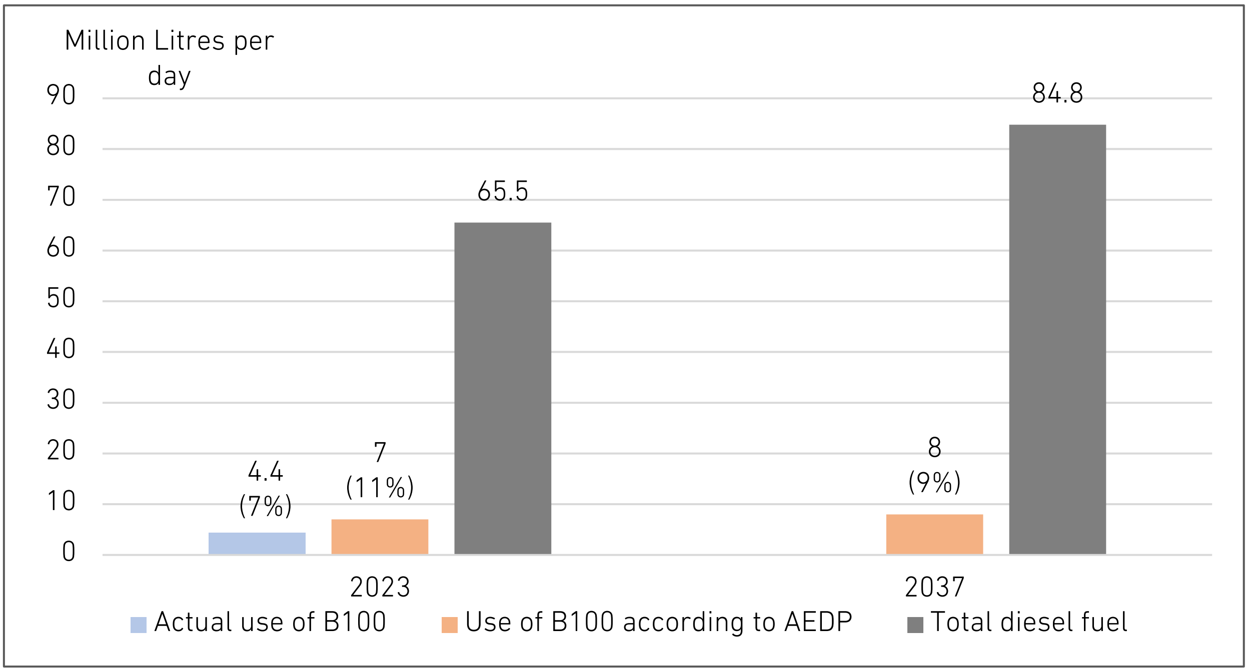


Figure 3.37. *Continued*



B = biodiesel.
Source: Authors based on biofuel status tracking dashboard, Ministry of Energy (accessed 7 May 2024).

Figure 3.38. Status and Goals of B100 Use



AEDP = Alternative Energy Development Plan, B = biodiesel.
Source: Authors based on PTIT meeting materials.

3.4.1.1. Biodiesel production

Regarding biodiesel production, total installed capacity of biodiesel was 10.13 MLD in 2022. Total production capacity in 2022 was 3.63 MLD. The utilisation rate is about 36%, still at a low rate (Table 3.10).

Table 3.10. Production, Production Capacity, and Utilisation Rate of Biodiesel

	Unit	2018	2019	2020	2021	2022
Biodiesel						
Total Installed Capacity	Million litres per day (MLD)	10.13	10.13	10.13	10.13	10.13
Total Production Capacity	MLD	4.34	5.05	5.04	4.55	3.63
Utilisation Rate	%	43	50	50	45	36
Consumption Volume	MLD	4.25	4.90	5.11	4.59	3.61

Source: Authors based on Energy Research Institute (ERI), Chulalongkorn University meeting materials.

In 2023, there were 15 B100 biodiesel factories, and the breakdown is four large-scale factories, seven mid-scale, and four small scale. The large-scale factories provide about a 60% share of total production capacity (Table 3.11).

Table 3.11. Production Capacity of B100 Factory, Classified by Factory Size, 2023

Factory Size	Number of Factories	Total Production Capacity
MLD		MLD
1.0–1.8	4	6.0
0.3–0.7	7	3.7
0.03–0.2	4	0.6
Total	15	10.3

B = biodiesel, MLD = million litres per day.
Source: Authors based on PTIT meeting materials.

The development of second-generation biofuels from biomass and third-generation biofuels from algae is still at the university research stage and far from commercialisation in Thailand.

Price of bioethanol and biodiesel

The government is promoting the use of gasohol (gasoline containing ethanol) through price incentives at gas stations and excise tax reductions for E20 and E85 gasohol compatible vehicles.

Figure 3.39 shows the 'orange board' as of 9 May 2024 which is displayed on the website of the Ministry of Energy. This shows the retail oil prices in Bangkok and vicinities. As can be seen, normal gasoline (B47.24) is more expensive than gasohol 95 (E10) (B39.35), Gasohol 91 (E10) (B37.24), and gasohol E85 (B36.99) at PTT, the national oil company in Thailand, and at other oil companies. The same trend is seen for diesel prices. Normal diesel (B47.54) is more expensive than diesel B20 (B30.94) at PTT, BCP, and ESSO.

Figure 3.39. Gasoline and Diesel Retail Price in Bangkok and Vicinities (as of 9 May 2024)

Oil Price — 9 พฤษภาคม 2567 — Read More

UNIT	PTT	BCP	SHELL	ESSO	CALTEX	IRPC	PT	SUSCO	PURE
Gasoline 95	47.24				48.41		47.74	47.39	
Gasohol 95	39.35	39.35	40.35	39.35	39.35	39.35	39.35	39.35	39.35
Gasohol 91	38.78	38.78	39.78	38.78	38.78	38.78	38.78	38.78	38.78
Gasohol E20	37.24	37.24	38.24	37.24	37.24		37.24	37.24	37.24
Gasohol E85	36.99	36.99							
Diesel	47.54	49.84	31.24	49.84					
Diesel B7	42.94	45.14	46.94	45.14	45.14	30.94	30.94	19.59	30.94
Diesel B20	30.94	49.84	31.24		30.94				
Premium Diesel	30.94	30.94	49.94	30.94	30.94				
Vpower Gasohol 95			31.24						

Note: In September 2023, the government began measures to set a ceiling on diesel fuel sales prices at B30 to support people's lives. The measure was for 3 months, and although it was repeatedly extended, it expired on 31 March 2024.
Source: Ministry of Energy website.

According to the Oil Fuel Fund Office (OFFO), the oil price structure of gasoline and gasohol in Bangkok on 9 May 2024 is as shown in Table 3.12.

Table 3.12. Price Structure of Gasoline, Gasohol, and H-Diesel in Bangkok (May 2024)

UNIT: BAHT/LITRE	EX-REFIN.	EXCISE TAX	M. TAX	OIL FUND	CONSV. FUND	WHOLESALE (WS)	VAT (WS)	WS&VAT	MARKETING MARGIN	VAT (MM)	RETAIL
ULG95	22.9827	6.5000	0.6500	9.7800	0.0500	39.9627	2.7974	42.7601	4.1868	0.2931	47.24
GASOHOL95 E10	22.9749	5.8500	0.5850	3.2000	0.0500	32.6599	2.2862	34.9461	4.1158	0.2881	39.35
GASOHOL91	22.5160	5.8500	0.5850	3.2000	0.0500	32.2010	2.2541	34.4551	4.0420	0.2829	38.78
GASOHOL95 E20	23.4098	5.2000	0.5200	1.2100	0.0500	30.3898	2.1273	32.5171	4.4139	0.3090	37.24
GASOHOL95 E85	28.4154	0.9750	0.0975	0.5600	0.0500	30.0979	2.1069	32.2048	4.4721	0.3131	36.99
H-DIESEL B7	23.4560	5.9900	0.5990	-3.0800	0.0500	27.0150	1.8911	28.9061	1.9008	0.1331	30.94
H-DIESEL B20	24.9209	5.1530	0.5153	-3.0800	0.0500	27.5592	1.9291	29.4883	1.3567	0.0950	30.94
FO 600 (1) 2%S	19.6358	0.6400	0.0640	0.0600	0.0500	20.4498	1.4315	21.8813			
FO 1500 (2) 2%S	19.1100	0.6400	0.0640	0.0600	0.0500	19.9240	1.3947	21.3187			
LPG (BAHT/KILOGRAM)	23.4450	2.1700	0.2170	-4.9141	0.0000	20.9179	1.4643	22.3822	3.2566	0.2280	25.87

Exchange Rate	=	37.1430	BAHT/USD
Ethanol	=	30.65	BAHT/LITRE
Biodiesel (B100)	=	34.49	BAHT/LITRE

Note: This retail price structure is only for public reference; it is not the government control price.
Source: Author based on Oil Fuel Fund Office (accessed 9 May 2024).

Retail price is calculated by the following methodologies:

- Wholesale Price (WS)=EX Refinery price + Exercise Tax + Municipal Tax + State Oil Fund + Conservation Fund
- Retail Price=WS + Value Added Tax (VAT)+Marketing Margin + VAT

The tax system is as follows:

(a) Excise Tax: Collected by the Ministry of Finance according to the Revenue Code, utilised for national development.
(b) Municipal Taxes: Collected by the Ministry of Finance at a rate of 10% of the Excise Tax according to the Revenue Code Article 150, then transferred to the Ministry of Interior for local development.
(c) Value Added Tax (VAT): Collected at a rate of 7% of the wholesale price of fuel, and an additional 7% of the marketing margin of each type of fuel.

The Oil Fuel Fund is a fund established as a safety net against price fluctuations of petroleum products, including imported gasoline. To stimulate demand for biofuels, the government is using the oil fuel fund, which is funded by tariffs on petroleum fuel imports, to promote sales by lowering the price of biofuels. The government changes the levied amount depending on the contributions of the Oil Fuel Fund. Since the government has reduced the subsidy for E85 in 2019, most users have switched from E85 to E20.

As of 9 May 2024, the Oil Fuel Fund levy for ULG95 is B9.78 per litre, whilst the levy for gasohol 95 (E10) and gasohol 91 (E10) are B3.2 per litre. Additionally, measures have been implemented to make the State Oil Fund cheaper with increasing ethanol content ratio. Specifically, the Oil Fuel Fund levy for E10 is B3.2 per litre), whilst that for E20 is B1.21 and that for E85 is B0.56 per litre. Furthermore, for biodiesel B7 and B20, the subsidy is B3.08 per litre. This price adjustment policy was originally scheduled to end in 2019 but was extended until 2024 (with the possibility of further extension until 2026).

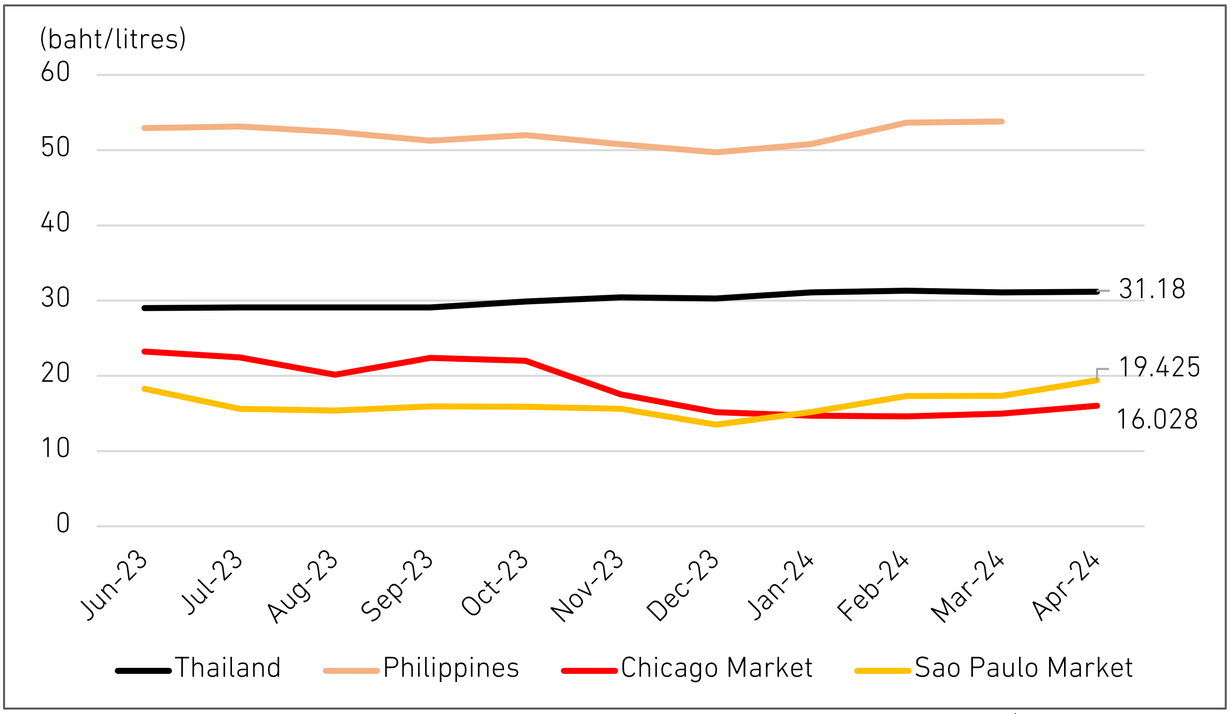
As of 9 February 2024, the Oil Fuel Fund posted a loss of B84.3 billion, with B37.8 billion spent to subsidise oil prices and B46.4 billion subsidising liquified petroleum gas (LPG) (Bangkok Post, 2024). Then, with the deficit approaching the B100 billion mark, the Ministry of Energy made four proposals, including continuing the diesel fuel tax reduction, and gradually raising retail prices. The four proposals are:

- Extend the diesel fuel excise tax cut, which was due to expire on 19 April 2024, by 3 months to a range of B1 to B2 per litre.
- Cut the prices of diesel fuel and liquefied petroleum gas (LPG) for cooking and allocate a supplementary budget.
- Gradually raise the upper limit on the retail price of diesel fuel from the current B30 per litre to B31–B32 per litre.
- Additional borrowing to ensure the fund's liquidity.

The oil fund's deficit as of 31 March was B99,821 million, with the oil account at B52,729 million and the LPG account at B47,092 million. In any case, there are concerns that the Oil Fuel Fund's huge deficit will affect the sustainability of biofuel policies based on subsidies.

Most of the sugarcane farms in the United States and Brazil are large-scale farms, but in Thailand there are many small-scale farms. As a result, they are less competitive in price than modern, large-scale farms in other countries, and this is reflected in the ethanol price in Thailand (Figure 3.40).

Figure 3.40. Ethanol Prices in Thailand, the United States, and Brazil



Source: Authors based on biofuel status tracking dashboard, Ministry of Energy (accessed 7 May 2024).

Number of bioethanol compatible cars

As shown Figures 3.34 and 3.41, the bioethanol utilisation rate was 11% and the biodiesel utilisation rate was 7% in 2023. Another challenge is increasing blending ratios of biofuel. Vehicles sold after 2000 can use blended bioethanol. Currently about 8.3 million vehicles and 22.3 million motorcycles are compatible with using blended biofuel (Table 3.13). Additionally, the types of fuel that can be provided at gas stations are limited by the number of fuel pumps.

Table 3.13. Number of Motorcycles and Vehicles Compatible with Bioethanol

Vehicle	Number	Motorcycle	Number
Gasoline and E10	3,092,631	Benzene and E10	1,237,567
E20	3.883,051	E20	20,440,593
E85	1,342,474	E85	586,033
Total	8,318,156	Total	22,264,193

E = ethanol.
Source: Authors based on Energy Research Institute, Chulalongkorn University meeting materials.

Technology plan related to automobiles

As explained in Section 3.3 (3.2.2 Transport), the government is providing subsidies for promoting EVs, which is a factor in decreasing demand for bioethanol and biodiesel. As part of the 30@30 strategy, EGAT, PTT, and other entities are promoting the spread of quick chargers and EVs, but it is difficult to expect rapid progress with EVs, as it will take a long time to develop infrastructure such as quick charging stations. Due to concerns about safety and convenience, the use of ICE vehicles may continue for a certain period. There are contradictory policies to promote EVs and biofuels simultaneously; however, Thailand's strategy is to focus on biofuels with efficient engine vehicles and utilisation of biofuel until 2030, then gradually spread EVs, and in 2045, EVs will become the mainstream, and FCVs will also be deployed (Table 3.14).

Table 3.14. Technology Plan of Long-term Mitigation Actions Related to Automobiles

	Transportation
2025	Efficient engine vehicles Renewable energy (E10, E20, E85, B10, B20)
2030	Phase down of internal combustion engines (ICE) Most efficient ICE vehicles Electric vehicle 30@30 Renewable energy (E10, E20, E85, B10, B20, B100)
2040	
2045	Most efficient ICE vehicles with biofuels High share of electric vehicle Fuel cell vehicle

Source: Authors.

