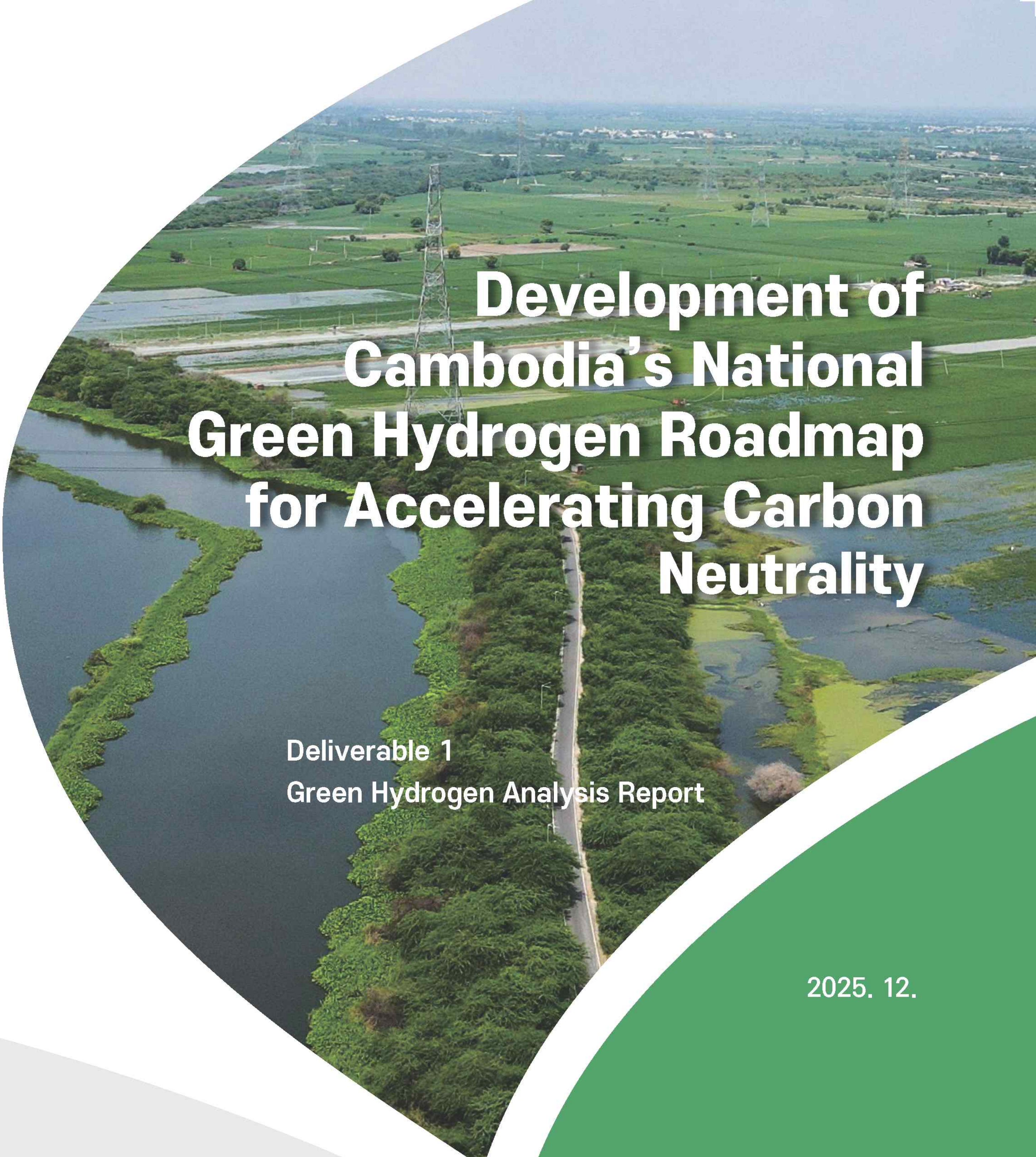


# Development of Cambodia's National Green Hydrogen Roadmap for Accelerating Carbon Neutrality

Deliverable 1

Green Hydrogen Analysis Report

2025. 12.

UN environment programme
CTCN UN Climate Technology Centre & Network
NATIONAL INSTITUTE OF GREEN TECHNOLOGY

# Development of Cambodia's National Green Hydrogen Roadmap for Accelerating Carbon Neutrality

**Deliverable 1**

**Green Hydrogen Analysis Report**

This research was supported by the Ministry of Science and ICT(MSIT) and the National Research Foundation (NRF) of Korea (RS-2025-25439920)


H2 HYDROGEN
ZERO EMISSION
CLEAN ENERGY OF THE FUTURE
ZERO EMISSION

# Development of Cambodia's National Green Hydrogen Roadmap for Accelerating Carbon Neutrality

Deliverable 1 Green Hydrogen Analysis Report

# CONTENTS

# Chapter 1. Introduction

## Section 1. Background and Necessity of the Study

Hydrogen is the most abundant element in the universe. It has been used for ammonia synthesis and as a primary feedstock in the petrochemical industry. Recently, hydrogen has gained attention as a new means to achieve carbon neutrality. Hydrogen ($H_2$) consists solely of two hydrogen atoms and produces no carbon dioxide upon combustion, making it a highly promising alternative to fossil fuels for energy combustion and a means to compensate for the intermittency of renewable energy. Through so-called power-to-gas (P2G), hydrogen can minimize the curtailment of renewable energy. Moreover, hydrogen produced in this manner can be traded without requiring extensive power infrastructure, acting as a medium for exchanging renewable energy between regions and countries.

Consequently, many countries have been establishing national hydrogen strategies. Japan established its hydrogen strategy in 2017, and major developed nations (such as South Korea, Germany, and Australia) have begun rapidly developing their own hydrogen strategies. Introducing hydrogen signifies a transition from the current system, and alongside the shift to renewable energy, this change will increase cost burdens. Nevertheless, hydrogen's key role in driving carbon neutrality, its potential to foster new industries, and the necessity of integrating it into the emerging economic order are compelling nations to focus on hydrogen.

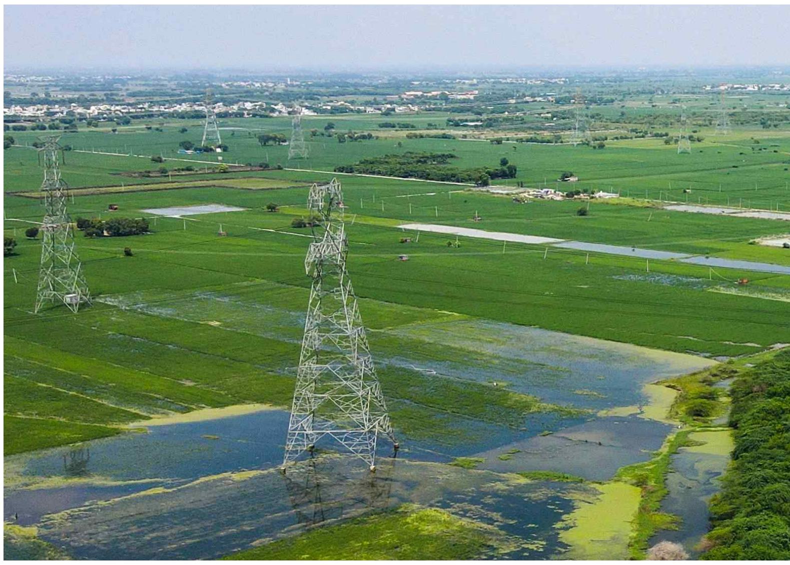
Despite burgeoning focus, Cambodia's policy foundation for hydrogen remains underdeveloped. Hydrogen is a key focus of the United Nations (UN)-submitted long-term low-emission development strategy, and some ASEAN (Association of Southeast Asian Nations) member countries (such as Indonesia, Malaysia, Vietnam, and the Lao People's Democratic Republic [Lao PDR]) have already established hydrogen strategies. At the same time, developing countries in Africa and Latin America are also formulating strategies. This momentum is expected to accelerate the transition to a hydrogen economy in developed nations and across the international community. Cambodia requires a national policy foundation to integrate into this new economic order; however, even basic research on potential hydrogen applications, their effectiveness, and suitable production methods remains scarce in the country. This lack of foundational knowledge constrains the establishment of a national hydrogen strategy or roadmap, making prompt analysis imperative.

## Section 2. Research Objectives and Methods

This study is part of a series aimed at establishing Cambodia's national green hydrogen roadmap and comprehensively assessing the country's hydrogen situation. This assessment must examine both the utilization and supply aspects of hydrogen. Physical infrastructure for hydrogen supply must be in place for hydrogen utilization; even if supply is feasible, slow utilization hinders the positive effects of hydrogen. Therefore, a country transitioning from a carbon to a hydrogen economy must balance supply and utilization when determining the direction of its hydrogen policy.

This study is structured around analyzing utilization and supply aspects. Regarding hydrogen utilization, this research explores sectors suitable for hydrogen use in Cambodia and assesses the potential climate benefits achievable through hydrogen deployment in these sectors. To this end, this study examines key economic sectors in which major global economies aim to utilize hydrogen, evaluating their policy alignment and economic significance from Cambodia's perspective. Subsequently, it selects the two most suitable economic sectors for Cambodia and calculates the greenhouse gas (GHG) reduction effects and benefits achievable through hydrogen utilization in these sectors.

On the supply side, this study first presents key hydrogen production technologies and global industry trends. This approach provides the latest trend data on hydrogen production technologies and can serve as a core reference for selecting appropriate technologies for Cambodia, as well as for development, introduction, and international cooperation. Subsequently, this research reviews Cambodia's renewable energy potential and technological capabilities, examines linkage strategies between hydrogen production and utilization sites, and proposes the most suitable hydrogen supply method for Cambodia.



# Chapter 2.
# Review of Global Hydrogen Policies and Key Application Sectors[1]

## Section 1. Developed Countries

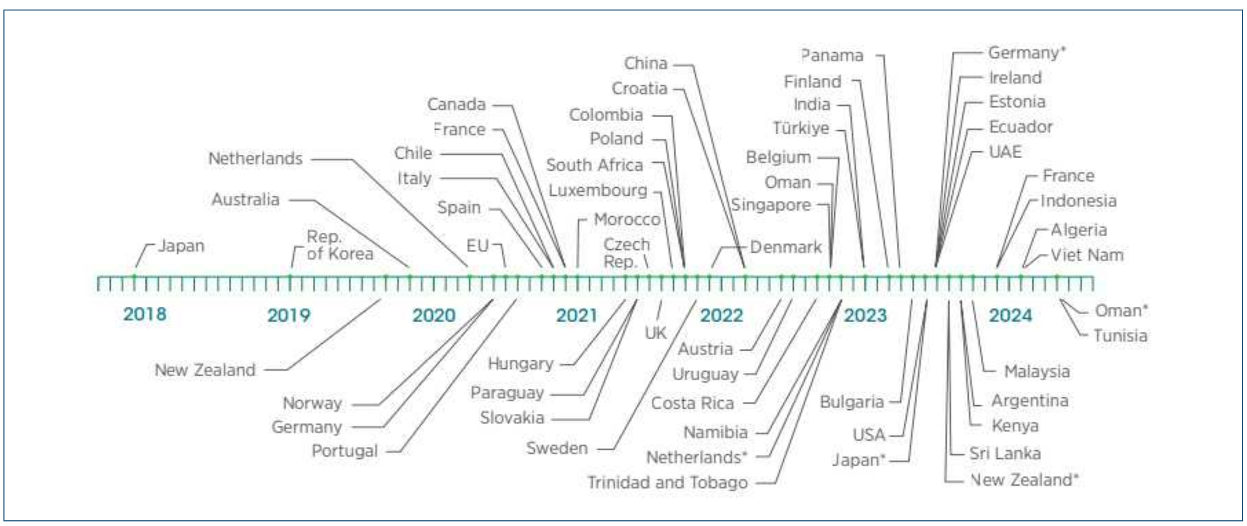
Hydrogen is one of the key means for achieving carbon neutrality goals, and since the 2020s, governments worldwide have accelerated the establishment of hydrogen strategies to foster the hydrogen industry. As of May 2024, over 52 countries have established and announced strategies outlining directions for clean hydrogen supply and utilization plans, technology development, and more (IRENA, 2024). Notably, advanced nations excelling in the hydrogen sector — such as South Korea, Japan, Germany, the United States, and Australia — have long announced strategies to build hydrogen ecosystems. This chapter reviews the content of these strategies, focusing on each country's hydrogen utilization sectors.

1 This chapter was developed utilizing and building upon NIGT(2023). National Institute of Green Technology, 2023, Development of a National Hydrogen Strategy and Action Plan for Accelerating Thailand's Net-zero Target, Deliverable 2, CTCN.

**Figure 2-1** Status of National Hydrogen Strategy Development – Map (As of May 2024)


Source IRENA (2024)

**Figure 2-2** Status of National Hydrogen Strategy Development – Timeline (As of May 2024)

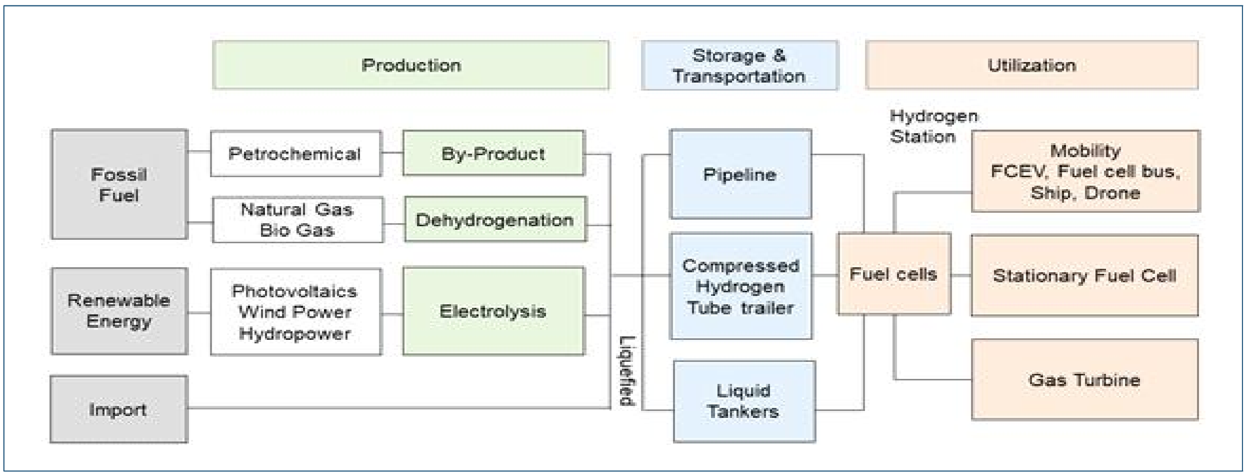



Source IRENA (2024)

## 1. Korea

South Korea has established an institutional foundation for fostering the hydrogen sector relatively early among developed nations. In January 2019, it announced the "Hydrogen Economy Activation Roadmap" to build a "hydrogen economy." Based on South Korea's technological strengths in hydrogen vehicles and fuel cells at the time, it presented a comprehensive strategy and concept for a hydrogen economy encompassing hydrogen production, storage and transportation, and utilization (Figure 2-3). The roadmap defined the hydrogen economy as "an economy that uses hydrogen as a key energy source, where hydrogen brings fundamental changes to the national economy, society as a whole, and citizens' lives, serving as a source of economic growth and eco-friendly energy"(Korean Government, 2019). It included policy directions, goals, and implementation strategies for activating the hydrogen economy by 2040. This strategy emphasized the necessity of a systematic legal and institutional foundation. It established plans for technological development in hydrogen utilization — a key focus area at the time — and the deployment of hydrogen vehicles, along with measures to build physical infrastructure enabling the demonstration and diffusion of technologies across the entire value chain.

**Figure 2-3** South Korea's Hydrogen Economy Value Chain




Source Lee & Kim (2021)

Following the Hydrogen Economy Activation Roadmap, key systems forming the foundation of subsequent hydrogen policies were established. In February 2020, the world's first 「Act on the Promotion of the Hydrogen Economy and the Management of Hydrogen Safety (abbreviated: Hydrogen Act)」 was enacted and implemented the following year (Enacted February 4, 2020; Implemented February 5, 2021). The Hydrogen Act serves as the legal foundation for creating the infrastructure to accelerate the transition to a hydrogen economy and for promoting the systematic development of the hydrogen industry. It not only codified the establishment of a basic plan for implementing the hydrogen economy (Article 5) and the establishment and operation of a deliberative decision-making body for hydrogen economy policies and plans (Article 6), but also provides the basis for establishing full-cycle policies, including the introduction of a clean hydrogen certification system[2], securing financial reSources, supporting businesses, and ensuring safety management. Furthermore, provisions regarding the responsibilities and participation of relevant stakeholders, such as the designation of competent ministries, local governments, and dedicated hydrogen economy agencies, were included, giving the government's policy proposals legal binding force.

Additionally, based on the basic plan establishment clause specified in Article 5 of the Hydrogen Act, Korea's first statutory plan, the "First Basic Plan for Hydrogen Economy Implementation," was announced in November 2021. The Basic Plan presents a blueprint for transitioning to a hydrogen economy utilizing clean hydrogen, including a clean hydrogen supply and demand plan through 2050 (Korean Government, 2021) : Aiming to supply 27.9 million tons of hydrogen as strategic clean hydrogen by 2050, it focuses on: 1) Producing green hydrogen based on renewable energy-linked electrolysis and securing overseas supply chains, 2) Building hydrogen port, pipeline network, and charging station infrastructure near major hubs, 3) Expanding utilization in hydrogen fuel cell power generation and mobility (hydrogen vehicles, ships, drones, trams, etc.), as well as industries (high greenhouse gas emitting industries such as steel, petrochemicals, and cement), and 4) Securing international standards and strengthening the institutional foundation. These four major strategic initiatives are accompanied by 15 detailed policy tasks (Table 2-1). The announcement of this basic plan provided legal legitimacy and sustainability to the government's hydrogen economy policy implementation.

**Table 2-1** Key Points of Korea's Hydrogen Economy Implementation Master Plan

| Category | Current (2020) | 2030 | 2050 |
|---|---|---|---|
| Production | **Clean Hydrogen Self-Sufficiency Rate 0%**<br>• Supply Volume 0.22Mt<br>- Gray 0.22Mt | **Clean Hydrogen Self-Sufficiency Rate 34%**<br>• Supply Volume 3.9 million tons<br>- Grey 0.94Mt<br>- Grey 0.25Mt<br>- Blue 0.75Mt<br>- Overseas 1.96 Mt | **Clean Hydrogen Self-Sufficiency Rate 60%**<br>• Supply Volume 27.9Mt<br>- Green 3Mt<br>- Blue 2Mt<br>- Overseas 22.9Mt |
| | • Byproduct and extracted hydrogen production | • Blue Hydrogen Production (25~) | |
| | • MW-scale electrolysis system<br>- Demonstration | • 10MW electrolysis system<br>- Commercialization | • GW-scale electrolysis system<br>- Commercialization |
| | • Overseas Ammonia Production(25) | • Ammonia Import (27)<br>• Ammonia Storage Base(30) | • 40 Overseas Supply Chains<br>- Establishment |
| Storage and Transportation | • Gas Tube Trailers Operation | • Liquefied/liquid Tankers(23) | |
| | • Hydrogen Refueling Stations 70 units | • Hydrogen Refueling Stations 660 units | • Hydrogen Refueling Stations 2,000 units or more |
| | • Hydrogen blending demonstration (22)<br>• Hydrogen blending demonstration (22) | • Hydrogen liquefaction plants (23)<br>• Hydrogen ports (28) | • Hydrogen Pipeline Network Construction |
| Utilization | **Clean Hydrogen Share 0%**<br>• Demand 0.22Mt<br>- Transportation 0.002Mt<br>- Power Generation 0.22Mt | **Clean Hydrogen Share 75%**<br>• Demand 3.9Mt<br>- Transportation 0.37Mt<br>- Power generation 3.53Mt | **Clean hydrogen share 100%**<br>• Demand 27.9Mt<br>- Transportation 2.2Mt<br>- Power generation 13.5Mt<br>- Industrial 10.6 Mt |

2 The Clean Hydrogen Certification System was included through the November 2023 revision.

| Category | Current (2020) | 2030 | 2050 |
|---|---|---|---|
| | • Over 10,000 hydrogen passenger vehicles<br>• 75 hydrogen commercial vehicles | • 850,000 hydrogen passenger vehicles<br>• 30,000 hydrogen commercial vehicles | • 515,000 hydrogen passenger vehicles<br>• Hydrogen commercial vehicles: 110,000 units<br>• Trams, ships, aircraft |
| | • Hydrogen fuel cell power generation | • Ammonia 20% co-firing power generation (27)<br>• Hydrogen 50% co-firing power generation | • Ammonia full-combustion power generation<br>• Hydrogen full-combustion power generation |
| 4 Major Strategies and 15 Key Tasks | | | |
| Domestic and International Clean Hydrogen Production-Driven | Seamless Infrastructure Development | Hydrogen in Everyday Life Utilization | Strengthening the Ecosystem Foundation |
| • Green Hydrogen Production<br>• Blue Hydrogen Production<br>• Overseas clean hydrogen production | • Hydrogen Distribution Infrastructure Development<br>• Hydrogen Pipeline Network Construction<br>• Expansion of Hydrogen Refueling Stations | • Full-scale expansion of hydrogen power generation<br>• Leading the global hydrogen mobility market | • Technology Development/ Human ReSource Development/ Standardization<br>• World-leading hydrogen safety |

Source Korean Government (2021)

In Korea, consistent policy support has been provided since the first roadmap announcement in 2019 to foster the hydrogen economy. Particular emphasis has been placed on leveraging fuel cells and hydrogen vehicles — recognized as key strengths — and building related infrastructure[3]. Furthermore, the value chain within the hydrogen economy was categorized into transportation, residential/commercial buildings, power generation, and gas turbines. The basic plan emphasized three key areas to expand and diversify hydrogen applications: 1) Full-scale expansion of hydrogen power generation, 2) Leading the global hydrogen mobility market, and 3) Establishing a foundation for industrial hydrogen utilization.

Regarding hydrogen power generation, the plan sets targets to expand fuel cell power generation facilities, achieve 20% ammonia co-firing in coal-fired power plants (~2027), and commercialize hydrogen-fired gas turbines (~2050) to scale up hydrogen power generation. Specifically, the plan involves transitioning from initial power generation using gray hydrogen to establishing a system incorporating clean hydrogen: Securing and demonstrating power generation technology that co-fires ammonia with existing coal to reduce carbon emissions from the coal power generation stage, and subsequently increasing the ammonia co-firing ratio. Additionally, it plans to develop and demonstrate technology for 50% hydrogen co-firing in LNG turbines and commercialize hydrogen co-firing technology for gas turbines. To achieve this, it proposes institutional support measures, including introducing a clean hydrogen power generation mandate system, strengthening

3 South Korea ranks first in the global market for hydrogen passenger vehicles (16,206 units)* and power generation fuel cells (688MW)**.
* United States: 11,088 units, Japan: 6,347 units, Germany: 697 units, Netherlands: 382 units (as of August 2021)
** United States 527MW, Japan 352MW (as of August 2021)
Source: KOTRA (2022) Trends in Major Countries' Hydrogen Economies and Entry Strategies for Korean Companies

environmental dispatch through restructuring tax burdens on power generation fuels, and revising environmental regulations related to adoption.

Second, to lead the mobility market, the goal is to secure production capacity for all hydrogen vehicle types (passenger cars, commercial vehicles, special-purpose vehicles, etc.) and expand application to various mobility sectors like ammonia-hydrogen ships, drones, and aviation. To this end, support measures include concentrated subsidies for commercial vehicles and ships, a clean vehicle purchase target system, and raising the mandatory purchase ratio for public institutions to accelerate fuel conversion.

Finally, to establish a foundation for hydrogen utilization in the industrial sector, the government will prioritize transitioning processes to hydrogen-based systems and replacing fossil fuels and raw materials in high greenhouse gas-emitting industries(steel, petrochemicals, refining, cement, etc.) and in aging and new industrial complexes. New complexes will be supplied with hydrogen energy as fuel and feedstock, while aging complexes will be guided toward becoming carbon-free by utilizing LNG + hydrogen co-firing power generation during equipment replacement. In the steel sector, existing blast furnace facilities will be fully converted to hydrogen-based reduction facilities by 2050. Heavy oil, the primary fuel in petrochemical processes, will be replaced with hydrogen and other alternatives to produce high-value green chemical products using clean hydrogen. In the cement sector, development of new carbon-free heat Source technologies using hydrogen hybrid systems will be pursued.

Based on these goals and strategies, Korea aims to maintain a super-gap in world-leading technology in hydrogen utilization while creating new demand by expanding hydrogen use in power generation and industry and diversifying hydrogen mobility.

## 2. Japan

Japan established the world's first national hydrogen strategy, the “Basic Hydrogen Strategy,” in December 2017. Subsequently, in March 2019, it specified key technology development targets through documents like the “Hydrogen and Fuel Cell Roadmap.” In December 2020, under the “Green Growth Strategy,” it is promoting innovation across all sectors with the goal of mass-supplying hydrogen for a decarbonized society.

In June 2023, six years after the first Basic Hydrogen Strategy was published, the strategy was revised to reflect changes in the domestic and international environment. This revision supplemented and introduced the 'Hydrogen Industry Strategy,' which promotes the overseas expansion of the hydrogen industry, and the 'Hydrogen Security Strategy,' which emphasizes safety as an essential means for large-scale hydrogen utilization and promotes the rationalization and optimization of the application of laws and regulations covering the entire supply chain.

The Hydrogen Basic Strategy (2017) outlines policy goals and implementation strategies encompassing all aspects of hydrogen supply, storage, transportation, and utilization to address environmental issues and strengthen energy security. It divides the development stages for realizing a hydrogen society by 2050 into three phases (present~, ~late 2020s, around 2040) and sets separate goals and key tasks for each phase. Phase 1 aims to dramatically expand hydrogen utilization by increasing the use of stationary fuel cells and FCVs, thereby establishing Japan's leading position in the global hydrogen and fuel cell sector. Phase 2 seeks to establish hydrogen as a new energy Source by creating a large-scale hydrogen supply system, shifting from the existing energy consumption structure centered on electricity and heat. Phase 3 focuses on establishing a $CO_2$-free hydrogen supply system. Key contents include: 1) establishing a low-cost hydrogen supply system, 2) developing international hydrogen supply chains, 3) expanding the use of hydrogen extracted from renewable energy, 4) hydrogen power generation, 5) hydrogen fuel cell vehicles, 6) fuel cells, and 7) industrial process heat utilization. By 2050, the hydrogen society aims to achieve price competitiveness equivalent to existing energy Sources, setting a hydrogen price target of 20 yen/$Nm^3$, replacing gas-fired power generation with a target of 15–30GW of power generation capacity (cost: 12 yen/kWh), among other goals (Table 2-2).

**Table 2-2** Key Targets in Japan's Hydrogen Basic Strategy

| Category | | Current | 2030 | 2050 |
|---|---|---|---|---|
| Supply | Form | • Fossil fuel-based (byproduct hydrogen, natural gas reforming)<br>• Public network construction demonstration and scale-up required | • Establishment of international hydrogen supply chains<br>• Establishment of renewable energy-based hydrogen production technology | • $CO_2$-free hydrogen |
| | Scale | • 0.02 million tons (2017) | • (2040) 12 million tons* | • 20 million tons* |
| | Price | • 100 yen/$Nm^3$ (refueling station price) | • 30 yen/$Nm^{3*}$ | • 20 yen/$Nm^{3*}$ |
| Usage | Power Generation | • Developing technology and Current stage<br>• Hydrogen power generation is scheduled to begin demonstration in the mid-2020s | • (Reference) Hydrogen consumption: 300,000 tons for power generation capacity<br>– Approximately 1 million kW | • (Reference) Hydrogen consumption of 5 to 10 million tons corresponds to a power generation capacity of approximately 15 to 30 GW |
| | Mobility | • 163 hydrogen refueling stations<br>• 3,800 FCVs<br>• 99 FC buses : 250 units (2020) | • 1,000 hydrogen refueling stations<br>• 800,000 FCVs<br>• 1,200 FC buses<br>• 10,000 forklifts | • Revenue improvement to replace existing<br>– Replacing gasoline stations with hydrogen refueling stations<br>• Replace gasoline vehicles with hydrogen vehicles through technological advancement and cost reduction of fuel cell stacks and FC conversion of large vehicles |
| Utilizing fuel cells | | • Deploy 330,000 Ene-PAM residential fuel cells | • Deploy 5.3 million Enepams | • Convert existing to hydrogen-based fuel cell systems |

Note Based on 2019 version; * Figures revised as of June 2023
Source METI (2020), KOTRA (2023)

The revised Hydrogen Basic Strategy broadly encompasses three key directions: 1) Accelerating the Realization of a Hydrogen Society, 2) Strengthening the Competitiveness of the Hydrogen Industry, and 3) Ensuring Safe Hydrogen Utilization. First, accelerating the realization of a hydrogen society aims to ensure stable hydrogen supply, reduce supply costs, and promote the transition to low-carbon hydrogen: The goal is to supply 12 million tons/year by 2040 and 20 million tons/year by 2050 at 20 yen/$Nm^3$. Additionally, it aims to establish international standards and certification systems for hydrogen-ammonia carbon intensity-based trading. Detailed strategies are included for supply and demand aspects, institutional improvements, local government coordination, innovative technology development, international cooperation, and public awareness. To enhance the competitiveness of the hydrogen industry, it includes detailed strategies concerning hydrogen production, decarbonized power generation, fuel cells (including mobility), and direct hydrogen utilization (steel, chemicals). Finally, it contains detailed strategies for scientific data and evidence-based approaches to ensure safe hydrogen utilization, rationalization and optimization of regulations for the phased implementation of a hydrogen society, and the improvement of the hydrogen utilization environment (Lee et al., 2023).

The 「Hydrogen and Fuel Cell Strategy Roadmap」(2019) concretized the implementation plan for realizing the hydrogen society outlined in the Basic Hydrogen Strategy[4] [5]. Examining the action plans within the roadmap reveals specific targets for hydrogen utilization and supply sectors, along with policy support measures to achieve these goals. Furthermore, the "Status of Responses for Achieving the Hydrogen and Fuel Cell Strategic Roadmap" (2020) categorizes and presents the roadmap, implementation plans, and the current status of responses for each area. These categories include: establishing an international hydrogen supply chain; expanding the use of renewable energy-based hydrogen; utilizing hydrogen in the power generation sector; utilizing hydrogen in the mobility sector; utilizing fuel cell technology; exploring the potential for hydrogen utilization in industrial processes for heat; and realizing a global hydrogen society (Lee & Kim, 2024).

Examining Japan's hydrogen policy, the utilization sectors are broadly categorized as: 1) Hydrogen Power Generation, 2) Transportation, 3) Industrial Processes, and 4) fuel cell technology, all aiming for commercialization and profitability by 2030 to achieve privatization. Japan's market size was approximately $150 million (¥17.5 billion) in 2020. The related market is projected to grow approximately 268-fold by 2035 due to rapid expansion in the power generation sector. Demonstration tests for ammonia co-firing power generation and hydrogen gas turbine power generation are scheduled to commence in 2024 and 2025, respectively, leading to a significant increase in hydrogen demand within the power generation sector. According to the Hydrogen Basic Strategy (2023), hydrogen power generation aims to develop and demonstrate small gas turbine co-firing/combustion systems and large gas turbines capable of co-firing over 30% or full combustion by 2030. Ammonia power generation targets achieving a co-firing rate of over 50% and developing full-combustion burners, which are currently in progress.

For the transportation sector, the goal is to deploy 200,000 hydrogen electric vehicles by 2025 and 800,000 by 2030. Additionally, the target is to deploy 1,200 hydrogen buses and 10,000 industrial forklifts by 2030. The hydrogen electric vehicle market is projected to grow over 100-fold by 2030 as infrastructure expands, with Japan's Toyota Mirai (2nd generation) and Korea's Hyundai Nexo continuing to dominate the global FCEV market as the two leading players. Japan currently operates the world's largest network of hydrogen refueling stations, and is pursuing related institutional and standardization efforts, along with technological development support, with a goal of establishing 900 stations by 2030. For residential fuel cells, demand is being established through the spread of Ene-Farm, a combined heat and power system that produces electricity and heat in ordinary homes by chemically reacting hydrogen extracted from city gas or LP gas with

4 First established as a comprehensive roadmap covering the entire hydrogen supply chain (June 2014) → Revised to clarify price targets for residential fuel cells (Ene-Farm), set FCV deployment targets, and promote specific technologies related to hydrogen power generation (2016)
* Revised to establish specific implementation policies (2019).

5 Established a hydrogen and fuel cell technology development strategy defining specific R&D items to achieve the sector-specific goals outlined in the Hydrogen and Fuel Cell Strategy Roadmap (September 2019).

oxygen in the air. To achieve early market self-sufficiency, the plan is to deploy 5.3 million residential fuel cells by 2030. Furthermore, in the fuel utilization sector, efforts will be made to advance RD&D for hydrogen-ammonia burners and boilers, as well as to demonstrate hydrogen-reduced ironmaking using large blast furnaces.

### 3. Germany

The German federal government views hydrogen as a key element in decarbonization. Through the establishment of the "National Hydrogen Strategy (Die Nationale Wasserstoffstrategie)" in June 2020, it is pursuing policies to lead the global energy transition and foster hydrogen as a competitive industry. As the EU nation with the largest hydrogen economy scale,

Germany's strategy concretizes the EU-level hydrogen strategy (European Commission, 2020) (Table 2-3), emphasizing alignment with the European internal market and regulatory framework, as well as leveraging Europe's hydrogen production potential and infrastructure[6].