3.4.2. Carbon Capture and Storage

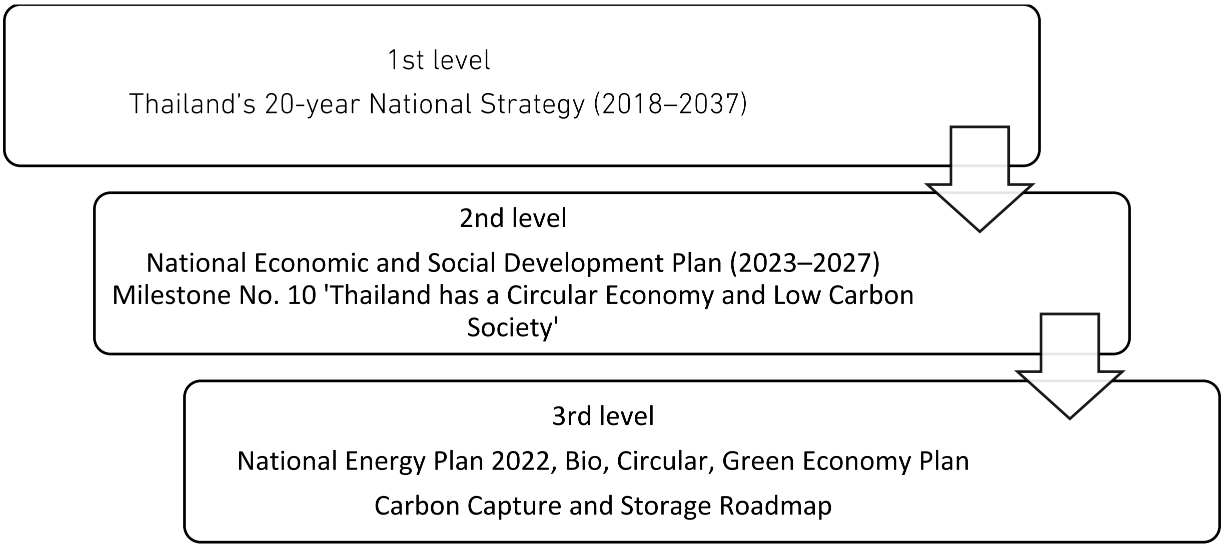
Thailand's plans on CCS technology in different level

Thailand 's CCS technology is being implemented in a three-level plan (Figure 3.41). The first level is Thailand's 20-year National Strategy (2018–2037). This is the top management long-term plan (20 years). In the chapter 'The Strategy for Eco-Friendly Development and Growth', energy is mentioned in item 5 – creating eco-friendly water, energy, and agricultural security. 'Creating national energy security and promoting eco-friendly energy use' will lead to renewable energy development, energy conservation, and decarbonisation in the current energy policy.

The second level is the National Economic and Social Development Plan (2023–2027). This is the middle management standing short-term plan. Milestone No. 10 'Thailand has a Circular Economy and Low Carbon Society' is the basis for promoting CCS.

The third level of the plan is the National Energy Plan 2022, the BCG Economy plan, and the CCS roadmap. This is an action plan. Especially, regarding CCS, in the energy field in the BCG model, five action plans are listed, one of which is Actions Plans on Carbon Sink (increase CO_2 absorption).

Figure 3.41. Three-level National Plan for Carbon Capture and Storage Technology

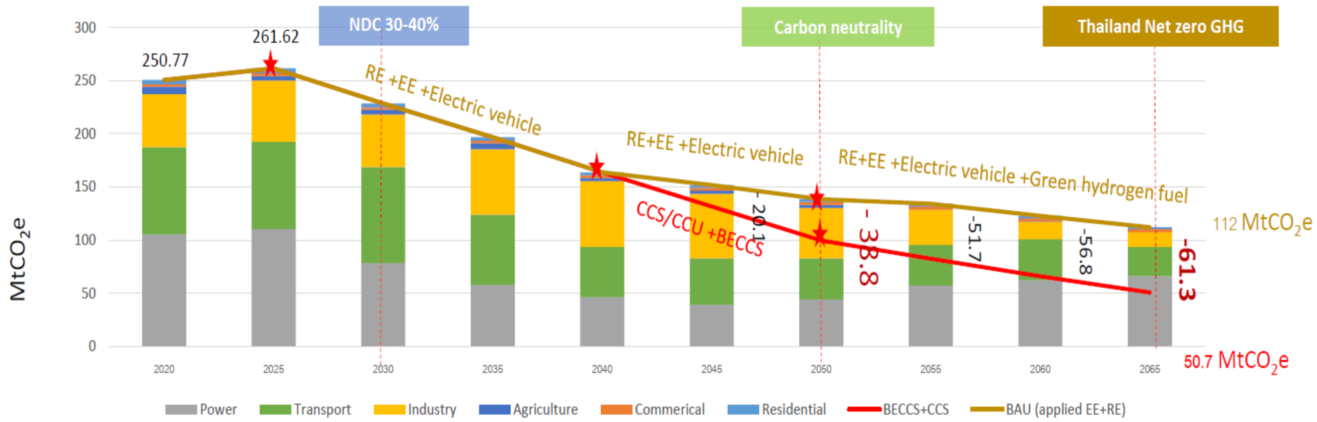


Source: Authors.

Critical points for introducing CCS technology

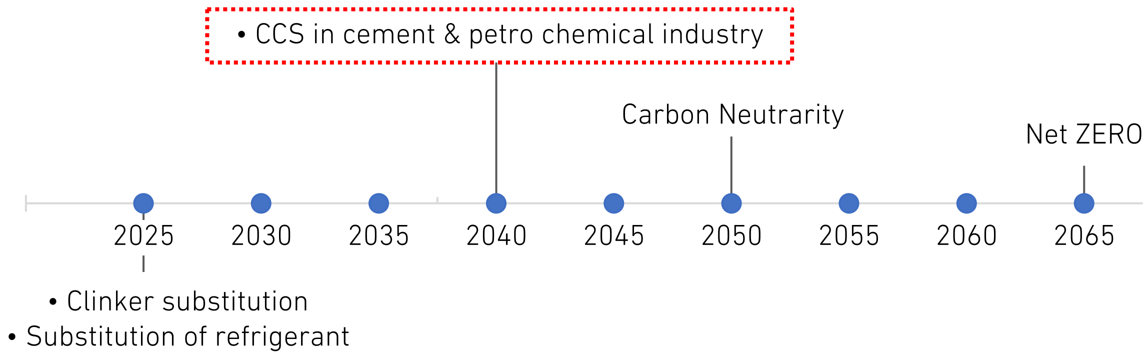
Figure 3.42 shows the path towards net zero in Thailand. It shows their plan to apply CCS technology. Figure 3.43 shows the timeline for achieving net zero in the industrial processes and product sector, and Figure 3.44 shows the timeline for the power generation sector. As can be seen from these figures, Thailand has a goal of using CCS in various fields from 2040 at the earliest, and practical implementation is expected.

Figure 3.42. Thailand Carbon Neutrality and Greenhouse Gas Net-zero Pathway



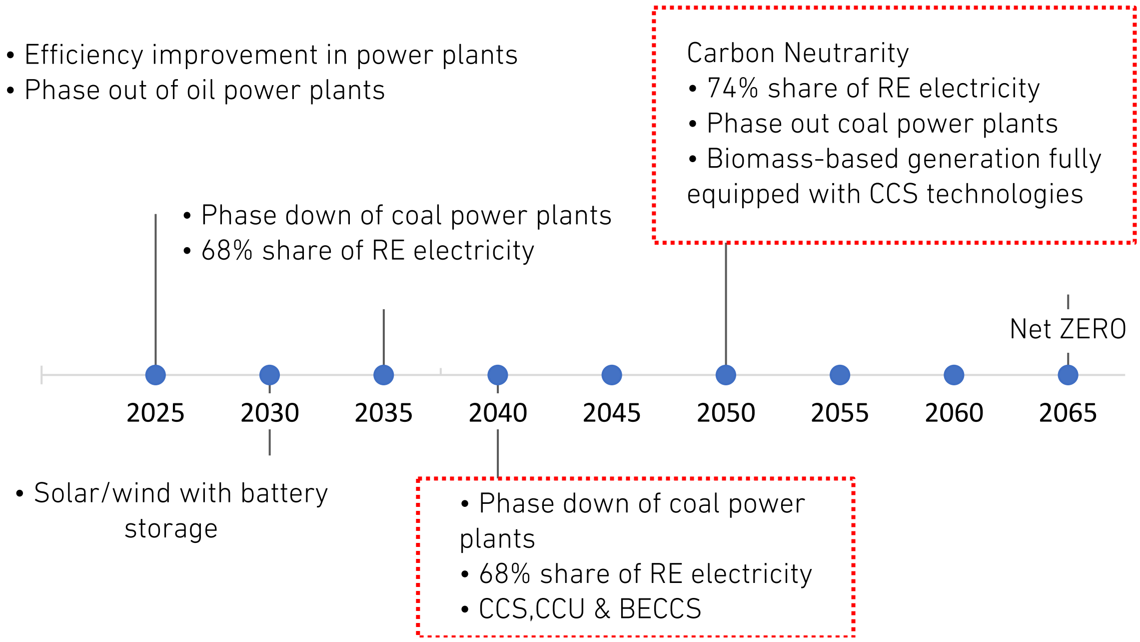
BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage, CCU = carbon capture and utilisation, EE = energy efficiency, NDC = nationally determined contribution, RE = renewable energy.
Source: Department of Mineral Fuels.

Figure 3.43. Net-zero Timeline for Thailand's IPPU Sector



CCS = carbon capture and storage, IPPU = industrial processes and product use.
Source: Authors.

Figure 3.44. Net-zero Timeline for Thailand's Power Generation Sector



BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage, CCU = carbon capture and utilisation, RE = renewable energy.
Source: Authors.

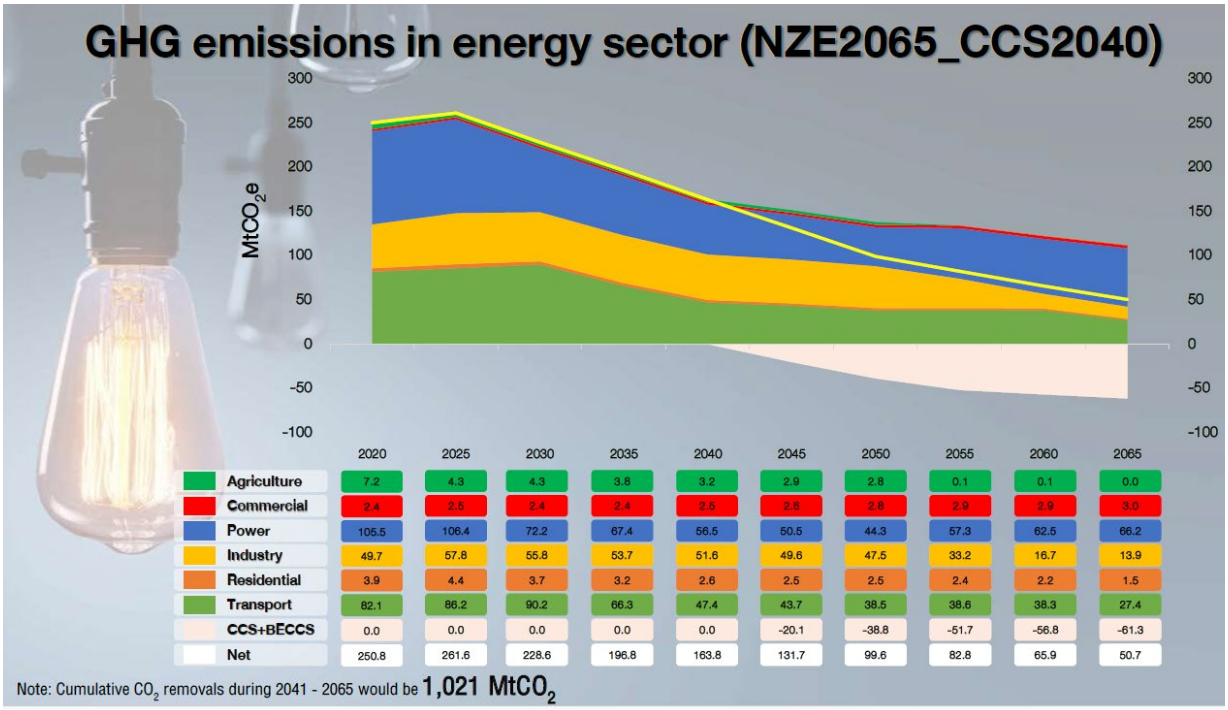
As for the specific amount of reduction, as shown in Figure 3.45, as of 2045, the CO_2 reduction by CCS and bioenergy with carbon capture and storage (BECCS) is 20.1 Mt CO_2e, and in 2065, when net zero is used, the target amount is 61.3 Mt CO_2e.

The breakdown in the power generation field is shown in Figure 3.45. Please note that the unit is based on GWh. As of 2045, the amount of power generated using CCS is planned to be 1,617 GWh, but as the amount of power generated from renewable energy gradually increases, the amount of power generated using CCS is expected to be on the decline by 2065.

Table 3.15 are excerpts of the roadmap for the cement and concrete sector. As of 2050, the expected reduction in emissions from socially necessary concrete manufacturing is 30.3 Mt CO_2, but the target reduction by using CCUS technology is 45% (compared with 2020 baseline, CO_2 reduction milestones is 13.7 Mt CO_2). Even in 2040, there is a reduction target of 6.9 Mt CO_2.

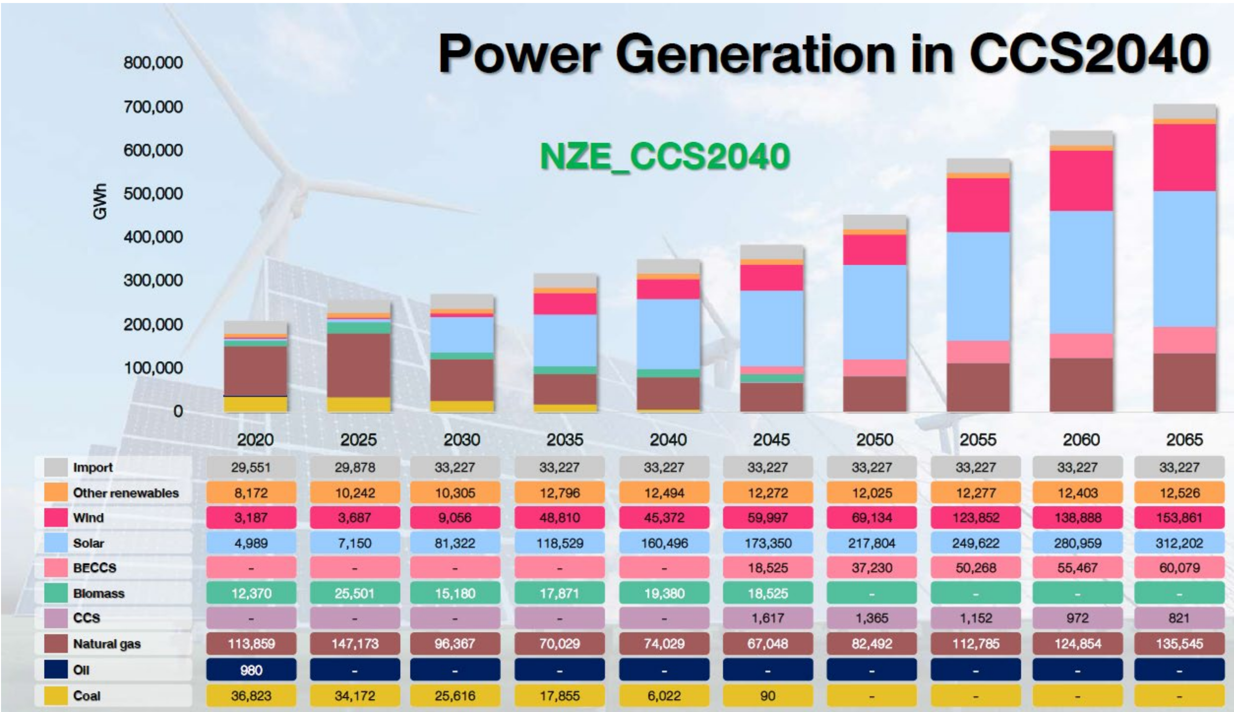
The target volumes from each of these sectors also show that early establishment of CCS technology is highly important.

Figure 3.45. Target Breakdown of Greenhouse Gas Emissions in the Energy Sector



BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage.
Source: Materials provided by Energy Research Institute.

Figure 3.46. Target Breakdown of Greenhouse Gas Emissions in the Power Sector



BECCS = bioenergy with carbon capture and storage, CCS = carbon capture and storage, GWh = gigawatt-hour, NZE = net-zero energy.
Source: Materials provided by Energy Research Institute.

Table 3.15. Greenhouse Gas Reduction Target Volumes for Cement and Concrete Roadmap

Year/Lever (Mt CO_2)	2020	2030	2040	2050
Business As Usual (BAU) Emissions	**32.2**	**31.8**	**31.1**	**30.3**
Lever 1: Efficiency in Design and Construction		2.8	3.8	4.8
Lever 2: Efficiency in Concrete Production		1.3	1.4	1.5
Lever 3: Saving in Cement and Binders		2.1	2.5	2.9
Lever 4: Saving in Clinker Production		4.1	3.8	3.5
Lever 5: Carbon Capture and Utilisation/Storage		0	6.9	13.7
Lever 6: Decarbonisation of Electricity		1.1	1.3	1.5
Lever 7: CO_2 Sink: Recarbonation		2.9	2.6	2.4
Net Emissions		**17.5**	**8.8**	**0**

$MtCO_2$ = million tons of carbon dioxide.
Source: Thai Cement Manufacturers Association (2023).