**Table 2-3** EU Hydrogen Economy Policies

| Category | Content |
|---|---|
| Renewable Energy Directive (2019) | • Mandates increasing the share of renewable energy in final energy consumption to 32% by 2030 |
| EU Hydrogen Strategy (2020) | • Announced as a follow-up to the European Green Deal<br>• Hydrogen is recognized as a key element for economic revitalization and energy transition<br>• Key Objectives: △Support installation of over 6GW of electrolysis equipment to produce 1 million tons of green hydrogen (2020-2024), △Support installation of over 40GW of electrolysis equipment to produce 10 million tons of green hydrogen (2025-2030), △Widespread use of green hydrogen even in sectors where decarbonization is difficult (2030-2050) |
| European Clean Hydrogen Alliance | • Participation of governments, industry, civil society, and the European Investment Bank to implement the EU Hydrogen Strategy |

Source KOTRA (2022)

Germany defines the scope of its hydrogen economy in this strategy as "Building up and securing the quality assurance infrastructure for hydrogen production, transport, storage, and use, and building trust." It comprehensively covers hydrogen-related energy, industry, technological innovation, and international cooperation policies, presenting objectives and vision, current status analysis, and concrete measures (Massnahmen) up to an action plan (Aktionsplan). The key objectives are: 1) Enhancing competitiveness by reducing hydrogen-related costs, 2) Developing the domestic hydrogen market in Germany, 3) Strengthening hydrogen transport and distribution infrastructure, 4) establishing an international hydrogen market and international cooperation framework. With Germany's hydrogen demand projected to reach up to 380 TWh by 2050[7], the strategy identifies eight key focus areas to meet this demand and outlines corresponding priority implementation directions (Table 2-4).

6 EU member states are structured to develop detailed national strategies aligned with the EU's hydrogen strategy direction.
7 Germany's current hydrogen demand is approximately 55 TWh (BMWi, 2020).

Table 2-4 Eight Key Areas and Content of Germany's Hydrogen Strategy

| Category | Content |
|---|---|
| Hydrogen production | • Expanding the domestic market is essential for the market introduction and export of hydrogen technologies. To use hydrogen sustainably and economically, a planned expansion of renewable energy generation capacity, such as wind and solar power, is necessary. |
| Industrial sector | • Expand existing hydrogen infrastructure in the chemical industry for other uses like steel production |
| Transport | • Fuel cells complement battery-electric vehicles in public transportation like buses and railways, as well as some freight transport |
| Heat market | • Long-term demand for gaseous fuels persists, necessitating hydrogen utilization |
| Hydrogen as a collaborative project | • Opportunities exist to produce green hydrogen long-term using North Sea wind power and Southern European solar power, with Europe's gas infrastructure also usable for hydrogen transport |
| International trade | • Germany will depend on renewable energy imports to achieve its climate goals, making international trade in hydrogen and its derivatives crucial |
| Transport and distribution infrastructure in Germany and abroad | • Beyond utilizing gas infrastructure for hydrogen in the long term, constructing dedicated hydrogen transport networks |
| Research, education, innovation | • Funding for research into new approaches covering key technologies or the hydrogen value chain |

Source BMWi (2020)

Subsequently, the existing strategy was applied in principle, but in July 2023, a revised National Hydrogen Strategy was announced to further accelerate the expansion of the hydrogen market by adjusting targets and introducing new measures. The revised strategy doubled the domestic hydrogen production capacity target for 2030 from 5GW to 10GW. It projected hydrogen demand of 95-130TWh from Sources like ammonia, methanol, and synthetic fuels[8], stating that 50-70% of this would be met through imports[9]. Furthermore, while the original national hydrogen strategy focused solely on green hydrogen, the revised plan permits the use of other types of hydrogen — such as blue, turquoise, and orange hydrogen — produced through different methods until sufficient green hydrogen is available to meet projected demand. However, direct financial support for hydrogen production is limited to green hydrogen.

In the hydrogen utilization sector, demand by 2030 is projected to reach at least 10 TWh in the industrial sector (chemicals, petrochemicals, steel), with further growth anticipated in hydrogen fuel cell vehicles and heating/thermal applications. Regarding hydrogen utilization, Germany implemented comprehensive policies centered on the "National Innovation Program Hydrogen and Fuel Cell Technology (NIP)" (2007) for research and development in hydrogen utilization even before

8 The original National Hydrogen Strategy projected demand at 90-100 TWh.
9 Accordingly, the "Import Strategy for Hydrogen and Hydrogen Derivatives" was announced in July 2023.

establishing a national strategy. Through the first NIP (2007–2016) and second NIP (2016–2026), Germany established large-scale investment plans and conducted R&D, field testing, and marketability improvements related to mobility, fuel cells, and refueling stations. Consequently, its hydrogen strategy also places significant emphasis on the fields of application (Table 2–5: Transportation – Measures 5–13, Industry – Measures 14–17, Heating/Thermal – Measures 18–19)[10].

**Table 2–5** Germany's Hydrogen Strategy: Implementation Plan for the Hydrogen Utilization Sector

| Category | Measure | Details |
|---|---|---|
| Transport | 5 | • Promoting policies such as expanding incentives in the hydrogen sector to implement the EU's Renewable Energy Directive (RED II)<br>– The German government aims to significantly exceed EU regulations by substantially increasing the minimum share of renewable energy consumption in the transport sector by 2030 and securing 2GW of electrolysis capacity as a target |
| | 6 | • Continuing the National Innovation Program (NIP) to support hydrogen–related technology development, such as fuel cells, and expanding subsidies for purchasing eco–friendly mobility solutions<br>– Utilizing the EKF (Energy and Climate Fund) established by the German government for its energy transition policy Fund) established for its energy transition policy. |
| | 7 | • Strengthening Investment in Electric Base Fuel Production |
| | 8 | • Expanding Hydrogen Charging Infrastructure Using the EKF Fund |
| | 9 | • Striving to develop infrastructure for Europe–wide fuel cell commercialization through guideline revisions, etc. |
| | 10 | • Supporting development to supply competitive fuel cell systems, including fuel cell stacks, for vehicles |
| | 11 | • Achieve the goal of supporting zero–emission vehicles within cities |
| | 12 | • Contribute to CO2–based differentiation of truck tolls within the EU through eco–friendly truck operations |
| | 13 | • Lead international standards for hydrogen fuel cell systems, including refueling standards, hydrogen quality, and hydrogen vehicle types |
| Industrial sector | 14 | • Hydrogen fuel plays a central role, particularly in the chemical and steel industries. Therefore, funding will be provided through the 'Hydrogen Use in Industrial Product Manufacturing (2020–2024)' program. |

Source BMWi (2020)

10 Among the 38 implementation plans, 4 are for production, 15 for utilization, 3 for infrastructure, and 16 for other areas like education and international cooperation.

## 4. United States

The United States announced the "US National Clean Hydrogen Strategy and Roadmap" in June 2023 to promote the production, processing, transportation, storage, and utilization of hydrogen across its entire value chain[11]. At the time of its release, the Biden administration viewed the economic and safe use of clean hydrogen as a key means to achieve economic and societal benefits. It aimed to establish a comprehensive framework through this hydrogen strategy, including specific sector-by-sector goals and implementation plans based on the current status and future projections of U.S. hydrogen production, transportation, storage, and utilization. This will play a crucial role in achieving the Biden administration's goals of 100% carbon-free electricity supply by 2035 and carbon neutrality by 2050. Domestic demand for clean hydrogen production is projected to reach 10 million metric tons (MMT) annually by 2030, 20 million metric tons annually by 2040, and 50 million metric tons annually by 2050. Achieving these targets is projected to reduce total U.S. greenhouse gas emissions by approximately 10% compared to 2005 levels. Additionally, the U.S. government allocated approximately $9.5 billion in investment funding over five years (2022-2026) through the Infrastructure Investment and Jobs Act of 2021 (IIJA) to build infrastructure for establishing a hydrogen economy[12], and through the Inflation Reduction Act of 2022 (IRA), it has proposed a large-scale subsidy support system for clean hydrogen[13].

The three core strategies presented in this plan to achieve the goals are: 1) Strategic utilization of clean hydrogen, 2) Cost reduction of clean hydrogen, 3) Establishment of regional networks: Through the first core strategy, the government plans to focus on using clean hydrogen to reduce carbon emissions in sectors difficult to electrify (e.g., chemicals, steel, refining), large-scale transportation (trucks and buses, marine and ports, aviation, rail), and the power sector; The second core strategy aims to support diverse clean hydrogen production pathways, targeting a price reduction to $1/kg — an 80% cut over approximately 10 years; The final strategy plans to establish and expand clean hydrogen hubs comprising producers, regional reSources/raw materials, infrastructure, and consumers. To support these three core strategies, the government also outlines plans to support activities across the entire spectrum of basic science through Research, Development, Demonstration, and Deployment (RDD&D) over short-term (2022-2025), medium-term (2026-2029), and long-term (2030-2035) periods.

The U.S. hydrogen utilization sector is broadly categorized into industrial, transportation, and power generation fields (Table 2-6). In the industrial sector, it mentions the chemical, refining, and steel industries, which are difficult to decarbonize. For the transportation sector, it presents plans for application in passenger and commercial vehicles, as well as ships and rail. For the power generation sector, it proposes directions for utilizing hydrogen in backup power, electricity generation, and grid services.

11 Based on the Bipartisan Infrastructure Law (BIL), the IIJA was drafted in early September 2022, incorporated public feedback, and was announced. It was planned to be updated at least every three years, but its future remains uncertain following the Trump administration.

12 $8 billion for clean hydrogen hub development, $1 billion for the electrolysis clean hydrogen program, and $500 million for clean hydrogen production and recycling technology R&D.

13 A production tax credit of up to $3 per kilogram of hydrogen is available based on the carbon intensity of new clean hydrogen production facilities in the United States.

**Table 2-6** Hydrogen Application Sectors in the U.S. Hydrogen Strategy

| Category | Content |
|---|---|
| Industrial Sector | • Over half of carbon emissions from industry result from the direct combustion of fossil fuels to produce heat and power required for industrial processes to produce heat and electricity required for industrial processes. Clean hydrogen is used to decarbonize these processes.<br>• Particularly in the chemical sector (e.g., ammonia and methanol production) and the steel sector, clean hydrogen use enables greenhouse gas emission reductions of over 90% and 40-70%, respectively |
| Transportation Sector | • The transportation sector accounts for 33% of U.S. greenhouse gas emissions (2019), with 51% comes from light-duty vehicles<br>• Hydrogen and fuel cells are used to decarbonize transportation sectors requiring long-distance travel, rapid refueling, and the transport of large, heavy cargo, such as mining equipment, ferries, and railways |
| Electricity Sector | • Hydrogen offers diverse applications for long-term energy storage, power generation, and grid services and can provide additional revenue streams as a feedstock or fuel for other sectors |
| Government Agencies | • Beyond the commercial market, government agencies are promoting hydrogen use for initial demonstrations in other critical situations, such as restoring energy and water reSources, providing backup power for military bases, and meeting the energy needs of federal facilities during emergencies and water reSources recovery, backup power for military bases, and other critical situations. |

Source DOE (2023)

Even before establishing this strategy, the U.S. had consistently advanced hydrogen technology R&D and demonstration projects through initiatives like the Hydrogen Program Plan (November 2020) and the H2@Scale initiative (March 2019), which integrate R&D and demonstration for the hydrogen economy under the DOE. Specifically, through H2@Scale, it established a fund of approximately $64 million to promote the large-scale utilization of clean hydrogen produced at low cost in the power generation sector, aiming to establish a virtuous cycle system for the national hydrogen economy and identify new application areas for the hydrogen industry. It also supported projects developing fuel cell application technologies for commercial vehicles such as medium and heavy-duty trucks.

## 5. Australia

Australia announced its first National Hydrogen Strategy in 2019, pursuing policies to become the world's largest hydrogen producer and exporter by establishing a large-scale hydrogen distribution and export hub to promote hydrogen as an export reSource. This strategy supports large-scale production of green hydrogen using carbon capture technology, setting a target to reduce hydrogen production costs to $1.39/kg by 2030 and aiming for net-zero emissions by 2050.

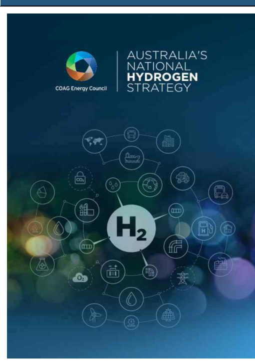
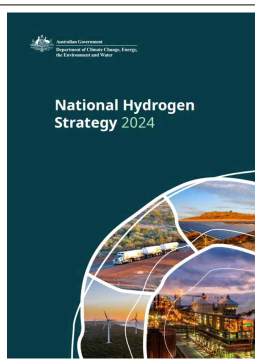
Australia pursued the establishment of a supply chain with the goal of exporting 75% of its total hydrogen production and securing its position as one of the top three exporters to Asia[14]. In addition to these federal-level hydrogen industry promotion policies, Australia's six states and two territories are also developing hydrogen strategies tailored to their regional characteristics.

14 Australia's primary hydrogen export destinations are South Korea, China, Japan, and Singapore (ARENA, 2018).

Since the first National Hydrogen Strategy was announced, the international policy environment for hydrogen technology and markets has undergone significant changes. and the international policy environment have rapidly evolved. The hydrogen industry needs to transition beyond the initial demonstration phase to a scale-up phase. Reflecting Australia's net-zero goals and its status as an export nation, objectives and means require strengthening. Consequently, following a comprehensive official review, the revised "National Hydrogen Strategy 2024" was announced in September 2024. The 2024 revision prioritizes 'renewable hydrogen' based on renewable energy, setting a new production target of up to 15 million tons annually by 2050 and establishing five-year production milestones. Additionally, intermediate goals related to demand and exports have been further specified, with four strategic objectives and 34 actions, along with enabling infrastructure and systems, newly established. Specifically, four major goals were established: 1) Supply, 2) Demand and Decarbonization, 3) Community Benefits, and 4) Trade, Investment, and Partnerships. Financial and policy incentives to revitalize the industry, such as the hydrogen production tax incentive and the hydrogen headstart program, were introduced and expanded. Furthermore, concrete international cooperation measures, such as a bilateral agreement with Germany, were included for exports and trade (DCCEEW, 2024).

Specifically, the strategy has been updated to focus more on scaling up and cost competitiveness, reflecting the recognition that hydrogen must move beyond being merely a promising technology to become a core national industry. Consequently, the revised version highlights strengthening human reSources and technological capabilities as more critical implementation factors, emphasizing technology commercialization, facility operation, and safety and certification systems.

**Table 2-7** Australian Federal Government's Hydrogen Strategy

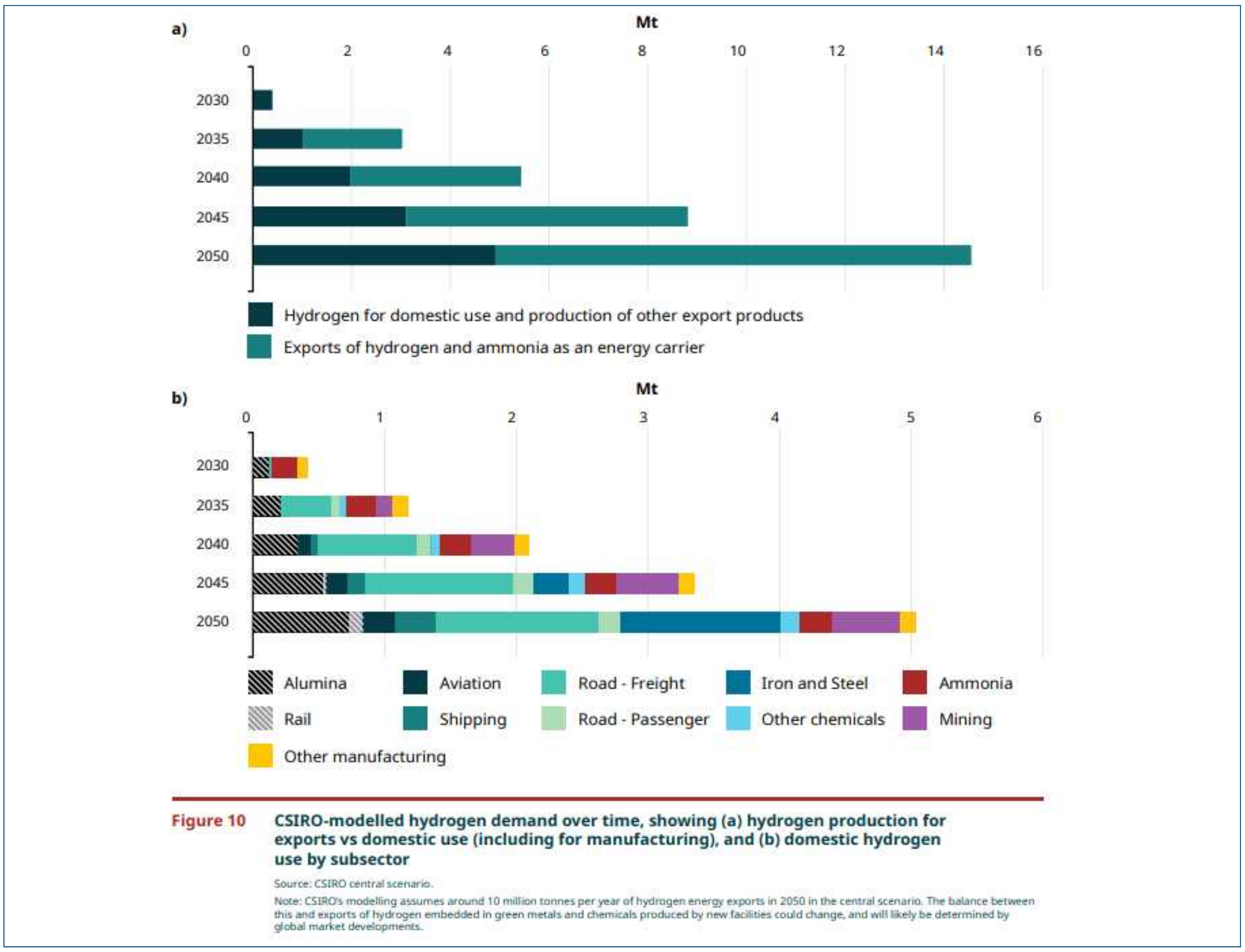
| Category | Key Content | |
|---|---|---|
| Australia's National Hydrogen Strategy (COAG, 2019) |  | • (Goal) Secure a position as a major global player in the hydrogen sector by 2030<br>• (Direction) Fostering the hydrogen industry through establishing a hydrogen hub and attracting investment, forming international markets, and invigorating trade, etc.<br>• (Phased Implementation Process) (2020-2025) Foundation Establishment and Demonstration, (2026-2036) Large-Scale Market Activation<br>• (Key Measures) Presentation of 21 key measures and 57 detailed tasks |
| National Hydrogen Strategy 2024 (DCCEEW, 2024) |  | • (Objective) Provide an implementation framework to establish Australia as a global hydrogen leader<br>• (Direction) Deliver benefits to the Australian economy, accelerate the net-zero transition, and secure a position as a global hydrogen leader<br>• (Key Actions) Outlines 34 actions and enablers |

Source COAG (2019), DCCEEW (2024)

Australia's hydrogen industry is primarily formed around production and export sectors, but strategically focuses on four major application sectors as demand drivers. Green metals (iron, alumina) focus on producing green iron and alumina embedded in export hydrogen through high-temperature heat and reduction hydrogen for steel and aluminum processes. Plans include utilizing ammonia as an export hydrogen carrier and marine vessel fuel. For long-haul transportation like freight roads, air, and maritime sectors. Furthermore, the power generation and grid support sector contributes to decarbonizing the electricity sector and enhancing energy security in importing countries. Domestically, it aims to store surplus renewable electricity as hydrogen to meet peak demand and stabilize the grid. In summary, examining state hydrogen utilization strategies reveals that New South Wales is promoting hydrogen bus pilot operations in central Sydney, while Victoria is pursuing a Zero Emission Vehicle (ZEV) roadmap.

Hydrogen utilization strategies at the state level, New South Wales is promoting a hydrogen bus pilot in Sydney's city center, while Victoria announced a AUD 100 million support package through its Zero Emission Vehicle (ZEV) roadmap to stimulate the hydrogen mobility market. Queensland is expanding hydrogen electric vehicle adoption by constructing hydrogen refueling stations (2021) and purchasing Hyundai Nexo hydrogen electric vehicles for official use.

**Figure 2-4** Australian Hydrogen Utilization Sector Overview




Source DCCEEW (2024), p.63

## Section 2. ASEAN Member States

### 1. Indonesia

#### A. Industrial Sectors Applications

Strategies are being pursued to utilise clean hydrogen as a core energy Source across various industrial sectors. In industries such as textiles, pulp and paper, machinery and transport, food and beverages, and wood processing, hydrogen supports the decarbonisation of respective production processes.

- Textile and paper industry: Used in manufacturing hydrogen peroxide for producing eco-friendly bleaching agents that replace chlorine-based chemicals
- Machinery and transport industry: Applied as a process heat Source replacing fossil fuels, contributing to carbon emission reduction
- Food and beverage industry: Used in the hydrogenation of fats for producing edible oils and margarine
- Wood industry: Utilised as a heating and processing fuel Source to replace fossil fuels. The industrial sector's demand for clean hydrogen is projected to reach approximately 70,000 tonnes by 2041 and surge to over 1.9 million tonnes by 2060.

#### B. Utilization in Residential Natural Gas Systems

Hydrogen is also gaining attention as a clean alternative fuel in the sector of natural gas for residential use. Options under consideration include blending a certain proportion of hydrogen into the existing natural gas network or constructing dedicated hydrogen pipelines. Based on an analysis indicating that 0.1 MMSCFD of hydrogen per day can supply approximately 10,000 households, the Indonesian government plans to gradually increase the hydrogen blending ratio and demand, starting with the new capital city, Nusantara.

#### C. Utilization in the Power and Transportation Sectors

In power generation, two approaches have been proposed for hydrogen utilization: direct combustion and conversion through fuel cells. Hydrogen can be burned in gas turbine power plants (PLTG) or in coal-fired power plants (PLTU) in the form of ammonia to produce electricity. When converted through fuel cells, it is also possible to develop a hybrid hydrogen-electric power generation system. In the transportation sector, the introduction of hydrogen fuel cell electric vehicles (FCEVs) is underway, and demand is expected to accelerate beginning in 2030.

### 2. Laos

#### A. Utilization in the Power Generation Sector

A model linking green hydrogen production utilizing hydropower and solar reSources with power generation is under review. Specifically, proposals are being made to apply hydrogen produced via electrolysis technology to hydrogen turbine power generation or fuel cell power generation systems. This model offers the advantage of utilizing surplus power from hydropower to enhance grid stability while simultaneously establishing a carbon-neutral power generation system. Furthermore, the possibility of collaborating on hydrogen power generation demonstration projects with countries like Japan and South Korea has been mentioned. It is projected that commercial power plants based on green hydrogen could be operational after 2030. The Lao government aims to establish a distributed power system based on renewable energy through these initiatives.

#### B. Transportation Sector Utilization

The transportation sector is considering the introduction of hydrogen fuel cell vehicles and hydrogen buses. The government is seeking a long-term transition to a hydrogen-based transportation system alongside expanding the adoption of electric vehicles. To achieve this, establishing hydrogen refueling station infrastructure and securing fuel supply chains have been identified as key tasks. Specifically, plans are under discussion to operate pilot hydrogen bus routes, primarily in major cities and industrial complexes. Furthermore, strengthening border infrastructure connectivity has been proposed to enable the operation of hydrogen vehicles within interconnected transportation networks with neighboring countries in the future.

#### C. Industrial Sector Utilization

Industrial hydrogen is evaluated as a key reSource that can be utilized in fertilizers, steelmaking, chemical processes, and other applications.

A strategy is underway to establish hydrogen supply systems within ammonia production facilities and chemical complexes to introduce green ammonia production systems. The ammonia produced in this process can also be utilized as export fuel and a storage medium. Furthermore, the emphasis is on using hydrogen as fuel for industrial processes to replace fossil fuels and reduce greenhouse gas emissions. Long-term, the creation of hydrogen-based industrial complexes and the formation of green industrial belts are expected to revitalize the regional economy.

#### D. Export and International Cooperation Sector Utilization

The goal is to leap forward as a hydrogen production and supply hub nation within Southeast Asia. Plans have been presented to export green hydrogen, produced using abundant hydropower and solar reSources, to neighboring and advanced markets such as Thailand, Vietnam, South Korea, and Japan. The primary hydrogen production areas will be centered around the southern hydropower generation zone, with export routes established through ports in Thailand and Vietnam. Additionally, discussions are underway regarding technological cooperation with Korean and Japanese companies, attracting investment, and jointly developing infrastructure.

#### E. Utilization of Storage and Transportation Infrastructure Sectors

Hydrogen storage and transportation methods — compressed hydrogen, liquefied hydrogen, and ammonia conversion — were compared and analyzed. After a comprehensive review of economic viability and technical difficulty, ammonia-based transportation was evaluated as the most realistic alternative in the initial commercialization phase.

### 3. Malaysia

#### A. Power Generation Sector Utilization

Demonstration of hydrogen co-firing technology in natural gas combined-cycle power plants is underway, with plans to expand to hydrogen-only power generation in the future. Mitsubishi Hitachi Power Systems (MHPS) plans to convert the Magnum plant in the Netherlands to hydrogen-only operation by 2023, while Petronas is leading the development and commercialization of blue hydrogen production technology based on CCUS (Carbon Capture, Utilization, and Storage).

#### B. Thermal and Industrial Sector Applications

The primary goal is to replace gray hydrogen used in industrial processes (refining, ammonia, methanol, steel, etc.) with clean hydrogen. Based on NREL research findings, hydrogen blending at 3-20% ratios into natural gas pipelines is feasible. Building on this, a hydrogen supply network for industrial and heating applications is under development.

#### C. Mobility Sector

A hydrogen bus and charging infrastructure demonstration project is underway in Sarawak. The Darul Hana Multifuel Station, promoted by SEDC

Energy, will simultaneously provide hydrogen refueling, electric vehicle charging, and conventional fuel supply. Sarawak Metro operates Southeast Asia's first hydrogen buses, aiming for commercialization by 2027. UMW is advancing hydrogen fuel cell applications for passenger vehicles (FCEVs) and industrial forklifts, while Digi is building hydrogen-solar hybrid power generation systems for communication towers.

#### D. Transportation and Storage Sector

Various hydrogen storage and transportation technologies are being developed and introduced, including gaseous (GH2), liquid (LH2), liquid organic hydrogen carriers (LOHC), and solid (SHC, NaBH4) forms. NaBH4-based solid hydrogen storage is highly safe and compatible with fuel cell temperatures, making it suitable for distributed clean energy supply. The LOHC method enables the storage and transportation of hydrogen in a chemically bonded state using compounds like methylcyclohexane (MCH) and is currently being demonstrated in Sarawak.

### 4. Vietnam

#### A. Power Sector

By 2030, we plan to conduct experiments on co-firing natural gas with hydrogen and coal with ammonia to verify the technical and economic feasibility of using hydrogen as fuel in existing thermal power plants. After securing the safety and cost-effectiveness of hydrogen fuel through these pilot phases, the plan is to transition LNG and gas power plants to hydrogen fuel and convert coal power plants to ammonia fuel by 2050, thereby transforming the entire power sector into a low-carbon energy system.

#### B. Transportation Sector

Demonstration projects targeting hydrogen fuel-based public transportation and long-distance transport vehicles will be pursued by 2030. Pilot operations for major transport modes — including buses, trucks, rail, ships, and aircraft — will assess infrastructure feasibility, safety, and economic viability. Based on these evaluations, the institutional and technological foundations for future commercialization will be established. By 2050, the plan is to complete the fuel transition by applying hydrogen and hydrogen-derived fuels (such as ammonia) across the entire transportation sector. This will be achieved by expanding the nationwide hydrogen refueling infrastructure, significantly reducing carbon emissions from the transportation sector.

#### C. Industrial Sector

In the fertilizer, petrochemical, and refining industries, replace existing gray hydrogen (fossil fuel-based hydrogen) with green hydrogen (renewable energy-based hydrogen). In the steel and cement industries, demonstrate low-carbon processes (green steel, eco-friendly cement) utilizing green hydrogen. By 2030, we will undergo research and experimental phases for this transition. By 2050, we plan to expand hydrogen use across all industries, achieving the replacement of fuels and raw materials within processes with hydrogen. This will enhance energy efficiency in manufacturing industries and minimize greenhouse gas emissions, thereby contributing to achieving the national carbon neutrality goal.

## Section 3. Comprehensive Comparison

Hydrogen is a raw material that can be secured without regional bias, emits little to no greenhouse gases or fine dust, and produces only water as a byproduct. Consequently, countries are establishing strategies and policies to lead the hydrogen economy society within the international community. Accordingly, to provide benchmarking and reference points for Cambodia in formulating its national hydrogen economy strategy, this study comprehensively compares and analyzes the hydrogen policy directions of major countries, encompassing their current hydrogen economy policies and hydrogen utilization sectors. The key countries selected for this analysis are South Korea and Japan, which established hydrogen strategies early; the United States, a global economic powerhouse leading in technology; Germany, possessing key technologies across various sectors of the hydrogen economy ecosystem; and Australia, a reSource-rich nation with significant potential for a large hydrogen production market. Additionally, the hydrogen utilization strategies of ASEAN member states adjacent to Cambodia — Indonesia, Laos, Malaysia, and Vietnam — were examined.

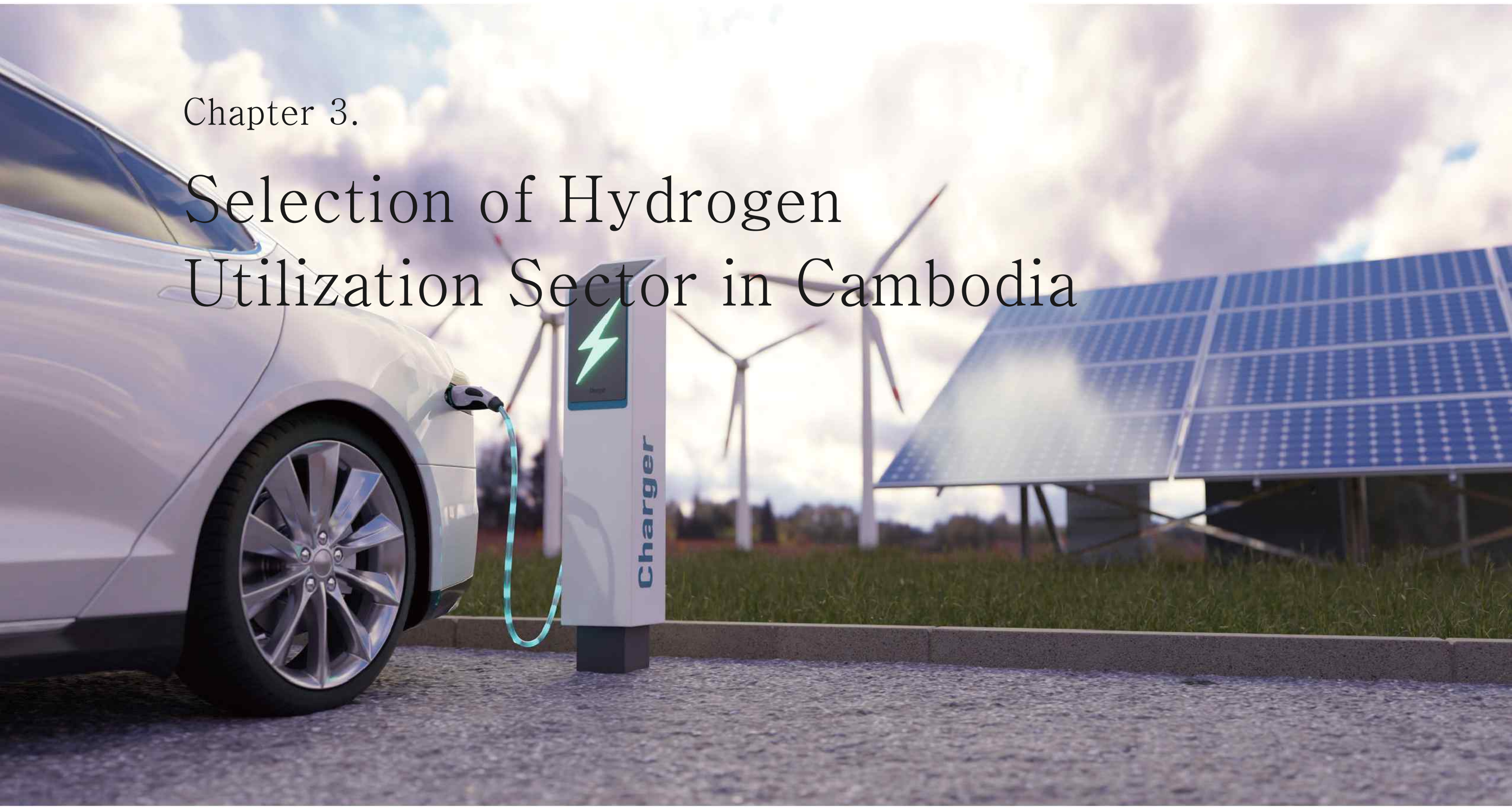
The common hydrogen utilization sectors identified in the national hydrogen strategies of the target countries are summarized in Table 2-8 below. It can be seen that utilization is primarily occurring in the transportation and power generation sectors.

**Table 2-8** Hydrogen Utilization Sectors in Global Countries

| Category | Transportation | Power Generation | Steel | Petrochemical | Refining | Cement |
|---|---|---|---|---|---|---|
| Korea | o | o | o | o | o | o |
| Japan | o | o | o | o | o | |
| Germany | o | | o | o | o | o |
| United States | o | o | o | o | o | |
| Australia | o | o | | | | |
| Indonesia | o | o | | | | |
| Laos | o | o | | | | |
| Malaysia | o | o | o | | o | |
| Vietnam | o | o | | o | o | |

**Note** Organized based on the presence of keywords within each country's hydrogen strategy

# Chapter 3.
# Selection of Hydrogen Utilization Sector in Cambodia




## Section 1. Policy Conformity Review

In this section, the potential for hydrogen utilization within Cambodia's key national policies is reviewed to identify sectors that align with government strategy. Given the nascent state of the global hydrogen market, active government support is essential to foster initial demand. Therefore, identifying sectors where hydrogen is already being considered, even at an exploratory level, is critical for determining future viability and government backing.