Thailand CCS roadmap and status

Table 3.16 is an excerpt of the action plan. The action plan until 2030 has specific plans for each of five items. Particular attention should be paid to regulations and incentives. As a result of field survey in Thailand, the progress of CCS in Thailand is still in the early stages towards commercialisation, and when asked about the future challenges, they found that there is a need for support from the government, an explicit policy framework, and financing, etc. Investments in CCS technologies are likely to be subject to government policies and regulations, as well as investment promotion policies. Currently, the BOI supports businesses that use CCUS technology by providing exemption from corporate income tax for 8 years and exemption from import duties on machinery. However, these measures were not evaluated as sufficient.

CCS technology assumes that carbon emissions are certified at an international level by government authorities. So, further development of the CCS technology and supportive funding model is required to enhance the CCS global market competitiveness of the domestic industry. At present, policy framework, regulations, and incentives are issues to be considered in the future.

Table 3.16. Thailand Carbon Capture and Storage Roadmap

	Action Plan until 2030	
Capacity building	Funding R&D programme for full scale CCS projects (including pilot project)	Training of Thailand's CCS experts internationally recognised
Project development	Full scale (>1 Mt) CCS projects in natural gas processing and power/industrial application	
Regulations	Establishment of Thailand CCS regulations	
Incentives	Develop potential national financial incentives	
Stakeholder engagement	Stakeholders' acceptance of CCS	Public understanding of key CCS role in climate change

CCS = carbon capture and storage, R&D = research and development, Mt = million ton.
Source: Ministry of Energy (2020).

Thailand CCS pilot projects

Thailand is implementing 13 pilot projects to develop CCS technology. An overview including the locations of the projects is summarised in Table 3.17.

The Arthit project of the CCS projects being developed in the North Malay Basin has progressed through feasibility, pre-FEED study, and front-end engineering design (FEED). Currently, the project is in the process of making a final investment decision. PTTEP expects to begin using CCS technology at the Arthit field in 2027, which will help reduce GHG emissions by 0.7-1 Mtpa over 10 years.

CCS in Thailand is currently only being considered for domestic use. As of now, the plan is to build a CCS hub in eastern Thailand first, with a pipeline distance not exceeding 70 km. PTTEP, together with partners, the first phase of the Eastern Thailand CCS Hub is expected to be operational by 2033 and will have a CO_2 storage capacity of approximately 6 Mtpa. The vicinity of Rayong Prefecture, where the location of the domestic CCS hub is being considered, has a concentration of petrochemical plants and fossil fuel power plants, as well as gas fields and the North Malay Basin. This is because access from the area is also good.

Table 3.17. Pilot Projects

Storage Area	Project Name (operator)		Map of Five Areas
1. North Malay Basin	CCS	Arthit Project (PTTEP)	
		A18 Project (MTJA)	
2. Kra Basin / West Kra Basin	CCS	North Gulf of Thailand (DMF)	
	CCU	Methanol Production (BLCP)	
		Ammonia Co-firing (BLCP)	
	Carbon Capture and Purification (PTT Group Industry)		
3. Sinphuhorm and Namphong fields	CCS	Phu Horm Project (PTTEP)	
		Nam Phong Power Plant (EGAT)	
4. Phitsanulok Basin (S1)	CCS	S1 Project (PTTEP)	
	CCU	Syngas and Hydrocarbon Chemical (SCG)	
5. Phitsanulok Basin (S1)	CCS	Lampang Basin Project	
		Mae Moh Basin Project	
	CCU	Artificial Carbonate Mae Moh Coal-fired Power Plant (EGAT)	

CCS = carbon capture and storage, CCU = carbon capture and utilisation.
Source: Authors.

Cooperation in CCS technology in Thailand

Below, international cooperation and agreements with Thailand are listed in chronological order.

(a) In April 2022, INPEX, JGC Holdings Corporation, and PTTEP announced the launch of the 'Thailand carbon capture and storage project', which aims to explore the possibility of developing CCS solutions for oil and gas upstream and downstream, heavy chemical industries, and power plants.

(b) In June 2022, Mitsui & Co. and Mitsui Oil Exploration announced that they would conduct a CCS feasibility study for the Arthit gas field development and production project in the Gulf of Thailand. PTTEP holds an 80% interest, Chevron holds a 16% interest, and Mitsui Oil Exploration's subsidiary Moeko Thailand holds a 4% interest.

(c) In January 2023, Mitsubishi Corporation and Chiyoda Corporation announced that they would jointly conduct a technical review and economic evaluation of CCUS and other technologies at a coal-fired power plant operated by BLCP Power.

(d) In January 2023, Nippon Steel Engineering collaborated with Thailand's SCG Cement Co., LTD., and the Siam Cement Co., LTD. and announced their intention to develop CO_2

separation, recovery, and utilisation technology (CCU) from cement factory exhaust gas in Thailand and surrounding countries in Southeast Asia.

(e) In March 2023, Memorandums of Cooperation on CCS/CCUS between the Ministry of Energy of Thailand and the Ministry of Economy, Trade and Industry of Japan was signed.

(f) In May 2023, the Global CCS Institute organised the Southeast Asia CCS Accelerator workshop to accelerate commercial CCS deployment in the ASEAN region, in cooperation with Thailand's Ministry of Energy and ASEAN Centre for Energy.

(g) In January 2024, PTTEP announced that it would jointly conduct a study on CCS commercialisation in the northern Gulf of Thailand in collaboration with INPEX.

3.4.3. Hydrogen

Formulation status of hydrogen strategy

According to the IEA, as of the end of 2022, a total of 32 governments had developed hydrogen strategies. Since then, hydrogen strategies have continued to be released. As of May 2024, amongst the ASEAN countries, four countries (Indonesia, Malaysia, Singapore, and Viet Nam) have formulated national hydrogen strategies or roadmaps (Table 3.18).

Table 3.18. Formulation Status Summary of Hydrogen Strategies of ASEAN Countries

Country	Hydrogen Strategy or Roadmap Formulation Status	Formulation
Brunei	NA	-
Indonesia	Strategi Hydrogen Nasional	Dec 2023
Cambodia	NA	-
Lao PDR	NA	-
Malaysia	Hydrogen Economy & Technology Roadmap (HETR)	Oct 2023
Myanmar	NA	-
Philippines	Currently formulating the strategic roadmap for hydrogen and its derivatives in 2023	-
Singapore	Singapore's National Hydrogen Strategy	Aug 2023
Thailand	Thailand has prepared the National Hydrogen Strategy; however, the hydrogen strategy should be in line with the National Energy Plan (NEP).	-
Viet Nam	The strategy on hydrogen energy production to 2030 with a vision to 2050	Feb 2024

NA = not available.
Source: Authors.

As of May 2024, the government has not yet set a national hydrogen strategy. However, when the government prepares the National Hydrogen Strategy, the hydrogen strategy should be in line with the National Energy Plan (NEP). The government recognises that hydrogen could be a key mitigation technology for emissions reduction in sectors like power generation, industry, and transport as alternative fuel. According to the Thailand's Long-term Low Greenhouse Gas Emission Development Strategy (Revised Version) (LT-LED), hydrogen is positioned as a key mitigation factor for emission reduction in the power generation, industry, and transport sectors. In addition, LT-LED states that green hydrogen fuel will likely be used in Thailand in 2045, FCVs will likely be used in 2045, and combined cycle turbine (Natural gas /Hydrogen) and fuel cell power plant will likely be used in 2050 (Table 3.19).

Table 3.19. Technology Plan of Long-term Mitigation Actions Related to Hydrogen

	Transportation	Industry	Power
2045	Most efficient internal combustion engine vehicle with biofuels High share of electric vehicles Fuel cell vehicles	Green Hydrogen fuel	
2050		Most efficient electrical devices/boiler Renewable energy	74% share of renewable energy electricity Combined cycle turbine (natural gas/hydrogen) Phase out of CFPPs Fuel-cell power plant

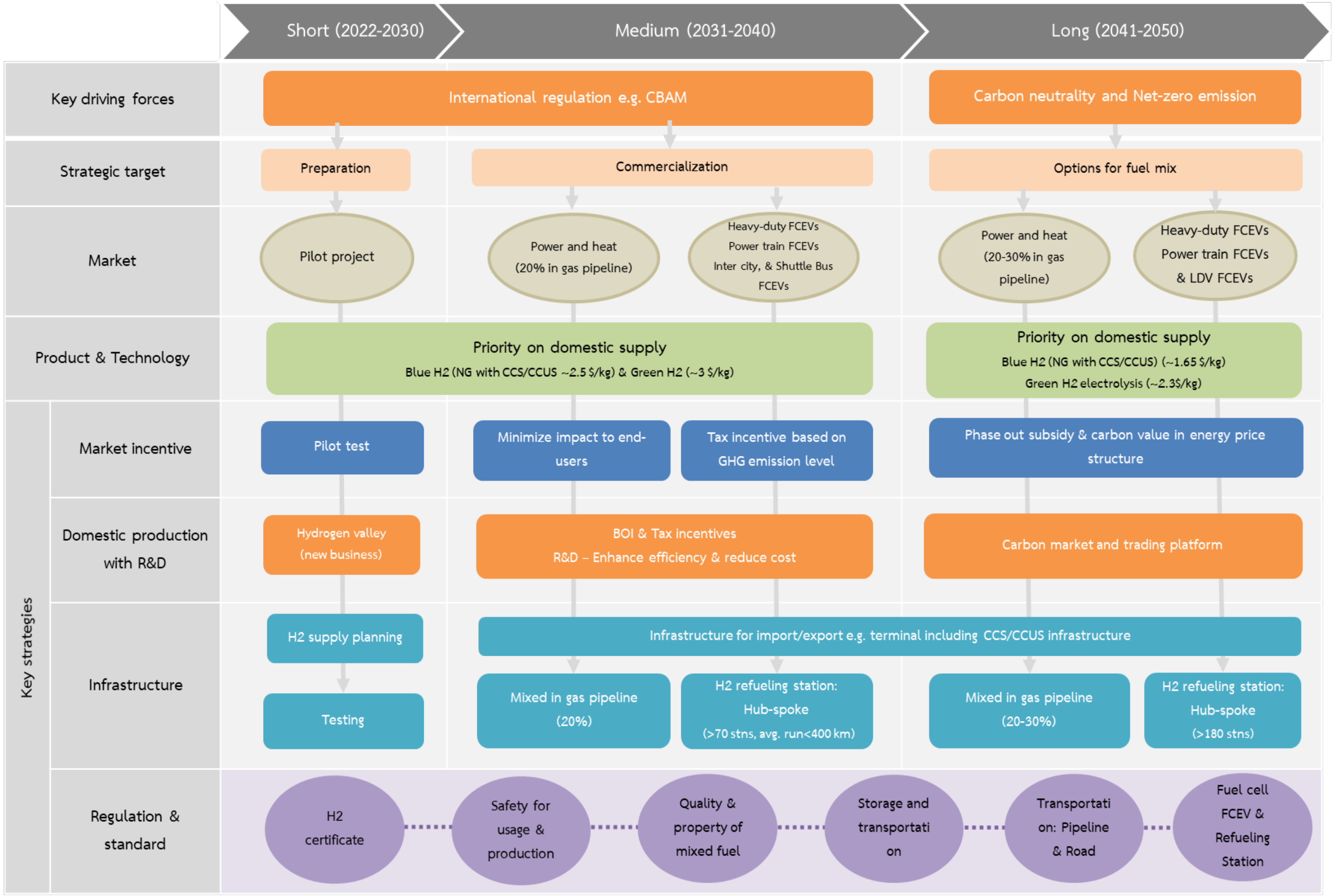
CFPP = coal-fired power plant.
Source: Authors based on LT-LEDS (2022).

Hydrogen roadmap

Thailand is also taking a phased approach to realising a hydrogen roadmap. Therefore, Thailand has divided the development stage of hydrogen into three periods: the short term (2020–2030), midterm (2031–2040), and long term (2041–2050). An overview is shown in Figure 3.47.

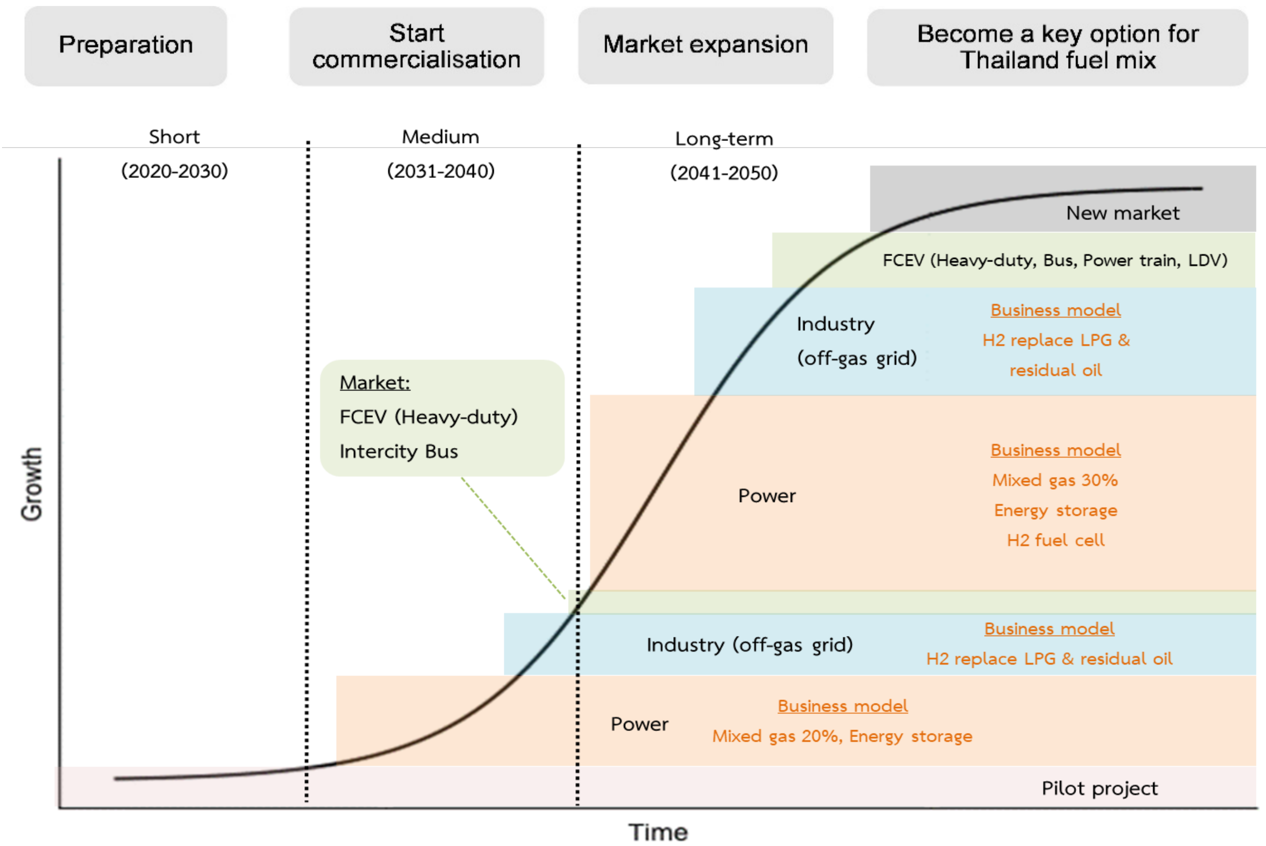
Thailand is positioning the short term (2020–2030) as preparation, the mid-term (2031–2040) as the start of commercialisation, and the long term (2041–2050) as market expansion and becoming a key option for Thailand fuel mix. Thailand plans to start a co-firing pilot project with natural gas and hydrogen in the power generation sector in the 2030s. Thailand will also start using hydrogen as an alternative to liquified petroleum gas (LPG) and oil in the off-gas grid in the industrial sector. From the 2040s, fuel cell electric buses will be introduced in inter-city bus transportation. In addition, Thailand plans to start 20%–30% co-firing in the power generation sector in the 2040s. Thailand envisions the e-fuel market as a new market for hydrogen in the long-term phase (Figure 3.48).

Figure 3.47. Overview of Hydrogen Roadmap in Thailand



Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

Figure 3.48. Potential Hydrogen Market in Thailand



FCEV = fuel cell electric vehicle, LPG = liquefied petroleum gas.
Source: EPPO (2021).

The breakdown of numerical indicators and targets in short term (2020–2030), mid term (2031–2040), and long term (2041–2050) is shown in Table 3.20.