This study examines policy coherence by analyzing five key government documents and strategic actions: the Long-Term Strategy for Carbon Neutrality (LTS4CN), the EnergyTech Roadmap (2023), the Power Development Plan (PDP) 2022–2040, and the Third Nationally Determined Contribution (NDC 3.0).

The LTS4CN was reviewed to assess hydrogen's role at the highest level of national climate vision. The MISTI EnergyTech Roadmap was analyzed to evaluate hydrogen's position as a national technology and innovation priority. The PDP, as the core energy plan, was examined for de facto and de jure inclusion of hydrogen in the power sector. The recently submitted NDC 3.0 was reviewed to understand the most current, committed mitigation measures.

### 1. Long-Term Strategy for Carbon Neutrality (LTS4CN)

The LTS4CN, submitted to the UNFCCC in 2021, is Cambodia's foundational vision for achieving a carbon-neutral economy by 2050 (Royal Government of Cambodia (RGC), 2021). This document provides the first official, high-level acknowledgment of hydrogen as a potential tool for decarbonization.

Within its mitigation actions, the LTS4CN specifically identifies the road transportation sector as a target. The strategy explicitly includes the "Study of hydrogen or other zero-carbon fuels as long-term alternatives to natural gas for the trucking sector" (RGC, 2021). This mention is significant as it highlights a challenging application where direct electrification (via batteries) faces difficulties, indicating a clear, long-term policy interest in hydrogen for heavy-duty transportation.

### 2. EnergyTech Roadmap

The EnergyTech Roadmap, developed by the Ministry of Industry, Science, Technology & Innovation (MISTI), outlines the technological direction for Cambodia's energy security and sustainable development. This document, supported by Korea's Science and Technology Policy Institute (STEPI), frames hydrogen as a key area for national research and innovation (MISTI, 2023).

The roadmap's executive summary highlights "possible new Sources of energy, including nuclear power and hydrogen power, which Cambodia shall explore through scientific research and development" (MISTI, 2023). As MISTI is the lead ministry for industrial development, this inclusion provides a strong policy foundation for exploring hydrogen's role in the industrial sector, particularly for applications requiring high-temperature heat or as a chemical feedstock that is not easily addressed by other renewable Sources.

### 3. Power Development Plan (PDP) 2022-2040

The PDP is the Royal Government's comprehensive long-term plan for the power sector (Ministry of Mines and Energy, 2022). The plan itself, as summarized by the Asian Development Bank (ADB), adopts a forward-looking de jure stance, noting that emerging technologies such as "CCUS and hydrogen" will be "evaluated and considered in the future" (ADB, 2023).

More importantly, the de facto policy action by the Ministry of Mines and Energy (MME) to carry out this exploratory mandate is significant. In January 2024, during a high-level delegation visit to France, the MME signed a Memorandum of Understanding (MoU) with the French company HDF Energy (HDF Energy, 2024). The justification for this assessment is straightforward: HDF Energy's press release explicitly states that the MoU commits the company to "supporting Cambodia's ambitious Power Development Plan (PDP)... 2022 to 2040" (HDF Energy, 2024).

The MoU's objective is a feasibility study for a 10MW "Renewstable®" hydrogen power plant, a technology designed to provide "green, stable, and baseload power 24/7" (HDF Energy, 2024; The Phnom Penh Post, 2024). This directly links hydrogen to the power generation sector, specifically for grid stabilization to complement Cambodia's high share of intermittent solar and seasonal hydropower. However, following the January 2024 announcement, no public information regarding the progress of this feasibility study has been made available as of late 2025

### 4. Third Nationally Determined Contribution (NDC 3.0) (2025)

The NDC 3.0, submitted in July 2025, represents Cambodia's most current and concrete implementation plan for GHG mitigation by 2035 (RGC, 2025). A review of the document's 163 mitigation, adaptation, and enabling measures finds no specific mention of 'hydrogen' (RGC, 2025). Instead, the NDC 3.0 focuses on mature, bankable, and ready-to-deploy technologies to achieve its 55% conditional emissions reduction target. For the energy and transport sectors, the key strategies listed are:

Energy: Increasing the renewable energy share to 80% (conditionally), promoting energy efficiency, and exploring Carbon Capture and Utilization (CCU) for existing plants.

Transport: Aggressively scaling up Electric Mobility (EVs) for motorcycles, cars, and buses; improving public transport; and shifting freight to rail and waterways.

The absence of hydrogen in the NDC 3.0 does not contradict the exploratory intent of other policies. It indicates a pragmatic, two-track approach: focusing on proven technologies (like EVs) for the core 2035 targets, while developing hydrogen on a parallel path for long-term, hard-to-abate sectors not covered by direct electrification.

## 5. Implications

The analysis of Cambodia's key policy documents reveals a clear and consistent alignment for hydrogen utilization across three specific sectors, though at different stages of development.

The road transportation sector (specifically trucking) is identified in the nation's highest-level climate vision (RGC, 2021). The industrial sector is designated as a priority for R&D by the government's technology ministry (MISTI, 2023a). The power generation sector (for grid stability) is the subject of the most concrete de facto action via the MME-HDF MoU (HDF Energy, 2024).

The most definitive evidence of this multi-sectoral strategy comes from the official UN CTCN Technical Assistance (TA) Request Form (MoE, 2024), submitted by the Ministry of Environment in October 2024. While not a finalized policy, this document serves as the official blueprint for the forthcoming "National Green Hydrogen Roadmap." This request explicitly confirms the government's intent by:

Selecting "Sustainable Mobility" and "Energy Systems" as the two primary transformation areas.

Defining the roadmap's scope to include a market analysis for "transport, industry and power generation".

Formally listing the key stakeholders: MPWT (Ministry of Public Works and Transport) for the transportation sector, MISTI for industrial applications, and MME for power generation.

This official request synthesizes the disparate threads from previous policies into a single, cohesive plan. It confirms that while mature technologies like EVs are the focus of the current NDC 3.0 (RGC, 2025), the government is simultaneously and formally building the foundation for a long-term hydrogen economy centered on power generation, industrial use, and heavy transport.

**Table 3-1** Analysis of Hydrogen Utilization Sector by Cambodia's Major Policies

| Sector | LTS4CN (2021) | EnergyTech Roadmap (2023) | PDP 2022-2040 (via MME MoU 2024) | NDC 3.0 (2025) |
|---|---|---|---|---|
| Road Transportation | ○[1] | | | |
| Power Generation | | ○[2] | ○[3] | |
| Industry | | ○[2] | | |

Note 1) Specified as "trucking sector" (RGC, 2021). 2) Included under "hydrogen power" for R&D (MISTI, 2023a). 3) For grid stability, via de facto MME-HDF MoU in support of the PDP (HDF Energy, 2024). Source: Author's analysis based on Cambodian government policy documents and official statements

## Section 2. Economic Significance

Cambodia's selection of priority sectors for hydrogen deployment must align with both its long-term socio-economic development strategy and current industrial structure.

### 1. National Development Strategy: The Pentagonal Strategy and Cambodia Vision 2050

In August 2023, the Cambodian government under Prime Minister Hun Manet launched the first phase of the "Pentagonal Strategy," a comprehensive 25-year socio-economic development framework (Royal Government of Cambodia, 2023). This strategy builds upon the Triangular Strategy (1998-2003) and Rectangular Strategy (2004-2023), and serves as the implementation roadmap for "Cambodia Vision 2050" — which targets upper-middle-income status by 2030 and high-income status by 2050.

The Pentagonal Strategy comprises five priority pillars, each containing five detailed policy measures(〈Table 3-2〉:

Table 3-2 Cambodia's Pentagonal Strategy Phase 1 (2023- 2028)

| Pillar | Policy Measures |
|---|---|
| Human Capital Development | • Upgrading education quality, science, technology, and skills training<br>• Strengthening health and social protection systems<br>• Enhancing food systems and overall welfare<br>• Fostering ethical, fair, and inclusive citizenship |
| Economic Diversification and Enhanced Competitiveness | • Improving special economic zone efficiency and investment attractiveness<br>• Strengthening the business and investment climate<br>• Innovating financing mechanisms and financial products<br>• Developing core economic sectors and new growth Sources<br>• Improving connectivity and efficiency in transport, logistics, energy, water, and digital infrastructure |
| Private Sector Development and Employment | • Supporting micro-enterprises and start-ups<br>• Formalizing the informal economy to increase inclusiveness<br>• Promoting SMEs, entrepreneurship, public-private partnerships, and competition<br>• Deepening and modernizing the financial sector |
| Resilient, Sustainable, and Inclusive Development | • Leveraging demographic trends and maximizing the demographic dividend<br>• Strengthening agriculture and rural development<br>• Promoting green economy and climate-resilient growth |
| Digital Economy and Society Development | • Building digital government, enterprises, and e-commerce<br>• Creating a reliable digital ecosystem and innovation environment<br>• Developing financial technologies and digital infrastructure |

Source RGC (2023)

Several priorities directly support hydrogen deployment. The emphasis on transport, logistics, energy, and water infrastructure efficiency, combined with commitments to green and climate-resilient development, positions low-carbon technologies like hydrogen as enablers of long-term competitiveness rather than isolated climate interventions.

## 2. Current Economic Structure and Sector Importance

An analysis of Cambodia's 2022 Input-Output Table of 35 sectors (ADB, 2023), reveals the key sectors driving the national economy. The largest industries by total output include (《Table 3-3》):

**Table 3-3** Cambodia's Input-Output (2022)

| Rank | Sector | Total Output (USD million) |
|---|---|---|
| 1 | Coke, refined petroleum, and nuclear fuel | 26,628 |
| 2 | Construction | 8,215 |
| 3 | Agriculture, hunting, forestry & fishing | 8,796 |
| 4 | Textiles and textile products | 10,254 |
| 5 | Electricity, gas, and water supply | 1,176 |
| 6 | Wholesale trade | 4,341 |
| 7 | Hotels and restaurants | 1,321 |
| 8 | Inland transport | 3,454 |
| 9 | Real estate | 1,690 |
| 10 | Financial intermediation | 730 |

Source ADB (2023)

Energy-related sectors — particularly electricity, refined petroleum, and transport — represent a substantial share of total industrial activity, reflecting Cambodia's high dependence on imported fossil fuels and energy-intensive logistics networks.

Among these sectors, electricity generation (USD 1.18 billion) and inland transport (USD 3.45 billion) emerge as both economically significant and strategically relevant for hydrogen deployment. Both sectors consume substantial fossil fuels and align with government priorities for power system modernization and energy security. By contrast, while textiles, agriculture, and retail trade contribute significantly to overall output, they offer limited near-term opportunities for hydrogen integration.

## 3. Implications for Hydrogen Prioritization

Cambodia's development vision and economic structure indicate that initial hydrogen deployment should target sectors that are both economically significant and policy-aligned:

Power and energy systems (electricity, gas and water supply; refined petroleum and fuel supply), where hydrogen can enhance energy security, provide system flexibility, and support green growth objectives

Road transport and logistics, where hydrogen can enable cleaner, more efficient freight and passenger mobility aligned with national goals for improved connectivity and competitiveness

# Section 3. Technical Applicability

This section assesses whether Cambodia currently possesses the industrial equipment and technological infrastructure necessary for hydrogen-based decarbonization. The evaluation focuses on major energy-intensive sectors such as steelmaking, cement, petrochemicals to determine where hydrogen can be feasibly deployed in the near to medium term.

## 1. Steel Sector: No Blast Furnace Capacity

Hydrogen steel making is not applicable due to the absence of integrated steelmaking facilities in Cambodia. Cambodia does not operate any integrated steel plants using blast furnace-basic oxygen furnace (BF-BOF) technology. The only large-scale project ever announced was the Cambodia Iron & Steel Mining Industry Group facility (2011), which planned to have 3 million tonnes per annum (tpa) blast furnace (ironmaking), 1 million tpa basic oxygen furnace (steelmaking) and fully integrated configuration with captive coal power and iron ore from Preah Vihear Province to be constructed from 2014 to 2018. However, according to OECD data (Nakamizu, 2024), this project was cancelled during the planning stage and never built. All announced BF and BOF capacities remain at zero. Existing domestic steel production is limited to small mills in Banteay Meanchey, Kampong Speu, and Sihanoukville Special Economic Zone (e.g., Huale Steel, USD 40 million investment, 2023). These facilities operate electric arc furnaces (EAF) or rolling mills, producing rebar, billets, and simple long products from scrap — not primary steel from iron ore (Whitehead, 2024).

Hydrogen-based steelmaking requires either direct reduced iron (DRI) produced with hydrogen, then melted in EAFs, or hydrogen injection into blast furnaces or basic oxygen furnaces(World Steel Association, 2024; SteelWatch, 2025). Cambodia possesses neither DRI reactors nor BF-BOF infrastructure, nor the upstream systems required for primary steelmaking (pelletization plants, coking facilities, or sintering operations). Thus, Cambodia has no industrial configuration suitable for hydrogen steelmaking. This sector should not be considered a near-term priority for hydrogen deployment.

## 2. Cement Sector: Potential Long-Term Application, but Not Near-Term Priority

Cambodia operates five integrated cement plants, all commissioned between 2008 and 2020, with combined capacity of approximately 7.7-9.0 million tonnes per year:

**Table 3-4** Cambodia's Existing Cement Plants

| Plant | Process type | Capacity (Mt/yer) |
|---|---|---|
| Battambang Conch Cement | Dry | 2.0 |
| Chip Mong Insee | Dry | 1.5 |
| Chakrey Ting | Dry | 1.24 |
| Kampot Cement | Wet | 2.0 |
| Thai Boon Roong | Dry | 1.0 |

Source Tkachenko et al. (2023)

Cement kilns require high-temperature heat (up to 1,450°C), which hydrogen can theoretically provide. However, several barriers limit near-term applicability due to the current fuel base is coal and petroleum coke, with established supply chains. Also, hydrogen burner retrofits require substantial kiln redesign and capital investment and hydrogen costs remain significantly above coal and petcoke price parity (Ivanova, 2025). Cambodia lacks hydrogen production, storage, or distribution infrastructure near cement production clusters. Therefore, while cement is technically compatible with hydrogen combustion in the long term, it does not represent a practical early-use case for Cambodia given current infrastructure and cost considerations.

### 3. Petrochemical and Refining Sector: No Applicable Infrastructure

Hydrogen is extensively used in refineries and chemical complexes for hydrocracking and hydrotreating processes, fuel desulfurization, ammonia and urea production, methanol synthesis and olefins production via steam cracking. However, looking into Cambodia's petrochemical capacity, it currently operates no oil refinery, naphtha cracker, ammonia nor urea production facility, methanol nor olefins infrastructure.

The substantial "refined petroleum products" output recorded in Cambodia's Input-Output Table as USD 26.6 billion (ADB, 2023), reflects fuel import, distribution, and retail activities and not domestic refining or petrochemical production. Therefore, Cambodia lacks the industrial base for hydrogen application in petrochemicals or refining. This sector is not applicable for hydrogen adoption in the foreseeable future.

## Section 4. Energy Consumption Profile

Cambodia's energy balance reveals strong structural dependence on petroleum products, with transport, power generation, and industry accounting for the majority of final energy consumption. This section uses data from the UNSD Energy Balance, UNDP Energy Statistics (2020-2021) (Ministry of Mines and Energy, 2023), and national energy supply tables to quantify fossil fuel use by sector and identify where hydrogen applications would yield the greatest decarbonization impact.

### 1. National Energy Supply: Petroleum-Dominated System

In 2021, Cambodia's total primary energy supply reached 7,573 ktoe, characterized by persistent reliance on oil and coal alongside a modest contribution from renewable electricity. Oil products dominated the energy mix at 3,244 ktoe, representing 42.8% of total supply. Biomass followed at 2,137 ktoe (28.2%), reflecting continued use of traditional fuels in rural and residential contexts. Coal accounted for 1,387 ktoe (18.3%), primarily serving cement production and baseload power generation. Renewable Sources remained limited: domestic hydropower contributed 439 ktoe (5.8%), imported electricity 291 ktoe (3.8%), and solar just 53 ktoe (0.7%).

**Table 3-5** Cambodia's Primary Energy Supply Mix(2021)

| Energy Source | Supply (ktoe) | Share (%) |
|---|---|---|
| Oil products | 3,244 | 42.8 |
| Biomass | 2,137 | 28.2 |
| Coal | 1,387 | 18.3 |
| Hydropower(domestic) | 439 | 5.8 |
| Imported electricity | 291 | 3.8 |
| Solar | 53 | 0.7 |
| Total | 7,573 | 100 |

Source Ministry of Mines and Energy (2023)

This composition has remained relatively stable over the past two decades, positioning Cambodia among the most petroleum-dependent economies in Southeast Asia. The dominance of oil reflects not only the country's near-total reliance on imported petroleum for transport but also the continued use of diesel and heavy fuel oil as backup and stabilizing fuels in the power sector.

### 2. Final Energy Consumption by Sector

Total final energy consumption in 2021 reached 6,657 ktoe. The sectoral breakdown reveals that industry and transport together account for more than 60% of national energy demand:

**Table 3-6** Final Energy Consumption by Sector (2021)

| Sector | Consumption (ktoe) | Share (%) |
|---|---|---|
| Industry | 4,748 | 30.8 |
| Transport | 4,533 | 29.4 |
| Residential/commercial/agriculture | 3,475 | 22.5 |
| Electricity generation | 2,371 | 15.4 |
| Non-energy use | 299 | 1.9 |
| Total | 15,426 | 100 |

Source Ministry of Mines and Energy (2023)

Industry, encompassing cement production, construction, mining, and various processing activities, consumed 4,748 ktoe (30.8%). Transport consumed 4,533 ktoe (29.4%), almost entirely in the form of gasoline and diesel. The residential, commercial, and agricultural sectors collectively consumed 3,475 ktoe (22.5%), relying heavily on biomass and, increasingly, electricity.

A notable feature of Cambodia's energy system is the substantial own-use consumption within electricity generation itself. At 2,371 ktoe (15.4%), this figure underscores the inefficiencies and fossil fuel dependence embedded in the power system, including auxiliary consumption, transmission losses, and plant operations. Non-energy uses, such as petrochemical feedstocks or industrial process inputs, accounted for just 299 ktoe (1.9%), reflecting the absence of refining and petrochemical industries in Cambodia.

## 3. Electricity System: Fossil Fuel Dependence for Reliability

Cambodia's electricity system is expanding rapidly in response to industrialization and urbanization, yet it remains dependent on fossil fuels to ensure grid stability and meet peak demand. The electricity supply mix in 2021 reflected a diversified but uneven composition:

**Table 3-7** Electricity Supply by Source (2021)

| Source | Supply (ktoe) | Share (%) |
|---|---|---|
| Imported electricity | 766 | 35.0 |
| Hydropower (domestic) | 732 | 33.4 |
| Coal-fired generation | 684 | 29.0 |
| Oil products (diesel & HFO) | 86 | 3.9 |
| Solar | 77 | 3.5 |
| Biomass | 10 | 0.5 |
| Total | 2,305 | 100 |

Source Ministry of Mines and Energy (2023)

Despite the presence of hydropower (33.4%) and growing solar capacity (3.5%), diesel and heavy fuel oil continue to play a critical role in maintaining grid reliability. This is particularly evident during the dry season, when hydropower output declines sharply, and during peak demand periods when dispatchable generation is required. Moreover, backup diesel generators remain widely deployed across commercial and industrial facilities, serving as insurance against grid outages and voltage instability.

The electricity generation sector itself consumed 2,371 ktoe in 2021, a figure that reflects not only auxiliary power requirements and transmission losses but also the continued reliance on fossil fuels for balancing services and system reserves. This embedded fossil fuel dependence represents a significant opportunity for hydrogen-based solutions, including co-firing, fuel cell backup systems, and long-duration energy storage.

## 4. Sector-Specific Fossil Fuel Consumption and Hydrogen Applicability

The transport sector is by far the most petroleum-intensive in Cambodia's economy. Accounting for approximately 29% of final energy consumption, or 4,533 ktoe in 2021, transport relies almost exclusively on gasoline and diesel. The Petroleum Master Plan (2022-2040) projects sharp increases in diesel and gasoline demand, particularly in Phnom Penh and along major logistics corridors, driven by rising vehicle ownership, freight activity, and urban mobility needs (ERIA, 2021). This near-total dependence on imported petroleum, combined with the technical feasibility of fuel cell vehicles for heavy-duty applications, makes transport a highly suitable sector for hydrogen deployment. Fuel cell trucks, buses, and logistics fleets offer direct substitution potential and align closely with Cambodia's objectives for energy security and emissions reduction.

The industrial sector, while consuming the largest share of final energy at 4,748 ktoe (30.8%), presents a more complex picture. Energy use in this sector is distributed across coal, biomass, diesel, and electricity, with cement production relying heavily on coal and petroleum coke, and construction and mining equipment powered predominantly by diesel. However, as discussed in Section 3.3, Cambodia lacks the large-scale, high-temperature industrial processes — such as integrated steelmaking or petrochemical refining — that are typically early adopters of industrial hydrogen. Hydrogen applications in Cambodian industry would be limited to eventual kiln conversions in cement plants or other high-temperature heat substitutions, both of which require substantial capital investment and are not feasible in the near term. As such, industry represents a moderate-to-low priority for hydrogen adoption.

The power generation sector, by contrast, emerges as a high-priority target. In 2021, electricity generation consumed 2,371 ktoe in own-use, auxiliary consumption, and losses, with diesel and heavy fuel oil providing essential balancing, backup, and peak capacity services. Coal remains a stable contributor to baseload supply, but the system's reliance on dispatchable fossil generation increases during periods of seasonal hydropower variability. Hydrogen and ammonia co-firing in existing coal and oil-fired plants, combined with fuel cell backup systems and long-duration energy storage, could significantly enhance energy security while reducing fossil fuel dependence. These applications are technically feasible in the near term and align closely with government priorities for power system modernization and climate resilience.

## 5. Priority Sectors for Hydrogen Deployment

Cambodia's energy consumption profile points clearly toward two priority sectors for hydrogen deployment: transport and power generation. Both sectors exhibit high fossil fuel dependence, structural reliance on imported petroleum, and technical readiness for hydrogen substitution.

Transport's near-exclusive dependence on petroleum, combined with rapid growth in diesel and gasoline demand, makes it the most compelling sector for early hydrogen adoption. Heavy-duty transport applications — such as freight trucks, urban buses, and logistics fleets — can integrate fuel cell technology relatively quickly, offering immediate reductions in petroleum imports and emissions. The government's emphasis on connectivity, logistics efficiency, and energy security further reinforces transport as a strategic priority.

Power generation, meanwhile, offers complementary opportunities for hydrogen deployment. The sector's continued reliance on diesel and heavy fuel oil for backup and balancing services, coupled with seasonal variability in hydropower output, creates a clear need for dispatchable, low-carbon alternatives. Hydrogen and ammonia co-firing can be implemented in existing thermal plants with relatively modest retrofitting, while fuel cell systems can provide decentralized backup power and long-duration energy storage to support grid stability. These applications address both energy security and decarbonization objectives, making power generation a high-priority sector alongside transport.

By contrast, industry, despite consuming the largest share of final energy, offers limited near-term opportunities for hydrogen adoption. The absence of blast furnaces, petrochemical complexes, and other hydrogen-intensive industrial processes, combined with the high capital costs and long payback periods associated with industrial heat substitution, relegates this sector to lower priority in the near to medium term. Residential and commercial sectors, relying primarily on biomass and electricity, present minimal opportunities for hydrogen integration.

In summary, Cambodia's energy balance confirms that transport and power generation are by far the most fossil-fuel-intensive and strategically important sectors for hydrogen deployment. Together, they account for the vast majority of petroleum consumption and represent the areas where hydrogen can deliver the greatest impact on energy security, import dependence, and emissions reduction in alignment with national development priorities.

# Section 5. Integrated Assessment and Priority Sector Selection

This section synthesizes findings from the preceding analyses — economic importance (Section 3.2), technical applicability (Section 3.3), and energy consumption patterns (Section 3.4) — to identify the sectors where hydrogen deployment would deliver the greatest strategic, economic, and environmental benefits for Cambodia.

## 1. Summary of Cross-Sectoral Findings

The preceding sections reveal three critical insights that shape Cambodia's hydrogen sector priorities. First, from an economic perspective, the 2022 Input-Output Table demonstrates that energy- and fuel-dependent sectors such as electricity, inland transport, and refined petroleum distribution contribute significantly to national economic output. These sectors are explicitly prioritized in the Pentagonal Strategy, which emphasizes improvements in transport, logistics, energy infrastructure, and long-term economic competitiveness.

Second, technical feasibility varies dramatically across sectors. Cambodia lacks the blast furnaces, direct reduction facilities, and petrochemical complexes that typically anchor industrial hydrogen demand in more developed economies. Steel and petrochemicals are therefore not applicable. Cement production, while theoretically compatible with hydrogen combustion, faces prohibitive costs and infrastructure barriers. By contrast, fuel cell electric vehicles for heavy-duty transport are technically mature and commercially available, while hydrogen and ammonia co-firing technologies for power generation have been successfully demonstrated in similar markets.

Third, energy consumption patterns underscore the dominance of petroleum dependence. Transport and industry together account for more than 60% of final energy consumption, with petroleum products representing 43% of total energy supply. Transport is nearly 100% petroleum-dependent, while power generation continues to rely heavily on diesel and heavy fuel oil for backup and seasonal balancing. According to the Cambodia Petroleum Master Plan, oil demand is projected to increase significantly through 2030 and 2040, driven primarily by transport growth in Phnom Penh and major logistics corridors.

## 2. Selection Framework for Hydrogen Priority Sectors

Hydrogen deployment priorities are determined by applying five criteria that reflect both technical feasibility and strategic alignment with national development objectives:

**Table 3-8** Criteria for Hydrogen Sector Prioritization

| Criterion | Definition |
|---|---|
| Economic leverage | • Size and importance of the sector in Cambodia's development strategy |
| Technical readiness | • Compatibility with commercially available hydrogen technologies |
| Energy and emissions impact | • Fossil fuel intensity and potential for hydrogen to displace petroleum or coal |
| Strategic alignment | • Fit with the Pentagonal Strategy's emphasis on diversification, competitiveness, resilience, and green growth |
| Infrastructure readiness | • Existing logistics, transport corridors, and fuel distribution networks that can support hydrogen deployment |

Source Author

Applying these criteria across Cambodia's major sectors reveals clear differentiation in hydrogen applicability and deployment potential.

## 3. Comparative Sectoral Assessment

The table below summarizes how each major sector performs against the selection criteria:

**Table 3-9** Assessment of Hydrogen Applicability by Sector

| Sector | Economic leverage | Technical Readiness | Energy/ Emissions Impact | Strategic Alignment | Infra-structure Readines | Overall Priority |
|---|---|---|---|---|---|---|
| Power generation | High | High | High | High | Moderate | High |
| Road Transport | High | High | Very high | High | High | Very high |
| Industry(cement) | Moderate | Low | Moderate | Low | Low | Low |
| Steel | None | Not applicable | None | None | None | Not applicable |
| Petrochemicals | None | Not applicable | None | None | None | Not applicable |
| Residential/commercial | Low | Low | Low | Low | Low | Very low |

Source Author

This assessment identifies power generation and road transport as the two sectors where hydrogen can deliver meaningful impact in the near to medium term.

## 4. Priority Sector 1: Power Generation

Power generation emerges as a high-potential early application for hydrogen due to the confluence of technical feasibility, energy security imperatives, and strategic alignment with national development goals.

The sector's continued dependence on diesel and heavy fuel oil for grid stability and backup supply creates both vulnerability and opportunity. Seasonal variability in hydroelectric output — particularly during the dry season — necessitates dispatchable fossil fuel generation, which hydrogen and ammonia can directly replace.

From a technical standpoint, hydrogen-ready gas turbines and ammonia co-firing technologies are commercially available and have been demonstrated in similar grid contexts. Fuel cells can provide backup and decentralized power solutions, particularly for industrial and commercial facilities that currently rely on diesel generators. These applications align closely with energy security objectives articulated in the Pentagonal Strategy, which prioritizes grid resilience and reduced dependence on imported fuels.

Moreover, hydrogen production can be strategically co-located with renewable energy zones to store surplus solar and hydroelectric output, addressing one of the grid's most persistent challenges: the mismatch between renewable generation profiles and demand patterns. This integration pathway positions hydrogen not merely as a fuel substitute but as an enabler of deeper renewable energy penetration.

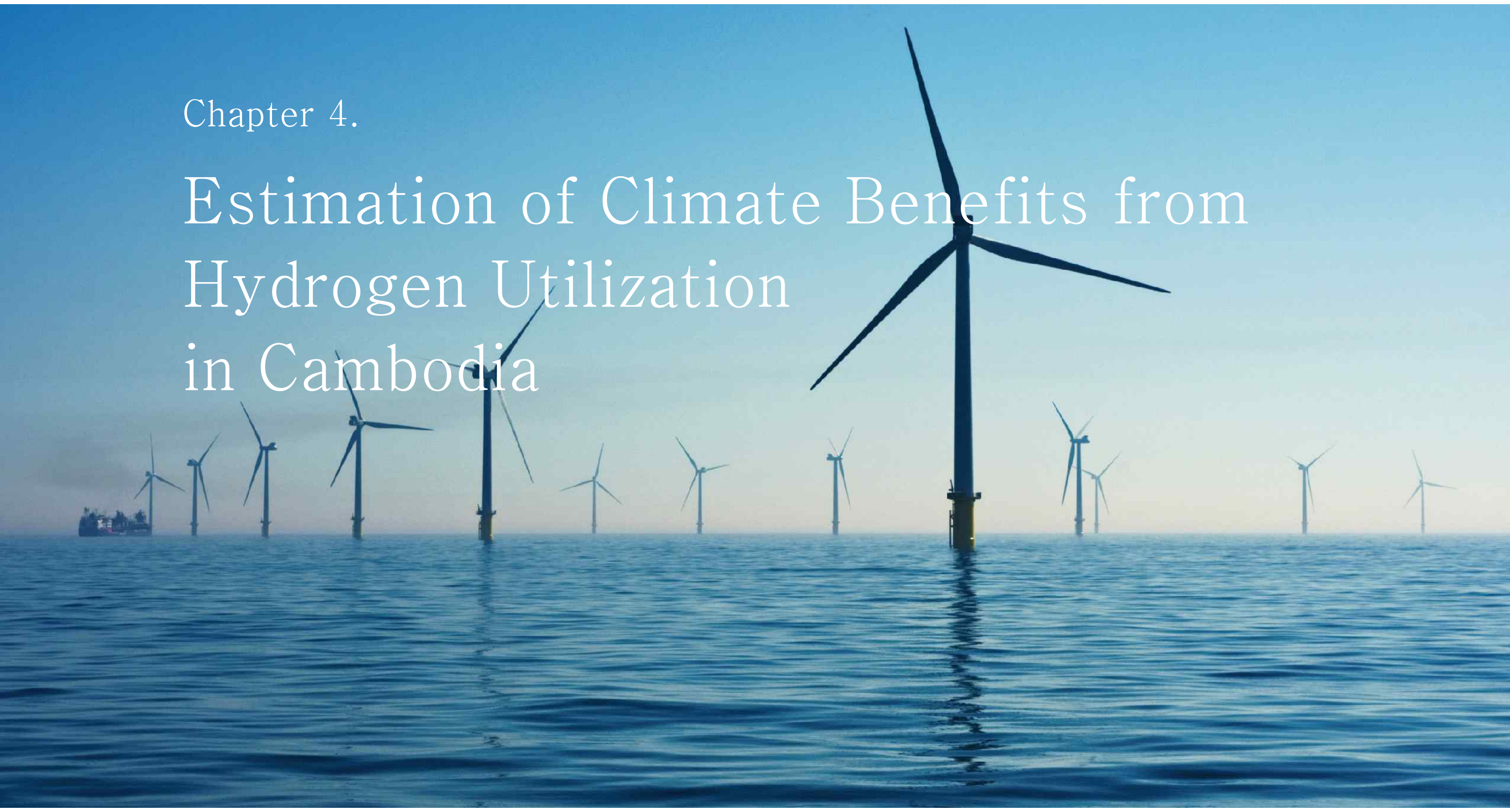
## 5. Priority Sector 2: Road Transport

Road transport is the largest petroleum consumer in Cambodia's economy and the primary driver of rising oil demand through 2040. Accounting for nearly 30% of final energy consumption and relying almost exclusively on gasoline and diesel, the sector presents both the greatest decarbonization challenge and the most mature technological solution pathway.

Fuel cell heavy-duty trucks, buses, and long-haul vehicles are already commercially deployed in multiple markets worldwide, offering proven technology that can be adapted to Cambodia's transport network. The country's primary logistics corridors — particularly the Sihanoukville-Phnom Penh-Battambang route — are well-suited for the establishment of hydrogen refueling hubs. These corridors already serve as critical arteries for freight movement and fuel distribution, providing existing infrastructure that can be leveraged for hydrogen deployment.

The Petroleum Master Plan identifies increasing fuel flows through Sihanoukville, Phnom Penh, and Mekong River terminals, alongside planned pipeline and railway rehabilitation projects. These infrastructure investments align naturally with the establishment of hydrogen supply and distribution corridors, reducing the incremental investment required for hydrogen adoption. Additionally, Phnom Penh — which is projected to account for more than 50% of national fuel demand by 2030 — would benefit substantially from reduced diesel emissions, addressing both air quality and public health concerns in the capital.

Heavy-duty freight and public transport therefore represent the most technically mature and strategically important applications for hydrogen in Cambodia's transport sector.



Chapter 4.

# Estimation of Climate Benefits from Hydrogen Utilization in Cambodia

## Section 1. Overview of Climate Benefit Estimation

### 1. Concept of Climate Benefits and Significance of Estimation

While explicit definitions in national laws or international agreements are scarce, the concept of "climate benefit" can be interpreted through the meanings of its constituent terms: "climate" and "benefit." Climate is generally defined as long-term average weather patterns (IPCC, 2021); however, in the context of "climate benefits," it is understood to refer to climate change rather than climate itself. In the social sciences, benefit refers to the utility or satisfaction derived from a specific activity, typically expressed as a measurable monetary value; thus, climate benefits can broadly be interpreted as "utility or satisfaction related to climate change." More specifically, climate and benefit can be understood as "positive benefits gained when specific activities or measures contribute to climate change mitigation or adaptation, or the monetary value assigned to those benefits." For example, if a country altogether banned the use of internal combustion engine vehicles (a specific activity or measure), GHG emissions from the road transport sector would immediately decline, thereby helping to mitigate climate change. The value this effect brings to specific groups or to society as a whole (the positive benefit) can be viewed as a climate benefit.