Table 3.20. Indicators and Targets

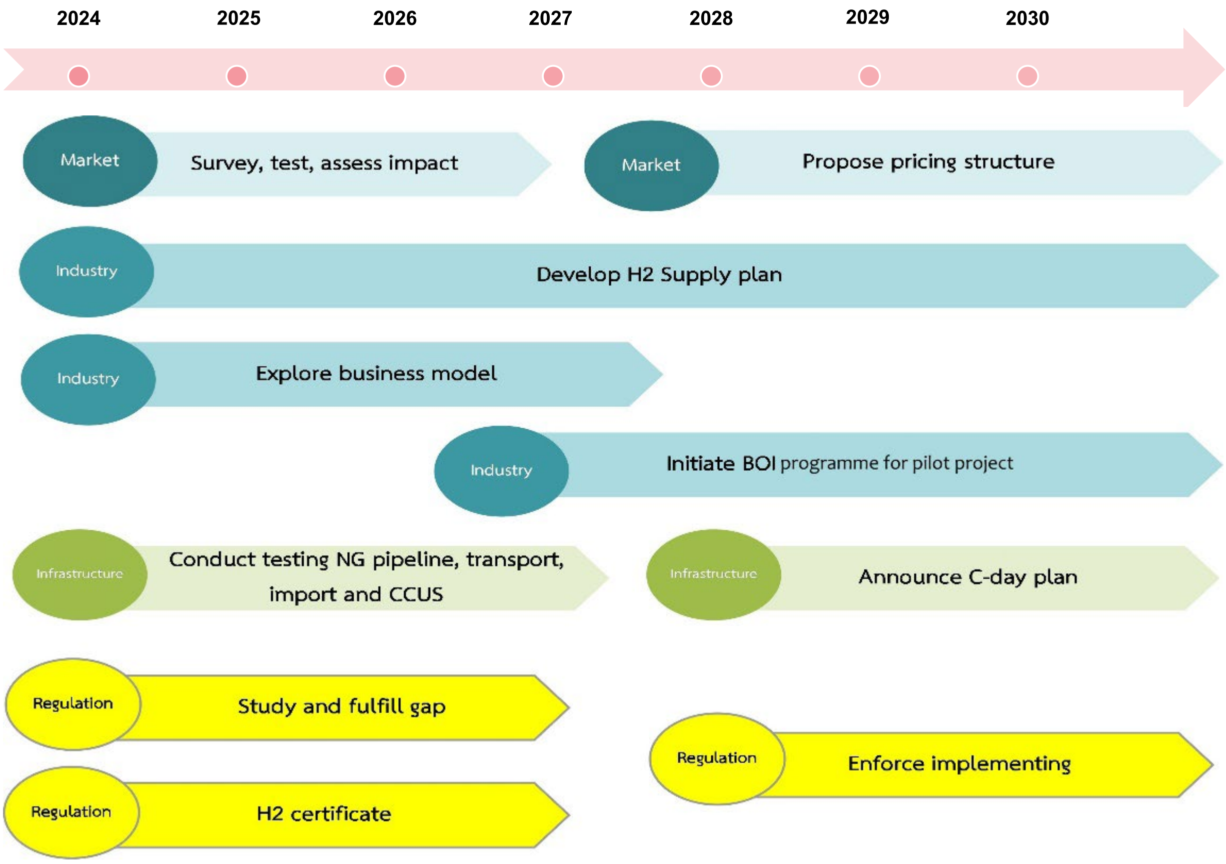
Strategies	Indicators	Target			
		Unit	2030	2040	2050
1. Market initialisation	Share of H_2 blending mix in power generation from natural gas	%	pilot	20	20
	Hydrogen demand in industry for heating	1,000 ton H_2	pilot	150	180
	Stock of Heavy-duty FCEVs	Unit	pilot	1,300	18,000

Strategies	Indicators	Target			
		Unit	2030	2040	2050
	Stock of LDV FCEVs	Unit	pilot	14,000	400,000
2. Industrial development with R&D	Share of green H_2 production of total supply	%	-	-	>50
	Cost of H_2 production	$/kg	-	<2.5 (Blue)	<1.65 (Blue)
			-	<3 (Green)	<2.3 (Green)
	H_2 & Ammonia related R&D budget	-	Government	Government / Private sector	Government / Private sector
3. Infrastructure	Share of H_2 blending mix in NG gas pipeline	%	-	20	20
	Coverage of H_2 refuelling station	Unit	pilot	70	180
	Import/Export capacity	%	-	50	100
4. Regulation and standard	Share of regulation & standard available of H2	%	100	-	-

Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

The short-term plan starting in 2024 is as follows, with a view to commercialisation in 2030 (Figure 3.49).

Figure 3.49. Short-term Preparation for Commercialisation in 2030



BOI = Board of Investment, CCUS = carbon capture, utilisation, and storage, NG = natural gas.
Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

Renewable energy potential

With regards to hydrogen production, Thailand has abundant potential. Thailand has gas fields and natural gas resources that are the source of grey hydrogen. Furthermore, renewable energy potential for electrolysis is also abundant. According to the *Renewable Energy Outlook for ASEAN* (2nd Edition) by IRENA, Table 3.21 shows ASEAN's renewable energy potential for power generation. Thailand has the abundant potential in solar power, wind power, and biomass.

Table 3.21. ASEAN's Renewable Energy Potential for Power Generation

	RENEWABLE ENERGY RESOURCES (GW)					
	PV	ONSHORE WIND	OFFSHORE WIND	BIOMASS	HYDRO	GEOTHERMAL
Brunei Darussalam	1.9	-	-	-	0.1	-
Indonesia	2 898	19.6	589	43.3	94.6	29.5
Cambodia	1 597	2.5	88.8	-	10	-
Lao PDR	983	11.9	-	1.2	26	0.1
Myanmar	5 310	2.4	-	1	40.4	-
Malaysia	337	-	53.3	4.2	29	-
Philippines	122.5	3.5	69.4	0.2	10.5	4
Singapore	0.3	0.1	-	-	-	-
Thailand	3 509	32.4	29.6	18	15	-
Viet Nam	844	31.1	322.1	8.6	35	0.3

PV = photovoltaic.
Source: IRENA (2022).

Especially, Thailand has abundant solar energy resources across the country, with high irradiance in the northeast and central parts of the country, or approximately 1/4 of the total land area. The peak density of solar radiation in these areas is in the range of 1,200-1,400 kilowatt per hour (kWh) per square metres per year, with the seasonal peak in April and the low point in December.

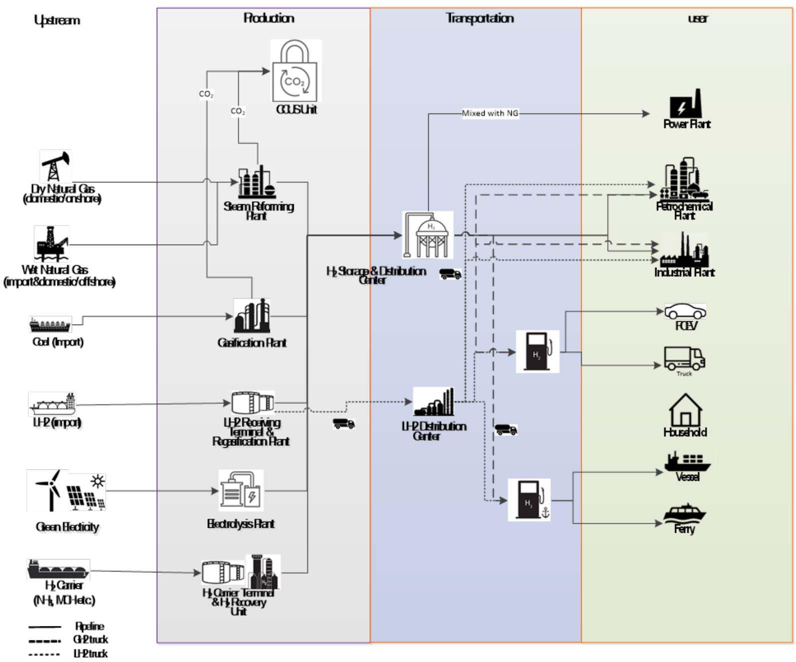
Thailand has wind potential with an average wind speed of 6 metres per second (m/s) at a height of 90 metres, whilst technical potential can reach 13 gigawatts (GW) in 21 areas across the country. However, the greatest wind potential is geographically located in the northeast, western, and southern regions of Thailand, which are generally far away from the loads. Offshore wind potential along the coast of the Gulf of Thailand is estimated at 7 GW, nearly half of which is in the northern part of the gulf.

As pointed out with biofuels, Thailand has traditionally been an agricultural country, so it has abundant biomass resources in addition to solar and wind power.

Codes and standards

Thailand considers the following acts to be relevant in the supply chain from hydrogen production to use; namely, the Factory Act (Act 1), the Industrial Product Standard Act, (Act 2), the Occupational Safety, Health, and Environment Act (Act 3), the Land Transport Act (Act 4), and the Hazard Substances Act (Act 5) (Figure 3.50).

Figure 3.50. Codes and Standards Regarding Hydrogen



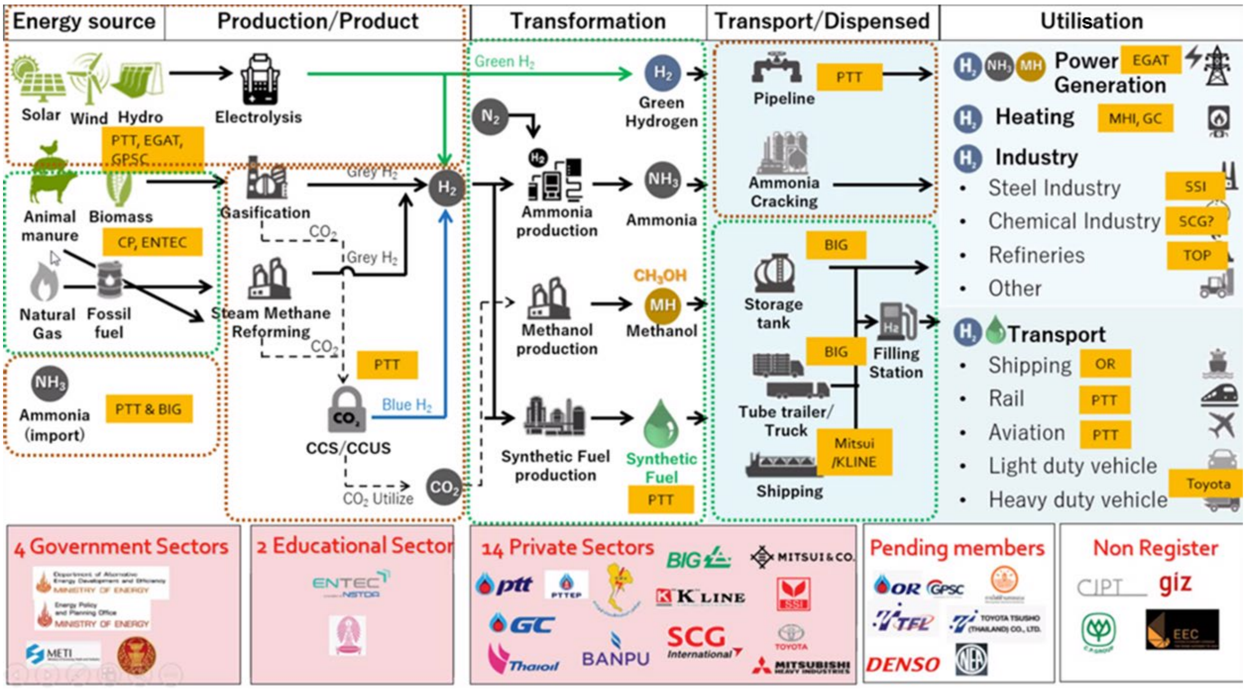
1. Production
   - Factory Act (Act 1)
   - Industrial Product Standard Act, (Act 2)
2. Usage
   - Occupational Safety, Health and Environment Act (Act 3)
3. Safety
   - Factory Act (Act 1)
   - Occupational Safety, Health and Environment Act (Act 3)
   - Land Transport Act (Act 4)
4. Storage
   - Industrial Product Standard Act, (Act 2)
   - Hazard Substances Act (Act 5)
5. Transport
   - Land Transport Act (Act 4)
   - Hazard Substances Act (Act 5)
6. Distribution
   - Occupational Safety, Health and Environment Act (Act 3)

Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

Projects regarding hydrogen

Some hydrogen projects are progressing, and alliances between Thailand and overseas companies are entering into memorandums of understanding (MOU). Figure 3.51 is an overview of projects and players.

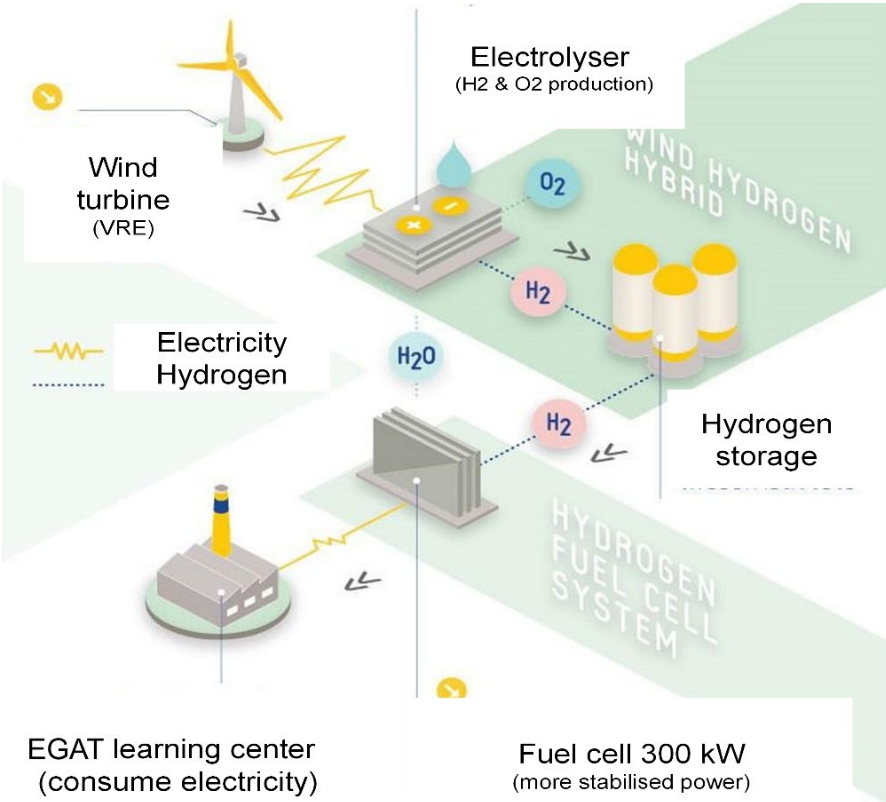
Figure 3.51. Overview of Developing Pilot Projects



Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

The individual pilot projects are as follows. Lam Takhong Wind Hydrogen Hybrid project is a pilot project of Green H_2, fuel-cell and energy storage, which is the first wind and hydrogen hybrid project in Thailand for stabilising energy (Figure 3.52). The Electricity Generating Authority of Thailand (EGAT) has deployed the hydrogen demonstration project at the Lam Takhong Dam in Nakhon Ratchasima Province. The demonstration site consists of 12 wind turbines (total 24 megawatts [MW] installed capacity), and hydrogen can be produced from an electrolyser and used in fuel cells (300 kilowatts [kw]).

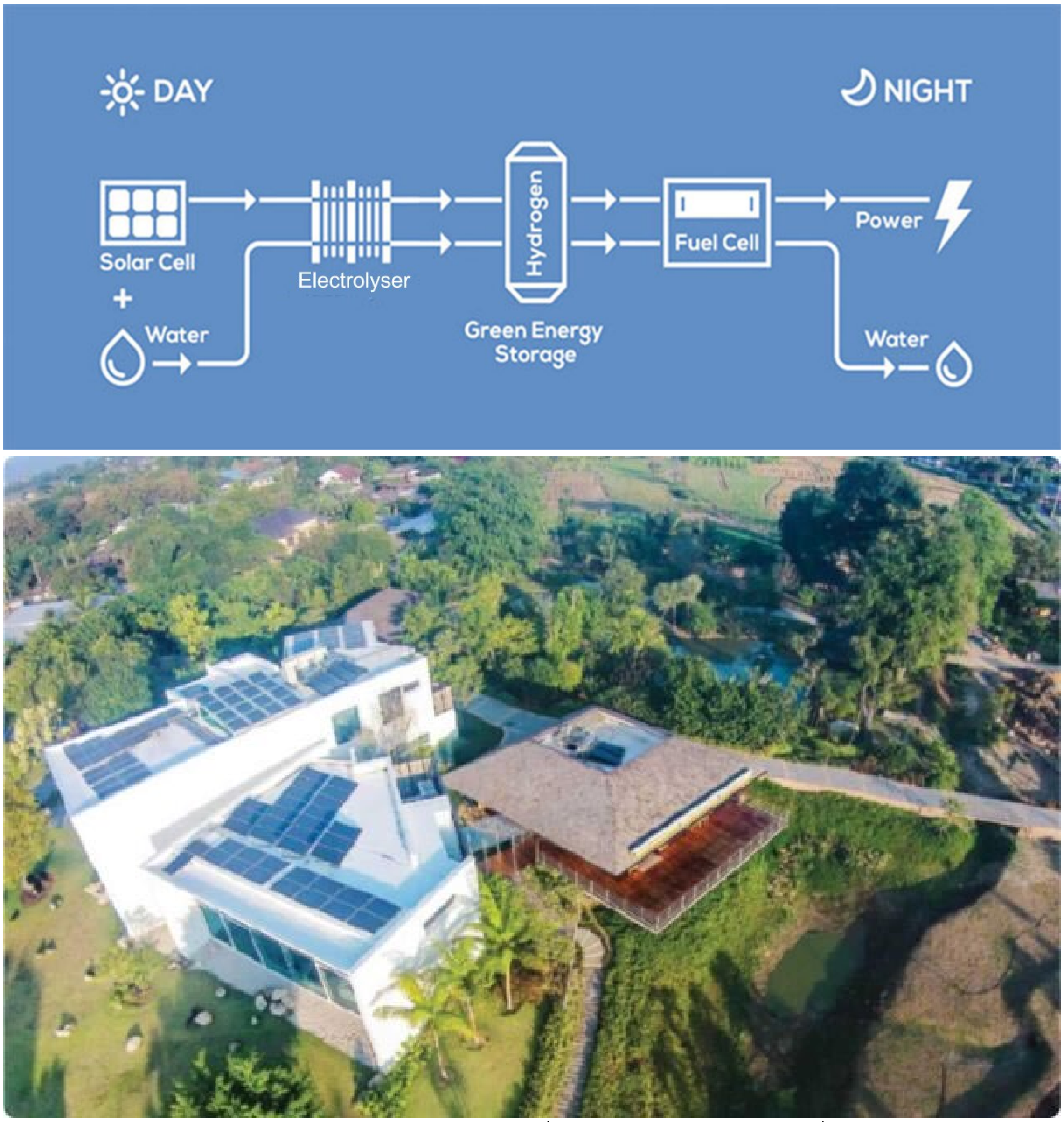
Figure 3.52. Lam Takhong Wind Hydrogen Hybrid Project



kw = kilowatt.
Source: Meeting materials with Energy Research Institute of Chulalongkorn University.