From this perspective, the climate benefits of hydrogen utilization refer to the benefits that specific groups or society as a whole can enjoy from the climate change mitigation effects generated by economic activities that utilize hydrogen. In other words, the climate benefits of hydrogen utilization focus solely on its effects on climate change, excluding secondary effects such as industrial development or job creation. Given that hydrogen is internationally recognized as having the potential to reduce GHG emissions, it is reasonable to examine its role in climate change response.

Given the concept of climate benefits from hydrogen utilization, estimating these benefits can help Cambodia establish and implement hydrogen policies in three ways. First, the climate benefits from hydrogen utilization provide an estimate of future gains when hydrogen is actively introduced into major economic activities, while simultaneously presenting a societal orientation. Second, climate benefits lend legitimacy to hydrogen policy formulation and enable coordination with broader climate change strategies that consider other GHG-reduction measures. Third, citizens and various groups within Cambodian society must accept hydrogen usage; thus, benefits expressed in monetary terms can serve as foundational data for building social consensus.

## 2. Assumptions and Methods for Estimating Climate Benefits

To estimate the climate benefits of hydrogen use, it is necessary to select economic activities that use hydrogen. This study assumes that the power generation and road transport sectors examined in Chapter 3 are Cambodia's key areas of hydrogen application. These sectors are major consumers of fossil fuels. This study assumes that Cambodia introduces hydrogen into these sectors to replace existing fossil-fuel-based power generation and internal combustion engine vehicles.

Carbon is the only GHG that can be reduced by utilizing hydrogen in Cambodia's power generation and road transportation sectors. Generally, GHGs managed for climate change response are the six substances specified by the 1997 Kyoto Protocol: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride ($SF_6$). While it is reasonable to calculate reductions for other GHGs to assess their effects, this study focuses solely on carbon dioxide. This approach is due to carbon dioxide accounting for the largest share of GHG emissions, and for analytical convenience.[15]

GHG reductions in Cambodia's power generation and road transport sectors would benefit operators in these sectors, local or central governments, or the public. The appropriate affected group must be defined based on the purpose of the climate benefit estimate. This study aims to present climate benefits as a basis for developing national strategies. Accordingly, from a social cost-benefit analysis perspective, Cambodian society as a whole is considered the beneficiary group.

Based on the above premise, this study's estimation method for climate benefits from hydrogen utilization proceeds in three main stages. The first stage estimates the long-term projected GHG emissions if economic activities in Cambodia's power generation and road transport sectors continue on their current trajectory. The second step involves projecting GHG emissions expected when hydrogen is used in power generation and road transport to replace specific fossil fuels, using a hydrogen utilization scenario. This projection is then compared with the results from the first step to estimate the expected GHG reduction (GHG reduction effect). The third step is to express the monetary benefits to Cambodian society as a whole from these GHG reductions.

15 However, this report uses the terms "carbon dioxide" and "greenhouse gases" interchangeably.

### A. Step 1: Estimating the Baseline Greenhouse Gas Emissions

The first step in estimating climate benefits is calculating the baseline emissions used to measure GHG reductions from hydrogen utilization. This step projects the GHG emissions that would result if Cambodia's current patterns of activity in the power generation and road transport sectors continue in the long term. In other words, this step estimates the business-as-usual (BAU) GHG emissions. Specifically, as Cambodia targets carbon neutrality by 2050 (Kingdom of Cambodia, 2021), this step primarily aims to estimate the baseline emissions projected for that year.

The above projection is a long-term outlook looking more than 20 years ahead from 2025; it requires quantitative estimates, making the appropriateness of the methodology to be used a key issue. Methods for projecting GHG emissions include assuming the recent years' emission growth rate will persist over the long term. Additional approaches include building a model using several macroeconomic variables to explain emissions, projecting emissions by forecasting these variables, and bottom-up projections that predict the activities of microeconomic entities. The most straightforward approach, assuming a constant emissions growth rate, may be appropriate; however, it risks being overly simplistic. At the same time, macro and micro models require substantial data.

This study selects the Kaya identity-based forecasting method, considering the availability of data for projections, the ease of future methodological revisions and enhancements, and third-party reproducibility. The Kaya identity expresses GHG emissions as the product of several influencing factors, as shown in Equation 4-1.

$$C = C/E \times E/G \times G/P \times P$$

(Equation 4-1)

Here, C represents GHG emissions, E represents energy consumption, G represents gross domestic product (GDP), and P represents population. The GHG emissions per unit of energy consumption (C/E) on the right-hand side represent the energy's emission intensity, defined as the amount of GHG emissions emitted per unit of energy consumed.[16] The energy consumption per unit of GDP (E/G) measures the total energy consumed to produce one unit of economic output and reflects the concept of energy intensity. Finally, GDP per capita (G/P) represents a nation's economic affluence, while population (P) denotes the size of that nation's population. Here, the numerator and denominator on the right-hand side cancel, leaving only GHG emissions (C), ensuring that Equation 4-1 holds. In other words, the Kaya identity attempts to explain a country's GHG emissions as a function of energy intensity of use, energy intensity of economic activity, economic affluence, and population size. An increase in any factor on the right-hand side (C/E, E/G, G/P, and P) increases GHG emissions; however, even if a specific factor increases, total GHG emissions may remain constant or even decrease due to reductions in other factors.

To project GHG emissions using the Kaya identity, projections are needed for each variable or factor; however, projections for the factors themselves may suffice. For example, when projecting energy emission intensity based on projections for each variable, future GHG emissions and energy consumption must be projected separately; however, this can be simplified to forecasting the indicator of GHG emissions per unit of energy consumption. This approach reduces the number of forecasts compared to forecasting each variable individually and offers the advantage of

16 The greenhouse gas emissions per unit of energy consumption ($C_i/E_i$) represent an emission coefficient and can be understood in a similar context.

potentially easier forecasting, as this indicator is likely to have an increasingly stable trajectory over time.

**Table 4-1** Greenhouse Gas Emission Identities by Economic Sector in Cambodia

| Category | Identity | Variables |
| --- | --- | --- |
| Power Generation | $C = \Sigma C_i/E_i \times E_i/Elec_i \times Elec_i/Elec \times Elec/Con \times Con/G \times G/P \times P$ | $C_i$: Carbon dioxide emissions from fuel i<br>$E_i$: Fuel consumption of fuel i<br>$Elec_i$: Electricity generation from fuel i<br>Elec: Total electricity generation<br>Con: Power consumption<br>G: GDP<br>P: Population |
| Road Transportation | $C = \Sigma C_i/E_i \times E_i/V_i \times V_i/V \times V/G \times G/P \times P$ | $C_i$ : Carbon dioxide emissions from fuel i<br>$E_i$: Fuel consumption of fuel type i<br>$V_i$: Number of vehicles using fuel i<br>V: Total number of vehicles<br>G: GDP<br>P: Population |

Source National Institute of Green Technology

This study extends the Kaya identity to reflect the characteristics of the development and road transport sectors (Table 4-1). Explanations of the Kaya identity for each sector, along with the variables and factors included in each identity, are provided in the sections analyzing each sector.

Estimating various variables and factors, including GHG emissions, inevitably involves significant uncertainty. This limitation applies to all methodologies; therefore, the results presented in this study indicate a general direction rather than definitive outcomes.

### B. Step 2: Calculating Greenhouse Gas Reduction from Hydrogen Utilization

To calculate the GHG reductions achievable through hydrogen use in power generation and road transportation, we must first estimate the GHG emissions associated with its use. Table 4-1 presents GHG emissions from hydrogen utilization, which can also be predicted using the Kaya identity. Unlike BAU emissions, this measure involves a specific intervention in hydrogen utilization; therefore, the changes resulting from this measure must be fully reflected in the Kaya identity.

The most direct changes resulting from hydrogen utilization in the power generation and road transportation sectors are increased hydrogen power generation and hydrogen vehicle adoption, and the consequent substitution of fossil fuels, which is the key point. GHG reductions from hydrogen utilization do not arise solely from hydrogen use; they occur when hydrogen partially substitutes for fossil fuels; therefore, fuel substitution must be considered when calculating GHG reduction effects. Such changes can be reflected by adjusting the variables for electricity generation by fuel type ($Elec_i$) and the number of vehicles by fuel type in the road transport sector ($V_i$); however, it is assumed that no other changes occur. Accordingly, other variables and factors remain the same as in the BAU emissions calculation.[17]

17 Strictly speaking, the transition to a hydrogen economy signifies a shift from a fossil fuel-based economy to a new system; therefore, this transition could affect various endogenous variables in the Kaya identity (most notably, GDP).

The main challenge in Step 2 is determining how hydrogen will penetrate each economic sector from a certain point onward and what share it will ultimately hold by 2050. Such information could be inferred from plans reflected in national policies; however, Cambodia currently lacks any officially announced policies on hydrogen utilization. Therefore, this study establishes scenarios for the proportion of fossil fuel replacement to calculate long-term GHG emissions and explores the benefits Cambodia could gain from hydrogen use.

Ultimately, the difference between the BAU emissions derived in Phase 1 and the emissions when hydrogen is utilized can determine the GHG reduction achieved through hydrogen utilization.

**C. Step 3: Calculating Greenhouse Gas Reduction Benefits**

Step 3 involves calculating the benefits that Cambodian society can gain from the GHG reductions calculated in Step 2, ultimately deriving climate benefits expressed in monetary value. To calculate the benefits, the utility or satisfaction Cambodia gains from the GHG reductions must be assumed. This study views the reduction in social costs that Cambodia would otherwise bear, equivalent to the amount of GHG reduced, as the corresponding utility.

To express the reduction in social costs from GHG reductions as monetary benefits, the GHG reduction amount must be multiplied by the unit value of social cost reduction per unit of GHG reduction (the unit value of the GHG reduction effect). In Stage 3, the appropriateness of this unit value is the key issue. The social burdens caused by GHG emissions can arise in diverse and complex ways, including reduced labor and agricultural productivity due to accelerated climate change, human and material damage from various natural disasters, and biodiversity loss. This study uses the social cost of carbon dioxide proposed by the US Environmental Protection Agency (2023) to ensure objectivity in social cost estimates. The Environmental Protection Agency (2023) proposes the social cost of carbon dioxide in 2050 to be between 200 USD and 480 USD per ton (based on 2020 prices).

## Section 2. Power Generation Sector

### 1. Identity Equation

In Cambodia's power generation sector, this study establishes the identity equation shown in Equation 4-2, where C represents total GHG (carbon dioxide) emissions from the sector, and $C_i$ denotes GHG emissions from fuel i. $E_i$ represents the consumption of fuel i in the power generation sector; $Elec_i$ and Elec denote the electricity generated using fuel i and the total electricity generated, respectively. Con represents Cambodia's electricity consumption, G denotes gross domestic product, and P represents population.

$$C = \Sigma C_i/E_i \times E_i/Elec_i \times Elec_i/Elec \times Elec/Con \times Con/G \times G/P \times P$$

(Equation 4-2)

Based on the above variables, GHG emissions from Cambodia's power generation sector are determined by seven factors (on the right-hand side of Equation 4-2). The first is the GHG intensity factor for energy ($C_i/E_i$), representing GHG emissions per unit of fuel used (i.e., the GHG emission factor for each fuel). The second is the fuel-use inefficiency factor ($E_i/Elec_i$), which is the reciprocal of the power generation efficiency typically expressed. It is calculated by dividing the fuel consumption i by the amount of electricity ($Elec_i$) produced from that fuel. In the power generation industry, higher fuel usage inefficiency increases carbon dioxide emissions required to produce the same amount of electricity. The third factor is the power mix factor ($Elec_i/Elec$), which is the amount of electricity generated using a specific fuel ($Elec_i$) divided by the total electricity generation (Elec). An increase in the proportion of electricity generated from fuels with high GHG emission factors increases GHG emissions from the power generation sector. The fourth factor is the electricity self-sufficiency ratio (Elec/Con), which indicates the proportion of domestic electricity demand met by domestic production. GHG emissions calculations typically apply only within a country's territory; therefore, this factor reflects the increase in total emissions when domestic fossil fuel power generation rises. The fifth factor is electricity consumption intensity (Con/G), which measures the amount of electricity consumed to produce one unit of goods or services—higher electricity consumption intensity means more electricity is consumed to achieve the same economic output, thereby increasing GHG emissions from the power generation sector. Finally, the economic scale factor (G/P) and population factor (P) are key indicators of a nation's size. When economic growth is robust or the population increases rapidly, energy consumption, including electricity, generally increases, leading to higher GHG emissions.

### 2. Data

This study compiled the following data to estimate the baseline GHG emissions (BAU) from Cambodia's power generation sector and the projected GHG reductions achievable through hydrogen utilization.

#### A. Carbon Intensity Factor

As previously explained, the carbon intensity factor ($C_i/E_i$) represents the carbon dioxide emission factor for each fuel type. This study used fuel-specific carbon dioxide emission factors from the 2006 IPCC Guidelines for National GHG Inventories, assuming they remained constant throughout the analysis period. The Electricity Authority of Cambodia (EAC) yearbook confirms the fuels used for power generation within Cambodia. According to the EAC (2025), as of 2024, Cambodia generates electricity using hydropower, diesel and hydrofluorocarbon (HFC) (hereafter diesel), coal, biomass, and solar. Diesel and coal are linked to IPCC emission factors, while the remaining renewable energy sources were assigned an emission factor of zero (Table 4-2).[18]

Table 4-2 Carbon Dioxide Emission Factors for Cambodia's Power Generation Sector

| Fuel (EAC) | Representative Fuel (IPCC 2006 Guideline) | $CO_2$ Emission factor (IPCC 2006 Guidelines) | $CO_2$ Emission factor |
|---|---|---|---|
| Natural gas | Natural gas | 56,100 $kgCO_2$/TJ | 201,960 $kgCO_2$/GWh |
| Coal | Other bituminous coal | 94,600 $kgCO_2$/TJ | 340,560 $kgCO_2$/GWh |
| Diesel/HFC | Gas/Diesel oil | 74,100 $kgCO_2$/TJ | 266,760 $kgCO_2$/GWh |
| Hydro | - | - | - |
| Biomass | - | - | - |
| Solar | - | - | - |

Note 1kWh = 3,600,000 Joules.
Source IPCC (2006)

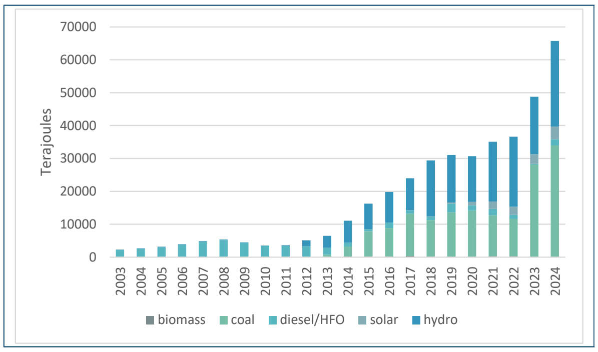
According to the Power Development Masterplan 2022–2040, Cambodia plans to introduce natural gas power generation around 2036, in addition to its current power generation sources (Ministry of Mines and Energy, 2022a); therefore, this study also collected the carbon dioxide emission factor for natural gas power generation from the IPCC report. The carbon dioxide emission factors provided by the IPCC are given in kilograms of carbon dioxide (kg-$CO_2$) per terajoule (TJ). This study converted these units to gigawatt hours (GWh) for use (Table 4-2).

### B. Fuel Use Inefficiency Factors

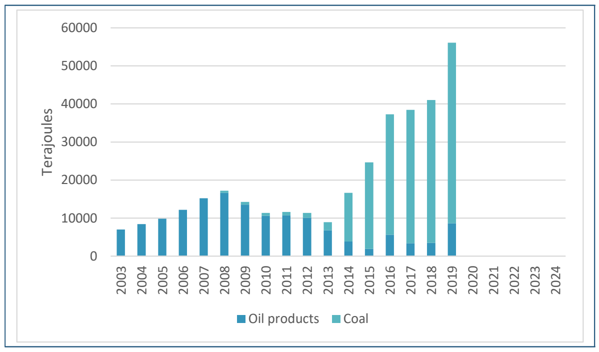
Inefficiencies in fuel use ($E_i/Elec_i$) must be calculated only for fuels with non-zero $CO_2$ emission factors (natural gas, coal, and diesel), which require detailed data on fuel consumption and electricity generation by fuel type in Cambodia's power sector. Electricity generation by fuel type for the power sector can be obtained from the time-series data in the EAC yearbook (Figure 4-1-(a)); however, fuel consumption by type is not provided as a statistical figure. Therefore, this study used data on annual coal and petroleum product inputs to the power generation sector from the Energy Balance table in the Cambodia Energy Statistics 2000–2019 by the Ministry of Mines and Energy (MoME) (2022b) (Figure 4-1-(b)). Based on these two datasets, the factors contributing to fuel use inefficiency by year (2003–2019) were calculated, as summarized in Figure 4-1-(c).

18 Biomass, like conventional fossil fuels, emits carbon dioxide upon combustion, and the IPCC report also provides emission factors for biomass; however, since plants absorb atmospheric carbon dioxide during their growth, biomass is considered a carbon-neutral fuel. Therefore, this study sets the emission factor to zero for analysis.

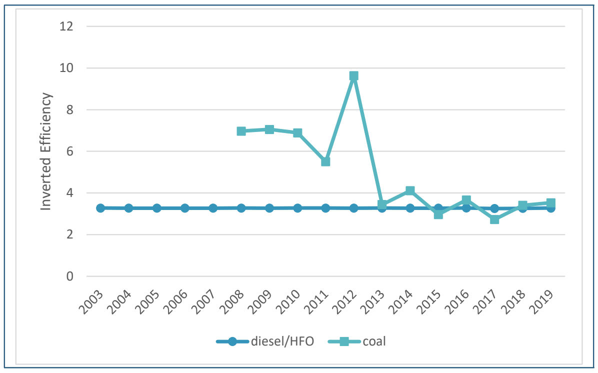
**Figure 4-1** Cambodia's Electricity Generation and Consumption by Fuel Type and Fuel Use Inefficiency Factors




(a) Electricity Generation by Fuel Type




(b) Fuel consumption by type



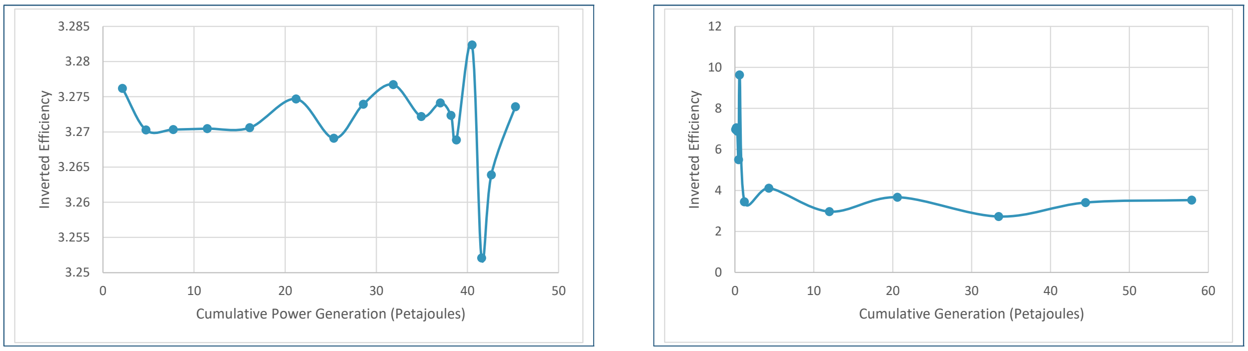

(c) Inefficiency factor in fuel use ($E_i$/ $Elec_i$)

**Note** Electricity generation and consumption by fuel type are converted values from GWh and kTOE, respectively

**Source** EAC (2004-2025), MoME (2022b)

This study examined whether a learning effect exists in the utilization of power generation fuels in Cambodia to forecast the inefficiency factor in fuel use by year. The learning effect, or learning-by-doing, refers to the effect in which accumulated experience in a specific production activity leads to the accumulation of expertise, resulting in improved performance, such as reduced production costs. The learning effect can be assessed by plotting a learning curve; the x-axis represents a variable signifying accumulated experience, and the y-axis represents a variable indicating inefficient factors. This approach allows examination of whether inefficient factors decrease, thereby gauging the existence of the effect. For the power generation sector, cumulative generation by fuel type can be plotted on the x-axis, and the inverse of generation efficiency per fuel type—representing fuel-use inefficiencies—on the y-axis. If a learning effect exists, it is reasonable to project a reduction in fuel-use inefficiencies (an increase in fuel-use efficiency) by 2050, reflecting this effect.

**Figure 4-2** Change in the Inverse of Power Generation Efficiency by Fuel Type Based on Cumulative Power Generation in Cambodia




(a) Diesel-Fired Power Generation (b) Coal-Fired Power Generation

**Note** Power generation and consumption by fuel type are converted values from GWh and kTOE, respectively
**Source** EAC (2004-2025), MoME (2022b)

Figure 4-2 shows graphs of the inverse of power generation efficiency for diesel and coal, Cambodia's primary fossil-fuel-based power generation fuels, as a function of cumulative power generation. If a learning effect exists in oil and coal power generation, the inverse of power generation efficiency should decrease as cumulative power generation increases; however, for oil power generation (Figure 4-2-[a]), the inverse of the generation efficiency shows some fluctuation but appears to remain within a narrow range. In coal power generation, efficiency initially improves but then appears to remain almost constant at values below 4; therefore, although this review used limited data, it concluded that it is difficult to observe a clear learning effect in coal- and oil-fired power generation in Cambodia. Consequently, this study assumes that notably significant efficiency improvements are rare in Cambodia's coal- and diesel-fired power generation, and that fuel-use inefficiencies persist at the most recently calculable level (2019) over the long term.

Meanwhile, although natural gas power generation is planned under the Power Development Masterplan, there is no operational experience in Cambodia. Accordingly, this study assumes a constant value of 3.0876, the reciprocal of the fuel efficiency of natural gas power generation (gas-fired combined cycle) in Thailand, a geographically adjacent country,[19] for the year 2022.[20]

### C. Power Mix Factor

The power mix factor ($Elec_i/Elec$) represents the proportion of each fuel's generation ($Elec_i$) relative to Cambodia's total generation (Elec). The simplest projection assumes no future policy intervention and maintains the current generation mix; however, if the government or power authorities have specific, committed power source deployment plans (even when projecting BAU emissions), it is necessary to reflect these plans as given conditions to estimate power generation and the power generation mix factor.

19 Many countries already utilize natural gas power generation; however, the operating performance of gas turbine power generation varies with ambient temperature and humidity, making it reasonable to utilize data from cases with similar ambient conditions.

20 According to the Ministry of Energy (Thailand) (2023), the natural gas consumed by the Electricity Generating Authority of Thailand (EGAT) as a power generation fuel in 2022 was 1,110 MMSCFD, equivalent to approximately 417,304.5 TJ. Meanwhile, EGAT's natural gas-based power generation in the same year was 37,542.9 GWh, equivalent to approximately 135,154 TJ.

From this perspective, this study incorporates the Power Development Masterplan 2022–2040 established by Cambodia's MoME. This plan serves as the Cambodian government's official comprehensive development plan for the power sector and outlines additional fuel-based power generation capacity to be installed from 2022 to 2040. To forecast future power generation, it is necessary to calculate the cumulative installed capacity, including newly added facilities and existing ones. This capacity can be estimated using the cumulative capacity by power source for additional installations from 2022 to 2040 (cumulative additional capacity) and the cumulative capacity by power source in 2040, including already installed generation facilities (cumulative total capacity)[21](Table 4-3). By applying the average capacity utilization rate of power generation facilities to these annual cumulative capacities, the annual power generation by fuel source can be projected.

Table 4-3 Projected Cumulative Power Generation Capacity by Fuel Type in Cambodia (Based on PDP)

| Year | Hydro | Diesel | Coal | Biomass | Solar | Natural Gas | Total |
|---|---|---|---|---|---|---|---|
| 2022 | 1,328 | 490 | 1,216 | 26 | 165 | - | 3,225 |
| 2023 | 1,328 | 490 | 1,916 | 26 | 205 | - | 3,965 |
| 2024 | 1,328 | 490 | 2,266 | 26 | 265 | - | 4,375 |
| 2025 | 1,328 | 490 | 2,266 | 48 | 455 | - | 4,587 |
| 2026 | 1,558 | 490 | 2,266 | 58 | 515 | - | 4,887 |
| 2027 | 1,558 | 490 | 2,266 | 68 | 585 | - | 4,967 |
| 2028 | 1,558 | 490 | 2,266 | 78 | 655 | - | 5,047 |
| 2029 | 1,558 | 490 | 2,266 | 88 | 705 | - | 5,107 |
| 2030 | 1,558 | 490 | 2,266 | 98 | 755 | - | 5,167 |
| 2031 | 1,558 | 490 | 2,266 | 108 | 815 | - | 5,237 |
| 2032 | 1,728 | 490 | 2,266 | 118 | 875 | - | 5,477 |
| 2033 | 2,066 | 490 | 2,266 | 128 | 935 | - | 5,885 |
| 2034 | 2,189 | 490 | 2,266 | 138 | 995 | - | 6,078 |
| 2035 | 2,255 | 490 | 2,266 | 148 | 1,055 | - | 6,214 |
| 2036 | 2,403 | 490 | 2,266 | 158 | 1,155 | 300 | 6,772 |
| 2037 | 2,593 | 490 | 2,266 | 168 | 1,505 | 600 | 7,622 |
| 2038 | 2,633 | 490 | 2,266 | 178 | 2,105 | 600 | 8,272 |
| 2039 | 2,853 | 490 | 2,266 | 188 | 2,505 | 900 | 9,202 |
| 2040 | 2,973 | 490 | 2,266 | 198 | 3,155 | 900 | 9,982 |

Unit MW
Source MoME (2022a)

However, to realistically estimate future fuel-specific generation volumes and power mix factors, it is necessary to reflect the publicly available installed power generation capacity at the time of analysis;

21 The Power Development Masterplan 2022–2040 presents the cumulative capacity of total installed power generation facilities expected in 2030 and 2040. This value is understood to include not only the cumulative capacity of new facilities to be deployed from 2022 onwards but also the cumulative capacity of power generation facilities already existing in the plan year. Therefore, the cumulative installed capacity for 2021 can be estimated by subtracting the cumulative capacity of facilities planned for installation from 2022 to 2040 (based on the new deployment plan) from the cumulative installed capacity for 2040; however, this value is calculated solely from the cumulative capacity of total installed capacity and new facilities as of 2040.

therefore, this study assumes that if the 2024 fuel-specific power generation capacity according to the EAC (2025) already meets the capacity deployment plan for a specific future year, no additional power generation facilities will be constructed until that specific year. Only in years with plans exceeding the 2024 capacity will additional facilities be constructed, in line with the Power Development Masterplan. Table 4-4 presents the cumulative power generation capacity outlook by fuel type for Cambodia, reflecting the above assumptions.

**Table 4-4** Cumulative Power Generation Capacity Forecast by Fuel Type in Cambodia (Reflecting 2024 Facilities)

| Year | Hydro | Diesel | Coal | Biomass | Solar | Natural Gas | Total |
|---|---|---|---|---|---|---|---|
| 2022 | 1,332 | 643 | 1,045 | 289 | 437 | 0 | 3,486 |
| 2023 | 1,332 | 646 | 1,410 | 49 | 437 | 0 | 3,873 |
| 2024 | 1,796 | 657 | 1,335 | 49 | 797 | 0 | 4,634 |
| 2025 | 1,796 | 657 | 2,266 | 49 | 797 | 0 | 5,565 |
| 2026 | 1,796 | 657 | 2,266 | 58 | 797 | 0 | 5,574 |
| 2027 | 1,796 | 657 | 2,266 | 68 | 585 | 0 | 5,372 |
| 2028 | 1,796 | 657 | 2,266 | 78 | 655 | 0 | 5,452 |
| 2029 | 1,796 | 657 | 2,266 | 88 | 705 | 0 | 5,512 |
| 2030 | 1,796 | 657 | 2,266 | 98 | 755 | 0 | 5,572 |
| 2031 | 1,796 | 657 | 2,266 | 108 | 815 | 0 | 5,642 |
| 2032 | 1,796 | 657 | 2,266 | 118 | 875 | 0 | 5,712 |
| 2033 | 2,066 | 657 | 2,266 | 128 | 935 | 0 | 6,052 |
| 2034 | 2,189 | 657 | 2,266 | 138 | 995 | 0 | 6,245 |
| 2035 | 2,255 | 657 | 2,266 | 148 | 1,055 | 0 | 6,381 |
| 2036 | 2,403 | 657 | 2,266 | 158 | 1,155 | 300 | 6,939 |
| 2037 | 2,593 | 657 | 2,266 | 168 | 1,505 | 600 | 7,789 |
| 2038 | 2,633 | 657 | 2,266 | 178 | 2,105 | 600 | 8,439 |
| 2039 | 2,853 | 657 | 2,266 | 188 | 2,505 | 900 | 9,369 |
| 2040 | 2,973 | 657 | 2,266 | 198 | 3,155 | 900 | 10,149 |

Unit MW
Source EAC (2025), MoME (2022b)

Information on capacity utilization rates for each power generation source is required to estimate fuel-specific power generation based on cumulative installed capacity by fuel type, calculated through 2040 (Table 4-4). The capacity factor is an indicator of how much a power generation facility was utilized, representing the ratio of actual power generation to the facility's theoretical maximum. This factor can be calculated as the ratio of actual power generation to the amount of power that could be produced if a specific power generation facility operated at maximum output for 24 hours a day, 365 days a year. Multiplying the capacity of a power generation facility (Table 4-4) by the fuel-specific capacity utilization rate enables forecasting generation volume by fuel type. This study calculated the capacity utilization rate for each fuel type (as shown in Table 4-5) based on installed capacity and power generation data for the five years from 2020 to 2024, as presented in the EAC yearbook. Power generation data is unavailable from 2025 to 2040; therefore, it was assumed that the facilities would operate at a constant rate based on the capacity utilization rate from the most recent five-year period. There is no operational experience with natural gas power generation in Cambodia; thus, the capacity utilization rate was assumed to be 40% annually.

**Table 4-5** Fuel-Specific Power Plant Capacity Utilization Rates in Cambodia

| Year | Hydro | Diesel | Coal | Biomass | Solar |
|---|---|---|---|---|---|
| 2020 | 33.05 | 7.72 | 66.09 | 24.41 | 11.11 |
| 2021 | 43.30 | 10.20 | 58.44 | 19.83 | 19.52 |
| 2022 | 50.56 | 6.14 | 34.35 | 4.96 | 18.18 |
| 2023 | 41.49 | 0.95 | 63.33 | 17.57 | 21.51 |
| 2024 | 45.80 | 9.23 | 80.40 | 18.16 | 15.29 |
| Avg. | 42.84 | 6.85 | 60.52 | 16.98 | 17.12 |

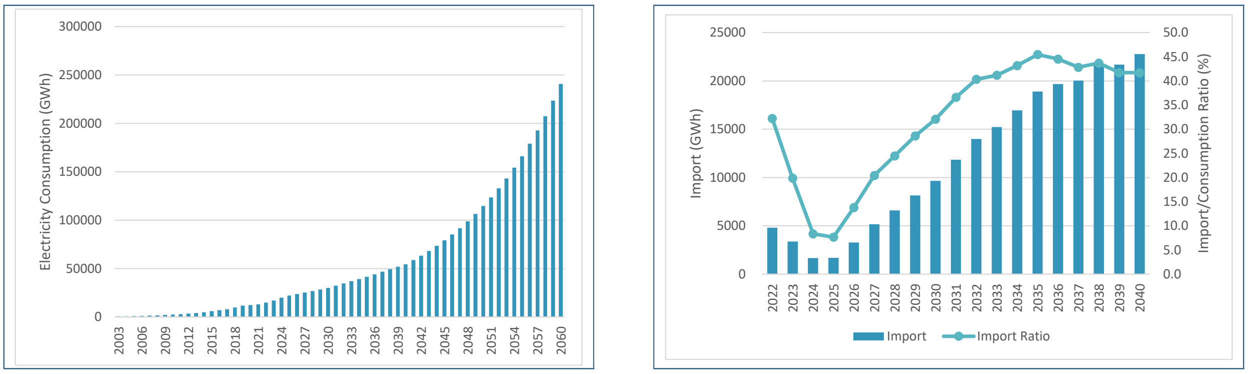
Unit %
Source EAC (2021-2025)

Meanwhile, to forecast power generation from 2041 onwards, it is necessary to examine 1) projected electricity consumption from 2041 onwards, 2) the amount of electricity that must be imported to meet that consumption, and 3) the fuels to be used to generate domestic power. First, the projected electricity consumption is assumed to follow the Power Development Masterplan's projections (based on the baseline with energy efficiency measures) from 2025 to 2040. From 2041 onwards, it is projected to follow the average annual growth rate of the baseline projection (7.7%) (Figure 4-3-[a]). Second, electricity imports are assumed to equal the difference between electricity consumption and domestic generation from 2025 to 2040 (Figure 4-3-[b]), with the import share relative to consumption in 2040 (approximately 41.7%) assumed to persist through 2050. By combining the first and second, the amount of electricity that must be generated domestically to meet consumption starting in 2041 is determined. Third, it was assumed that no additional diesel, coal, biomass, or natural gas power generation facilities would be constructed after 2041, and that the 2040 generation capacity would remain unchanged until 2050. The excess electricity consumption that existing facilities cannot cover was assumed to be met equally by solar and hydropower.[22]

Based on the above projections, Figure 4-4 presents the forecast results for generation volume and generation share (power mix factors) by fuel type. Cambodia's domestic power generation is expected to shift from petroleum-based to hydropower and coal-fired generation from the mid-to-late 2010s through 2040. After that, the share of coal-fired power generation is projected to decline, transitioning to a mix centered on solar and hydropower.

22 In other words, this assumption implies that new electricity demand from 2041 onwards will be met solely by solar and hydro power.