The Phi Suea House Project (private project by Enapter) (Figure 3.53), Chiang Mai Province, produces electricity from solar PV (86 kW) which can be used in households. The remaining electricity is used for hydrogen production, for which the volume of the hydrogen tank is 7.5 kilogrammes. Hydrogen is used as fuel for 4.5 kW fuel cells. The Phi Suea House is a 100% self-sustaining 24-hour solar powered multi-house residence. This project is a world's first in Solar-Hydrogen Residential Development. In daytime, the electricity that solar panels generate is direct current (DC power), and an electrolyser generates hydrogen and oxygen from water. Hydrogen is stored in a tank, but oxygen gas goes in the air. In nighttime, a solar inverter converts the electricity (DC power) from Hydrogen into alternating current (AC power) that can be used for television sets, computers, home appliances, etc. in the house.

Figure 3.53. Phi Suea House Project



Source: Enapter, 'The Phi Suea House Project' (accessed 25 April 2024).

PTT Public Company Limited (PTT), PTT Oil and Retail Public Company Limited (OR), Bangkok Industrial Gas Company Limited (BIG), Toyota Daihatsu Engineering and Manufacturing Co., Ltd. (TDEM), and Toyota Motor Thailand Company Limited (TMT) opened Thailand's first hydrogen refuelling station (HRS) for fuel cell vehicles in Bang Lamung district, Chonburi province (Figure 3.64). The project cost nearly B100 million, and its facility can blend compressed hydrogen with oxygen in electrochemical cells to produce electricity for vehicles in 3 to 5 minutes.

Figure 3.64. Prototypes of Fuel Cell Vehicle and Refuelling Station, Bang Lamung, Chonburi

Source: BIG (2022).

The Energy Policy and Planning Office (EPPO) plans to run a pilot project using hydrogen for electricity generation at a gas-fired power plant, operated by state-run EGAT in Ayutthaya's Wang Noi district. H_2 blend in gas turbine is planned to be 5%-20 % volume (EGAT website). There are also plans for hydrogen co-firing pilot projects at combined cycle power plants such as Nam Pong power plants, Korn Kaen (2 x 325 MW), Phra Nakhon Tai, Samut Prakan, Bangprakong, and Chachoengsao (2 x 700 MW).

- The Hydrogen Thailand Club has been established, consisting of experts from the government and private sector, to ramp up the use of hydrogen energy in Thailand, including driving hydrogen to be the future alternative energy source.
- In December 2021, Bloom Energy, ATE, EGAT, and EGCO Group signed an MOU to explore investment opportunities in solid oxide fuel cells and electrolyser technologies, new fuel alternatives for power generation.
- In January 2023, JERA Co. Ltd. (JERA, 2023a), announced that its subsidiary, JERA Asia Pte. Ltd. (JERA Asia) will collaborate with Electricity Generating Public Company Limited (EGCO Group), a major power generation company in Thailand, to cooperate in studies to decarbonise its business and co-firing using ammonia at a coal-fired power plant. For ammonia co-firing at a coal-fired power plant, JERA has signed an MOU with Mitsubishi Heavy Industries (MHI), Mitsubishi Corporation (MC) , BLCP Power Limited,

EGCO Group, and Banpu Power Public Company Limited (BPP) to jointly study the technical application, economic evaluation, and CO_2 reduction plan for up to 20% ammonia co-firing at the BLCP coal-fired power plant (1,434 MW) of BLCP Power Limited, a joint venture (50:50) between BPP and EGCO Group.

- In April 2023, PTT Group announced it will invest USD7 billion to produce green hydrogen with Saudi Arabia's leading renewable energy company, ACWA Power, aiming to power electric vehicles in ASEAN (Nikkei Asia, 2023). The project aims to build a plant in Thailand with a production capacity of 225,000 tons of hydrogen per year, equivalent to around 1.2 million tons of ammonia. The two companies, joined by EGAT, signed an MOU in November to proceed with the project. The investment pledge is a step forward in realising the plan.
- In May 2023, JERA Co. Inc. signed an MOU with PTT Public Company Limited (PTT), a state enterprise operating petroleum and related businesses under the Energy Ministry of Thailand, to collaborate on initiatives for expanding the supply chain and use of hydrogen and ammonia (JERA, 2023b).
- In August 2023, the Industrial Estate Authority of Thailand (IEAT), Bangkok Industrial Gas Co., Ltd. (BIG), Hitachi Zosen Co., Ltd. (HZ), PTTPLC., Toyota Motor (Thailand) Co., Ltd. (TMT) Toyota Tsusho (Thailand) Co. Ltd., and Thai Takasago Co. Ltd. collaborated to studying the feasibility of the procurement and utilisation of hydrogen in the Smart Park Industrial Estate and Mab Ta Phut Industrial Estate demonstration project.
- In August 2023, Kawasaki Heavy Industries announced that its local subsidiary in Thailand, Kawasaki Heavy Industries (Thailand) Co. Ltd. (KHIT) had signed an MOU with PTT Global Chemical Public Company Ltd. (GC) to study the development, construction, and operation of a hydrogen gas turbine power generation facility using a hydrogen gas turbine developed by Kawasaki (KHI, 2023).
- In September 2023, PPT and Registro Italiano Navale (RINA) of Italy signed an MOU for collaboration on hydrogen blending with a natural gas pilot project (RINA, 2023).
- In November 2023, EGAT has been funded by the Ministry of Economy, Trade, and Industry (METI) of Japan for the Study and Development Project on Clean Hydrogen and Ammonia Value Chain, and have kicked off a feasibility study under the signing of an MOU with Mitsubishi Corporation (Thailand) Ltd., Chiyoda Corporation (CC), and Mitsui O.S.K. Lines (Thailand) Co. Ltd (EGAT, 2023) .
- In January 2024, PTT Global Chemical Public Company Limited (GC) and Mitsubishi Heavy Industries (MHI) signed an MOU to jointly study the technologies required to develop a large-scale, carbon-neutral petrochemical complex in Thailand. The complex would be developed from PTT's existing assets in Thailand (currently centred in Rayong, south of Bangkok) and powered by low-carbon hydrogen or ammonia-fuel (MHI, 2024).
- In January 2024, a Chinese new energy company Beijing Mingyang Hydrogen Technology Co. Ltd. (BMHT) signed an agreement with Thailand's first liquefied natural gas distributor, IBCLNG Co., Ltd., to jointly develop a 25-MW electrolysis project.

- In February 2024, PTT Global Chemical Public Company Limited (GC) has partnered with Siemens Energy to sign a collaboration agreement to study and develop a project for generating electricity from hydrogen energy.
- In March 2024, Mitsubishi Heavy Industries Asia Pacific Pte. Ltd. (MHI-AP), a subsidiary of Mitsubishi Heavy Industries (MHI), signed an MOU with PTT Public Company Limited (PTT) to jointly conduct a pre-feasibility study to explore using 100% ammonia for gas turbine power generation in Thailand. Under the MOU, PTT and MHI-AP will assess the economic feasibility of using ammonia as a fuel for power generation, as well as the potential demand for clean and stable power generated from ammonia. Both parties will also evaluate the timeline and potential site locations for a 100% ammonia direct combustion gas turbine power plant.

Hydrogen R&D map

As mentioned previously, various hydrogen-related projects and collaborations are underway in Thailand. The R&D map for each hydrogen supply chain is summarised in Table 3.22.

Table 3.22. Research and Development Map of Hydrogen Technologies in Thailand

Supply Chain	Technologies	R&D Status	Project	Player
Production	Water electrolysis	Demonstration	‣Lam Takhong Wind Hydrogen Hybrid project ‣Phi Suea House Project	EGAT PTT Enapter
		MOU	25 MW electrolysis	BMHT IBCLNG
	Solid oxide fuel cells and Electrolysis technologies	MOU	-	Bloom Energy ATE EGAT EGCO group
	Green hydrogen production	MOU	Build a hydrogen production plant (250,000 tons per year)	PTT ACWA Power
Transport and Storage	Liquified hydrogen	Fundamental research	-	-
	MCH as hydrogen carrier	Fundamental research	-	-
	Ammonia as hydrogen carrier	Fundamental research	-	-

Supply Chain	Technologies	R&D Status	Project	Player
Utilisation	Hydrogen refuelling station and FCVs	Demonstration	Prototypes of FCV and refuelling station at Bang Lamung, Chonburi	PTT OR BIG TDEM TMT
	Hydrogen gas turbine	MOU	-	KHIT GC
	Ammonia gas turbine	MOU	-	MHI PTT
	Generating electricity from hydrogen energy	Collaboration agreement	-	GC Siemens Energy
	Procurement and utilisation of hydrogen	Demonstration	Smart Park and Mab Ta Phut Industrial Estate	EIAT BIG HZ TOYOTA Group Takasago
	Hydrogen co-firing	Demonstration	‣Wang Noi Power Plant ‣Nam pong power plants, Korn Kaen ‣Phra Nakhon Tai ‣Samut Prakan ‣Bangprakong, Chachoengsao	EPPO EGAT
		MOU	-	RINA PTT
	Ammonia co-firing	MOU	Up to 20% ammonia co-firing at BLCP coal-fired power plant (1,434 MW)	JERA EGCO Group MHI MC BLCP Power Limited Banpu
	Powered by low-carbon hydrogen or ammonia-fuel	MOU	GC's existing plant in Rayong, Thailand.	GC MHI
Total Supply Chain	Hydrogen and ammonia	MOU	-	JERA PTT EMOT

Supply Chain	Technologies	R&D Status	Project	Player
	Clean hydrogen and ammonia production	MOU and kick-off	-	EGAT Mitsui O.S.K. Lines MC Chiyoda Corporation

FCV = fuel cell vehicle, MOU = memorandum of understanding.
Source: Authors.

As shown in Table 3.21, hydrogen technologies development in Thailand is in the early stages. Thailand's hydrogen technologies development is focusing on production, utilisation, and total supply chain. Hydrogen is utilised in power generation, and it has just begun; a large part of the status is MOU, whilst hydrogen use in transport is being demonstrated. On the other hand, R&D development in transport and storage is at the fundamental stage. Advance hydrogen transport and storage technology such as liquified hydrogen, MCH, and ammonia as hydrogen carrier is not available in Thailand, and there are no players at this moment. The main players are EGAT, EPPO, PTT, GC, etc. on the Thailand side, and Japanese, Chinese, and German companies are collaborating with Thailand counterparties.

Chapter 4
Implications of the R&D Map

This chapter summarises the analysis from Chapters 2 and 3 in the framework of a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis: Thailand's geography, energy and economy, biofuel, CCS, and hydrogen. A SWOT analysis will be used to consider challenges, opportunities, and risks. Amongst these, the focus will be on technologies that should be in-housed but are technically less developed. Finally, examples of technologies from around the world that are ahead of the curve in these projects will be introduced, and the importance of learning from and participating in leading projects will be emphasised.

4.1. Summary

4.1.1. SWOT of Thailand

This section summarises the analysis from Chapters 2 and 3 in the framework of a SWOT analysis as shown in Table 4.1. Thailand is located in a tropical area where it is exposed to abnormal weather such as flood, high temperature, etc. Thailand is located at the centre of the Cambodia–Viet Nam–Lao PDR–Myanmar (CVLM) fan and is equidistant from Australia, China, India, Japan, and the Republic of Korea. This is a unique geographical advantage for Thailand. In past few decades, the country's economy has developed steadily, and it has become an upper middle-income country. The country has established a strong industrial base and position as an automotive hub in ASEAN. However, the country is vulnerable to the middle-income trap. To cope with these challenges, Thailand 4.0 policy was introduced. To revive the economy, which has fallen due to the impact of the novel coronavirus, the government includes BCG economy in its national agenda alongside Thailand 4.0.

Looking at the external environment, there is the decreasing energy self-sufficiency rate and worsening carbon intensity due to increasing energy demand. While achieving economic growth, Thailand is under pressure to resolve the trilemma of energy security and decarbonisation. To address these challenges, Thailand is keen to develop net-zero techs to solve the trilemma.

Thailand can open new horizons and opportunities by taking advantage of its strengths. With regards to the NZ techs, Thailand's energy technology development is still at a domestic stage and early stage. Therefore, cooperation with neighbouring countries, ASEAN countries, and other Asian countries could advance to a new stage and potentially lead to the resolution of challenges. On the other hand, there are concerns that global warming will have a serious impact on Thailand's agriculture. Concerns about the depletion of the country's own gas fields and increasing energy imports such as LNG cast a serious shadow over energy security.

Table 4.1. SWOT Analysis of Thailand's Geography, Climate, Economy, and Energy

Strengths	Weaknesses
• Geographical advantage • Upper middle-income country • Industrial base • Integrated infrastructure • Human resources	• Facing climate change • Middle-income trap/ageing population • Decreasing energy self-sufficiency • Poor energy efficiency • Worsening carbon intensity
Opportunities	**Threats**
• Cooperation with ASEAN countries • Opportunities for energy export • Keep the position of car manufacturing hub in ASEAN and obtain new technologies such as batteries • Energy integration progress with neighbouring countries	• Crop failure due to global warming. • Middle-income trap/ageing population, low birth rate progress further • Gas field depletion • Delay of technological innovation • Unexpected surge in energy demand (data centres, artificial intelligence, etc.)

Source: Authors.

4.1.2. SWOT of Bioethanol and Biodiesel

The bio, circular, and green (BCG) economy is a strategy that takes advantage of Thailand's strong point: agriculture. Bioethanol and biodiesel are playing a central role in the BCG economy. Biofuels have a long history of use in Thailand, thanks to the country's abundant sugarcane and cassava. The infrastructure is already in place. Measures to promote biofuel use have also already been put in place. On the other hand, farms are small, and modernisation is lagging. In addition, utilisation ratio of plants is low. The above are the reasons why ethanol prices are higher than in the United States and Brazil. The focus is on the popularisation and penetration of current first-generation biofuels, and development of next-generation biofuels has yet to progress. Measures to promote biofuel use also rely on subsidies, and the Oil Fuel Fund is running a large deficit.

Meanwhile, biofuels have been attracting attention again in recent years as carbon-neutral fuels, and transition to EVs is also facing various challenges. At present, the idea of combining hybrid vehicles with biofuels is one answer that utilises existing resources.

Thailand can export some bioethanol. It will contribute to the advancement of the bioethanol industry, and its deployment both domestically and internationally. On the other hand, Thailand is keen to promote EVs, as seen in 30@30. This policy decreases the demand for bioethanol and biodiesel. Subsidies may also be reduced or even eliminated in the future. At first glance, biofuel and EV policies seem contradictory, but their roles differ depending on the era. Thailand's strategy is to focus on biofuels with efficient engine vehicles and utilisation of biofuel until 2030, then gradually spread EVs, and in 2045, EVs will become the mainstream, and FCVs will also be deployed. SWOT analysis of bioethanol and biodiesel is below (Table 4.2).

Table 4.2. SWOT Analysis of Bioethanol and Biodiesel

<u>Strengths</u> • Abundant agricultural products • Long history of bioethanol and biodiesel • Integrated infrastructure and supply chain (plants, gas station, and flex vehicles) • Promotion scheme (subsidy, tax reduction, Oil Fuel Fund)	<u>Weaknesses</u> • High ethanol price compared to the United States, Brazil • Low utilisation ratio of plants • Delays in the development of next-generation biofuels (E2G, E3G) • Bioethanol and biodiesel demand peak out • Subsidy dependence and Oil Fuel Fund huge amount deficit
<u>Opportunities</u> • Refocusing on biofuels as carbon neutral fuels • Export potential of biofuel • Biofuel × most efficient ICE vehicles (HV) • No policy contradiction between agriculture and bioenergy	<u>Threats</u> • Policy contradiction biofuel vs EV • Biofuel subsidy decrease or abolishment in the future

Source: Authors.

4.1.3. SWOT of Carbon Capture and Storage

Increasing CO_2 absorption is also an important factor in the BCG economy. The technological development of CCS in Thailand is still in the early stages towards commercialisation. The lack of a comprehensive legal and regulatory framework for CCS creates uncertainty and risk for investors. On the other hand, Thailand has abundant gas fields and an existing gas grid in the country, making it possible to store CO_2 domestically.

Currently, Thailand is only aiming for domestic use of CCS, and there is no vision for CCUS with a view to cooperation with neighbouring countries and CO_2 trade. If Thailand uses CCUS to fuse hydrogen with CO_2, it could see expansion into synthetic fuels (e-fuel) and methanation. Once carbon pricing is implemented and a CO_2 trading market is established, it may be able to take advantage of its geographical location to expand projects within the ASEAN region. Although CCS technology is already established, there are legal and technical risks, such as leakage, during long-term monitoring. In addition, there are concerns that power plants, cement plants, and chemical plants equipped with CCS will experience a decrease in overall efficiency and an increase in operating costs. Although Thailand has the potential to become a CCS hub in ASEAN, but there are concerns about policy friction with other countries, and it is desirable to establish global standard rules. Competition from other NZ techs such as RE sources may make CCS less attractive in the long term. The SWOT analysis of CCS is in Table 4.3.

Table 4.3. SWOT Analysis of Carbon Capture and Storage

Strengths	Weaknesses
• Abundant gas fields • Existing infrastructure derives affordable energy price. • Geopolitical advantage	• Early stage of demonstration project • Lack of a comprehensive legal and regulatory framework • Need to updated CCS action plan
Opportunities	**Threats**
• To become CCS hub in ASEAN • Carbon credit market development • Carbon pricing • Establish CO_2 trade platform • Improve energy self-sufficiency and energy security	• Few commercialisation cases • Investment uncertainty and risk • Long-term monitoring and legal/technical issues in the future • Reduced efficiency and increased operational costs (power plants, etc.) • Confliction for CCS policy with ASEAN countries • Competition with RE may reduce the attractiveness of CCS in the long term

CCS = carbon capture and storage, RE = renewable energy.
Source: Authors.

4.1.4. SWOT of Hydrogen

Hydrogen technologies development in Thailand is in the early stages. As of May 2024, there is no national hydrogen strategy, but it is expected that one will be released in line with the upcoming NEP. Thailand is advancing projects to promote hydrogen, including electrolysers, HRS and FCVs. A Thai company is focusing on production and utilisation, but there are few projects in transportation and storage technologies. To cope with this situation, MOUs have been signed with many foreign companies, including China, Japan, and Saudi Arabia, in recent years.

Thailand has abundant RE potential, especially solar power. Therefore, the potential for green hydrogen is high, and further strengthening of the power grid is necessary. Safety standards and regulations have yet to be established, and human resource development to respond to them is required. Thailand is close to demand areas such as China, Japan, and the Republic of Korea. First, Thailand can solve its high-cost problem by using domestic natural gas to generate grey hydrogen, while at the same time expanding its market. Once a carbon market is established through the introduction of a carbon price, it will be possible to export hydrogen to demand areas in East Asia. Thailand must also comply with international hydrogen standards and prepare to compete with low-cost hydrogen-producing countries such as India, Australia, and the Middle East. The SWOT analysis of hydrogen is in Table 4.4.

Table 4.4. SWOT Analysis of Hydrogen

<u>Strengths</u> • Abundant hydrogen feedstock • (natural gas, solar, wind, biomass, etc.) • Collaboration with foreign countries • (China, Italy, Japan, Saudi Arabia, etc.) • Integrated transmission and gas grid • Geographically close to the demand countries (China, Japan, Republic of Korea, etc.)	<u>Weaknesses</u> • Early stage of technology development • Lack of transportation and storage technology • Shortage of hydrogen infrastructure • No hydrogen promotion scheme • (subsidy, tax reduction, etc.) • Shortage of specialists (technically and politically) • High cost and low demand
<u>Opportunities</u> • Carbon credit market development • Carbon pricing • Establish hydrogen trade platform. • Refocusing on hydrogen as carbon	<u>Threats</u> • Delay of national hydrogen strategies • Delay of transmission grid development to support with renewable energy • Delay of establishing laws and

neutral fuels • Existing ammonia industry and infrastructure	regulations. • Stricter global hydrogen certification requirements • Competition with low-cost producers (India, Australia, Middle East, etc.)

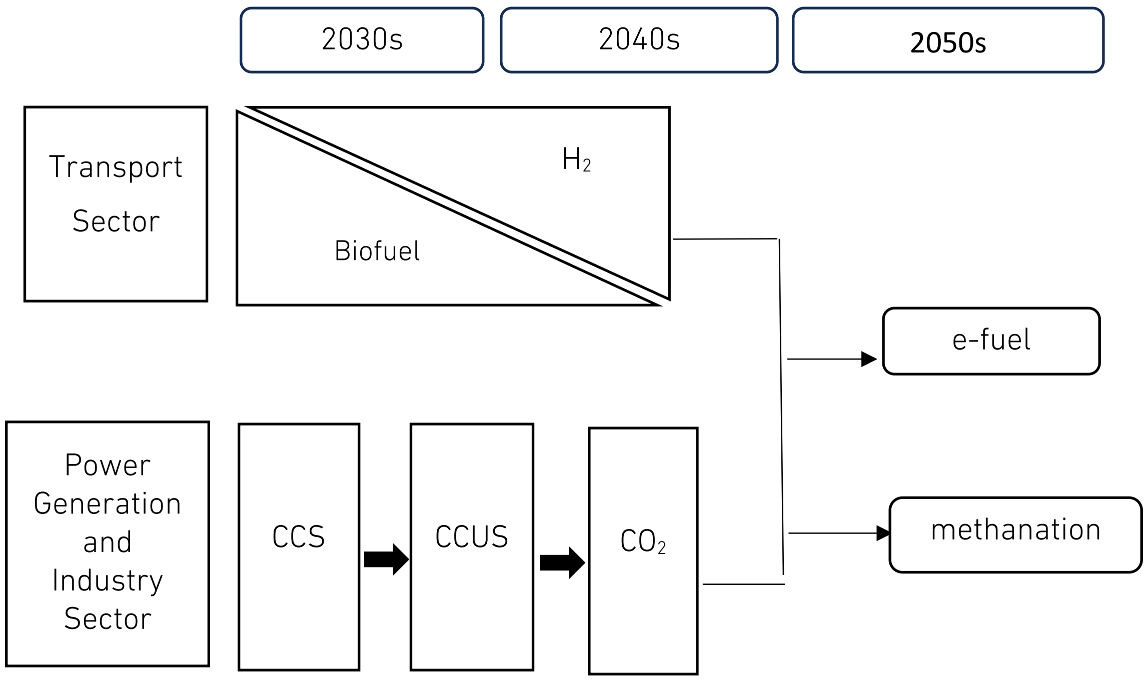
Source: Authors.

4.1.5. Carbon Neutral Fuel Strategy in Thailand

To summarise further, Thailand appears to be focusing on 'fuel' and 'combustion'. Until around 2037, decarbonisation measures will be implemented using biofuels. For the time being, existing internal combustion engines (ICE) will continue to be used. CO_2 generated from fuel will be reduced by using biofuels. Bioethanol and biodiesel technology is already in place, and this will help Thailand maintain its position as a hub for the automobile industry in ASEAN. Biofuels will be gradually replaced by hydrogen and synthetic fuels (e-fuel).

CO_2 generated from thermal power generation and the industrial sector will be filled with CCS. Thailand's hydrogen technology is in the early stages, and the transition to a hydrogen society will take time. If a certain amount of CO_2 will be generated during the period until the transition to hydrogen, it will be stored with CCS. In the future, the stored CO_2 will be used to transition to synthetic fuels and methanation. Thailand has existing gas fields, and CCS is possible within the country, and there are gas pipelines available. In the future, hydrogen can be mixed with existing gas infrastructure, and methanation is possible. Carbon neutral fuels (biofuels → hydrogen +CO_2 → e-fuel, methanation) are considered to be a consistent strategy for Thailand (Figure 4.1).

Figure 4.1. Carbon Neutral Fuel Strategy in Thailand



CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage.
Source: Authors.

4.2. Proposals

4.2.1. Biofuel

Further utilisation of abundant biomass resources must be sought. The reason biofuel prices are low in Brazil and the United States appears to be due to large-scale agriculture that takes advantage of economies of scale. In Thailand as well, domestic agriculture, especially biofuel production, should be made as large-scale as possible to improve production efficiency and reduce domestic biofuel prices. To continue to expand the domestic use of biofuels, Incentives currently in place should be strengthened to continue expanding the use of biofuels in the country. On the other hand, it must be considered that these incentives are provided by the oil fuel fund, and the oil fuel fund is running a large deficit due to subsidies. Given this current situation, it is essential to create a system that can sustainably run on its own.

Furthermore, in anticipation of the future increase in global demand for biofuels, it is in the national interest to build cooperative relationships with neighbouring countries to improve biofuel production technology. Cooperation in the development of next-generation biofuels such as E2G and E3G technologies would also be effective. Ultimately, it is recommended to work with Thailand and multilateral countries to further expand biofuel production and stimulate trade transactions to raise the profile of biofuels as a decarbonised fuel and to export them to the rest of the world.

4.2.2. Carbon Capture and Storage

Regarding CCS technology in Thailand, various policy supports, legal developments, and technical studies are being carried out, but there are still many issues to be solved to start operation in 2040.

During the field survey, we heard that the cost of introducing CCS is high, but that business incentives and government incentives are insufficient. Additionally, comprehensive laws and regulations are yet to be established, creating uncertainty and risk for investors.

To resolve this situation, it is necessary to introduce internationally unified emissions measurement standards and an international carbon price market.

It is assumed that these important issues are being implemented, and it also will be necessary to raise funds and expand government aid and incentives by introducing carbon pricing for fossil fuel use.

Furthermore, currently in Thailand, CCS technology is intended to be used only domestically, but cooperation with neighbouring countries and CO_2 trade through CCS could be important.

Specifically, since neighbouring Malaysia also has abundant gas fields, it can be possible to create a market by increasing the trading volume of CO_2 by importing and exporting CO_2 generated within each country. It may be possible in the future to reduce costs if the number of trading participants increases.

Furthermore, Thailand is also located in a very important geographical location. Thailand is located at the centre connecting East Asia such as China, Japan, and the Republic of Korea, as well as Australia, India, and the Middle East, and could become a hub for CCS when the international CO_2 market becomes active in the future.

To make maximum use of Thailand's unique resource, gas, fossil fuel decarbonisation technology is important, and early commercialisation of CCS, which is central to this, is important.

4.2.3. Hydrogen

Regarding hydrogen, a scheme similar to the biofuel subsidy scheme will be applied to solve the high-cost problem.

By collecting money such as a renewable energy levy from the fossil fuel industry and using it to compensate for the hydrogen price difference, demand will be stimulated, and a market will be formed. As mentioned in the section on biofuels, improved allocation is important because, as with the oil fuel fund in Thailand, the current level of collection and subsidy is not balanced, resulting in huge deficits.

Apart from financial aspects, support from the tax system and accounting aspects will also be considered.

(a) Accelerated depreciation: quickly recover costs
(b) Tax credits: Tax credits and rebates for clean hydrogen such as IRA
(c) Tax exemption or reduced tax rate: Application of exemptions from or reductions in value added tax (VAT) and other taxes to hydrogen stations and industrial hydrogen demand
(d) Carrying forward losses: offsetting current hydrogen losses and future profits

As an example, the Japanese and United States governments are trying to mutually utilise corporate incentives (IRA tax deductions and green transformation price differential support) to promote the spread of hydrogen. For example, under this system, if a Japanese company imports hydrogen produced in the United States to Japan, it will receive a tax deduction from the United States and receive support from Japan on the price difference.

This may be good system that utilises IRA and price differential support in the United States applicable to Thailand as well. Of course, it should be pointed out here that there are concerns that Thailand's hydrogen industry will be hollowed out due to the need for negotiations with the US and investment in the US.

4.2.4. Proposals (phased approach)

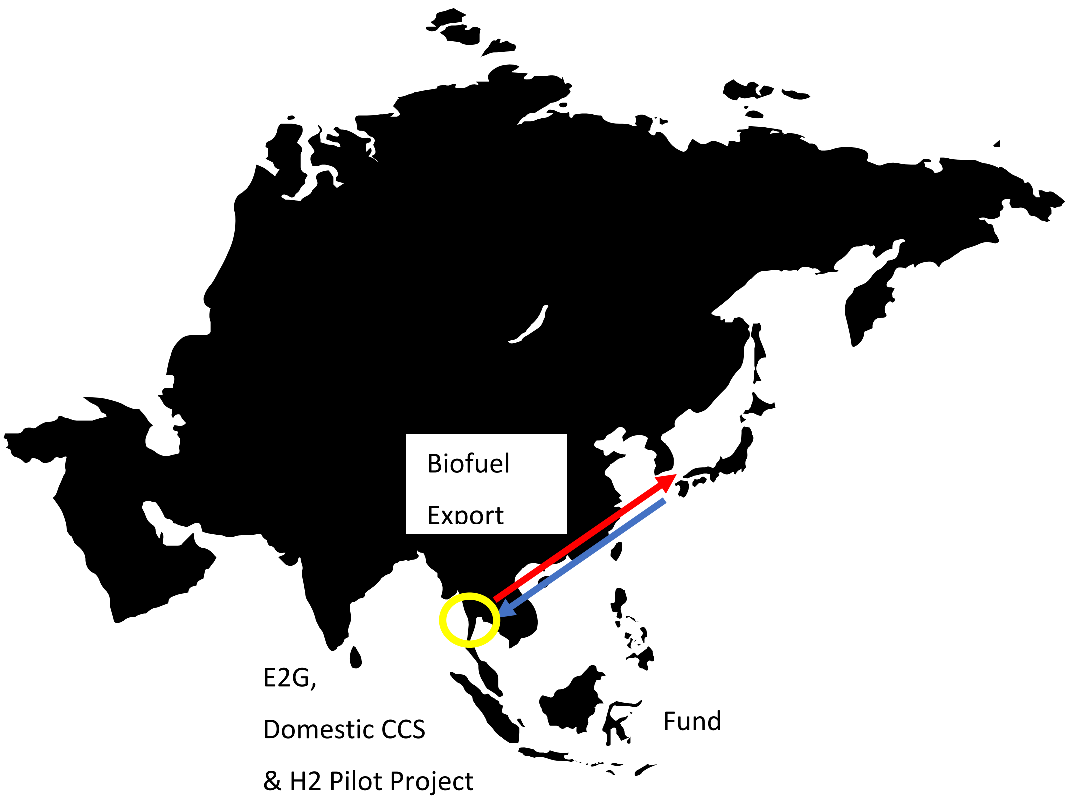
There are a great many difficulties and challenges in bringing decarbonisation technologies in-house, and methods for solving them are still being explored. However, most of the technologies and mechanisms for biofuels have already been established, and since there are abundant biomass resources, biofuels should be promoted because they contribute to energy self-sufficiency and are expected to attract more and more attention in the future as decarbonisation technology.

In addition, Thailand has domestic resources of fossil fuels such as gas fields, and from the perspective of utilising domestic resources, new technologies such as CCS and hydrogen that decarbonise fossil fuels should be put into operation as soon as possible. On the other hand, it is still essential to invest in technological development and policy incentives for technologies such as CCS and hydrogen.

Given this situation, biofuels in particular, as an existing technology, can be a low-cost way to achieve domestic low-carbonisation and decarbonisation, and can be a source of investment capital for new technologies such as CCS and hydrogen, and for decarbonisation projects with growth potential. Focusing growth and internalisation on decarbonisation technologies that are more affordable and feasible for Thailand, whilst maintaining and enhancing Thailand's energy security, is the most efficient way to achieve the 2050 carbon neutral and 2065 NET ZERO target.

Therefore, a step-by-step approach would be effective in steadily progressing the above. Phase 1 is the phase for consolidating its own country's systems in 2030s. As for biofuels, exports will be made to East Asian countries such as China, Japan, and the Republic of Korea, where there is a growing need for biofuels. The funds obtained will be used for research into next-generation biofuels such as E2G, and for the expansion and modernisation of Thailand's sugarcane and cassava farms. By improving the operating rate of bioethanol plants, the retail price of biofuels will be reduced, and the market will be further expanded. As for CCS, CO_2 will be steadily stored in the country's CCS. Based on the technical knowledge and know-how gained from this, the in-house of CCS technologies will be promoted. As for hydrogen, Thailand should increase production of grey hydrogen using its own natural gas as a feedstock and work to develop a domestic hydrogen market. Whilst increasing the number of transportation and storage projects, which are currently in short supply, efforts will be made to accumulate production technology, transportation technology, and storage technology in the country and develop the hydrogen market. In other words, Phase 1 is the phase to solidify the domestic market, domestic technology, legal systems, human resource development, etc. Figure 72 shows the image of Phase 1.

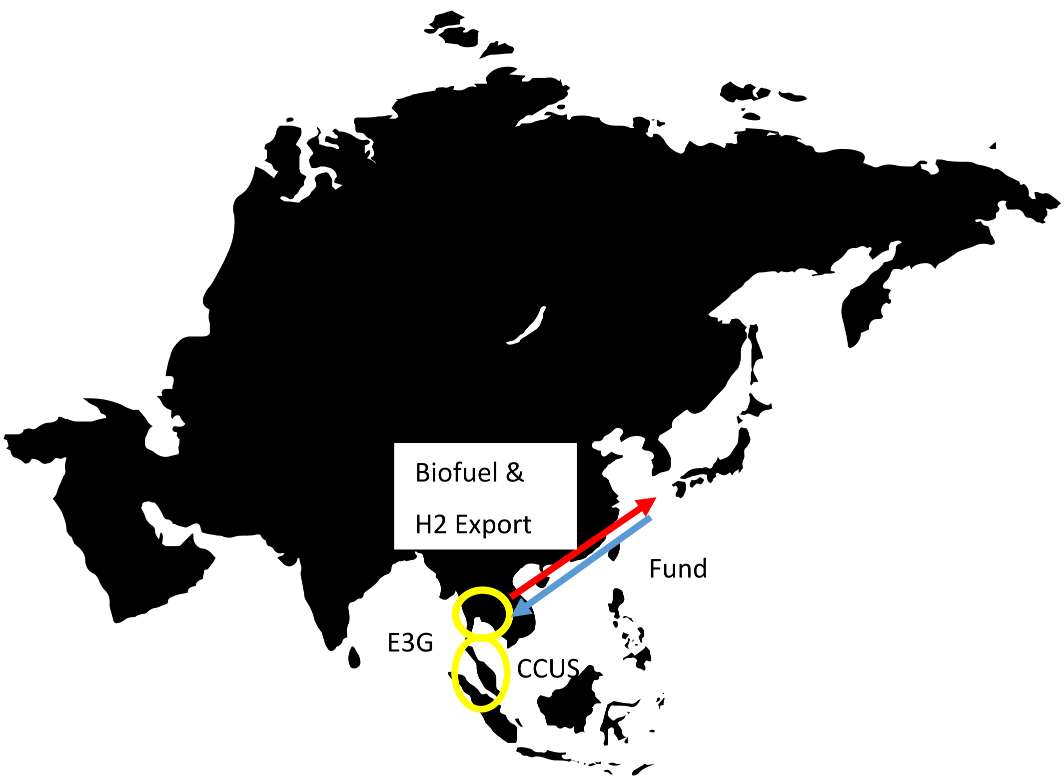
Figure 4.2. Phase 1 (2030s)



CCS = carbon capture and storage, E2G = second-generation ethanol.
Source: Authors.