**Figure 4-3**. Cambodia's Electricity Consumption Forecast and Import Share



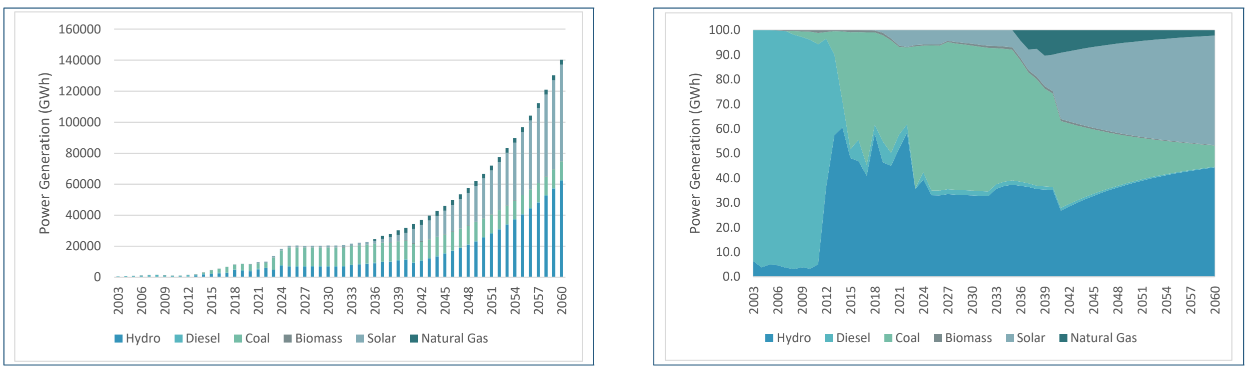

(a) Electricity Consumption Forecast

(b) Import Share Relative to Consumption

**Note** Figures up to 2024 are actual values; figures from 2025 onwards are projections

**Source** EAC (2004-2025), MoME (2022a)

**Figure 4-4**. Forecast of Cambodia's Electricity Generation by Fuel Type and Share (Power Mix Factors)




(a) Projected Electricity Generation by Fuel Type

(b) Projected Share of Power Generation by Fuel

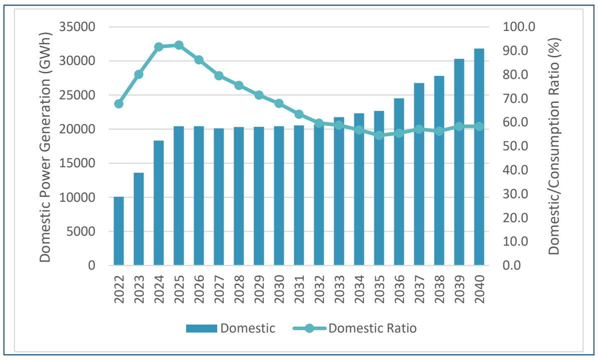
**Note** Figures up to 2024 are actual values, while figures from 2025 onwards are projections.

**Source** EAC (2004-2025), MoME (2022a)

### D. Electricity Self-Sufficiency Rate Factor

The electricity self-sufficiency rate factor (Elec/CON) indicates the extent to which domestic generation can meet a country's electricity consumption. Electricity consumption can be balanced by domestic generation and imported electricity. Based on this logic, the proportion of domestic generation relative to total electricity consumption (the electricity self-sufficiency factor) can be estimated by subtracting the proportion of imported electricity from 100%. When projecting the generation mix factor, the proportion of imports relative to electricity consumption was calculated and projected. Figure 4-5 presents the results of the electricity self-sufficiency rate factor estimation. Assuming the proportion of imports relative to power consumption remains constant from 2041 to 2040, the power self-sufficiency factor was also assumed to remain constant, with no significant change from 2041 onwards to maintain consistency in the assumptions.

Figure 4-5. Projection of Cambodia's Electricity Self-Sufficiency Rate Factor



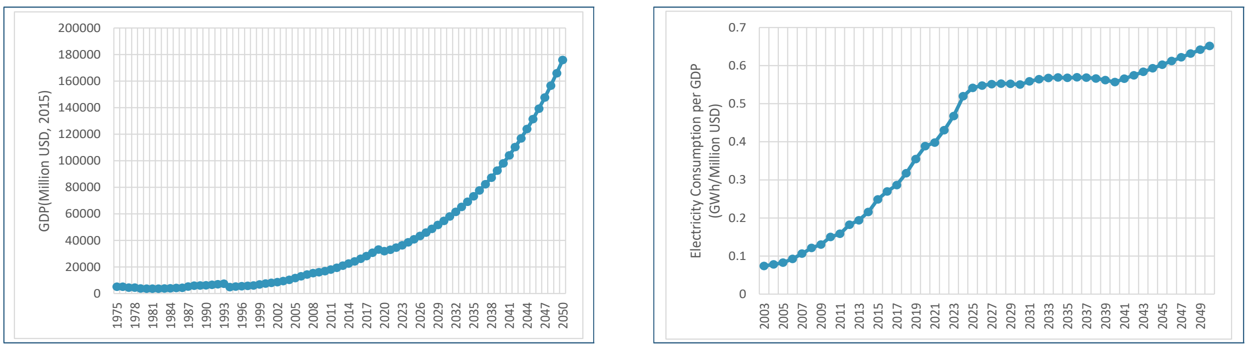

Note Figures up to 2024 are actual values, while figures from 2025 onwards are projections

Source EAC (2004-2025), MoME (2022a)

### E. Electricity Consumption Intensity Factor

The electricity consumption intensity factor (Con/G) is calculated as Cambodia's electricity consumption per capita divided by its GDP per capita. The projected GDP value is required because Cambodia's electricity consumption has already been forecast. Cambodia's GDP data were obtained from the World Bank as a time series, and the projection assumes that the 2024 GDP growth rate of 6.02% continues through 2050.

Figure 4-6. Forecast of Cambodia's Gross Domestic Product and Electricity Consumption Intensity Factors




(a) GDP Forecast

(b) Electricity Consumption Intensity Factor Forecast

Note Figures up to 2024 are actual values; figures from 2025 onwards are projections

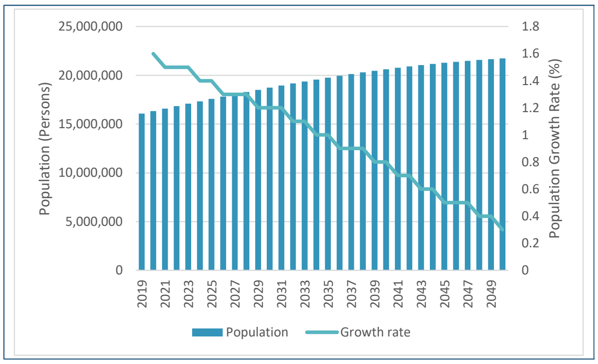
Source EAC (2004-2025), MoME (2022a), World Bank (2025b)

### F. Economic Scale Factor and Population Factor

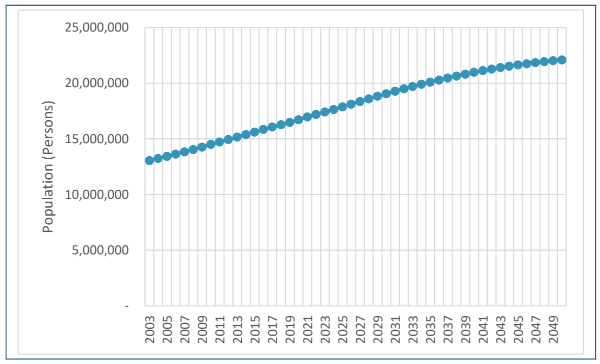
The economic scale factor (G/P) is GDP per capita, calculated as GDP divided by population. The population factor (P) refers to population size. The GDP included in the economic scale factor was already forecast when estimating the electricity consumption intensity factor; therefore, given Cambodia's projected population size (population factor forecast), the economic scale factor can also be forecasted.

Cambodia's population data, like GDP data, was obtained from the World Bank database through 2024. For population projections, this study intended to use the long-term projections to 2050 from the National Institute of Statistics (NIS) for the 2019 general population census; however, comparing the two datasets from 2019 to 2024, the World Bank data, based on actual figures, showed a larger population. Therefore, this study did not directly adopt the absolute values of the NIS long-term population projections; instead, it projected the population by applying the annual population growth rate (%) derived from those projections to each year from 2025 onward (Figure 4-7).

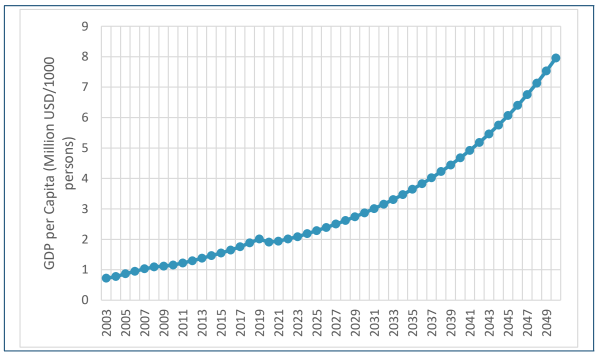
**Figure 4-7.** Projections of Cambodia's Population Factors and Economic Scale Factors




(a) NIS Population Projections




(b) Population Factor Projection




(C) Economic Scale Factor Projection

**Note** Figures up to 2024 are actual values, while figures from 2025 onwards are projections.
**Source** NIS and MoP (2021), World Bank (2025b).

## 3. Hydrogen Utilization Scenarios

Hydrogen utilization is envisioned to replace coal-fired power generation in Cambodia's power sector through hydrogen-based technologies, such as fuel cells and hydrogen gas turbines. Coal currently accounts for the largest share of Cambodia's power generation. Projections for the share of power generation by fuel type suggest it will decrease around 2050 (to approximately 8.6% by 2050); however, replacing part of coal-fired power generation with hydrogen could accelerate the transition to a low-carbon power mix. Furthermore, while its share will decrease, its overall generation will be maintained; therefore, specific measures will be necessary to decarbonize Cambodia's power sector, and hydrogen power generation can be considered one such alternative. For hydrogen gas turbine power generation, the emission factor may vary with the co-firing ratio with natural gas; however, since the ultimate goal is a "hydrogen-only firing method" using hydrogen alone for power generation, this study set the emission factor for hydrogen power generation to zero.

Diesel is another power generation fuel that hydrogen could potentially replace, besides coal-fired power generation. Diesel power generation was one of Cambodia's primary power sources in the past; however, its projected share in 2050 is negligible (approximately 0.3%). It is required to serve as a power source or emergency power source in areas with insufficient power supply infrastructure, such as islands and mountainous regions; therefore, diesel was excluded from the hydrogen utilization scenarios.

Five scenarios were constructed to replace coal-fired power generation with hydrogen power, varying the share of replacement by 2050. It was assumed that the introduction would occur linearly, starting in 2041. The 2050 replacement share was set starting at 20% in the first scenario (PS1), increasing steadily until the final scenario (PS5) achieves 100% replacement of coal-fired power generation.

**Table 4-6** Hydrogen Utilization Scenarios for Cambodia's Power Sector

| Scenario Number | Description |
|---|---|
| PS1 | Hydrogen power replaces 20% of coal-fired power generation by 2050. |
| PS2 | Hydrogen power replaces 40% of coal-fired power generation by 2050. |
| PS3 | Hydrogen power replaces 60% of coal-fired power generation by 2050. |
| PS4 | Hydrogen power replaces 80% of coal-fired power generation by 2050. |
| PS5 | Hydrogen power replaces 100% of coal-fired power generation by 2050. |

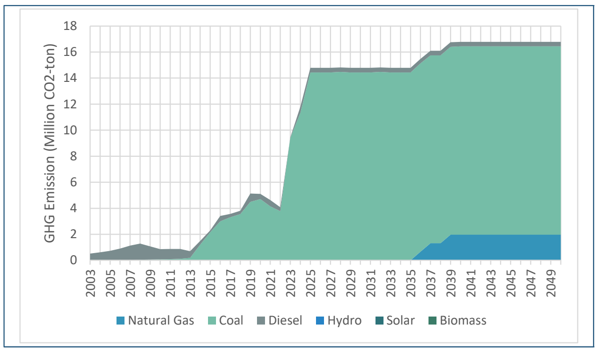
Source Author's compilation

## 4. Estimated Climate Benefits

### A. Estimation Results for Greenhouse Gas Emissions Baseline (BAU)

Based on the Kaya identity described above and the projected values for variables and emission factors, Figure 4-8 presents the estimated baseline (BAU) for GHG emissions in Cambodia's power generation sector. GHG emissions from Cambodia's power generation sector are projected to increase sharply starting in the mid-2020s, driven by the large-scale introduction of coal-fired power plants under the Power Development Masterplan, followed by a relatively gradual increase thereafter. Carbon dioxide emissions are projected to reach 14.8 million tons in 2030 and 16.8 million tons in 2050.[23]

**Figure 4-8.** Carbon Dioxide Emission Projections for Cambodia's Power Sector (BAU)




Source National Institute of Green Technology

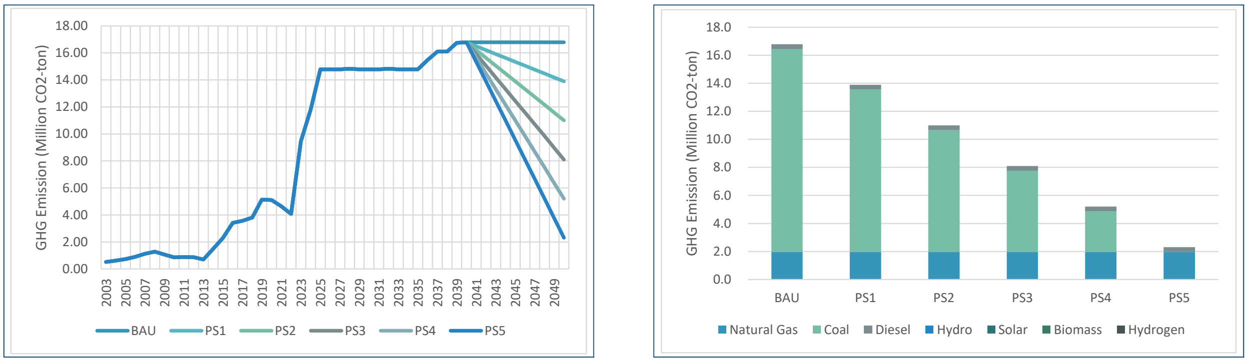
### B. Estimated Greenhouse Gas Reduction Quantities and Climate Benefits

Figure 4-9-(a) presents the $CO_2$ emission pathway for hydrogen utilization scenarios in Cambodia's power sector, while Figure 4-9-(b) illustrates the projected 2050 $CO_2$ emissions by fuel type for each scenario. As expected, GHG emissions decrease as the replacement rate of coal-fired power generation increases; when the

23 It was assumed that there would be no expansion of fossil fuel power generation from 2041 onwards, and only additional hydroelectric and solar power generation facilities would be constructed.

replacement rate reaches 100% (PS5), 2050 emissions would be 2.3 million tons, potentially returning to pre-2020s emission levels. If the replacement rate for coal-fired power generation is 80% (PS4), emissions in 2050 would decrease to 5.2 million tons, matching current GHG emissions levels.

**Figure 4-9**. Projected $CO_2$ Emissions by Scenario for Cambodia's Power Sector




(a) Emission Pathways by Scenario

(b) Emissions in 2050 by Scenario

Source National Institute of Green Technology

Based on the above emissions projection results, the $CO_2$ reduction effect achieved by using hydrogen in the power generation sector, along with the corresponding climate benefits, is shown in Table 4-7. Depending on the replacement rate of coal-fired power generation, GHG reductions ranged from 2.9 million to 14.5 million tons. The maximum reduction of 14.5 million tons (PS5) represents approximately 9.3% of the 155.6 million ton reduction projected for 2050 in Cambodia's Long-term Strategy for Carbon Neutrality report (Kingdom of Cambodia, 2021). When this reduction is converted into climate benefits by multiplying it by the social cost of GHG emissions of 480 USD per ton (Environmental Protection Agency, 2023), it is estimated to be approximately 6,949 USD million (27,797 billion KHR), equivalent to about 18% of 2024 GDP.

**Table 4-7** Greenhouse Gas Reduction and Climate Benefits from Hydrogen Utilization in the Power Generation Sector (2050)

| Scenario | Emissions (million tons of CO2) | Reduction (million tons of $CO_2$, %) | | Climate Benefit | |
|---|---|---|---|---|---|
| | Total | Amount | Rate | in KHR (billion) | in USD (million) |
| BAU | 16.8 | - | - | - | - |
| PS1 | 13.9 | 2.9 | 17.2 | 5,559 | 1,390 |
| PS2 | 11.0 | 5.8 | 34.5 | 11,119 | 2,780 |
| PS3 | 8.1 | 8.7 | 51.7 | 16,678 | 4,170 |
| PS4 | 5.2 | 11.6 | 69.0 | 22,238 | 5,559 |
| PS5 | 2.3 | 14.5 | 86.2 | 27,797 | 6,949 |

Note Exchange rate applied: 4,000 KHR/USD
Source National Institute of Green Technology

### C. Discussion on Related Cost

Market values have not been established for goods or services utilizing future technologies, and the availability of cost data is insufficient, limiting the ability to perform cost–benefit analysis. Nevertheless, this study conducted a simplified cost–benefit analysis for the first scenario (PS1) in the power generation sector, estimating costs using a simplified approach; however, these results are for reference only, and more rigorous estimates are required to determine the actual economic feasibility.

For hydrogen gas turbine power generation, the technology is insufficiently mature. Moreover, cases of power generation using only hydrogen (hydrogen–only power generation) are rare, creating challenges when estimating its capital cost; however, some economic feasibility studies adjust the cost based on the capital cost of existing natural gas–based gas turbine power generation, taking technical difficulties into account. Accordingly, this study also assumes that the cost of hydrogen gas turbine power generation increases by approximately 50% compared to natural gas turbine power generation. Using the capital cost of natural gas turbine power generation at 900 million KRW per MW (approximately 600,000 USD) (Cho and Park, 2015) as a benchmark, the capital cost of hydrogen power generation facilities is estimated at 900,000 USD per MW.

Furthermore, the required hydrogen power generation capacity for the scenario (PS1) must be determined to calculate the total capital cost rather than the unit capital cost. Assuming hydrogen power generation replaces coal power generation in the scenario, and a 40% utilization rate for the hydrogen power generation facilities, the required capacity for 2050 is approximately 688 MW. Therefore, the capital cost of the hydrogen power generation facilities required to replace coal–fired power in 2050 under Scenario PS1 is approximately 623 million USD. For simplicity of analysis, this facility cost is assumed to be incurred entirely by the end of 2040, implying that the utilization rate increases annually.

Regarding the operating expenses (OPEX) of hydrogen power generation, Cho and Park (2015) assumed that the cost of 33.36 million KRW per MW (approximately 22,240 USD) used to calculate the cost of natural gas turbine power generation would also apply to hydrogen power generation.

Assuming a hydrogen power generation efficiency of 60%, 50 tons of hydrogen are required per 1 GWh of power generation (Lee, 2022). The unit hydrogen cost can be calculated by multiplying this hydrogen consumption by the hydrogen price of 5 USD per kg; this price was used by the IEA (2020) in its scenario analysis (based on the delivered hydrogen price for transport vehicles). In estimating the climate benefits, this study calculated the annual coal–fired power generation replaced by hydrogen power generation; therefore, the annual total hydrogen cost can also be calculated by multiplying the annual hydrogen power generation by the unit hydrogen cost.

**Table 4–8** Simple Cost–Benefit Flows for PS1

| End of Year | CAPEX (million dollar) | OPEX (million dollar) | Hydrogen Cost (million dollar) | Climate benefit (Million dollar) |
|---|---|---|---|---|
| 2040 | 623.56 | | | |
| 2041 | | 15.29 | 60.23 | 138.99 |
| 2042 | | 15.29 | 120.47 | 277.97 |
| 2043 | | 15.29 | 180.70 | 416.96 |
| 2044 | | 15.29 | 240.94 | 555.95 |
| 2045 | | 15.29 | 301.17 | 694.93 |
| 2046 | | 15.29 | 361.41 | 833.92 |
| 2047 | | 15.29 | 421.64 | 972.91 |
| 2048 | | 15.29 | 481.88 | 1,111.89 |
| 2049 | | 15.29 | 542.11 | 1,250.88 |
| 2050 | | 15.29 | 602.34 | 1,389.87 |

Source National Institute of Green Technology

Based on the above costs, conducting a cost-benefit analysis from 2041 to 2050 yields a net present value (NPV) of 1,570 million USD for 2040 under a 10% social discount rate; when discounted back to the end of 2025, this is estimated to be approximately 376 million USD. The economic lifespan of typical large-scale power generation facilities, such as gas turbine power plants, is generally longer than 10 years; therefore, extending the analysis period within this cost-benefit analysis framework is likely to increase the NPV.

However, as mentioned, the above analysis was simplified using minimal cost data; it does not include costs associated with hydrogen production required to operate the hydrogen gas turbine power generation, costs associated with supplying hydrogen to the power plant, or costs incurred in supplying electricity generated by the hydrogen gas turbine power generation. Furthermore, the costs associated with decommissioning existing coal-fired power generation facilities were also not considered. The limitation is that only climate benefits were reflected among the benefits that hydrogen utilization in the power generation sector would bring; however, in reality, additional economic gains or environmental benefits will likely occur.

## Section 3. Road Transport Sector

### 1. Identity Equation

This study adjusted the Kaya identity to reflect the characteristics of the road transport sector (Equation 4-3). Similar to the identity for the power generation sector, it was adjusted to reflect the road transport sector's fuel consumption characteristics. C represents the total GHG (carbon dioxide) emissions from Cambodia's road transport sector, and $C_i$ denotes the GHG emissions from fuel i in that sector. $E_i$ and $V_i$ represent the fuel consumption of type i in the road transport sector and the number of vehicles consuming that fuel, respectively. V denotes the total number of vehicles. Finally, G and P denote GDP and population, respectively, as in the power generation sector's identity.

$$C = \Sigma C_i/E_i \times E_i/V_i \times V_i/V \times V/G \times G/P \times P$$

(Equation 4-3)

As shown on the right-hand side of Equation 4-3, GHG emissions from the road transport sector are broken down into six factors. The first factor is the GHG intensity factor ($C_i/E_i$) (identical to that in the power generation sector), representing the GHG emission coefficient per fuel type for vehicles. The second factor is the fuel consumption factor by vehicle type ($E_i/V_i$); this factor represents the average amount of fuel i consumed per vehicle using fuel i. All other conditions being equal, an increase in fuel consumption per vehicle increases GHG emissions. The third factor is the fuel composition factor ($V_i/V$), calculated as the number of vehicles consuming fuel i (out of the total number of vehicles in the road transport sector). If the proportion of vehicles consuming fossil fuels increases, GHG emissions from the road transport sector will rise; conversely, if the proportion of electric or hydrogen vehicles increases, emissions will decrease. The fourth factor is the vehicle intensity factor (V/G), defined as the number of vehicles per unit of GDP, indicating whether the number of vehicles is high or low relative to the economy's size. The fifth and sixth factors are the economic scale factor (G/P) and the population factor (P). As in the power generation sector, if a country has a large economy or population, vehicle purchases and operations are expected to expand, leading to increased GHG emissions from the road transport sector.

### 2. Data

To project the baseline GHG emissions (BAU) for Cambodia's road transport sector and the expected

GHG reduction achievable through hydrogen utilization in this sector, the data construction methodology and the results of this study are presented as follows.

### A. Carbon Intensity Factor

The carbon intensity factor ($C_i/E_i$) represents the GHG emission factor per vehicle fuel. This study used the carbon dioxide emission factors for mobile combustion from the IPCC's Guidelines for National GHG Inventories, assuming these factors will not change significantly until 2050. According to MoME (2022b), the road transport sector in Cambodia primarily consumes gasoline, diesel, and LPG. The $CO_2$ emission factors for these fuels are provided by the IPCC (Table 4-9).

**Table 4-9** Emission Factors for Cambodia's Road Transport Sector

| Fuel (MoME, 2022) | Representative Fuel (IPCC 2006 Guideline) | $CO_2$ Emission factor (IPCC 2006 Guideline) |
|---|---|---|
| Gasoline | Motor Gasoline | 69,300 $kgCO_2/TJ$ |
| Diesel | Gas/Diesel oil | 74,100 $kgCO_2/TJ$ |
| LPG | Liquefied petroleum gas | 63,100 $kgCO_2/TJ$ |

Source IPCC (2006)

### B. Fuel Consumption Factors by Vehicle Type

Fuel consumption factors by vehicle type (Ei/Vi) represent the average annual fuel consumption per vehicle consuming a specific fuel type i. This information utilizes values from the MoME (2021) Cambodia Petroleum Master Plan 2022-2040, which were employed to estimate the number of vehicles per fuel type based on fuel consumption data. According to MoME (2021), the 2018 consumption volumes for gasoline, diesel, and LPG in the road transport sector were 812,896, 1,133,255 kl, and 87,409 tons, respectively. The corresponding numbers of gasoline, diesel, and LPG vehicles were 1,476,344, 94,459, and 35,704 units, respectively.[24] Based on this, the average fuel consumption per vehicle type (fuel consumption factor per vehicle type) can be calculated, with the results shown in Table 4-10.[25]

This study assumes that the fuel consumption factors ($E_i/V_i$) by vehicle type in 2018 remained constant throughout the analysis period. This assumption is identical to that used by MoME (2021) when estimating road transport sector fuel demand for 2040; however, these factors may change over the long term. Long-term improvements in vehicle fuel efficiency could reduce the fuel consumption factor per vehicle type. Simultaneously, economic development may alter vehicle usage patterns and increase leisure travel, potentially raising fuel consumption per vehicle; however, as statistical data on the number of vehicles registered by fuel type is currently unavailable in Cambodia, it has been difficult to observe changes in fuel consumption by vehicle type to date. Consequently, it was assumed to be constant over the long term.

24 MoME (2021) estimated the number of vehicles per fuel type using the average gasoline, diesel, and LPG consumption per vehicle surveyed in the plan and the energy balance table. According to the Statistical Yearbook of Cambodia 2021, published by the National Institute of Statistics and the Ministry of Planning (2021), annual registrations by vehicle type (tourism cars, minibuses, trucks, trailers, motorcycles) are provided. However, the number of vehicles by fuel type is not.

25 Since motorcycles typically consume gasoline, it is judged that the fuel consumption per gasoline vehicle used by MoME (2021) likely included a mix of fuel consumption patterns from gasoline passenger cars and motorcycles; therefore, the estimated number of gasoline vehicles based on this data cannot be taken as the sum of gasoline passenger cars and motorcycles.

**Table 4-10** Fuel Consumption Factors by Vehicle Type in Cambodia's Road Transport Sector

| Fuel | Fuel Consumption | Estimated Number of Vehicles | Fuel Consumption per Vehicle | | |
|---|---|---|---|---|---|
| | | | Original | TJ/unit | TOE/unit |
| Gasoline | 812,896 kl | 1,476,344 units | 0.5506 kl/unit | 0.0181 | 0.4312 |
| Diesel | 1,133,255 kl | 94,459 units | 11.9973 kl/unit | 0.4490 | 10.7238 |
| LPG | 87,409 tons | 35,704 units | 2.4482 tons/unit | 0.1158 | 2.7658 |

Note The mass-to-volume ratios for gasoline and diesel are applied as 1,351 and 1,149 l/ton, respectively. The mass-to-energy ratios for gasoline, diesel, and LPG are applied as 44.3, 43.0, and 47.3 GJ/ton for conversion. The TOE conversion factor applied is 41.868 GJ/TOE.

Source MoME (2021)

**C. Fuel Composition Factor**

The fuel composition factor ($V_i/V$) is calculated by dividing the number of vehicles by fuel type by the total number of vehicles; however, as official statistics on vehicle numbers by fuel type in Cambodia are difficult to verify, separate estimates are required. Therefore, following the methodology of MoME (2021), this study estimated the number of vehicles per fuel type using average fuel consumption per vehicle type and fuel consumption data by fuel type in the road transport sector.

The average fuel consumption by vehicle type is presented in Table 4-10, and fuel consumption by type in the road transport sector is shown in the MoME (2022b) energy balance. The MoME (2022b) energy balance provides fuel consumption in the road transport sector from 2000 to 2019 in kTOE units; fuel types consumed up to 2019 are limited to gasoline, diesel, LPG, and other petroleum products (Table 4-11).

Dividing the fuel consumption by type in Cambodia's road transport sector by the average fuel consumption per vehicle type (fuel consumption factor by vehicle type) allows the calculation of the number of vehicles per fuel type for each year. Table 4-11 presents the results; other petroleum products were excluded because the fuel type is unclear, and the average fuel consumption data needed to calculate the number of vehicles are unavailable.

Table 4-11 Fuel Consumption and Number of Vehicles by Fuel Type in Cambodia's Road Transport Sector

| Year | Energy Consumption (kTOE) | | | | Number of Vehicles (Unit) | | | |
|---|---|---|---|---|---|---|---|---|
| | Gasoline | Diesel | LPG | Other | Gasoline | Diesel | LPG | Sum |
| 2000 | 125 | 281 | - | 3 | 289,865 | 26,203 | - | 316,069 |
| 2001 | 126 | 344 | - | 3 | 292,184 | 32,078 | - | 324,262 |
| 2002 | 122 | 270 | - | 3 | 282,909 | 25,178 | - | 308,086 |
| 2003 | 108 | 271 | - | 5 | 250,444 | 25,271 | - | 275,715 |
| 2004 | 101 | 267 | - | 6 | 234,211 | 24,898 | - | 259,109 |
| 2005 | 135 | 188 | - | 7 | 313,055 | 17,531 | - | 330,586 |
| 2006 | 166 | 246 | 15 | 7 | 384,941 | 22,940 | 5,423 | 413,304 |
| 2007 | 249 | 245 | 18 | 11 | 577,412 | 22,846 | 6,508 | 606,766 |
| 2008 | 306 | 196 | 16 | 12 | 709,591 | 18,277 | 5,785 | 733,653 |
| 2009 | 327 | 429 | 22 | 17 | 758,288 | 40,004 | 7,954 | 806,247 |
| 2010 | 401 | 543 | 25 | 16 | 929,888 | 50,635 | 9,039 | 989,562 |
| 2011 | 416 | 580 | 27 | 17 | 964,672 | 54,085 | 9,762 | 1,028,519 |
| 2012 | 405 | 638 | 32 | 17 | 939,164 | 59,494 | 11,570 | 1,010,228 |
| 2013 | 409 | 652 | 38 | 18 | 948,440 | 60,799 | 13,739 | 1,022,978 |
| 2014 | 446 | 713 | 43 | 11 | 1,034,240 | 66,487 | 15,547 | 1,116,274 |
| 2015 | 530 | 769 | 62 | 20 | 1,229,029 | 71,709 | 22,417 | 1,323,156 |
| 2016 | 536 | 863 | 74 | 24 | 1,242,943 | 80,475 | 26,756 | 1,350,173 |
| 2017 | 587 | 886 | 85 | 12 | 1,361,208 | 82,620 | 30,733 | 1,474,560 |
| 2018 | 633 | 952 | 103 | 11 | 1,467,879 | 88,774 | 37,241 | 1,593,893 |
| 2019 | 758 | 1133 | 130 | 13 | 1,757,744 | 105,652 | 47,003 | 1,910,399 |

Source MoME (2021), MoME (2022b)

The number of vehicles by fuel type from 2020 onwards can be projected by calculating the average annual growth rate based on the estimated vehicle numbers for 2018 and 2040 from MoME (2021); that growth rate is then applied to the 2019 estimates in Table 4-11. The 2018 fuel-type vehicle counts presented by MoME (2021) are as described in Table 4-10. Assuming the same fuel consumption patterns continue, the vehicle counts based on MoME (2021)'s projected 2040 fuel consumption[26] are 4,449,249 gasoline vehicles, 377,899 diesel vehicles, and 70,771 LPG vehicles. Using vehicle counts by fuel type for these 2 years, the

26 MoME (2021) projected 2040 road transport fuel consumption as follows: gasoline 2,449,820kl, diesel 4,533,775kl, LPG 173,258 tons.

average annual growth rates are 5.1% for gasoline vehicles, 6.5% for diesel vehicles, and 3.2% for LPG vehicles. Assuming these growth rates remain constant until 2050, the number of vehicles for each fuel type will increase steadily at these respective rates.

However, before fully projecting vehicle numbers by fuel type, it is necessary to account for the increase in EVs. Although this is not reflected in the MoME literature (2021, 2022b), press releases from the Ministry of Public Works and Transport (MoPWT) confirm that EVs have recently been registered in Cambodia. Therefore, incorporating EV growth would allow for a more objective estimate of the baseline GHG emissions (BAU).

**Table 4-12** Electric Vehicle Adoption Outlook for Cambodia's Road Transport Sector

| year | Electric Motorcycle (%) | Electric Car (%) | Electric Heavy Vehicle (%) |
|---|---|---|---|
| 2020 | 0 | 0 | 0 |
| 2025 | 0 | 0 | 0 |
| 2030 | 2 | 1 | 0 |
| 2035 | 7 | 4 | 0 |
| 2040 | 20 | 11 | 1 |
| 2045 | 31 | 18 | 1 |
| 2050 | 40 | 24 | 2 |

Note This refers to the proportion of electric vehicles within the total vehicle stock.
Source MoPWT (2023)

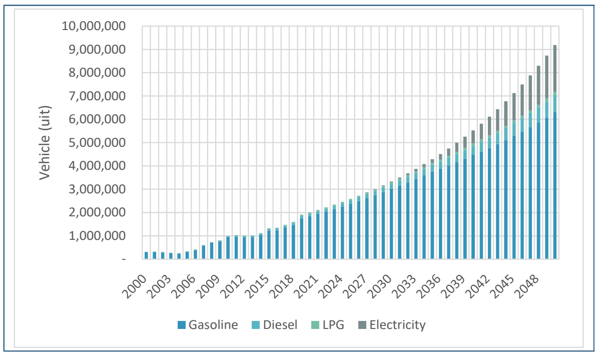
However, the challenge lies in incorporating projected EV growth into the forecast when no relevant statistics are available. EV registrations have occurred only recently; thus, assuming the growth rate from this period will persist until 2050 would be unreasonable. Consequently, this study proposes to use the EV penetration ratio presented in MoPWT (2023)'s Roadmap for the Development of an EV Charging Station Network in Cambodia. According to Scenario EV2 in MoPWT (2023), 1% of conventional vehicles are projected to be electrified by 2030 and 24% by 2050. Heavy vehicles are expected to be adopted more slowly, with only 2% of the total vehicle fleet being electric by 2050 (Table 4-12).