Phase 2 is the phase for cooperating with neighbouring countries in the 2040s. Whilst continuing to export biofuels to East Asia, Thailand should be researching E3G biofuel. Thailand would consider promoting the establishment of an ASEAN CCS hub with neighbouring countries such as Malaysia which country has a large potential of CCUS in the region. Presuming that a carbon price and carbon market are established, Thailand should shift from CCS to CCUS and develop technologies for transporting, storing, and trading CO_2. Regarding hydrogen, Thailand should export grey hydrogen to East Asia on a bilateral basis and use the proceeds to further the development of hydrogen-related technologies such as electrolysers. Thailand should also expand its subsidy system to guarantee the price difference scheme between hydrogen and natural gas and expand the domestic hydrogen market. In other words, Phase 2 is the phase to expand the cooperation with neighbouring countries. Figure 4.3 shows the image of Phase 2.

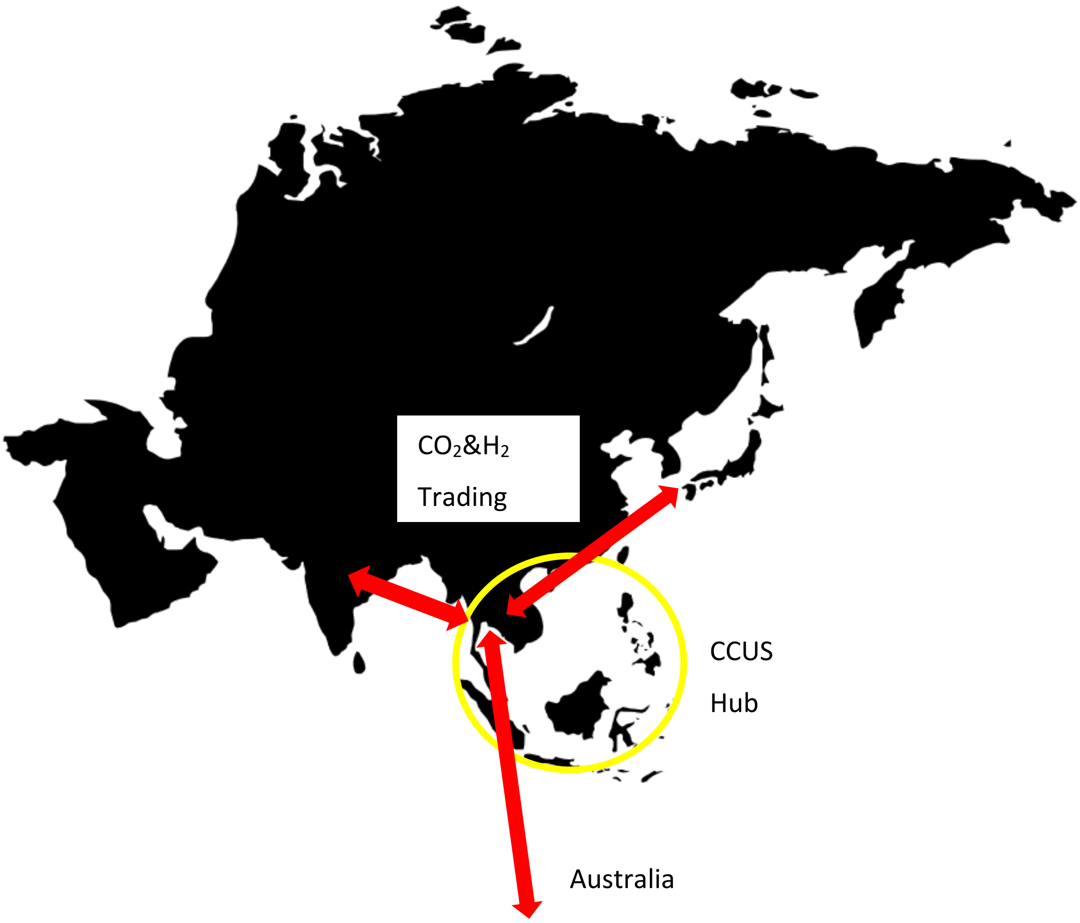
Figure 4.3. Phase 2 (2040s)



CCUS = carbon capture, utilisation, and storage, E3G = third-generation ethanol.
Source: Authors.

Phase 3 is the phase for cooperation with multilateral countries in 2050s. Thailand continues to export next-generation biofuels; however, it trades not only with East Asia but also with other regions. Thailand would be consider promoting the establishment of an ASEAN CCUS hub with ASEAN countries. Presuming that a carbon price and carbon market are established, Thailand should be entering the CO_2 market and trade CO_2 in region with, India, Australia, and East Asia. By this time, Thailand's green hydrogen technology is expected to be mature, and costs will fall. Development towards CCUS will allow use of stored CO_2. ICE vehicles using biofuels will gradually be replaced by EVs and FCVs, and next-generation fuels such as e-fuels and methanation will emerge instead. In other words, Phase 3 is the phase to expand the trading with multilateral countries. Figure 4.4 shows the image of Phase 3.

Figure 4.4. Phase 3 (2050s)



CCUS = carbon capture, utilisation, and storage.
Source: Authors.

The above step-by-step approach can be summarised in Table 4.5. This is a strategy that leverages Thailand's strengths, whilst minimising risks and seeking opportunities to expand globally. As NZ technologies that Thailand should develop in-house, it should work on developing E2G and E3G technologies to maintain its advantage in biofuels. With a view to future CO_2 use, it should develop in-house technologies to transition from CCS to CCUS, and in anticipation of becoming an Asian CCUS hub, it should develop in-house CO_2

transportation and storage technologies. In addition, Thailand should develop in-house technologies for e-fuel and methanation, which synthesise CO_2 and hydrogen, and develop in-house production technologies such as electrolysers, hydrogen transport technologies such as liquified hydrogen, ammonia, MCH, and toluene, and utilisation technologies such as hydrogen co-combustion in thermal power plants and developing FCV and HRS networks.

Table 4.5. Three-step Approach of In-house Technologies (2030s-2050s)

Very High Priority 3 Area	Phase 1 (2030s)	Phase 2 (2040s)	Phase 3 (2050s)
Expansion Axis	Domestic	Neighbouring	Multilateral
Biofuel	Export	Export	Export
CCS	CCS Domestic pilot Project	CCUS Cooperation with neighbouring countries	CCUS ASEAN CCUS Hub
Hydrogen	Domestic pilot Project	Export (bilateral)	Trading (multilateral)
In-house Technology	E2G CO_2 capture and storage technology Green H_2 production and utilisation	E3G CO_2 utilisation technology H_2 transport and storage technology	e-fuel, methanation CO_2 transport technology H_2 transport and storage technology

CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, E2G = second-generation ethanol, E3G = third-generation ethanol.
Source: Authors.

Brazil's Raízen is working on E2G bioethanol and began producing E2G in 2015. Raízen is a partnership between Shell and Brazilian sugar and energy conglomerate Cosan. Raízen is working with Sulzer as a technology provider for E2G (Sustainability Magazine, 2023). Regarding e-fuel, the Haru Oni project in Chile which is operated by HIF is the first operating e-fuel facility in the world. The plant uses renewable energy from wind power and a process called electrolysis to produce green hydrogen. The project captures CO_2 from a biogenic source and use a process of synthesis to combine the CO_2 and hydrogen to produce e-fuels.

Europe continues to make progress to advance CO_2 transport and storage infrastructure with now over 160 Mt CO_2 of storage capacity planned by 2030, mostly around the North Sea. The Porthos transport and storage project in the Netherlands reached a final investment decision in October 2023.

The United States continues to increase CO_2 storage capacity with a 2.5-fold increase in planned capacity by 2030 in 2023 compared to 2022. In April 2024, the United States announced USD11 million for four CO_2 transport projects.

CO_2-free Hydrogen Energy Supply-chain Technology Research Association (HySTRA) is a hydrogen energy supply chain pilot project between Australia and Japan. The HySTRA project will produce hydrogen from lignite in Australia, convert it to liquefied hydrogen at a liquefaction terminal, and transport it to a cargo handling base in Japan by a special carrier ship (Hydrogen Frontier). In addition, in the AHEAD project, Japan, and Brunei are conducting an international transportation demonstration using MCH as a hydrogen carrier (AHEAD, 2019).

By learning from and participating in the leading projects, Thailand can acquire the strategic NZ tech in-house. Thailand will be able to complete the supply chain by participating in the leading projects to fill in the technology gaps in not only three very high priority areas but also other areas in the future.

4.3. Significance and Potential Uses of Research and Development Maps

By using the R&D map, it is possible to understand the status of technological development, strengths, weaknesses, opportunities, and risks of the study country. The report choses Thailand as a case study country, however by creating R&D maps for other ASEAN countries, it is possible to understand the characteristics of each member country. By conducting a comparative analysis, it is possible to consider the possibility of regional or outside of regional cooperation specifically (Tables 4.6 and 4.7).

Table 4.6. Template of Research and Development Benchmark Map in ASEAN

Tech	BRN	IDN	KHM	LAO	MYS	MMR	PHL	SGP	THA	VNM
A	0	4	0	0	4	0	3	4	4	3
B										
C										

BRN = Brunei, IDN = Indonesia, KHM = Cambodia, LAO = Lao PDR, MYS = Malaysia, MMR = Myanmar, PHL = Philippines, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Note: 0 is not existing, 1 is fundamental research, 2 is applied research, 3 is prototype, 4 is demonstration, 5 is commercial.
Source: Authors.

Table 4.7. Template of Net-zero Tech Players and Market Map

Tech	Player			Market
	Thailand	ASEAN	Global	
SAF	Bangchak Group (5) PTT Oil and Retail Business Public Company Limited (OR) (5) Thai Airways International (THAI) (5)	PETRONAS EcoCeres Malaysia Airways PT Pertamina Garuda Indonesia Neste Singapore	Lanza Jet (US), Neste (Finland), TotalEnergies, Shell, bp, Chevron, Eni, Fulcrum Bioenergy (US), Aemetis Inc. (US), Gevo Inc. (US), World Energy (US), Honeywell UOP, Vattenfall, ENEOS, Idemitsu, Cosmo, Fuji oil, JGC, Itochu, Marubeni, Mitsui&co., IHI, Mitsubishi Heavy Industry, Toyo Engineering, Nomura Jimsho, Airbus, Boeing, British Airways, Virgin Atlantic, JAL, ANA	Global SAF demand forecast 2025: 8 2030: 23 2035: 90 2040: 229 2045: 346 2050: 449 Unit: billion litres IATA Net Zero 2050: Sustainable Aviation Fuels

SAF = Sustainable Aviation Fuel, US = United States.
Source: Authors.

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Appendix
Overview of High Priority Technologies in Thailand

1. Biofuel

Bioethanol

Bioethanol is ethanol produced by fermenting biomass such as sugarcane, corn, or wood. Biomass refers to the amount (mass) of biological resources (bio), and biomass also includes straw, rice husk, livestock manure, sewage sludge, waste cooking oil, etc. that are used or recycled as energy sources derived from animals and plants. Biofuel is a fuel produced from biomass, and bioethanol is one type of fuel.

In Thailand, ethanol is produced from sugarcane-derived molasses and cassava, which is the raw material for tapioca starch, and is widely used throughout the country, primarily as a fuel for automobiles.

Bioethanol is positioned as carbon neutral under the United Nations Framework Convention on Climate Change (UNFCCC) and is not included in CO_2 emissions. This is based on the idea that plants, which are the raw materials for bioethanol, originally absorb CO_2 from the atmosphere through photosynthesis, so even if they emit CO_2 through combustion, they do not increase the overall amount of CO_2. Substituting bioethanol for fossil fuel will lead to a reduction in CO_2 emissions.

Bioethanol is positioned as one of the biofuels for transportation. The raw materials for bioethanol are mainly starchy raw materials such as corn, sweet potato, wheat, and tapioca, and carbohydrate raw materials such as sugar cane and sugar beets. The sugars contained in these plants are fermented by microorganisms and then distilled.

In addition, there is also bio-ethyl tertiary butyl ether (bio-ETBE), which is produced from bioethanol, and both are used by mixing them with gasoline. ETBE is manufactured by chemically synthesising isobutene, which is a by-product in the gasoline refining process, and ethanol. ETBE produced using bioethanol is also called bio-ETBE.

The method of directly mixing gasoline and bioethanol has been adopted in US, Brazil, and Thailand, and is mainstream in worldwide. Bio-ETBE has been adapted in Japan and Europe. As shown Table A1, each method has its own characteristics.

Table A1. Types of Bioethanol

Name	Overview	Characteristics
Bioethanol	Liquid alcohol made from plant polysaccharides such as agricultural products, wood, and wastepaper	➢ Can be used as a substitute for gasoline or mixed with gasoline at any concentration ➢ Blended gasoline is expressed as E10 (10% blend) or E20 (20% blend) depending on the blending ratio of ethanol
Bio-ETBE	Manufactured by synthesising ethanol and isobutene	➢ Can be added to gasoline as an octane number[1] improver

ETBE = ethyl tertiary butyl ether.
Note: [1]The octane number is a number that indicates how unlikely knocking is to occur; the higher the octane number, the less likely it is that knocking will occur.
Source: Authors.

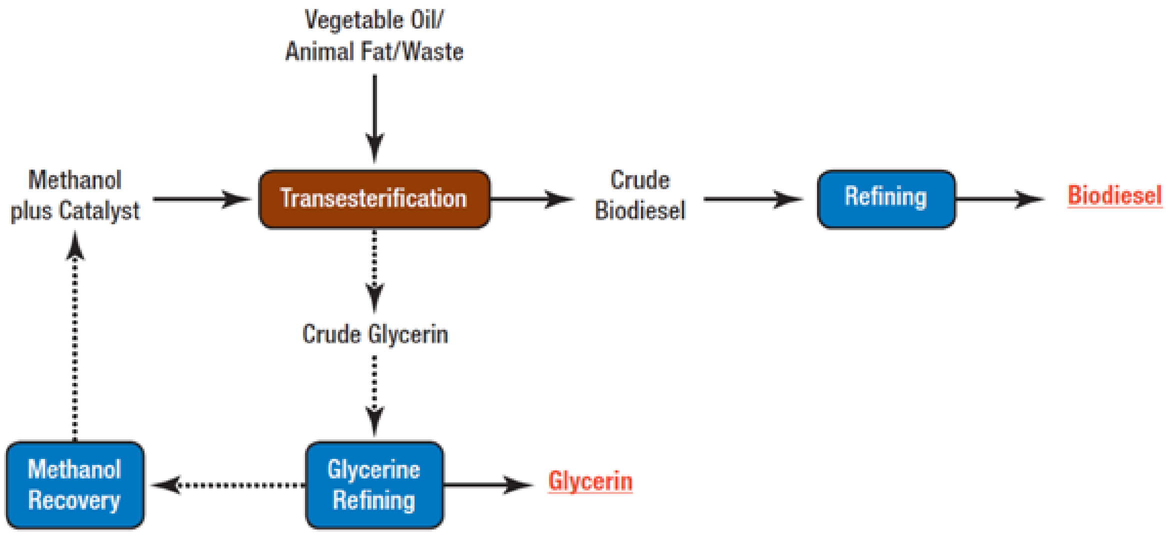
Ethanol is easily soluble in water, so if more than a certain amount of water gets mixed in when mixing it with gasoline, the ethanol will mix with the water and separate from the gasoline, potentially making it impossible to maintain the desired fuel properties. For this reason, when using bioethanol blended gasoline, it is necessary to prevent entry of moisture. ETBE, on the other hand, is used as an octane-boosting additive. There is no separation due to moisture contamination, but there is a corrosive property. However, it is necessary to conduct a risk assessment of ETBE in terms of degradability, long-term toxicity to humans, toxicity to animals and plants, etc., and take risk reduction measures.

Biodiesel fuel (BDF)

Biodiesel is a biofuel made from vegetable or animal fats. For example, palm oil, rapeseed oil, soybean oil, camelina oil, and jatropha oil are used as vegetable oil, and tallow oil is used as animal fat. Vegetable oil (waste cooking oil) used for cooking may also be used.

Methanol and catalyst are added to the raw material vegetable oil and heated. Fatty acid methyl ester (FAME) is obtained by transesterification. After that, the glycerine produced as a by-product is separated and removed, and then refined into the biodiesel fuel. This is called first generation BDF and is currently the mainstream and stable production method (Figure A1).

Figure A1. Biodiesel Fuel Production Process from Vegetable Oil/Animal Fat/Waste



Source: United States Department of Energy (accessed 18 April 2024).