This study utilized MoPWT (2023) data and assumed that gasoline vehicles would be replaced as electric cars became more prevalent, and diesel vehicles would be replaced as electric heavy vehicles became increasingly widespread.[27] Specifically, the number of gasoline, diesel, and LPG vehicles was projected using the average annual growth rate based on MoME (2021). The adoption rate of EVs was then subtracted from the number of gasoline and diesel vehicles for each year, and the resulting reduced number of vehicles was calculated as the number of EVs. Table 4-12 shows that MoPWT (2023) does not provide EV adoption rate information for all years; linear interpolation based on the adoption rate figures from the two closest preceding and following years was used for years without data.

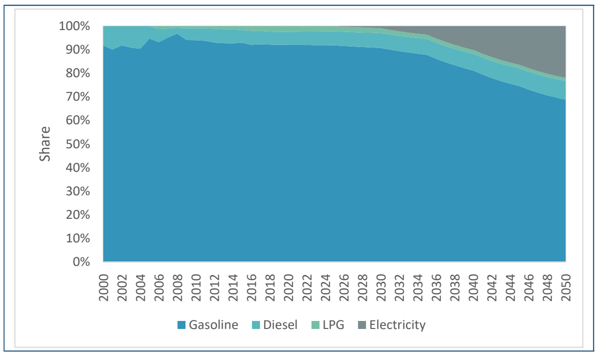
Finally, reflecting the annual average growth rates for gasoline, diesel, and LPG vehicles while considering EV adoption, Figure 4-10-(a) illustrates the projected number of vehicles by fuel type. The projected fuel share (fuel composition factor) derived from this result is shown in Figure 4-10 (b).

27 The vehicle classifications used by MoPWT (2023) and MoME (2021) do not align, making it difficult to determine the replacement ratio of gasoline vehicles by electric motorcycles and electric cars. This study utilized the adoption rate of electric cars, which appears to be relatively conservative.

**Figure 4-10** Projected Number of Vehicles by Fuel Type and Fuel Mix Factor in Cambodia




(a) Projected Vehicle Numbers by Fuel Type



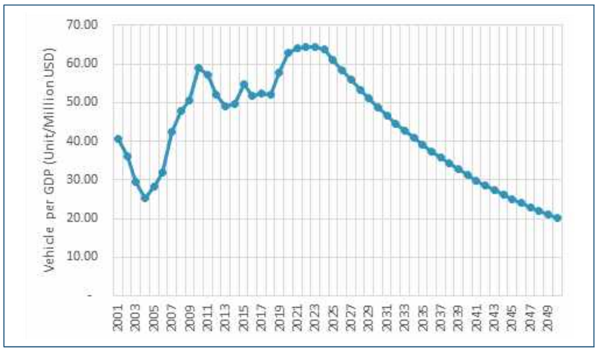

(b) Projected Fuel Composition Factors (Vehicle Share by Fuel Type)

Source MoPWT (2023), MoME (2021), MoME (2022b)

### D. Vehicle Intensity Factor

The vehicle intensity factor (V/G) is calculated by dividing the sum of the estimated vehicle numbers by fuel type from the fuel composition factor by Cambodia's GDP. Consistent with the methodology for estimating GHG emissions from the power sector, Cambodia's GDP was estimated using World Bank data. It was assumed to grow steadily at a constant rate of 6.02% during the analysis period, based on the 2024 GDP growth rate. Figure 4-11 presents the projected values for the vehicle intensity factor.

**Figure 4-11** Projected Vehicle Intensity Factor for Cambodia




Source MoPWT (2023), MoME (2021), MoME (2022b), World Bank

### E. Economic Scale Factor and Population Factor

The economic scale factor (G/P) and population factor (P) for the road transport sector are defined using the same variables as those for the power generation sector; therefore, the same projections used for the power generation sector were applied (Figure 4-7).

## 3. Hydrogen Utilization Scenarios

In Cambodia's road transport sector, it was assumed that diesel vehicles would be replaced with hydrogen vehicles. Although diesel vehicles currently do not constitute a large share of Cambodia's road transport sector, they are characterized by high GHG emission factors per unit of fuel (74,100 kg-$CO_2$/TJ) and high average energy consumption (0.4490 TJ/unit), and are used in medium- and heavy-duty commercial vehicles such as trucks and buses. Furthermore, the MoPWT (2023) EV Charging Stations Network Roadmap assumes a low penetration rate for large commercial EVs, which implies a need for complementary measures to decarbonize the road transport sector. Consequently, this study assumes that replacing diesel vehicles with hydrogen vehicles reduces GHG emissions in the road transport sector, and sets the GHG emission factor for hydrogen vehicles within the road transport sector boundary as zero.

Five scenarios were constructed for replacing diesel vehicles with hydrogen vehicles in 2050, assuming a linear introduction starting in 2031. This approach represents an introduction beginning 10 years before hydrogen power generation in the power generation sector, reflecting an early adoption assumption considering currently commercialized hydrogen vehicles. The 2050 replacement share starts at 20% in the first scenario (RS1) and increases steadily, reaching 100% in the final scenario (RS5) (Table 4-13).

**Table 4-13** Hydrogen Utilization Scenarios for Cambodia's Road Transport Sector

| Scenario Number | Description |
|---|---|
| PS1 | Hydrogen cars replace 20% of diesel cars by 2050. |
| PS2 | Hydrogen cars replace 40% of diesel cars by 2050. |
| PS3 | Hydrogen cars replace 60% of diesel cars by 2050. |
| PS4 | Hydrogen cars replace 80% of diesel cars by 2050. |
| PS5 | Hydrogen cars replace 100% of diesel cars by 2050. |

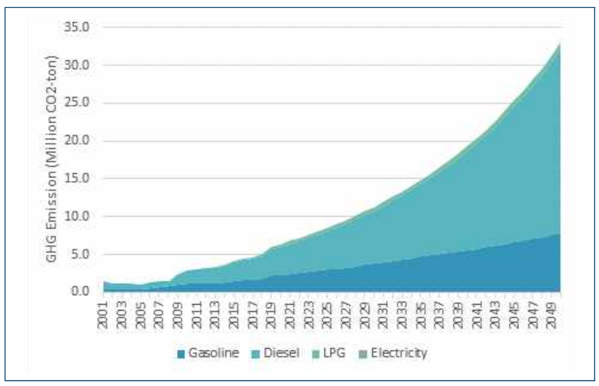
Source National Institute of Green Technology

## 4. Estimated Climate Benefits

### A. Estimation Results for Greenhouse Gas Emissions Baseline (BAU)

The results of estimating baseline GHG emissions (BAU) for Cambodia's road transport sector, based on the Kaya identity and projected values for variables and emission factors, are shown in Figure 4-12. GHG emissions from Cambodia's road transport sector are projected to increase steadily as vehicle proliferation continues, with diesel vehicles expected to contribute significantly to emissions (Figure 4-12). Cambodia's road transport sector GHG emissions are projected to increase approximately threefold, from 11.3 million tons in 2030 to 33.1 million tons in 2050. By 2050, diesel vehicle emissions are projected to reach 24.3 million tons, accounting for approximately 73% of total $CO_2$ emissions.

**Figure 4-12** Projected Carbon Dioxide Emissions from Cambodia's Road Transport Sector (BAU)

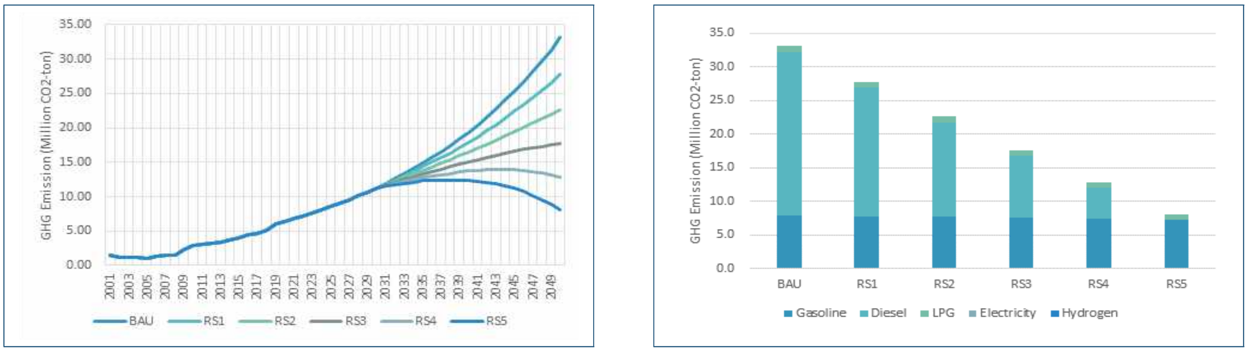



Source National Institute of Green Technology

### B. Estimated Greenhouse Gas Reduction and Climate Benefits

Figure 4-13-(a) presents the $CO_2$ emission pathway for hydrogen utilization scenarios in Cambodia's road transport sector. Figure 4-13-(b) illustrates the projected 2050 $CO_2$ emissions by fuel type for each scenario. The higher the proportion of diesel vehicles replaced, the steeper the projected decrease in GHG emissions. In the case of 100% diesel vehicle replacement (RS5), emissions in 2050 are projected to decrease to 8.11 million tons. This emission level is similar to that around 2025; thus, the current level of GHG emissions can be maintained only by replacing all diesel vehicles with hydrogen vehicles.

**Figure 4–13** Projected $CO_2$ Emissions by Scenario for Cambodia's Road Transport Sector




(a) Emission Pathways by Scenario (b) Emissions in 2050 by Scenario

**Source** National Institute of Green Technology

Based on the above emissions projections, the CO2 reduction and corresponding climate benefits from introducing hydrogen into the road transport sector are calculated (Table 4–14). GHG reductions ranged from 5.3 million tons to 25.0 million tons, depending on the diesel vehicle replacement rate. The maximum reduction of 25.0 million tons (RS5) represents approximately 16.1% of the 2050 reduction target of 155.6 million tons projected in Cambodia's Long-term Strategy for Carbon Neutrality report (Kingdom of Cambodia, 2021). Multiplying the reduction amount in the final scenario by the social cost of GHG emissions (480 USD per ton, Environmental Protection Agency, 2023) yields a monetary value of approximately 48,002 million USD (12,000 billion KHR), which represents about 31% of the 2024 GDP.

**Table 4–14** Greenhouse Gas Reduction and Climate Benefits from Hydrogen Use in the Road Transport Sector (2050)

| Scenario | Emissions (million tons of $CO_2$) | Reduction (million tons of $CO_2$, %) | | Climate Benefit | |
|---|---|---|---|---|---|
| | Total | Amount | Rate | in KHR (billion) | in USD (million) |
| BAU | 33.1 | – | – | – | – |
| RS1 | 27.8 | 5.3 | 16.0 | 10,194 | 2,548 |
| RS2 | 22.6 | 10.5 | 31.6 | 20,091 | 5,023 |
| RS3 | 17.6 | 15.5 | 46.7 | 29,691 | 7,423 |
| RS4 | 12.8 | 20.3 | 61.3 | 38,995 | 9,749 |
| RS5 | 8.1 | 25.0 | 75.5 | 48,002 | 12,000 |

**Note** Exchange rate applied: 4,000 KHR/USD
**Source** National Institute of Green Technology

### C. Discussion on Related Cost

As in hydrogen gas turbine power generation in the power sector, the road transport sector also involves future technologies; however, compared to the power sector, it is relatively mature, with some technologies already commercialized. Nevertheless, hydrogen vehicles have been deployed primarily in countries such as South Korea, China, and Japan, making it difficult to definitively state the technical specifications and costs they would be deployed with in Cambodia. Accordingly, this study conducted a simplified cost-benefit analysis for the first scenario (RS1) based on the cost data used by the IEA (2020) to forecast the hydrogen sector. Like the power generation sector, the results of this analysis are for reference only—a more rigorous analysis is required to assess economic viability from a national perspective.

This study assumes that hydrogen utilization in the road transport sector occurs by replacing diesel vehicles, primarily heavy vehicles; therefore, the cumulative number of hydrogen vehicles deployed equals the cumulative reduction in diesel vehicles, and the number of new hydrogen vehicles deployed annually can be calculated as the annual increase in cumulative deployment. The power of the hydrogen vehicle is set to 350 kW, the value for trucks presented by the IEA (2020). Assuming this power is entirely supplied by the fuel cell capacity, multiplying by the fuel cell price (95 dollars/kW, long-term forecast for trucks) yields the price of the fuel cell that should be included in one hydrogen vehicle (33,250 USD/vehicle). Assuming the fuel cell accounts for approximately 30% of the hydrogen vehicle's price, [28] the hydrogen vehicle's price can be estimated at approximately 110,833 USD per vehicle. However, for cost-benefit analysis, only the incremental cost of choosing a hydrogen vehicle over a diesel vehicle is considered. Assuming a diesel vehicle with the same specifications costs half as much, the additional purchase cost of a hydrogen vehicle is USD 55,417 per vehicle. This cost is considered to occur at the end of the year preceding its deployment (for hydrogen vehicles deployed in 2031, the purchase cost occurs at the end of 2030). Furthermore, the disposal and salvage value of hydrogen vehicles are not considered for analytical convenience.

The operating cost of hydrogen vehicles is calculated based solely on hydrogen fuel costs. The annual mileage of hydrogen vehicles is required to estimate the cost of consumed hydrogen fuel. This information is assumed to be 100,000 km, as presented by the IEA (2020), consistent with the previous figure. Hydrogen consumption is 7.8 MJ per km (IEA, 2020), and hydrogen has a net calorific value of 120 MJ per kg; thus, the hydrogen consumption per vehicle is estimated at approximately 6,500 kg per year. This annual hydrogen consumption can be multiplied by the number of hydrogen vehicles to calculate total consumption; the number of hydrogen vehicles should be the cumulative total, not the number of new hydrogen vehicles supplied annually. Similarly, hydrogen fuel costs are measured as the incremental cost relative to diesel fuel use. Assuming a fuel efficiency of 4 km per liter, a heavy-duty diesel vehicle consumes 25,000 liters of diesel annually; at USD 1 per liter, the corresponding fuel cost can be calculated.

28 Fuel cells currently account for about 50% of the cost of hydrogen vehicles, and the IEA (2020) reports a current price of 250 USD per kW.

**Table 4-15** Simple Cost-Benefit Flows for RS1

| End of Year | CAPEX (million dollar, incremental cost) | Hydrogen Cost (million dollar, incremental cost) | Climate benefit (Million dollar) |
|---|---|---|---|
| 2030 | 124.73 | | |
| 2031 | 140.95 | 16.88 | 39.60 |
| 2032 | 158.76 | 35.96 | 84.34 |
| 2033 | 178.29 | 57.44 | 134.72 |
| 2034 | 199.69 | 81.57 | 191.28 |
| 2035 | 220.48 | 108.60 | 254.62 |
| 2036 | 245.23 | 138.44 | 324.37 |
| 2037 | 272.38 | 171.63 | 401.89 |
| 2038 | 302.11 | 208.49 | 487.94 |
| 2039 | 334.66 | 249.38 | 583.35 |
| 2040 | 373.31 | 294.67 | 688.99 |
| 2041 | 412.76 | 345.19 | 806.66 |
| 2042 | 455.79 | 401.06 | 936.71 |
| 2043 | 502.70 | 462.74 | 1,080.28 |
| 2044 | 553.81 | 530.78 | 1,238.60 |
| 2045 | 595.27 | 605.73 | 1,412.97 |
| 2046 | 654.06 | 686.29 | 1,599.78 |
| 2047 | 718.18 | 774.81 | 1,804.99 |
| 2048 | 788.04 | 872.01 | 2,030.28 |
| 2049 | 864.13 | 978.66 | 2,277.45 |
| 2050 | | 1,095.61 | 2,548.47 |

Source National Institute of Green Technology

Based on the above costs, a cost-benefit analysis conducted for the period from 2031 to 2050 indicates that the NPV at the end of 2030 is estimated to be 74 million USD under a 10% social discount rate. When converted to the end of 2025, it is estimated to be approximately 45 million USD, indicating a net benefit. Despite the greenhouse gas mitigation potential in the transport sector, the primary reason why the estimated benefits are lower than those in the power generation sector is identified as the burden of hydrogen fuel costs arising from the accumulation of hydrogen vehicles, Although hydrogen vehicle purchases around 2050 will continue operating beyond 2050, generating GHG-reduction effects, the net effect may be limited by hydrogen fuel costs. Therefore, this result suggests that policies to subsidize or reduce hydrogen fuel costs are necessary to support its use in the road transport sector.

However, the above analysis was conducted using limited data and focused only on the purchase and operation of hydrogen vehicles, thereby limiting its scope. That is, from the perspective of the entire nation, the costs of hydrogen production and the deployment of hydrogen refueling stations also represent a net increase that must be appropriately reflected. Furthermore, the analysis results may vary depending on factors such as the air pollution reduction benefits from replacing diesel vehicles.

## Section 4. Comprehensive Comparison

Table 4-16 summarizes the estimated GHG reduction effects and climate benefits achievable through hydrogen utilization in the power generation and road transport sectors selected for study in Cambodia. Based on the first hydrogen utilization scenario for each economic sector (replacing 20% of fossil fuels by 2050), the GHG reduction in the road transport sector is greater than that in the power generation sector. Consequently, greater climate benefits are also expected. This outcome appears partly attributable to the assumption that Cambodia meets approximately 40% of its electricity demand through imports and, starting in 2041, satisfies the remaining demand with hydropower and solar power, without installing additional fossil-fuel power generation facilities. [29] Furthermore, based on the GHG reduction rate, the power generation sector showed the largest reduction.

Combining the GHG reduction effects from hydrogen utilization in both the power generation and road transport sectors totals 8.2 million tons (based on the first scenario); this figure represents a reduction of approximately 16.4% compared to 2050 BAU emissions. Converted into climate benefits, this amounts to 15,733 billion KHR (3,938 million USD), approximately 10.2% of Cambodia's 2024 GDP.

**Table 4-16** Greenhouse Gas Reduction and Climate Benefits from Hydrogen Utilization by Economic Sector (2050)

| | | Power | Road transport | Total |
|---|---|---|---|---|
| BAU emissions (million tons of $CO_2$) | | 16.8 | 33.1 | 49.9 |
| Replacement | | coal-fired power generation | diesel vehicle | - |
| Comparison Scenario | | PS1 | RS1 | - |
| Reduction (million tons of $CO_2$, %) | Amount | 2.9 | 5.3 | 8.2 |
| | Rate | 17.2 | 16.0 | 16.4 |
| Climate benefit | in KHR (billion) | 5,559 | 10,194 | 15,733 |
| | in USD (million) | 1,390 | 2,548 | 3,938 |

Note Exchange rate applied: 4,000 KHR/USD
Source National Institute of Green Technology

29 According to Cambodia's Power Development Masterplan, there are no plans for additional large-scale coal-fired power plant installations beyond the 2020s until 2040.

Chapter 5.

# Introduction to Hydrogen Supply Technologies[30]

Hydrogen supply technologies refer to those applied until hydrogen reaches its point of use, encompassing hydrogen production, storage, and transportation technologies. Hydrogen is classified by color based on the feedstock and process used in production. Representative examples include blue hydrogen, produced via steam methane reforming (SMR)[31] combined with carbon dioxide capture; green hydrogen, produced through water electrolysis using renewable electricity; and pink hydrogen, produced through water electrolysis using electricity and thermal energy from nuclear power generation. Hydrogen storage is broadly categorized by state: gas, liquid, or solid. Gas storage refers to storing hydrogen as high-pressure gaseous hydrogen, while solid storage involves technologies that store hydrogen within solid metal compounds (metal hydrides) or porous metal-organic frameworks. Hydrogen stored in gas or solid form is transported as gaseous hydrogen during transit. Liquid-state storage is divided into liquefied hydrogen, where hydrogen is liquefied, and liquid compounds where hydrogen is combined with other elements, such as ammonia,

30 Based on NIGT (2024). National Institute of Green Technology (2024) Carbon Neutrality Technology White Paper: Hydrogen Supply Sector.

31 Natural Gas Reforming (Steam Methane Reforming): This process uses a catalytic reaction to convert natural gas, primarily composed of methane, into a gas containing hydrogen, with carbon dioxide generated as a byproduct.

methylcyclohexane, and methanol. Hydrogen transportation employs various methods depending on the state of hydrogen and the distance traveled, including tube trailers, tank trucks, pipelines, and maritime transport. Given the existence of diverse production, storage, and transportation methods, it is crucial to apply the optimal technology by considering factors such as geographical characteristics, economic viability, environmental impact, efficiency, and safety.

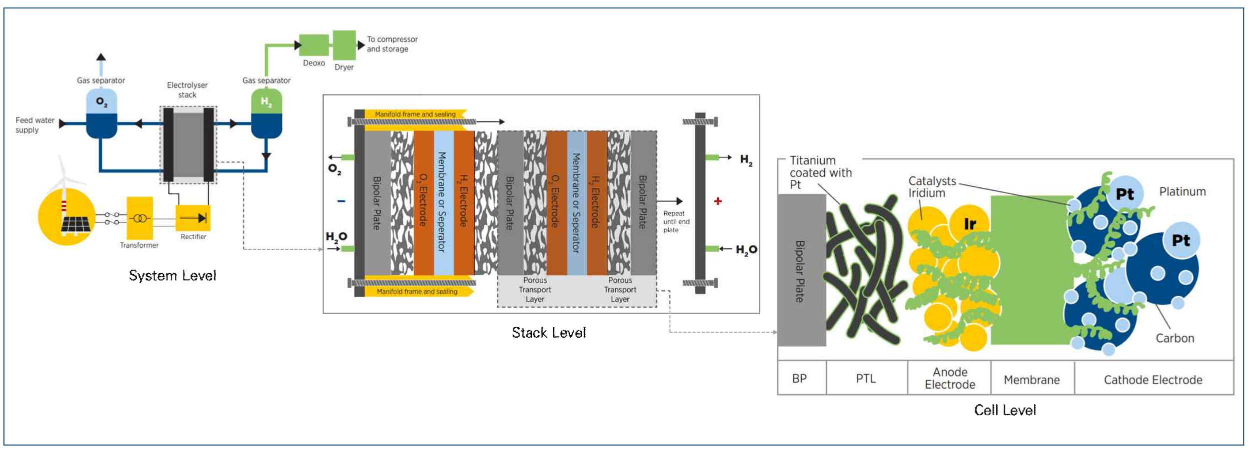
## Section 1. Hydrogen Production Technologies

Hydrogen production methods include thermochemical hydrogen production technologies such as steam reforming (SR), catalytic decomposition of methane (CDM), and hydrogen production via biomass gasification. These methods produce blue hydrogen based on natural gas, methane, or biomass. In contrast, electrolytic hydrogen production technology, an electrochemical hydrogen production method, produces green hydrogen based on renewable energy. This section introduces electrolysis technology, a representative method for producing green hydrogen[32].

Hydrogen production via electrolysis is achieved through an electrochemical reaction that uses electrical energy to decompose water ($H_2O$) into hydrogen ($H_2$) and oxygen ($O_2$). This process is based on the materials composing the electrolytic cell and the electrodes.

Electrolyzer systems are classified and named based on the reactions occurring and the ions moving through the electrolyte. An electrolyzer system consists of a stack formed by stacking single cells where reactions occur, equipment for supplying reactants (water or steam) and collecting the generated gas, and equipment supplying power to the electrolyzer system. A single cell consists of two electrodes (anode and cathode) where the reaction occurs, an electrolyte enabling ion exchange between the two electrodes, pathways for the internal and external movement of reactants and products, and a separator plate (bipolar plate) that blocks gas exchange between cells and connects them in series to allow current flow.

**Figure 5-1** Basic Components of an Electrolysis System




**Source** IRENA (2020)

32 Other hydrogen production methods include photoelectrochemical hydrogen production technology and biological hydrogen production technology.

## Hydrogen Production Technologies

First, in an alkaline water electrolyzer (AWE; alkaline electrolysis cell, AEC), hydroxide ions ($OH^-$) migrate from the cathode to the anode through an alkaline (KOH) solution. Oxygen is produced at the anode, and hydrogen is produced at the cathode. An alkaline solution is supplied to both electrodes for ion conduction, and a porous membrane is positioned between the electrodes to prevent mixing of hydrogen and oxygen. Among electrolysis systems, it has been studied the longest, has high technological maturity, and has low hydrogen production costs, making it the first to enter the commercialization stage. It operates at temperatures between 60 and 90°C and offers high price competitiveness due to the use of relatively inexpensive materials like nickel (Ni) and iron (Fe) based catalysts. However, because a porous membrane is positioned between the two electrodes to prevent mixing of hydrogen and oxygen, control technology is required to minimize the pressure difference. This makes atmospheric pressure operation relatively easier than pressurized operation. Additionally, compared to other electrolysis technologies, it has the disadvantage of lower hydrogen production density under the same voltage conditions, resulting in larger system sizes.

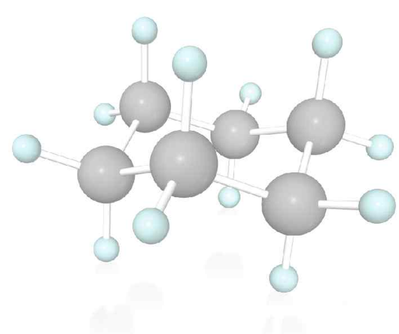
PEM electrolysis, or Polymer Electrolyte Membrane Water Electrolyzer, PEMWE). To clearly distinguish it after the advent of anion exchange membrane electrolysis, it is also referred to as Proton Exchange Membrane Water Electrolyzer (PEMWE). In PEM electrolysis, hydrogen ions ($H^+$, protons) move from the anode to the cathode through a proton-conductive polymer. Oxygen is produced at the anode, and hydrogen is produced at the cathode. A polymer electrolyte membrane capable of proton conduction is positioned between the two electrodes. Proton-conducting polymers are also distributed within the electrodes, and ultra-pure water (deionized water) without added ions is supplied. It operates at temperatures between 50 and 80°C, and the presence of the electrolyte membrane enables high-pressure and high-current operation. These characteristics enable the production of high-purity hydrogen and offer the advantage of high energy density due to the compact system size. Conversely, a disadvantage is the high cost resulting from the use of expensive materials such as platinum (Pt) and iridium (Ir) catalysts, perfluorinated carbon acid (PFSA) electrolytes, and titanium (Ti)-based porous diffusers.

Beyond alkaline and PEM electrolysis, next-generation electrolysis technologies currently in fundamental R&D or demonstration phases include high-temperature electrolysis and anion exchange membrane electrolysis. High-temperature electrolysis refers to devices that decompose water vapor electrically at temperatures above 500°C using ceramic (metal oxide) materials. Typically, this refers to Solid Oxide Electrolysis Cells (SOEC), where oxygen ions (O2−) move from the cathode to the anode, producing oxygen at the anode and hydrogen at the cathode. Anion Exchange Membrane Water Electrolyzer (AEMWE) replaces the porous separator and electrolyte used in alkaline water electrolysis with an anion exchange membrane, similar to PEM water electrolysis technology which uses a cation exchange membrane.

Looking at global technology and industry trends, alkaline water electrolysis is similar to the chlor-alkali process system used for producing chlorine and caustic soda. Consequently, alkaline electrolysis technology has developed primarily among companies possessing chlor-alkali process technology and alkaline electrolyzer manufacturers in China. German company Thyssenkrupp developed a 20MW-class alkaline water electrolysis system and based on this, signed a contract to supply a 2GW+ electrolysis plant to Saudi Arabia's Neom. France's McPhy developed a 4MW-class alkaline electrolysis stack, while Japan's Asahi Kasei demonstrated a 10MW-class alkaline electrolysis facility through its solar-linked green hydrogen production P2G demonstration project (FH2R project). In March 2024, it commenced operation of a commercial multi-module electrolysis plant and aims to build a 100MW-class electrolysis facility.

PEM electrolysis is led by Germany's Siemens Energy. Siemens Energy has secured the Silyzer 300 model capable of producing up to 2 tons/h of hydrogen and 17.5MW system technology has secured the Silyzer 300 model capable of producing up to 2 tons/hour of hydrogen and 17.5MW system technology. In 2022, it supplied a 20MW-scale PEM electrolysis system to Germany's Trailblazer project. Norway's Nel Hydrogen and France's Elogen each secured 20MW PEM electrolysis system technology. America's Plug Power and Britain's ITM Power developed 10MW PEM electrolysis systems. The U.S. Department of Energy (DOE) is conducting various research on PEM electrolysis through the H2NEW Project-LTE, a consortium of 10 U.S. research institutions including NREL, Argonne National Lab., Los Alamos National Lab., Berkeley Lab., and INL. This research focuses on reducing precious metal usage, improving performance and durability, and scaling up.

In Korea, Hydrogen Energy Co. has successfully demonstrated a 500kW-class alkaline water electrolysis system linked to wind power on Jeju Island and is currently demonstrating an additional 2MW-class system on Jeju Island. Lightbridge is developing a 10kW alkaline electrolysis stack applying next-generation zero-gap technology, while LG Chem is developing 500kW-class alkaline electrolysis stacks, electrodes, and separator materials based on chlor-alkali electrolyzer technology. In addition, companies such as Elchemtech and Doosan Fuel Cell, along with institutions including the Korea Institute of Science and Technology (KIST), the Korea Research Institute of Chemical Technology (KRICT), and the Korea Advanced Institute of Science and Technology (KAIST), are conducting various research projects related to electrolysis materials.



## Section 2. Hydrogen Storage and Transportation Technologies

Hydrogen storage and transportation technology refers to the storage and transportation methods for supplying hydrogen within regions accessible by land transport. Hydrogen is the lightest substance on Earth and exists as a gas at room temperature. Therefore, small volumes of hydrogen must be stored as high-pressure gaseous hydrogen or in solid form, while large volumes require conversion to liquid hydrogen for storage. "Hydrogen storage technology" applies suitable methods based on application characteristics, such as large-scale underground hydrogen storage, building-integrated hydrogen storage, and mobility-specific hydrogen storage. Hydrogen transportation considers ease and efficiency, transporting it in either gaseous or liquid form. Gaseous hydrogen is transported via tube trailers or hydrogen pipeline networks, while liquid hydrogen is transported using tank trucks. As hydrogen is a flammable gas that can cause major accidents if leaked, technological development to enhance the safety of hydrogen storage and transportation is also required.

Gaseous hydrogen storage and transportation technology refers to the technology for storing gaseous hydrogen and transporting it in its gaseous form. It consists of high-pressure gaseous hydrogen storage and transportation, and low-pressure solid hydrogen storage technology. Low-pressure solid hydrogen storage technology is classified as a gas hydrogen storage and transportation technology due to its characteristic of converting gaseous hydrogen into a metal compound for storage and then reconverting it back to gaseous hydrogen for use or transportation.

High-pressure gaseous hydrogen storage and transportation can be divided into high-pressure gaseous hydrogen storage technology and transportation technology. High-pressure gaseous hydrogen storage technology is the most commercially advanced technology, with proven durability compared to other storage technologies. It has proven durability and good weight-to-storage efficiency, making it applicable in various fields such as mobility, stationary use, and transportation. High-pressure gaseous hydrogen storage tanks come in four types (Type 1 to 4), as shown in the figure, with maximum charging pressures ranging from 200 bar to 900 bar depending on the tank type and application. Recently, Type 5 high-pressure gaseous hydrogen storage tanks without liners have also been developed. High-pressure gaseous hydrogen transportation is carried out using tube trailers equipped with these storage tanks.

Low-pressure solid hydrogen storage utilizes hydrogen's extremely small size, allowing it to be stored atomically within metal hydride or porous metal-organic framework structures. This method offers high safety because hydrogen storage and release can be controlled by temperature differences. Additionally, compared to atmospheric-pressure gaseous hydrogen, it offers the advantage of storing the same amount of hydrogen in a volume 1/1,000th as large. Due to the high weight of the metals involved, "low-pressure solid hydrogen storage" is not utilized for transportation and is primarily being developed for stationary or submarine applications requiring large-capacity hydrogen storage.

Liquid hydrogen storage and transportation technology involves liquefying gaseous hydrogen for storage and transport. It consists of hydrogen liquefaction technology, liquefied hydrogen storage technology, and liquefied hydrogen transportation technology.

Hydrogen liquefaction technology is the process of producing low-pressure liquid hydrogen by cooling gaseous hydrogen at ambient temperature and pressure to cryogenic temperatures. Liquefying hydrogen requires cooling it to -253°C, demanding significant energy for cooling. Additionally, exothermic reactions occur during cooling due to changes in hydrogen's electronic structure, necessitating technological development to address this issue.

Liquid hydrogen storage technology enables large-scale storage of liquid hydrogen. Its energy density is 780 times higher than that of atmospheric pressure gaseous hydrogen storage and 1.75 times higher than that of high-pressure gaseous hydrogen storage. Liquid hydrogen storage operates at a low storage pressure of approximately 3 bar or less, offering a safety advantage over high-pressure gaseous hydrogen storage.

Liquid hydrogen transportation technology involves transporting liquid hydrogen using tank trucks, achieving 7 times higher transportation efficiency than high-pressure gaseous hydrogen transport. However, technological development is required to address issues such as reduced stability of liquid hydrogen due to movement during transport and increased pressure caused by hydrogen vaporization within the liquid hydrogen storage tank.

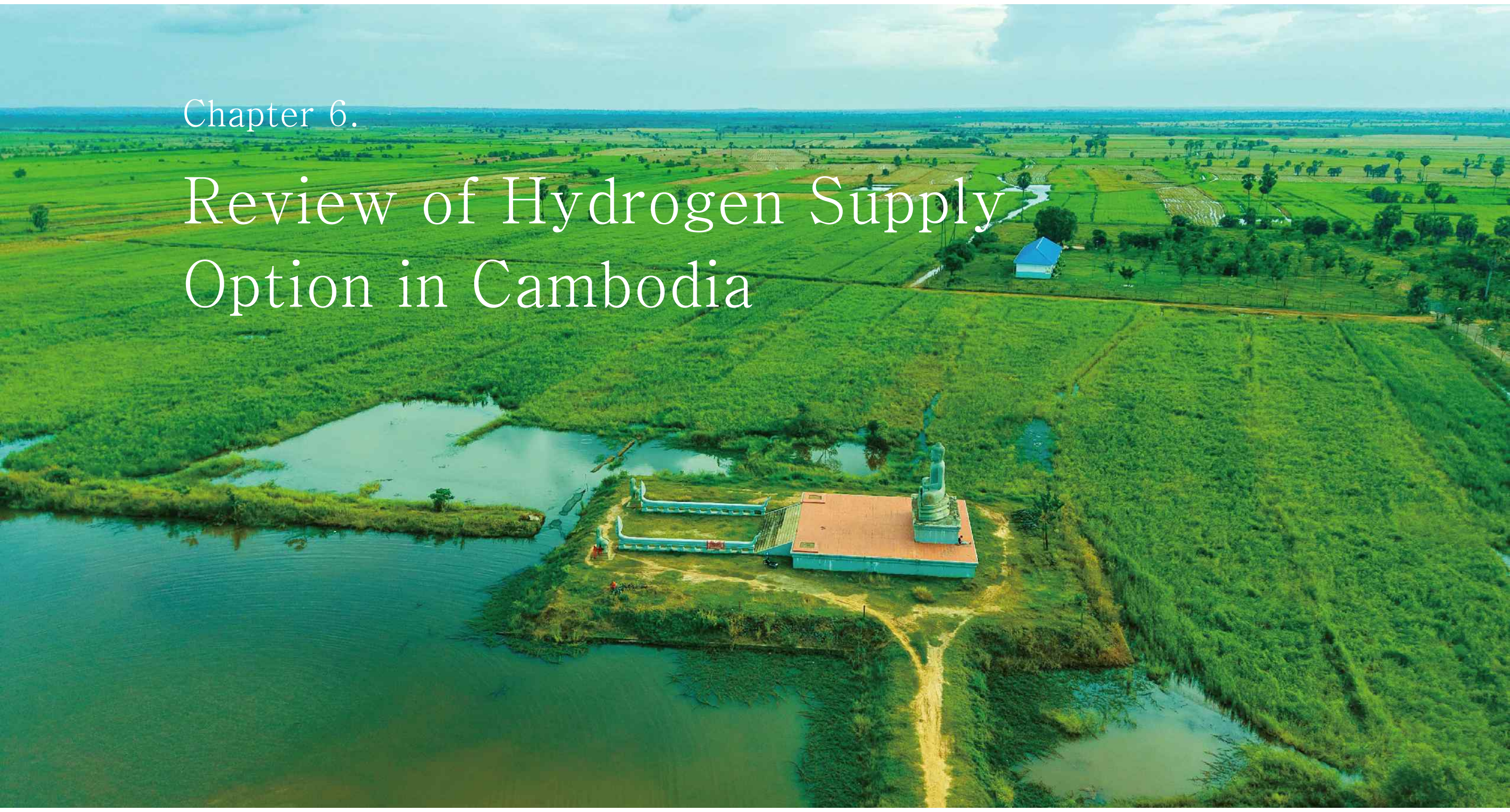
Hydrogen-dedicated pipeline network technology is for supplying large volumes of hydrogen via pipelines, encompassing material technology, large-scale hydrogen supply/operation and safety technology, welding/joining, and corrosion prevention technology. As efficiently supplying hydrogen to various end-uses becomes crucial for realizing the hydrogen economy, technologies for large-scale supply via dedicated hydrogen pipelines, similar to natural gas networks, are gaining prominence. Pipeline transportation is the most efficient, stable, and economical method for supplying large volumes of hydrogen. When supplying hydrogen at high pressure through pipelines, hydrogen embrittlement occurs in the metal base material. The base material and welded joints of the pipeline experience hydrogen embrittlement, where contact with hydrogen reduces ductility or toughness. Since hydrogen-dedicated pipelines exhibit greater susceptibility to hydrogen embrittlement with higher strength, they are currently manufactured using materials of X52 grade or lower, which are relatively lower in strength than the X65 and X70 grades used for domestic natural gas pipelines.

Additionally, technologies required for importing hydrogen from overseas include large-scale ammonia-hydrogen storage and transportation technology, liquid organic hydrogen carrier (LOHC) technology, liquid hydrogen carriers, and liquid hydrogen receiving terminals.

In the hydrogen storage and transportation sector, global technology and market leadership is held by companies such as Japan's Toyoda Gosei, Norway's Hexagon Purus, Germany's GE and Linde, France's Air Liquide, the US's Air Products, Italy's Electro Power Systems, and Denmark's Topsoe. In Korea, various companies and research institutions — including Doosan Mobility Innovation, POSCO, Hyundai Motor Company, Lotte Chemical, Hyrium Industries, the Korea Institute of Energy Research, and the Korea Institute of Machinery and Materials — are actively developing technologies either independently or in collaboration with global advanced companies.

Chapter 6.

# Review of Hydrogen Supply Option in Cambodia



## Section 1. Renewable Energy and Water ReSources

### 1. Hydropower

Hydropower possesses the highest operational capacity among all power Sources, with 1,298 MW currently in operation. Notably, announced projects, classified as having high future development potential, total 4,000 MW, indicating that the hydropower sector still holds significant potential for large-scale expansion. The prospective capacity, which combines the potential capacity at the construction, pre-construction, and announced stages, totals 4,330 MW. This represents the largest scale compared to solar, wind, and bioenergy.

Table 6-1 summarizes Cambodia's currently operational or announced hydropower projects. The currently operational plants are primarily in the 100-400 MW range and commenced commercial operation in phases between 2011 and 2017. Among these, the Lower Sesan 2 hydroelectric plant, operational since 2017, is the largest at 400 MW. Additionally, hydroelectric projects with capacities of 1,400 MW and 2,600 MW have been announced. The Sambor hydroelectric project is scheduled to begin operation in 2027. The Stung Treng Hydropower Project is planned for construction in the Mekong River basin. It is currently in the permitting phase and is expected to commence in 2028, with commercial operation beginning in 2032 (Power Technology, 2024a, b).

**Table 6-1** Operational Status of the Cambodia Hydropower Project

| Project Name | Capacity (MW) | Status | Start Year |
|---|---|---|---|
| Sambor hydroelectric plant | 2,600 | announced | - |
| Stung Treng hydroelectric plant | 1,400 | announced | - |
| Lower Sesan 2 hydroelectric plant | 400 | operating | 2017 |
| Stung Tatay hydroelectric plant | 246 | operating | 2015 |
| Russei Chrum Krom Upper hydroelectric plant | 206 | operating | 2013 |
| Kamchay hydroelectric plant | 194 | operating | 2011 |
| Russei Chrum Krom Lower hydroelectric plant | 132 | operating | 2015 |
| Stung Atay hydroelectric plant | 120 | operating | 2013 |

Source Global Energy Monitor (2025b)

## 2. Solar Power

Solar power generation currently has 486MW in operation, holding the second-largest operational capacity after hydropower. While there are no projects under construction, 209MW of pre-construction stage capacity and 1,761MW of announced projects exist, indicating potential for expansion. The largest solar photovoltaic (PV) power project currently operating in Cambodia is 60 MW. Projects totaling 60 MW are summarized in Table 6-2.

**Table 6-2** Operational Status of Cambodia's 60MW-Class Solar Power Project

| Project Name | Capacity (MW) | Start Year | State/Province |
|---|---|---|---|
| Battambang solar farm | 60 | 2021 | Battambang |
| Cambodia National Solar Park | 60 | 2022 | Kampong Chhnang |
| Kampong Chhnang solar farm | 60 | 2020 | Kampong Chhnang |
| Kampong Speu solar farm | 60 | 2020 | Kampong Speu |
| Pursat solar farm | 60 | 2020 | Pursat |

Source Global Energy Monitor (2025c)

## 3. Other Renewable Energy

### A. Bioenergy

In Cambodia, bioenergy currently operates at a scale of 9MW, classified as a small-scale power Source. However, an additional 50MW is planned in the pre-construction phase and 28MW in the announcement phase, bringing the total potential capacity for future development to 78MW.

### B. Wind Power

No operational wind power plants currently exist in

Cambodia. However, a 180MW wind power project is in the pre-construction phase, indicating potential for future development. Among these, plans have been announced to operate a 150MW wind power plant in Mondulkiri Province, with future expansion planned to a total 900MW wind power complex. This project is scheduled to be operated by France's Blue Circle (AIF Asean, 2025).

### 4. Water ReSource Risk

Cambodia's water reSource risk is approximately 1.87, which is relatively low compared to other countries (Kuzma et al,, 2023). Possessing the Mekong River and Tonle Sap Lake, it boasts the most abundant freshwater supply in Southeast Asia. Due to the extremely large inflow into the Mekong basin, the risk of water scarcity is low (Mekong River Commission, 2023). To enhance water security amid frequent floods and droughts, ten large dams are either operational or planned along the Mekong River mainstem. Cambodia is one of the countries with the highest annual water availability in the world, with an average total available water reSources of approximately 472 billion $m^3$ and a per capita water availability of approximately 26,445 $m^3$ (Sim, 2025). This figure is more than 20 times higher than that of our country. Actual water usage is estimated to be approximately 6.3% of the available water reSources per capita (Korean Weekly Newspaper in Cambodia, 2021).

## Section 2. Technology Development Achievements and R&D Capabilities

### 1. WIPO Innovation Index

Cambodia ranked 100th out of 139 countries in the 2025 Global Innovation Index (GII), showing a slight improvement compared to the previous year. However, there remains significant room for improvement. Cambodia is classified as a country with low output relative to input, indicating inefficient results generation per investment. The Global Innovation Tracker, which measures adaptation to recent technological changes and social impact, also shows some short-term improvements. For example, in the science and technology sector, the growth rate of academic papers increased by 3.6% in the short term, and the fixed broadband penetration rate increased by 3.8% in the short term.

Among the seven innovation components, Market Sophistication (29th) ranked highest. Other areas performing above the overall ranking (100th) included Institutions (90th), Infrastructure (93rd), and Knowledge and Technology Outputs (92nd). Conversely, the most vulnerable areas were Business sophistication (133rd), Human capital and research (114th), and Creative outputs (113th), confirming that business activity, research capacity, and creative content represent structural weaknesses in the innovation ecosystem.

Overall, Cambodia demonstrates competitiveness in financial accessibility and market maturity, but persistent vulnerabilities remain in foundational innovation elements like human capital, R&D, and corporate capabilities. Key strategic tasks to enhance output efficiency relative to inputs include strengthening corporate innovation capabilities, building higher education and research ecosystems, and expanding technology startup support infrastructure (Global Innovation Index, 2025).

### 2. High-Tech Exports

The scale of high-tech product exports serves as a key indicator for gauging a nation's technological capabilities. Generally, countries with higher high-tech exports are more likely to possess superior research, development, and innovation capabilities in advanced technology fields such as hydrogen. This indicator is calculated by aggregating export values for high-tech, medium-high-tech, medium-low-tech, and low-tech industrial groups, as defined by the OECD based on Hatzichronoglou's (1997) classification system (Hatzichronoglou, 1997). The total output and value added for each industry group are calculated based on R&D expenditure.

High-tech industries include aircraft, aerospace, energy, computers, and pharmaceuticals. Medium-high tech industries encompass automobiles, electrical equipment, and most chemical products. Medium-low tech industries consist of rubber and plastics, basic metals, and shipbuilding. Low-tech industries are centered on traditional manufacturing sectors like food processing, textiles, apparel, and footwear. This indicator is based on statistics submitted by countries to UN COMTRADE, and the World Bank export figures use the value obtained by subtracting re-exports from total exports.

As hydrogen technology is classified as a high-tech industry, technologically advanced countries like South Korea, Japan, and Germany are achieving significant results across the entire hydrogen value chain, including production, storage, transportation, and utilization. Collaboration with these nations can play a crucial role in promoting diverse innovation activities, including demonstration projects.

Meanwhile, according to World Bank (WB) data, Cambodia's high-tech exports reached USD 2.35 billion in 2023 (World Bank, 2024).

### 3. R&D investment as a percentage of GDP

The ratio of R&D investment to GDP in UIS Statistics serves as a key indicator for evaluating each country's technological capabilities (UNESCO Institute of Statistics, 2025). Countries with high levels of R&D investment relative to their income generally possess greater potential to develop and commercialize new hydrogen technologies, which directly impacts their readiness to adopt hydrogen technologies. Indeed, Gumus and Celikay (2015) presented findings from an analysis of 52 countries from 1996 to 2010, showing that R&D expenditure has a positive and statistically significant impact on a country's economic growth in the long term (Gumus and Celikay, 2015).

These research findings suggest that even developing countries can secure a relatively advantageous position in international cooperation strategies by actively expanding R&D investment. According to World Bank data, Cambodia's R&D investment as a percentage of GDP stands at 0.12% (World Bank, 2025a).

### 4. Comparison of Cambodia’s Science and Technology Capacity (Publications)

In recent years, the ASEAN region has accelerated its efforts to promote development for science and technology innovation. In July 2025, the ASEAN Economic Community adopted the “ASEAN Plan of Action on Science, Technology and Innovation (APASTI) 2026-2035.” In this context, the Science and Technology Policy Institute (STEPI) has identified ASEAN’s priority research fields by examining country-level research capacity and technological levels within the region, based on an analysis of scientific publications (SCOPUS/Web of Science papers from 2021-2023) and World Intellectual Property Organization (WIPO) patent data (Kim et al., 2024). Between 2021 and 2023, the ten ASEAN member states produced approximately 444,000 publications in total, and the top five countries (Indonesia, Malaysia, Thailand, Singapore, and Viet Nam) account for about 96% of this output, revealing a highly unbalanced structure.

**Table 6-3** Number of Publications by ASEAN Member State, by Year (3-Year Period)

| no | countries | 2021 | 2022 | 2023 | Total | percent (%) |
|---|---|---|---|---|---|---|
| 1 | Indonesia | 88,177 | 81,546 | 88,952 | 258,675 | 58.2 |
| 2 | Malaysia | 22,404 | 19,722 | 18,743 | 60,869 | 13.7 |
| 3 | Thailand | 14,531 | 15,075 | 14,479 | 44,085 | 9.9 |
| 4 | Singapore | 11,310 | 10,248 | 10,586 | 32,144 | 7.2 |
| 5 | Viet Nam | 10,016 | 10,141 | 11,093 | 31,250 | 7.0 |
| 6 | Philippines | 3,848 | 4,226 | 5,132 | 13,206 | 3.0 |
| 7 | Cambodia | 550 | 679 | 907 | 2,136 | 0.5 |
| 8 | Myanmar | 389 | 267 | 337 | 993 | 0.2 |
| 9 | Brunei | 292 | 256 | 334 | 882 | 0.2 |
| 10 | Laos | 72 | 85 | 101 | 258 | 0.1 |

Source Kim et al. (2024). A Study on the Establishment of a Korea-ASEAN Joint Research Program in Science and Technology. Science and Technology Policy Institute (STEPI). p.7.

Indonesia accounts for approximately 58 percent of the total publications, making it by far the largest contributor, followed by Malaysia, Thailand, Singapore, and Viet Nam. Cambodia produced a total of 2,136 papers over the three years (550 in 2021, 679 in 2022, and 907 in 2023), showing a gradual upward trend. However, its share represents only about 0.5 percent of the combined output of the ten ASEAN member states (around 444,000 papers), revealing a very large gap compared with the top five countries (Indonesia, Malaysia, Thailand, Singapore, and Viet Nam).

**Table 6-4** Number of Publications by Sector in ASEAN Countries (3 Years)

| Field | IDN | MYS | THA | SGP | VNM | PHL | KHM | MMR | BRN | LAO | percent (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Agricultural and Biological Sciences | 72,874 | 7,128 | 7,638 | 1,223 | 4,235 | 2,726 | 186 | 164 | 97 | 88 | 13.6 |
| Biochemistry, Genetics and Molecular Biology | 16,658 | 6,578 | 8,433 | 4,341 | 3,804 | 1,491 | 238 | 139 | 89 | 64 | 5.9 |
| Chemical Engineering | 785 | 1,206 | 788 | 440 | 476 | 56 | 3 | 3 | 14 | 0 | 0.5 |
| Chemistry | 5,037 | 2,990 | 2,408 | 1,419 | 1,840 | 405 | 23 | 19 | 50 | 1 | 2.0 |
| Computer Science | 71,527 | 9,100 | 4,077 | 6,048 | 4,945 | 2,624 | 133 | 176 | 143 | 12 | 14.0 |
| Dentistry | 2,882 | 982 | 909 | 199 | 241 | 97 | 43 | 97 | 14 | 3 | 0.8 |

| Field | IDN | MYS | THA | SGP | VNM | PHL | KHM | MMR | BRN | LAO | percent (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Earth and Planetary Sciences | 7,920 | 2,050 | 1,003 | 887 | 1,240 | 532 | 31 | 49 | 46 | 6 | 1.9 |
| Energy | 3,162 | 2,952 | 1,326 | 1,039 | 1,266 | 247 | 27 | 12 | 81 | 3 | 1.4 |
| Engineering | 50,954 | 26,343 | 12,771 | 13,123 | 12,016 | 2,944 | 299 | 179 | 353 | 30 | 16.8 |
| Environmental Science | 34,225 | 9,614 | 5,015 | 2,651 | 4,785 | 2,302 | 168 | 112 | 162 | 62 | 8.4 |
| Health Professions | 32,414 | 2,649 | 1,565 | 1,210 | 657 | 900 | 146 | 82 | 59 | 14 | 5.6 |
| Immunology and Microbiology | 3,378 | 1,368 | 2,249 | 864 | 733 | 358 | 111 | 56 | 17 | 33 | 1.3 |
| Materials Science | 9,732 | 8,547 | 5,743 | 4,371 | 4,302 | 523 | 43 | 25 | 140 | 2 | 4.7 |
| Mathematics | 2,887 | 935 | 1,231 | 534 | 1,521 | 314 | 23 | 7 | 13 | 7 | 1.1 |
| Medicine | 69,182 | 15,260 | 17,319 | 10,799 | 6,925 | 3,928 | 1,435 | 400 | 207 | 110 | 17.7 |
| Neuroscience | 2,051 | 1,279 | 1,110 | 1,177 | 389 | 236 | 65 | 18 | 10 | 3 | 0.9 |
| Nursing | 4,831 | 924 | 1,135 | 310 | 402 | 280 | 42 | 32 | 13 | 5 | 1.1 |
| Pharmacology, Toxicology and Pharmaceutics | 2,719 | 882 | 1,126 | 240 | 624 | 105 | 19 | 12 | 7 | 5 | 0.8 |
| Physics and Astronomy | 1,744 | 1,797 | 1,341 | 2,272 | 1,333 | 250 | 22 | 19 | 15 | 1 | 1.2 |
| Veterinary | 340 | 168 | 402 | 55 | 111 | 40 | 7 | 13 | 1 | 4 | 0.2 |

Source Kim et al. (2024). A Study on the Establishment of a Korea-ASEAN Joint Research Program in Science and Technology, Science and Technology Policy Institute (STEPI). p.8~9.

In terms of research fields, ASEAN countries as a whole tend to focus their major research activities in Medicine (17.7%), Engineering (16.8%), Computer Science (14.0%), and Agricultural and Biological Sciences (13.6%). Cambodia's main research output is also highly concentrated in the medical and health sectors, which can be attributed to the substantial support provided to Southeast Asian countries by WHO, the World Bank, USAID, JICA, the EU, and various bilateral ODA programs (Sophie Goyet, 2015). By contrast, in non-medical fields such as engineering, natural sciences, and ICT, the lack of research personnel and infrastructure has resulted in relatively limited publication output, and thus a persistent and sizable gap in research capacity across different disciplines.

### 5. Comparison of Cambodia's Science and Technology Capacity (Patents)

Next, an examination of the patent landscape in ASEAN shows that 93.3 percent of all patents are concentrated in Singapore, indicating that, in effect, a single country — Singapore — almost monopolizes patenting activity in this field. Malaysia (2.5 percent), Thailand (1.8 percent), Viet Nam (1.3 percent), and the Philippines (0.7 percent) together account for only a little over 7 percent, with annual patent filings remaining at a relatively small scale of around 20 to 50 cases per year. In Indonesia, Cambodia, and Brunei, patent activity is highly limited, with only about 1 to 5 filings per year, while Lao PDR and Myanmar recorded no patent applications over the past three years. From a technological perspective, these countries can therefore be regarded as being at an early stage of development.

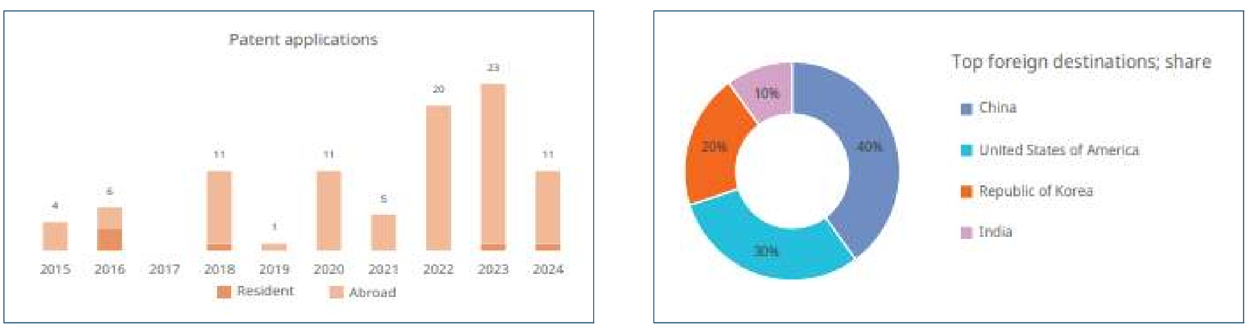
**Table 6-5** Annual Number of Patents in ASEAN Countries (3 Years)

| no | countries | 2021 | 2022 | 2023 | Total | percent (%) |
|---|---|---|---|---|---|---|
| 1 | Singapore | 1,814 | 1,796 | 1,595 | 5,205 | 93.3% |
| 2 | Malaysia | 47 | 49 | 46 | 142 | 2.5% |
| 3 | Thailand | 35 | 41 | 27 | 102 | 1.8% |
| 4 | Viet Nam | 26 | 22 | 25 | 73 | 1.3% |
| 5 | Philippines | 17 | 10 | 12 | 39 | 0.7% |
| 6 | Indonesia | 5 | 2 | 5 | 12 | 0.2% |
| 7 | Cambodia | 4 | 1 | 1 | 6 | 0.1% |
| 8 | Brunei | 1 | 1 | 0 | 2 | 0.0% |
| 9 | Laos | 0 | 0 | 0 | 0 | 0.0% |
| 10 | Myanmar | 0 | 0 | 0 | 0 | 0.0% |

Source Kim et al. (2024). A Study on the Establishment of a Korea-ASEAN Joint Research Program in Science and Technology, Science and Technology Policy Institute (STEPI). p.11.

According to Cambodia's intellectual property profile (Intellectual Property Statistical Country Profile 2024) published by WIPO, Cambodia filed a total of 11 patent applications in 2024 (1 by residents and 10 by non-residents), ranking 127th worldwide in terms of the number of applications. During the period from 2015 to 2023, patent filings also remained very small in scale, at around 4 to 23 applications per year. When adjusted for population and GDP, Cambodia's patent application indicators likewise remain low, at around 117th to 120th in the world.

**Figure 6-1** Patent applications from 2015 to 2024 and Destination Share

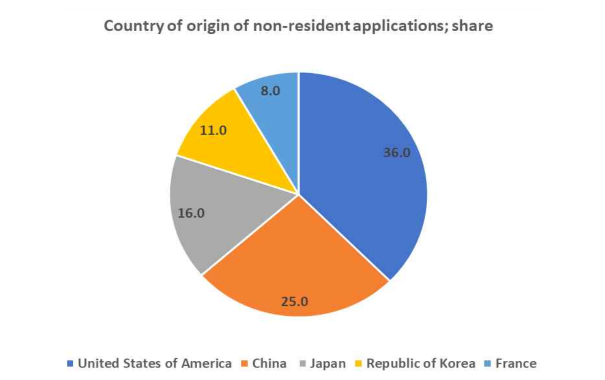



Source WIPO (2024)

Within Asia and Southeast Asia, Cambodia's shares are also very small, at around 0 percent and 0.1 percent, respectively. Overseas patent filings are concentrated in China (40 percent), the United States (30 percent), the Republic of Korea (20 percent), and India (10 percent), indicating that Cambodian firms and institutions primarily regard these four countries as target markets and key cooperation partners.

Looking at the main countries filing patents in Cambodia in 2024, non-resident applications are led by the United States (24 percent), followed by China (16.7 percent), Japan (10.7 percent), the Republic of Korea (7.3 percent), and France (5.3 percent). This suggests that companies from these countries are actively developing a wide range of business activities — such as manufacturing, distribution, construction, infrastructure, and consumer goods — while seeking to protect their technologies in the Cambodian market.

**Table 6-6** Major Five Countries of Patent Applications with Cambodian IP Office (Share of Total)




| Country of origin of non-resident | | |
|---|---|---|
| Country | applications | share |
| USA | 36 | 24.0 |
| China | 25 | 16.7 |
| Japan | 16 | 10.7 |
| South Korea | 11 | 7.3 |
| France | 8 | 5.3 |
| other | 54 | 36.0 |

Source WIPO (2024)

## 6. Cambodia's Public-Sector Project Implementation and Management Capacity

According to climate finance data provided by Climate Funds Update, Cambodia secured approval for climate-related international cooperation projects totaling approximately USD 367.5 million between 2003 and 2024 through a range of multilateral funds, including the LDCF, GEF, PPCR, UN-REDD, GCF, SREP, and CTF. By year, medium- to large-scale projects (in the range of USD 30-70 million per year) were concentrated in 2011-2015, 2018, and 2023-2024, indicating that Cambodia has steadily accumulated project experience in the areas of climate adaptation and low-carbon transition.

In terms of implementing entities (recipient institutions), ministries such as the Ministry of Environment (MOE), the Ministry of Agriculture, Forestry and Fisheries (MAFF), the Ministry of Public Works and Transport (MPWT), and the Ministry of Water ReSources and Meteorology (MOWRAM) appear repeatedly across different funds and years. This suggests that these ministries serve as the primary counterparts for negotiations with international organizations and multilateral funds, as well as for project design, implementation, and reporting. For example, in the agriculture and rural sectors, LDCF, AF, and GCF projects have repeatedly supported initiatives to enhance the resilience of agricultural livelihoods and improve small-scale irrigation systems. In the environment, forestry, and disaster sectors, instruments such as UN-REDD, FCPF-REDD, and PPCR have been used to implement multiple projects on forest monitoring and flood and drought response. Transport, water reSources, and water supply infrastructure have likewise benefited from repeated PPCR and GEF operations aimed at building climate-resilient infrastructure.

From the perspective of financing structure, approved amounts typically combine grants and concessional loans. More recently, projects utilizing the GCF, SREP, and CTF have promoted renewable energy and the mobilization of private investment, and in 2024 a green finance facility in the financial and banking sector based on GCF-2 was introduced. These developments indicate that Cambodia's capacities have expanded beyond the implementation of stand-alone infrastructure projects to the ability to manage more complex programmatic interventions that also encompass policy and institutional reforms and financial mechanisms.

**Table 6-7** Overview of Climate Fund Projects in Cambodia

| Approved year | Fund | Name of Project | Amount of Funding Approved (USD millions) |
|---|---|---|---|
| 2003 | Least Developed Countries Fund (LDCF) | Programme of Action for Adaptation to Climate Change | 0.2 |
| 2008 | Global Climate Change Alliance (GCCA) | Increasing Cambodia's Government Capacities to Deal with Climate Change Challenges | 2.5 |
| | Global Environment Facility (GEF4) | Reducing Greenhouse Gas Emissions through Improved Energy Efficiency in the Industrial Sector | 1.2 |
| | Least Developed Countries Fund (LDCF) | Promoting Climate-Resilient Water Management and Agricultural Practices | 1.9 |
| 2010 | Global Environment Facility (GEF4) | TT-Pilot (GEF-4): Climate Change Related Technology Transfer for Cambodia: Using Agricultural Residue Biomass for Sustainable Energy Solutions | 1.7 |
| | Least Developed Countries Fund (LDCF) | Vulnerability Assessment and Adaptation Programme for Climate Change in the Coastal Zone of Cambodia Considering Livelihood Improvement and Ecosystems | 1.6 |
| 2011 | Forest Carbon Partnership Facility – Readiness Fund (FCPF-RF) | Readiness Fund Grant | 8.8 |
| | Least Developed Countries Fund (LDCF) | Strengthening the adaptive capacity and resilience of rural communities using micro watershed approaches to climate change and variability to attain sustainable food security | 5.2 |
| | Pilot Program for Climate Resilience (PPCR) | Provincial Roads Improvement Project – Climate Proofing of Roads in Prey Veng, Svay Rieng, Kampong Chhnang and Kampong Speu Provinces (ADB) | 16.0 |
| | UN-REDD Programme | 00076663 Cambodia UN REDD National Programme | 3.0 |

| Approved year | Fund | Name of Project | Amount of Funding Approved (USD millions) |
|---|---|---|---|
| 2012 | Adaptation Fund (AF) | Enhancing Climate Resilience of Rural Communities Living in Protected Areas of Cambodia | 5.0 |
| | Pilot Program for Climate Resilience (PPCR) | Enhancement of Flood and Drought Management in Pursat Province (ADB) | 9.7 |
| | | GMS Southern Economic Corridor Towns Development Project | 9.4 |
| | | Mainstreaming Climate Resilience into Development Planning in Key Vulnerable Sectors (ADB) | 9.0 |
| 2013 | Global Environment Facility (GEF5) | Reduction of GHG Emission through Promotion of Commercial Biogas Plants | 1.5 |
| | Least Developed Countries Fund (LDCF) | Reducing the Vulnerability of Cambodian Rural Livelihoods through Enhanced sub-national Climate Change Planning and Execution of Priority Actions | 4.6 |
| | | Strengthening Climate Information and Early Warning Systems in Cambodia to Support Climate Resilient Development and Adaptation to Climate Change | 4.9 |
| | Pilot Program for Climate Resilience (PPCR) | Climate Proofing of Agricultural Infrastructure and Business-focused Adaptation | 9.5 |
| 2014 | Adaptation for Smallholder Agriculture Programme (ASAP) | Agricultural Services Programme for Innovations, Resilience and Extension (ASPIRE) | 15.0 |
| | Global Climate Change Alliance (GCCA) | Cambodia Climate Change Alliance – Phase II. | 7.6 |
| | Pilot Program for Climate Resilience (PPCR) | Flood-Resilient Infrastructure Development in Pursat and Kampong Chhhang Towns as part of the Integrated Urban Environmental Managment in the Tonle Sap Basin Project | 10.0 |
| | | Promoting Climate-resilient Agriculture, Forestry, Water Supply and Coastal ReSources in Koh Kong and Mondulkiri Provinces (ADB) | 7.4 |
| 2015 | Pilot Program for Climate Resilience (PPCR) | Climate resilient Rural Infrastructure in Kampong Cham Province(as part of Rural Roads Improvement Project (RRIP-II)) | 16.0 |
| | Special Climate Change Fund (SCCF) | Building Adaptive Capacity through the Scaling-up of Renewable Energy Technologies in Rural Cambodia (S-RET) | 4.6 |
| 2016 | Green Climate Fund IRM (GCF IRM) | PwC Direct Access Entity Support | 0.0 |
| 2017 | Global Environment Facility (GEF6) | Low-carbon Development for Productivity and Climate Change Mitigation through the Transfer of Environmentally Sound Technology (TEST) Methodology | 1.8 |
| | | Strengthening Capacity in the Agriculture and Land-use Sectors for Enhanced Transparency in Implementation and Monitoring of Cambodia's Nationally Determined Contribution (NDC) | 0.9 |
| | Green Climate Fund IRM (GCF IRM) | ESS Gender Roster Environmental and social safeguards and gender roster support | 0.0 |
| | | KHM-RS-001 NDA Strengthening + Country Programming | 0.3 |

| Approved year | Fund | Name of Project | Amount of Funding Approved (USD millions) |
|---|---|---|---|
| 2018 | Global Climate Change Alliance (GCCA) | Cambodia Climate Change Alliance – Phase III. | 7.6 |
| | Green Climate Fund IRM (GCF IRM) | (FP076) Climate-Friendly Agribusiness Value Chains Sector Project | 40.0 |
| | Least Developed Countries Fund (LDCF) | Climate Adaptation and Resilience in Cambodia's Coastal Fishery Dependent Communities | 4.4 |
| | Scaling Up Renewable Energy Program (SREP) | National Solar Parks Program | 14.0 |
| 2019 | Clean Technology Fund (CTF) | BDF: Support for a Sustainable Power Sector | 0.4 |
| | Green Climate Fund IRM (GCF IRM) | KHM-RS-002 Promoting Green Mobility through Electric Motorcycles in Cambodia | 0.2 |
| | | KHM-RS-003 Readiness for Enhancing Access to Green Finance in Cambodia | 0.5 |
| | | KHM-RS-004 Technology needs assessment and action plans for the support of climate-friendly technology implementation in Cambodia's special economic zones. | 0.2 |
| 2020 | Global Environment Facility (GEF7) | Global Cleantech Innovation Programme: Accelerating cleantech innovation and entrepreneurship in start-ups and SMEs in Cambodia | 1.4 |
| | Green Climate Fund (GCF-1) | KHM-RS-005 Support to Direct Access Entity in Cambodia to meet accreditation conditions | 0.5 |
| | Scaling Up Renewable Energy Program (SREP) | Grid Reinforcement Project | 4.7 |
| 2021 | Adaptation Fund (AF) | Climate Change Adaptation through Protective Small-scale Infrastructure Interventions in Coastal Settlements of Cambodia | 5.0 |
| | Green Climate Fund (GCF-1) | KHM-RS-006 Enhanced actions to respond to climate change through sustainable waste management in Coastal Cities in Cambodia | 0.3 |
| | | KHM-RS-007 Climate Technology Deployment Roadmap for E-mobility Ecosystem in Cambodia | 0.2 |
| | | KHM-RS-008 Resilient Recovery Rapid Readiness Support in Cambodia | 0.3 |
| | Least Developed Countries Fund (LDCF) | Promoting Climate-Resilient Livelihoods in Rice-Based Communities in the Tonla Sap Region | 8.9 |
| 2022 | Green Climate Fund (GCF-1) | KHM-RS-009 Establishing an Evidence-Based National Adaptation Plan NAP process at National and Subnational Scales in Cambodia Phase 1 | 1.6 |

| Approved year | Fund | Name of Project | Amount of Funding Approved (USD millions) |
|---|---|---|---|
| 2023 | Green Climate Fund (GCF-1) | (FP199) Public-Social-Private Partnerships for Ecologically-Sound Agriculture and Resilient Livelihood in Northern Tonle Sap Basin (PEARL) | 36.2 |
| | Scaling Up Renewable Energy Program (SREP) | RFS: Energy Transition Sector Development Program (SDP) | 11.0 |
| 2024 | Adaptation Fund (AF) | Increasing Climate Resilience Through Small-Scale Infrastructure Investments and Enhancing Adaptive Capacity of Vulnerable Communities in Kampot and Koh Kong Provinces in Cambodia | 10.0 |
| | Green Climate Fund (GCF-2) | (FP228) Cambodian Climate Financing Facility | 55.0 |
| | | KHM-RS-010 Capacity building and accreditation support of Direct Access Entity to private banks for on-lending and/or blending fiduciary functions | 0.6 |
| | | KHM-RS-011 A Framework and Manual to launch a Sub-national Climate Fund aligned with LGCC-LoCAL in Cambodia | 0.4 |
| | Least Developed Countries Fund (LDCF) | Climate Resilience Enhancement for Building Adaptive Capacity in Agri-Value Chains in Cambodia (CREA) | 4.9 |
| | | | 367.5 |

Source Climate Fund Update (n.d.)