Hydrotreated vegetable oil (HVO), which is obtained by hydrogenating fats and oils, is expected to be used as the second-generation BDF. Like FAME, HVO can also be manufactured using vegetable oil or waste cooking oil as raw materials. Hydrogenation improves the physical properties of fuel oil, such as making it more stable against oxidation. As a result, HVO has better low-temperature performance than conventional FAME and has a higher cetane number[1] than diesel fuel.

BDF is generally used by mixing it with diesel oil, and depending on the mixing ratio, it is expressed as B5 (5% blend), B7 (7% blend), B10 (10% blend), etc.

2. Carbon Capture and Storage

CCS is a technology for carbon capture and storage. The CO_2 emitted from power plants, chemical factories, etc. is separated from other gases, collected, and stored and injected deep underground.

CCS involves three major steps: Capturing CO_2 at the source, compressing it for transportation, and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored.

1) Capture: The separation of CO_2 from other gases produced at large industrial process facilities such as coal and natural-gas-fired power plants, steel mills, cement plants,

[1] The cetane number is an indicator of the ignitability of fuel; the higher the cetane number, the easier it is to ignite and prevent diesel engine knocking.

and refineries.

2) Transportation: Once separated, the CO_2 is compressed and transported via pipelines, trucks, ships, or other methods to a suitable site for geological storage.
3) Storage: CO_2 is injected into deep underground rock formations, usually at depths of 1 kilometre or more.

On the other hand, carbon capture, utilisation, and storage (CCUS) aims to utilise separated and stored CO_2. According to a report by the International Energy Agency (IEA), CCS is expected to account for 14% of total CO_2 reductions by 2060.

CO_2 capture/separation methods

There are five main methods for separating and capturing CO_2, as shown in Table A2. In CO_2 sequestration, 'chemical absorption' is an often used and useful technology, in which CO_2 is separated from other components and recovered by absorption into an alkaline solution. CO_2 with a purity of over 99% can be recovered from gases at atmospheric pressure and low CO_2 concentration, such as combustion exhaust gas from thermal power plants and blast furnace gas from steel plants. The problem is that it consumes a large amount of energy, resulting in poor fuel efficiency. There are also several other methods, such as adsorption to porous solids and separation based on differences in condensation temperature.

Table A2. CO_2 Separation Methods

Technology Name	Technology Overview
1. Chemical absorption	CO_2 is separated through a chemical reaction with an alkaline solution that can selectively dissolve CO_2. A large amount of steam is required to extract the absorbed CO_2. As alkaline solutions, amines and potassium carbonate aqueous solutions are used.
2. Physical absorption	CO_2 is brought into contact with a liquid that can dissolve a large amount of CO_2 under high pressure and physically absorbed. The CO_2 is then recovered by reducing the pressure (heating).
3. Membrane separation	Gas is passed through a porous gas separation membrane, and CO_2 is separated using the sieving effect and differences in diffusion speed depending on the pore size.
4. Physical adsorption	By bringing gas into contact with an adsorbent such as activated carbon or zeolite, CO_2 is physiochemically adsorbed

Technology Name	Technology Overview
	into its micropores, and then desorbed using pressure and temperature differences.
5. Cryogenic separation	After compressing and cooling the gas, CO_2 is separated by phase separation using a distillation operation.

Source: Authors.

The largest source of CO_2 emissions is the combustion of fossil fuels, especially in power plants. Three main methods have been developed to capture CO_2 from power plants that use coal or gas (Table A3).

Table A3. CO_2 Capture Methods

Pre-combustion	Post-combustion	Oxyfuel
Converts fuel into a gas mixture of hydrogen and CO_2. Hydrogen can be separated and burned without producing CO_2. The CO_2 is then compressed for transport and storage. The complexity of the fuel conversion steps makes it difficult to apply this technology to existing power plants. This is primarily used in industrial processes (e.g. natural gas processing)	Separates CO_2 from flue gas. CO_2 is captured using liquid solvents or other separation methods. In absorption-based approaches, CO_2 is released upon heating once absorbed in a solvent, forming highly pure CO_2. This technology is also widely used to capture CO_2 for use in the food and beverage industry.	It uses oxygen instead of air to burn the fuel. This produces exhaust gases that are primarily water vapor and CO_2, which can be easily separated to produce high-purity CO_2.

Source: Author based on Global CCS Institute.

CO_2 transport methods

Pipelines are the most common method for transporting large amounts of CO_2 in CCS-related projects. There are already millions of kilometres of pipelines around the world, and their use for future CO_2 transport is also being considered.

Shipping by ship could be another option. Small-scale CO_2 transport by ship is already underway in the EU, with food-grade CO_2 (approximately 1,000 tonnes) being transported. Large-scale transportation of CO_2 (100,000 to 400,000 cubic metres) has many similarities with the transportation of liquefied petroleum gas, and the know-how is expected to be utilised.

CO_2 underground storage methods

Next is the storage and sequestration of CO_2. Possible locations for CO_2 sequestration are underground or in the strata of the ocean floor. Oil fields, depleted gas fields, deep coal seams, and saline aquifers all have potential as reservoirs. The reason CCS is so promising is that existing enhanced oil recovery (EOR) technology can be repurposed. Specifically, in actual oil and gas wells, CO_2 separated from natural gas and other liquids is injected into geological formations to increase the yield, and this technology can be used for CCS.

In underground storage, wells are dug to a reservoir layer located approximately 1,000 to 3,000 metres and CO_2 is stored. To store CO_2 underground, a geological structure consisting of a storage layer (porous rock) and a shielding layer (cap rock) covering the top is required. The shielding layer acts as a lid to prevent the escape of CO_2 stored in the reservoir. $CO_2$is stored in the pores of the sandstone in the reservoir. It is believed that if underground pressure can be properly controlled, there will be no influence of major earthquakes or faults.

There are four methods of underground CO_2 storage (Table A4).

Table A4. CO_2 Underground Storage Methods

Technology	Technology Overview
1. Depleted oil and gas reservoir	CO_2 is injected into depleted oil and gas reservoirs, thereby storing it.
2. Use of CO_2 in enhanced oil and gas recovery	CO_2 is injected into oil and gas formations, thereby accelerating oil and gas recovery, and storing CO_2. The recovered oil and natural gas are used in power plants, etc.
3. Deep saline formation (aquifer storage)	CO_2 is transported by tanker or pipeline, injected into underground aquifers, and stored. An aquifer is a geological layer made of sandstone or other materials with large pores between particles and is saturated with water or salt water. It is expected that there will be a large amount of storage potential in the future, and it is considered the most promising type of underground storage.
4. Use of CO_2 in enhanced coal bed methane recovery	CO_2 is injected into underground coal seams, thereby promoting methane recovery, and adsorbing and storing CO_2. The recovered methane is used at power plants, etc.

Source: Authors.

3. Hydrogen

Hydrogen is an energy source that can be created from various sources, including water, oil and gas, methanol, ethanol, sewage sludge, waste plastic, etc. It can be combined with oxygen to generate electricity, or burned to be used as thermal energy or power source of a fuel cell vehicle (FCV), etc. The environmental friendliness of hydrogen depends on how it is produced. For example, if hydrogen is produced by electrolysing water using renewable energy (wind, hydro, solar power, etc.), almost no CO_2 will be emitted. Hydrogen can be classified based on the production process, raw materials, energy source, and CO_2 emissions. A commonly used classification at present is to classify energy sources by colour, as shown in Table A5.

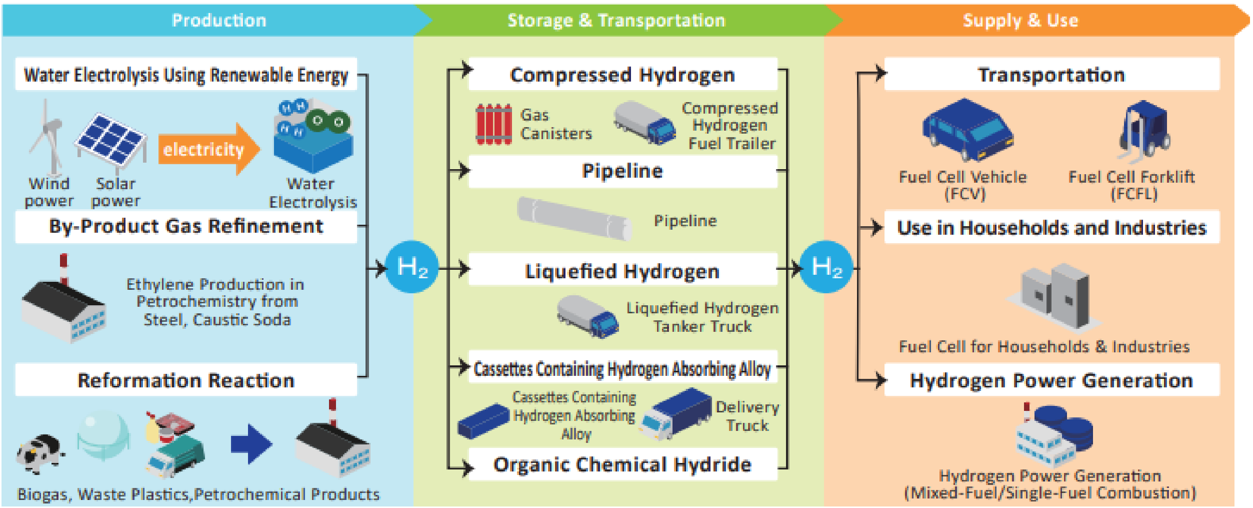
Table A5. Common Classification of Hydrogen

Type of Hydrogen	Production Process
Brown hydrogen	Hydrogen is produced through a process that converts raw material coal into gas
Grey hydrogen	Hydrogen is produced by burning natural gas without using CCUS
Blue hydrogen	Hydrogen is produced by burning natural gas while using CCUS
Green hydrogen	Hydrogen is produced through electrolysis using electricity generated from renewable energy (wind, hydro, solar power, etc.)

Source: Authors.

There is also classification other than colour. The US, UK, Germany, and other countries create definitions and standards such as low-carbon hydrogen based on the emission intensity of hydrogen, rather than colour. Hydrogen can be stored and transported in various states, such as gas, liquid, and solid, and is expected to have high energy efficiency, low environmental impact, and use in emergencies, and is expected to play a central role in the net-zero era. The technologies in hydrogen supply chain mainly consist of three stages: production, storage and transportation, and utilisation (Figure A2).

Figure A2. Hydrogen Supply Chain



Source: Ministry of Economy Trade, and Industry, Japan.

Production

Currently, the two main methods of hydrogen production are steam methane reforming (SMR) and electrolysis. 97% of the world's hydrogen production at present is produced by SMR. SMR is an already established technology, so if it can be scaled up and use inexpensive raw materials such as lignite to reduce the cost of hydrogen, it is expected to help expand the use of hydrogen and stabilise its supply. On the other hand, there is also a manufacturing method that creates hydrogen by using electrolysis. By using electricity derived from renewable energy (RE), green hydrogen can be produced. However, electrolysis requires a large amount of electricity, so if cheaper electricity can be used, the cost of hydrogen can be reduced. It is also important to reduce the cost of the equipment itself by advancing the development of water electrolysis equipment. There are two main types of water electrolysers. One uses alkaline water electrolysis (AWE), another is proton exchange membrane electrolysis or polymer-electrolyte membrane (PEM). The features of AWE are:

- Uses a strong alkaline solution of potassium hydroxide
- Characterised by high long-term stability and comparatively low investment costs
- Works at high temperatures and high pressure
- Ready for industrial-scale use

On the other hand, the features of PEM are:

- Uses water as electrolyte.
- Excellent in terms of flexibility and compactness compared to renewable energy, where power generation is greatly affected by weather.
- Works at low temperatures and at elevated pressures.

- The technology has been used in science historically and is currently in a scale up phase to industrial use.

Storage and Transportation

Hydrogen is a very light gas, so storing it at a temperature of 1 atmospheric pressure after production requires a very large space and is not efficient. Therefore, the following four methods are mainly used to store hydrogen: compression and storage at high pressure, liquefication, and storage at low temperature, storage by occluding or adsorbing on metal etc., conversion into other substances and storage. Ordinary steel cannot be used for high-pressure hydrogen tanks. This is because high-pressure hydrogen has the property of penetrating metals such as steel and making them brittle. Therefore, high-pressure hydrogen tanks are made of special stainless steel, aluminium alloy, or polymer composite materials that do not become brittle due to hydrogen.

To store it as a liquid, cool the hydrogen to –253 Celsius and then store it in a double-walled container with a vacuum area like a thermos flask.

The following four methods are currently used to transport the produced hydrogen as follows: compression and transport at high pressure, liquefication at low temperature, transport by pipeline, conversion into other substances and transport. Hydrogen can be compressed and transported under high pressure using FCVs or special trailers (lorries) equipped with high-pressure hydrogen tanks. When hydrogen is cooled to –253 Celsius, it liquefies and its volume becomes approximately 1/800th, making it possible to transport more hydrogen in the same volume. When transporting large quantities of hydrogen, lorries and special carrier ships equipped with liquefied hydrogen tanks are used.

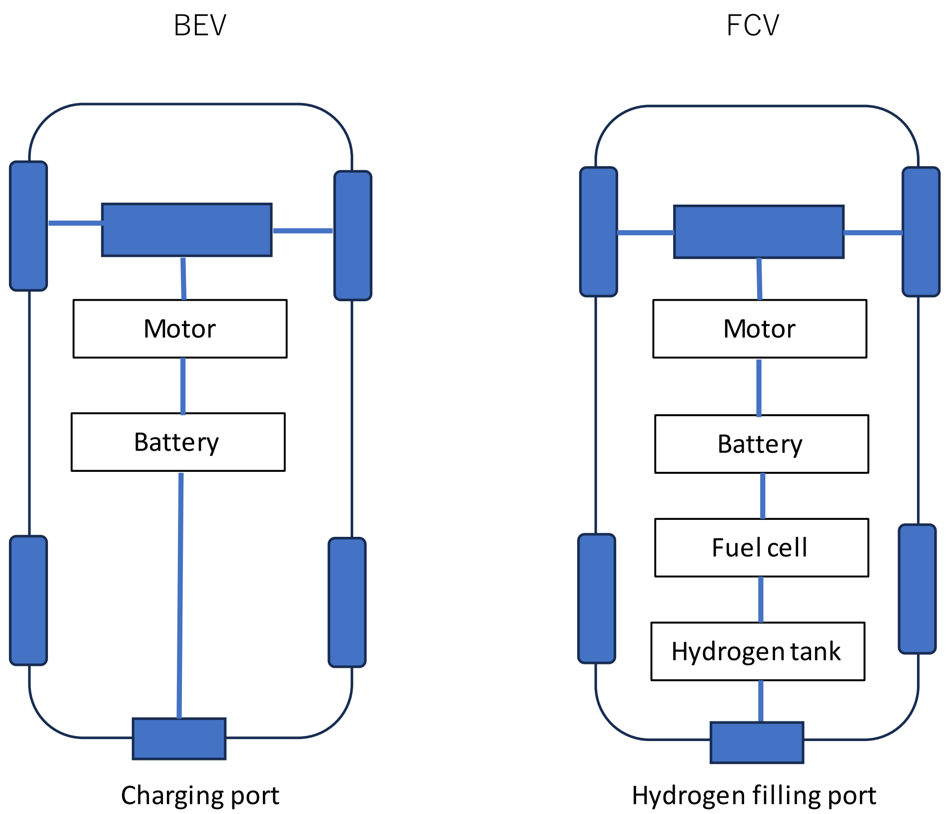
Using a new hydrogen pipeline is ideal for transporting large amounts of hydrogen, but installation costs increase depending on the length of the pipeline. When leveraging existing pipelines, technical issues such as leaks can occur. Furthermore, instead of transporting the produced hydrogen as is, a method is being developed in which it is transformed into another chemical substance, transported, and then converted back into hydrogen at the point of use. For example, demonstrations are underway to commercialise a technology that reacts toluene with hydrogen and converts it into methylcyclohexane (MCH), which is then transported. Toluene and methylcyclohexane can be transported by chemical tanker at room temperature and pressure and have the advantage of being 1/500 times smaller in volume.

Utilisation

There are two main ways to use hydrogen: burning it and using it to generate electricity. It can be used as energy in a variety of situations, including large-scale thermal power plants, power generation for homes and industrial use, power for transportation equipment such as cars and trains, and heat supply in factories. In the transport sector, there are ways to use fuel FCVs, fuel cell buses, fuel cell trains, etc.

An FCV runs on fuel cells. A fuel cell is a device that generates electricity by chemically reacting hydrogen and oxygen to produce water. The FCV is equipped with a hydrogen tank, and the hydrogen is used to generate electricity with a fuel cell, and the motor drives the car. Although the term 'battery' is used, the function of the fuel cell is a 'power generation device'. It is easy to understand if you think of it as a battery electric vehicle (BEV) equipped with a power generation device called a fuel cell. Only electricity and water are emitted during driving, and no CO_2 is emitted (Figure A3).

Figure A3. Basic Structures of Battery Electric Vehicles and Fuel Cell Vehicles



BEV = battery electric vehicle, FCV = fuel cell vehicle.
Source: Author based on TEPCO website.

It is planned to generate electricity using hydrogen or ammonia as a power generation fuel instead of natural gas or coal. First, technology is being developed for co-combustion, in which hydrogen or ammonia is burned together with natural gas or coal, and then technology is being developed to achieve single combustion which completely replaces fossil fuels with hydrogen.

Additionally, in the industry sector, the use of hydrogen instead of fossil fuels is being considered as a fuel for equipment that generates heat, such as boilers that produce hot water and steam, and burners that heat materials. The use of hydrogen in chemical processes, cement processes, steel manufacturing processes, etc. is also being considered.

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