## Section 3. Integration of Green Hydrogen Production and Utilization

This section examines how Cambodia's Special Economic Zones (SEZs) can become strategic nodes for integrated green hydrogen production and utilization. Cambodia's economic growth is accelerating through industrialization, particularly within SEZs, which are energy-intensive and heavily reliant on fossil fuels. Concurrently, the government has pledged ambitious decarbonization targets through its Long-Term Strategy for Carbon Neutrality (LTS4CN) and Nationally Determined Contribution (NDC 3.0), which aim to increase renewable energy to 72% of installed capacity by 2035 (conditionally up to 80%) and to promote the transition of SEZs into Eco-Industrial Parks (EIPs).This dual reality — rising energy demand in concentrated industrial zones and internationally communicated climate commitments climate commitments — positions SEZs as both the primary Source of hydrogen demand and the optimal sites for deploying centralized, renewable-based hydrogen production systems. The feasibility of establishing green hydrogen hubs is assessed by comparing energy demand profiles, renewable energy supply potential, water reSource availability, and alignment with national climate policy across Cambodia's SEZ network.

To evaluate which SEZs are best positioned for green hydrogen production, this analysis examines three critical dimensions:

**Proximity to Energy Demand Zones**: Locations near transport corridors, industrial centers, and power grid hubs where hydrogen can serve freight logistics, industrial processes, or grid balancing.

**Renewable Energy ReSources**: Availability of solar and wind potential to power electrolyzers with clean electricity, ensuring zero-carbon hydrogen production.

**Water ReSources**: Access to freshwater (rivers, hydropower reservoirs) or seawater needed for electrolysis, with co-location near hydropower sites serving as an indicator of both water and renewable power availability.

Through this multi-criteria framework, the analysis identifies SEZs capable of producing green hydrogen for three primary applications: (1) Road Transportation — fueling freight trucks on major corridors and serving logistics hubs; (2) Industrial Usage — supplying hydrogen for steam generation, high-temperature processes, or feedstock production (e.g., fertilizer, refining) in nearby industries; and (3) Power Generation — storing surplus renewable energy as hydrogen and converting it back to electricity for grid support during peak demand or renewable intermittency periods.

## 1. Proximity to Major Energy Consumption Zones

### A. Transport & Logistics Corridors

Many Cambodian SEZs lie along the primary trade routes where fuel demand for freight transport is perticularly high. Notably, SEZs at international gateways - Poipet on the Thai border (NW) and Bavet on the Vietnam border (SE) - lie along some of Cambodia's the busiest highway corridors. Poipet's O'Neang SEZ is just 7 km from Thailand's Aranyaprathet checkpoint, and Bavet's Manhattan/Tai Seng SEZ cluster is 6 km from the Vietnam border, only 86 km by highway from Ho Chi Minh City. These locations sit on freight corridors (Phnom Penh-Bangkok via NR5/ NR6 and Phnom Penh-Hồ Chí Minh City via NR1) with heavy truck traffic. Hydrogen production in these SEZs could directly serve long-haul trucking and cross- border logistics by providing refueling hubs along the routes. For example, the Phnom Penh-Bavet route (166 km) and Phnom Penh-Poipet route (407 km) are key trade highways; SEZs there could supply hydrogen to trucking fleets on those corridors (Jetro, 2024).

### B. Industrial and Urban Demand Centers

Other SEZs are located near Cambodia's main industrial and population centers, where energy demand for industry and power is high. The Phnom Penh Special Economic Zone (PPSEZ) is only 18 km from downtown Phnom Penh, essentially on the capital's outskirts (Adrianople Group, 2019). This puts it at the nexus of the country's largest urban energy consumption zone - Phnom Penh and surrounding Kandal province host the large share of manufacturing, commercial activity, and electricity load. Being near the capital means PPSEZ (and nearby zones like Royal Group's Kandal SEZ) can easily supply hydrogen for city bus fleets, distribution trucks, and industrial users in the Phnom Penh metro. Likewise, Kandal and Takéo province SEZs (e.g. Phnom Den SEZ near the Vietnam border in Takéo) benefit from proximity to the Mekong delta industrial belt and the national grid.

On the coast, the Sihanoukville SEZ (also known as Cambodia-Sino SEZ) lies adjacent to Cambodia's only deep-sea port and a growing industrial city. It is about 12 km from Sihanoukville Port and 3 km from the airport, and now just 2 hours by expressway from Phnom Penh (Jetro, 2024). Sihanoukville province has seen a boom in garment, light manufacturing, and even heavy industry (a large oil refinery and coal power plants are in development). The SEZ's power demand is so high that a dedicated 100 MW coal power plant has been planned to supply it (Ham, 2021). This indicates a significant industrial energy load on-site, which green hydrogen (produced from local renewables) could help replace or supplement in the future. Hydrogen from Sihanoukville SEZ could fuel port equipment, trucks, and supply nearby factories (for process heat or backup power). Similarly, the Stung Hav and Asia Sunrise SEZs in Preah Sihanouk province are near industrial fishing ports and a planned logistics center, aligning with both transport and industrial demand.

#### C. Power Generation Hubs

For hydrogen as an electricity storage medium, proximity to grid infrastructure or power plants is important. Many SEZs are well-connected to the national grid via nearby substations. For instance, Poipet's Sanco SEZ can draw up to 30 MW from the grid via a local substation, and PPSEZ is integrated into Phnom Penh's power network (Jetro, 2024). Hydrogen produced at these sites could be stored and later fed into gas turbines or fuel cells to support the grid during peak hours. Additionally, SEZs near planned power projects stand out: the planned Koh Kong green SEZ, a proposed project in Koh Kong province aims to host green industries and could in future act as a hydrogen hub, leveraging the area's clean energy reSources (Fibre2Fashion, 2023). Koh Kong's strategic location by the Thai border and Gulf of Thailand gives it access to export routes and a less-developed local grid – an opportunity for hydrogen power generation to support local needs or export electricity.

In summary, SEZs around Phnom Penh, Sihanoukville, and the primary border crossings score highest for demand proximity. They sit at crossroads of transportation (road/port/rail) and near clusters of factories and power consumers. Hydrogen from these sites could readily fuel trucks on the main freight corridors, supply heat and feedstock to nearby industries, and integrate into the electricity grid for Phnom Penh or cross-border power trade.

### 2. Renewable Energy Resource Availability

Cambodia enjoys abundant solar energy potential across most of the country. The national average solar irradiance is around 5 kWh/m$^2$ per day, with the central plains receiving the highest levels (up to 5.6 kWh/m$^2$/day). This makes solar PV a viable power Source for electrolyzers in virtually all SEZ locations. The sunniest areas tend to be the interior regions away from the coast – for example, Kampong Chhnang, Kampong Thom, and Svay Rieng provinces boast excellent solar conditions (Koons, 2024). Coastal and southern zones have slightly lower (but still strong) solar radiation due to more cloud cover. Overall, every SEZ can tap into significant solar PV generation, but those in the central and border provinces might achieve the highest PV output.

Solar photovoltaic power potential map of Cambodia. The country receives high solar irradiation (5 kWh/m$^2$/day on average), with the central plain and border regions showing particularly strong potential (darker areas). The highest solar resource (up to 5.6 kWh/m$^2$/day) occurs in central provinces, benefiting SEZs in those areas (Koons, 2024). Even coastal and southern zones have solid solar potential, ensuring all major SEZs can access ample solar power for hydrogen production.

Wind energy, by contrast, is a more limited resource in Cambodia. The country's wind power potential (6 GW) is much smaller than its solar potential (44 GW) and is highly location-specific (Reccessary, 2025). Usable wind speeds (>6 m/s at hub height) are found mainly in higher altitude areas and along the coast. For instance, the first large wind farm (150 MW) is under development in the Mondulkiri highlands (northeast), taking advantage of ridge-top wind (Enerdata, 2025). However, no SEZ is located in Mondulkiri, and most existing SEZs are in lowland areas with modest wind speeds. Some coastal sites (e.g. Koh Kong and Kampot provinces) may have sea breezes or mountain-gap

Integration of Green Hydrogen Production and Utilization

winds – notably, the planned Koh Kong SEZ could explore offshore or onshore wind in the Gulf of Thailand and Cardamom Mountains. Likewise, Sihanoukville's proximity to the coast might allow moderate wind generation. In general, solar will be the primary renewable energy for most SEZs, with wind playing a supplemental role if specific local conditions allow. The complementarity of solar and wind (solar strong in daytime, wind potentially at night or different seasons) could help provide a more continuous renewable supply for hydrogen production in a few promising locations (Reccessary, 2025).

Hydropower resources are significant in Cambodia and correlate with water availability. The country has 2.5 GW of installed hydropower capacity (more than 10 large dams) (Open Development Cambodia, 2025), concentrated in two regions: the southwest (Cardamom Mountains) and the northeast (Mekong tributaries) (International Hydropower Association, 2025). SEZs near these regions can benefit in two ways – clean electricity from the grid and physical proximity to water reservoirs for electrolysis. For example, the Koh Kong area (southwest) hosts several big hydropower dams (Stung Tatai, Stung Russey Chrum, etc.) and abundant rivers. An SEZ in Koh Kong (similar to the upcoming green SEZ) could leverage cheap hydroelectricity and year-round water from these Sources. Similarly, Kampot SEZ in the south is located near the 193 MW Kamchay Dam and a high-rainfall zone, providing both power and water. By contrast, SEZs in Svay Rieng (Bavet) or Banteay Meanchey (Poipet) are located in flatter plains with no large dams; they rely on the national grid (which carries hydro power from other regions) and local groundwater or small streams for water.

### 3. Water Availability for Electrolysis

Access to water is a critical practical factor for green hydrogen production. Each kilogram of hydrogen requires about 9 liters of water for electrolysis, so industrial-scale $H_2$ plants need a reliable water Source or recycling systems. In Cambodia's tropical climate, overall water resources are ample, but distribution is uneven. SEZs adjacent to major rivers or lakes have a clear advantage in water supply.

#### A. Mekong River Basin

Several SEZs lie near the Mekong and its branches. The Phnom Penh/Kandal area sits on the Mekong-Tonle Sap confluence, providing abundant freshwater year-round. Any SEZ near Phnom Penh (such as PPSEZ or Kandal's sites) can draw from municipal water systems fed by the Mekong/Bassac rivers. Even border SEZs in the southeast (Svay

Rieng/Prey Veng) are not far from the Mekong's Bassac branch and could potentially get surface water via pipelines or canals. In practice, however, the Bavet SEZs currently rely on groundwater wells – tenants in Tai Seng Bavet dig their own wells and use groundwater (free of charge aside from well installation) (Jetro, 2024). While this suffices for today's needs, a large hydrogen facility would likely require an upgraded water supply (e.g. piped water from Mekong or a local reservoir) to avoid depleting aquifers.

**B. Coastal and Riverine Zones**

Coastal SEZs (Sihanoukville, Koh Kong, Kampot) have multiple water options – they can use seawater (with desalination), tap nearby rivers, or utilize existing hydropower reservoirs. Sihanoukville's SEZ is near the sea and has some reservoir capacity from upstream (though city water can be strained in dry season). Stung Hav SEZ north of Sihanoukville is adjacent to a bay and river mouth, implying accessible water. Koh Kong's planned green SEZ would be near rivers like the Tatai; likewise, Kiri Sakor SEZ in Koh Kong is on a coastal peninsula with potential for desalination or surface water from the extensive mangrove estuaries. These areas also see high rainfall. Thus, water availability is high in the southwest coastal cluster, supporting hydrogen electrolysis coupled with abundant rain and river flow.

**C. Dry Interior Zones**

Some SEZs in interior or upland areas have more limited water. The Poipet region (Banteay Meanchey in the NW) has no large perennial rivers (aside from seasonally-flowing streams). Poipet O'Neang SEZ has addressed this by connecting to municipal water supply from Poipet City, with up to 4,000 $m^3$/day available (Jetro, 2024). This is adequate for current factories but might constrain a large hydrogen project (for context, 4,000 $m^3$/day could support roughly 450 tons of $H_2$ per day at best, assuming all water is for electrolysis). Additional water storage or import may be necessary during the dry season. Similarly, the new Snuol SEZ (Kratie province) is located in an area without nearby large rivers, potentially relying on groundwater, small tributaries, or developing water treatment facilities. Pursat's Thma Da SEZ (if developed in the far west) would actually be near the Cardamom foothills and streams, but that project is still nascent.

In summary, SEZs near major water bodies (Mekong, Tonle Sap, large dams, or the sea) are well-positioned to meet the water demands of electrolysis. Others can still manage by upgrading infrastructure (e.g. city water pipelines, water recycling systems). This criterion slightly favors Phnom Penh/Kandal, coastal SEZs, and any zone adjacent to a hydropower reservoir, while places like Poipet or Bavet would need investment in water sourcing for sustained hydrogen production.

## 4. Profiles of High-Potential SEZs

Bringing together the above factors – renewable energy supply, water access, demand proximity, and infrastructure – a few Special Economic Zones emerge as especially promising for green hydrogen initiatives. These SEZs have the right mix of abundant clean power, available water, nearby hydrogen markets, and existing infrastructure. Below highlighted are three high-potential SEZ locations and the rationale for each:

**A. Phnom Penh & Kandal Area SEZs (PPSEZ and Neighbors)**

The Phnom Penh Special Economic Zone (PPSEZ) and nearby zones in Kandal province top the list due to their central location and infrastructure. They sit at the heart of Cambodia's energy consumption – Phnom Penh's metro area, which concentrates industrial demand (garment factories, food processing, electronics assembly) and will drive future hydrogen use in industry and transportation. PPSEZ is only 18 km from central Phnom Penh and 8 km from the international airport, with direct access to National Road 4 and rail links (Adrianople Group, 2019). This proximity means hydrogen production on-site can immediately serve city bus fleets, trucks, and industrial parks around the capital (Jetro, 2024). Additionally, Phnom Penh is a grid hub; power generation or storage at PPSEZ can reinforce the capital's electricity supply.

The area has excellent solar potential (around 5 kWh/m$^2$/day) and is already seeing solar investment. For example, a 30 MW solar farm is under development in nearby provinces, and the national 100 MW Solar Park (supported by ADB), located just west of Phnom Penh in Kampong Chhnang, has connected to the grid (Phase 1: 60 MW completed in 2022) (Summit Energy, n.d.) Wind is minimal here, but the high solar output and existing transmission infrastructure (Phnom Penh is the nexus of 230 kV lines) make it feasible to integrate utility-scale PV for hydrogen.

Being on the Mekong-Tonle Sap rivers, water supply is secure. Phnom Penh's water utility draws from these rivers, and Kandal SEZs could tap either municipal supply or directly draw river water with treatment. This guarantees ample water for large electrolyzers without stressing groundwater.

Hydrogen use and infrastructure: Hydrogen from this cluster could be distributed via road to fuel stations along the national highway network radiating from Phnom Penh. Demand is nearby – city garbage trucks, buses, and logistics operators could convert to fuel-cell vehicles if fuel is available. Industries in PPSEZ (which include food/beverage, electronics, automotive parts) can use hydrogen for process energy or captive power. Notably, Coca-Cola's bottling plant in PPSEZ could even use green $H_2$ for clean process heat or in combined heat-and-power. The presence of a one-stop customs service and developed logistics facilities in these SEZs would aid in rapidly scaling hydrogen projects (Adrianople Group, 2019). In short, Phnom Penh's SEZ cluster offers top-tier renewable supply, abundant water, and immediate local markets for hydrogen in all three categories (transport, industry, power).

**B. Sihanoukville (Preah Sihanouk) SEZ and Stung Hav**

The Cambodia-Sino Sihanoukville SEZ (a joint China-Cambodia venture) and the nearby Stung Hav SEZ form a coastal industrial hub that is highly promising for green hydrogen. This area uniquely combines industrial demand, port logistics, and renewable resource access. Sihanoukville's SEZ is one of the country's largest (over 1,100 ha) and hosts over 200 factories (mainly textiles, electronics, tire manufacturing, etc.). Its energy appetite is so large that a private 100 MW coal plant is operational (two 50 MW units) to supply it (Ham, 2021). This creates an opportunity to replace polluting power with green hydrogen: electrolyzers could store solar energy at scale and feed hydrogen into a turbine or fuel cell plant, providing zero-carbon electricity to the zone's grid.

Preah Sihanouk province can harness solar and some wind, but more importantly, it is adjacent to Cambodia's biggest hydropower cluster. The western mountains (in Koh Kong/Pursat) host >700 MW of hydro capacity, and 230 kV lines transmit that power directly to Sihanoukville and Phnom Penh (International Hydropower Association, 2025). The SEZ can draw on this mostly renewable grid mix[33] while adding its own solar farms on site (Open Development Cambodia, 2024). There is also potential for wind: studies have indicated moderate wind along the coastal ridge near Sihanoukville/Kampot. Over the longer term, offshore wind in the Gulf of Thailand could be an exciting resource to pair with hydrogen production here.

As a coastal zone, Sihanoukville has ocean access (allowing desalination if needed) and local reservoirs (used for the city's water supply). The Stung Hav area includes a river estuary which could supply water. The

33 Cambodia's grid already has a high share of clean energy (~62%, largely hydro) and targets 70% by 2030.

new industries (e.g. a planned oil refinery and power plants) have already led to infrastructure for water import and management. Thus, water for electrolysis at an industrial scale is feasible with proper planning.

This SEZ cluster is ideal to serve multiple hydrogen markets. For transport, the National Road 4 corridor from Phnom Penh to Sihanoukville carries intense truck traffic (port freight, fuel tankers, etc.) – hydrogen trucking could start by servicing this route. A hydrogen refueling station at Sihanoukville (and along the expressway) could cater to port drayage trucks and inter-city buses. For industry, many factories in the zone (e.g. tire and rubber plants, textile dyeing) use heat and could switch from fuel oil/coal to hydrogen for steam generation. Hydrogen can also feed into the port's power systems: Sihanoukville port might utilize hydrogen fuel cells for cold ironing (providing power to ships at berth) or backup power. Additionally, Sihanoukville is uniquely positioned for export of hydrogen or its derivatives – it has a deep-water port from which green ammonia or liquefied hydrogen could be shipped regionally. In the near term, given Cambodia's own power needs, a more likely use is blending hydrogen into a new gas-fired power plant or using it in a fuel cell plant to displace diesel generators. The combination of renewable power availability, heavy energy demand, and port infrastructure makes Sihanoukville's SEZ a top contender for a hydrogen hub.

**C. Bavet SEZ Cluster (Svay Rieng)**

The Bavet SEZs in Svay Rieng province (e.g. Manhattan, Tai Seng, Dragon King, etc.) stand out as a high-potential cluster in the eastern part of Cambodia. Bavet is on National Road 1 at the Vietnam border, directly connecting to Ho Chi Minh City. This location benefits from cross-border energy and trade linkages that few other zones have. There is significant freight movement through Bavet (it's a key ASEAN highway), and Vietnam's power grid is interconnected here – Cambodia imports some electricity from Vietnam at Bavet (Power Technology, 2024c). A green hydrogen facility in Bavet could thus serve road transport on both sides of the border, industrial parks in Svay Rieng and nearby Vietnamese provinces, and potentially feed into Vietnam's burgeoning demand for clean energy. Ho Chi Minh City (only 86 km away) is a massive market that could be reached by hydrogen trucks or pipelines in the future.

Svay Rieng has excellent solar irradiance (flat, dry plains) and indeed was chosen for Cambodia's first utility-scale solar farms. A 10 MW solar farm near Bavet launched in 2017, followed by a 20 MW farm in 2019 (Global Energy Monitor, 2025d), and more projects are in pipeline (e.g. a 60 MW solar park) (Summit Energy, n.d.). This established solar capacity and experience in Bavet means a green hydrogen project could plug into an existing renewable supply from day one. While Bavet is low elevation (no wind of note), solar alone can drive a significant electrolyzer operation, perhaps complemented by imported hydroelectric power via the grid (Cambodia's grid mix would deliver night-time hydro power to Bavet).

Bavet does not sit on a major river (the Mekong is 50-60 km west), so water is a concern. Currently, the SEZs mainly use groundwater and some trucked-in water for factories (Jetro, 2024). However, a green hydrogen project could catalyze investment in water infrastructure – for instance, building a pipeline or canal from the Mekong/Bassac, or constructing a water reservoir for rainwater harvesting. The scale of hydrogen production would demand this, but given the relatively short distance to the Mekong, it's an achievable solution. Moreover, any water solution could also improve water supply for the city of Bavet itself, creating a co-benefit.

What makes Bavet especially promising is its proximity to diverse demand centers. In terms of transportation, it could host a hydrogen refueling station for trucks on the Trans-Asia Highway linking Vietnam and Cambodia. Both Cambodian and Vietnamese trucking companies operating on this route might adopt hydrogen vehicles if fueling is available halfway. Bavet's border checkpoint processes hundreds of trucks daily, making it an ideal location for a pilot hydrogen trucking corridor. Regarding industry, the Bavet SEZs host dozens of factories involved in garments, bicycles, and electronics assembly. Currently, they mainly use grid electricity and some diesel; hydrogen fuel cells could provide reliable backup power, especially since Bavet relies on imported power that can be unstable. Across the border, Vietnam's Tây Ninh and Long An provinces contain factories that could also utilize hydrogen or ammonia for cleaner operations. The idea of a cross-border "green freight" zone could emerge, where trucks switch to hydrogen drayage for last-mile delivery into Ho Chi Minh City to reduce urban pollution. Concerning power generation, in the longer term, Bavet could develop a Renewstable® hybrid plant. A recent MoU with HDF Energy hints at multi-megawatt hydrogen power plants in Cambodia. Such a plant in Bavet would combine solar power with hydrogen storage to provide 24/7 electricity, strengthening the local grid and reducing reliance on imported Vietnamese power. This aligns with Cambodia's vision to use hydrogen for grid stability as renewable energy penetration increases.

Overall, the Bavet SEZ cluster combines strong solar resources, a location on a major international corridor, and access to both Cambodian and Vietnamese markets. With some investment in water supply, it could become a showcase for hydrogen in transportation (freight corridors) and as a cross-border green energy hub in the Mekong region.

Each of these zones can play a distinct role in Cambodia's green hydrogen ecosystem: Phnom Penh's SEZs as the urban hydrogen supply hub (for domestic mobility and industry), Sihanoukville as the renewables-to- hydrogen powerhouse (leveraging hydro/solar and port infrastructure for heavy industry and export), and Bavet as the cross-border clean corridor (fueling regional transport and linking into Vietnam's energy network). Together, these high-potential sites align with Cambodia's vision to use green hydrogen in transportation, industry, and power generation, accelerating decarbonization where direct electrification is challenging.

## 5. Conclusion

Cambodia's Special Economic Zones vary in their suitability for green hydrogen, but a clear pattern emerges from our mapping: SEZs with the best prospects lie at the intersection of strong renewable resources, ample water, and immediate energy demand. Zones near the capital and key trade nodes have the advantage of "demand pull" – trucks to fuel, factories to decarbonize, and grids to support. Those in renewable-rich and water-rich areas provide the "supply push" – cheap clean power and feedwater for efficient hydrogen production. By overlaying these factors, identified a few prime candidates (Phnom Penh/Kandal, Sihanoukville, Bavet) where green hydrogen hubs could naturally emerge.

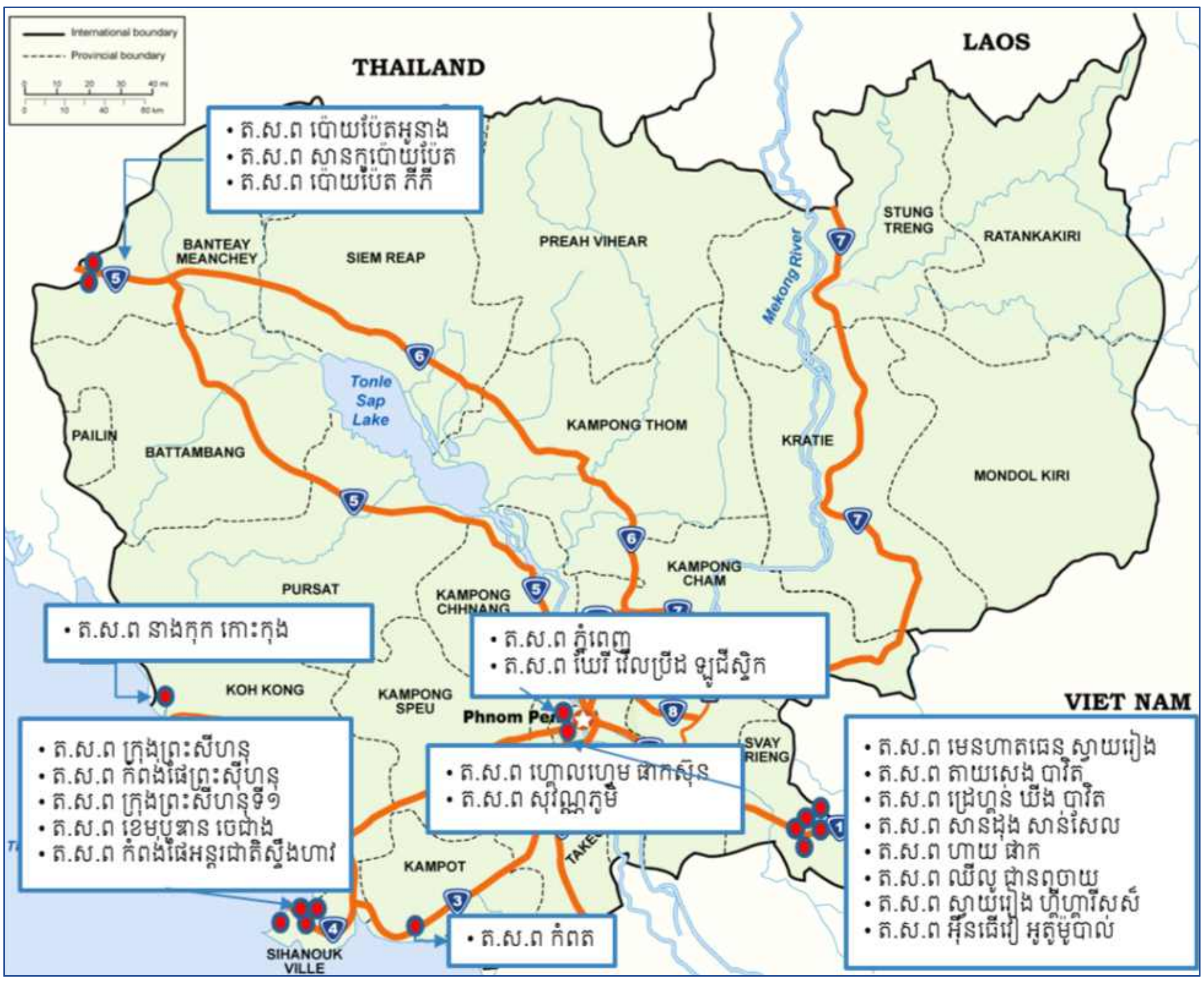
Implementing projects in these zones will require coordinated development of solar/wind farms, electrolyzer installations, water supply systems, and hydrogen distribution (tanker trucks or pipelines to end-users). Fortunately, these locations already benefit from existing infrastructure: national roads, substations, and in some cases, dedicated zone utilities. For example, Poipet area has a planned/ongoing wastewater treatment upgrade (including SEZ support) and vocational training facilities that could incorporate hydrogen safety training, and Koh Kong's green SEZ plans explicitly target renewable energy and automotive investments (Fibre2Fashion, 2023) – indicating policy support.

Cambodia is still formulating its hydrogen strategy, but early indicators show momentum. A memorandum with HDF Energy aims to develop "Renewstable" hydrogen power plants for grid stability, and the government is keen on attracting green manufacturing into zones

(Fibre2Fashion, 2023). The SEZs highlighted in this analysis are well positioned to host such pilot projects. By starting in these high-potential zones, Cambodia can build technical and regulatory experience, create success stories, and then expand hydrogen solutions to other regions and uses.

In conclusion, Phnom Penh's SEZ, Sihanoukville SEZ, and the Bavet border SEZs stand out as optimal launch pads for a green hydrogen ecosystem in Cambodia. Each offers a unique synergy of renewable energy supply, water for electrolysis, proximity to eager hydrogen consumers, and available infrastructure. Focusing efforts on these locations will maximize early impact – supplying clean fuel for trucking fleets on busy routes, lowering industry emissions in SEZ factories, and enhancing grid reliability with stored renewable energy. These zones can become showcases of Cambodia's green transition, helping the country realize its vision of leveraging green hydrogen to drive sustainable growth and energy security (Green Hydrogen Organisation, n.d.). By developing hydrogen production in tandem with solar, wind, and hydropower investments, Cambodia's SEZs could transform into green energy hubs that not only power domestic development but also integrate into a regional clean energy network across ASEAN.

**Figure 6-2** Map of Special Economic Zone




Source CDC (n.d.)

Chapter 7.

# Summary and Conclusion

This study comprehensively reviewed the conditions for hydrogen utilization and supply in Cambodia, a country where fundamental analysis has yet to be conducted despite hydrogen's importance. Regarding hydrogen utilization, it assessed whether globally considered hydrogen application strategies are appropriate within Cambodia's context and estimated the climate benefits for the two most suitable economic activities. The results indicate that hydrogen utilization in the power generation and road transport sectors should be prioritized in Cambodia. In the power generation sector, replacing coal-fired power generation entirely is estimated to yield an 86.2% reduction compared to BAU. In the road transport sector, replacing diesel vehicles entirely is projected to achieve a 75.5% reduction compared to BAU. Converting these effects into climate benefits equates to 18% and 31% of Cambodia's 2024 GDP, respectively.

Regarding hydrogen supply, the study examined key trends in hydrogen production, storage, and transportation technologies, and reviewed Cambodia's renewable energy resources, technologies, and conditions for linking production and consumption sites. The results indicate Cambodia possesses promising potential for hydropower and solar power generation, and its water resources are deemed abundant for green hydrogen production. Specifically, SEZs centered around Phnom Penh can drive demand for hydrogen utilization while also possessing excellent resource conditions for hydrogen supply, suggesting strong potential for linking production and consumption sites. However, despite these strengths, Cambodia's technological development conditions remain immature. Therefore, it is judged that efforts are required to strengthen the technological innovation ecosystem in the long term, alongside an appropriate hydrogen technology introduction strategy.

The significance of this study is as follows. As stated in the introduction, the primary significance lies in attempting a comprehensive analysis of Cambodia's hydrogen conditions, an area where sufficient research has yet to be conducted. Future studies can build upon this research to conduct more sophisticated analyses or expand its scope. Second, this study quantitatively presents greenhouse gas reduction effects and also expresses them in monetary value. This means it concretely demonstrates the benefits hydrogen can bring, and it can serve as key data to enhance the legitimacy of future policy formulation and the acceptability within local communities. Third, it presented comprehensive information on hydrogen production technologies. It introduced viable technology options and companies across the entire value chain, from hydrogen production to storage and transportation. This information can serve as foundational data for future technology selection or collaboration.

However, a major limitation of this study is that data constraints necessitated numerous assumptions in the analysis. Specifically, the absence of vehicle statistics by fuel type when calculating the climate benefits of hydrogen use in the road transport sector prevented a full consideration of Cambodia's road transport environment, including motorcycles. Furthermore, this study was conducted as part of a larger research process and faced time constraints, necessitating a focus on specific economic activities. Additionally, it did not sufficiently consider overall policy coordination or the balance between different energy sources.

Therefore, when establishing detailed sectoral policies in the future, it is deemed necessary to thoroughly review and supplement statistical infrastructure and data, followed by objective verification and analysis. Furthermore, a process of policy priority adjustment alongside other renewable energy and energy efficiency policies appears necessary. Although this study analyzed hydrogen conditions by reflecting the PDP and electric vehicle infrastructure roadmap as given conditions, hydrogen cannot necessarily be considered subordinate to current policies, nor can it be said that it must be prioritized. Therefore, it is necessary to thoroughly review whether there are any conflicting points in the policies and to sufficiently perform analyses to find the overall greenhouse gas reduction effects and optimal solutions based on each policy.

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